Induced Mass Movements of Small Mammals

A Suggested Program of Study

by

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Table of Contents

I. Introduction

A number of investigators collaborating with the North American Census of Samll Mammals conducted studies providing insight into phenomena relating to how social interactions control spatial distribution of the members of small mammal communities. Consideration of these results and the derived insights suggest that it may be possible to initiate mass movements of small mammals such that the population from an extensive area may be caused to leave their homes and move for long distances toward a convergence point. Although elimination of all individuals at such a convergence point might have value as a control procedure for species causing damage to extensive tracts of agricultural crops, the initiation and study of such a phenomenon will contribute materially to our conceptualization of certain aspects of panic reactions, community social disorganization, and disaster planning on the human level.

I have elsewhere (submitted for inclusion in the forthcoming book, Physiological Mammalogy, to be published by Academic Press) summarized much of the background data and derived theory. In addition Dr. Kyle Barbehenn and I are preparing a paper providing much greater detail of many individual studies. However, there are a few individuals who might wish to explore the possibility of inducing mass movements prior to awaiting the publication of the above papers. To this end I have prepared the present brief summary along with a description of the minimum type of effort required to demonstrate the feasibility of inducing such movements.

II. Spatial distribution and social inhibition

1. Home range

Each individual's use of the space about its home (i.e., home range center, HRC) may be described by the bivariate normal distribution function. That is to say it spends 39% of its time within a one sigma distance of its HRC, 86% within a two sigma distance, and 99% within a three sigma distance.

2. The one-species community

or

The dominant species of a multi-species community

In its initial phase there develops a uniform distribution of HRCs in which the HRC of any one individual is exactly two sigma distance from each of its six equidistant nearest neighbors. The density function of the bivariate normal distribution essentially represents the relative probability of encountering an individual per unit of area with reference to distance from its HRC. With such a distribution the home range of each individual overlaps those of its six nearest neighbors and the twelve next-nearest neighbors. At every point the summated probability of all individuals arriving at each point may be calculated. With the HRCs two sigma apart every point has essentially equal probability of animals arriving at it. This is the maximal spacing of HRCs at which this holds. For this reason it is assumed that the process of evolution has altered systems of communication and perception of neighbors so that a uniform utilization of the habitat may be attained while at the same time maximizing the distance between neighbors.

For terrestrial small mammals in the 3-300 gram range in the absence of associated species sigma likely, as a rule, is about 50 feet. This means that the radius of the average animal's home range is of the order of 150 feet. An ideal census procedure involves establishing a grid of trapping stations, at least 100, with a 150-200 foot distance between stations and with 3-6 kill-traps per station. Were such a grid of 10x10 stations established and run for 30 days most of the residents would be removed without confounding the picture by invasion from peripheral habitats. Each day the number of individuals taken will be less than the previous day.

As time goes on social attraction partially counteracts the antagonisms leading to the prior uniform distribution. A few individuals, whom we may call alpha individuals, become slightly dominant, but also attractive, to their six nearest neighbors. These latter, whom we may call beta individuals, both slightly contract their home ranges and shift their HRCs toward that of their dominant alpha associate. Alpha : beta home range radii have the ratio of 1.0 : 0.96. In like fashion each alpha individual will on the average attract towards itself five of its twelve next nearest neighbors, whom we may call gamma individuals. Although such gamma individuals move toward this alpha associate, their home ranges still lie peripheral to those of the alpha's beta associates. Such individuals markedly reduce the size of their home ranges. In fact the home range radii of alpha : gamma individuals has the ratio of 1.0 : 0.65. This "condensation of the community into groups or "constellations," which on the average have 12 individuals each, leaves an inter-constellation "matrix" with a much lower probability of encountering members of the species in question.

When traps are set (in the pattern described above) in a community so structured the sequence of catch over time becomes quite different from that characterizing the earlier stage of uniform distribution. For approximately the first ten days the sequence is similar, that is, on each successive day the number of individuals removed is less than on the previous day. Beginning on about the 10th day of removal trapping the catch on each day exceeds that of the prior day. Such increase continues for about 5-8 days after which the catch on each day again becomes less than on the prior one, until by day 30 very few individuals are taken. The number of animals taken before the secondary increase to those taken to day 30 has the ratio of approximately 7 : 5. The "7" represents mostly alpha and beta individuals whose initial large home ranges exposed them to traps. The "5" represents mostly gamma individuals, who were originally not highly exposed to traps because of their small home ranges, but who later expanded them as the inhibitory influences exerted by the alpha and beta members disappear simultaneously with the removal of these latter individuals.

3. <u>The two-species community</u>

It frequently happens that members of two species numerically predominate in a community. When this condition holds there is one species, which we may call the alpha species. The home ranges of its members, along with the distances intervening between HRCs, conform to the patterns described under II-2 above. This spatial distribution indicates that it is uninfluenced by the presence of the second, or beta, species.

Members of the beta species locate their HRCs so as to minimize the probability of contacting any and every neighbor of the alpha species. To visualize this condition consider the following with the alpha species in the temporal developmental stage of uniform distribution of HRCs:

Plot on graph paper a uniform distribution of points representing the HRCs of the members of the alpha species. Then draw circles about each having a radius of half the distance between each two nearest-neighboring points. These circles just meet and they fill the space, within which the uniform distribution of dots have been plotted. Each of these circles represents a one sigma radius area about each HRC. This pattern of circles leaves small areas, interstices between circles, that lie outside of the limits of the one sigma range of members of the alpha species. The center of each such area represents a location at the center of the equilateral triangle formed by every group of three nearest neighbors of the alpha species. Such points represent the locations of the HRCs of members of the beta species.

I highly recommend that each of you interested in this topic prepare such a graphic representation of HRCs in which there are roughly 225 HRCs of the alpha species. Then plot in the HRCs for the beta species. About each such latter point circumscribe a very small circle such that its circumference just meets the circumference of each of the three neighboring alpha species members. These tiny circles will then encompass a one sigma area about the HRCs of members of the beta species.

Now an interesting relationship may be noted. There are twice as many home ranges of members of the beta species as for the alpha species. And yet when any widely distributed pattern of traps is employed for censusing and removal trapping is continued for only one to three days, the ratio of alpha : beta species trapped is about 95:5. However, when removal trapping is continued for 30 days this ratio changes to 1:2.

The reason for such different results obtained from short and longer term removal trapping is as follows: Initially the home ranges of members of the beta species are so small that the probability of a trap lying within them is very low. However, one or more trapping stations are likely to fall within the home ranges of each member of the alpha species, because their home ranges are so large. For this reason they are rapidly removed. As the members of the alpha species are removed, the inhibitory influences exerted by them, which caused the marked contraction of the home ranges of beta species in the first place, disappear. As these inhibitory influences disappear the members of the beta species enlarge their home ranges. As this enlargement takes place more and more beta species individuals become exposed to traps, so that each successive day more beta species individuals are trapped than on the preceding day. Following maximal expansion of home range, usually by day 15 of trapping when few members of the alpha species remain, the numbers of beta species captured each successive day also declines, until by day 30 very few of them remain.

4. Other types of species

a. Socially inhibited species

and gamma species

Highly specialized species

In general this category encompasses those species which avoid contact with the alpha species through adaptation for microhabitats of usually restricted occurrence which tend not to be suitable for use by the alpha species. Included here are also species which avoid contact with alpha species through subterranean or arboreal habits. Members of such species as a rule are actually quite rare, and appear even rarer in censuses made by short-term removal trapping. However, in 30-day continuous removal trapping members of such gamma species enter traps quite late, frequently not until after 10-15 days of trapping. This indicates that their normal expression of certain cryptic habits or their confinement to localized microhabitats is in part a function of social inhibition exerted upon them by the alpha species. As soon as the alpha species become few in number the cryptic behaviors of the members of the gamma species diminish, and they also tend to wander out of the localized microhabitats to which they were formerly confined.

b. Omega, "extra-community" species

Such species are members of the community in the sense that they are physically present, but are absent in the sense of having evolved the capacity to become unaware or psychologically "blind" to the inhibitory influences (signals) of their associates of other species, and probably even of their own kind. For this reason they are able to tolerate excessively high densities. They have relatively small home ranges with a high degree of overlap of home ranges or common use of the same home range. Omega species tend to be grass eaters and probably represent a relatively late evolutionary stage in accommodating to the developing complexities of small mammal communities. The genus, *Microtus*, includes such species.

c. Subordinate alpha and beta species

In many communities there is at least one other species which can assume the dominant role in the community provided some other circumstance caused most of the dominant alpha species to die. We may call the usually dominant alpha species, the alpha sub-one species, α_1, and likewise the competitively subordinate alpha species may be called the alpha sub-two species, α_2. Usually the α_2 species occurs in much fewer numbers than is true for α_1. In continuous removal trappings the numbers of α_2 taken per day increase to about day 5, after which the customary decline sets in. This pattern holds in the presence of numerically more α_1 present. This pattern means that the home range of α_2 individuals is contracted as a result of the presence of α_1.

In like fashion there may be two beta type species, β_1, and β_2, of which one may usually assume that beta role to the near exclusion of the other, although occasionally β_2 replaces β_1. There may be such a marked cryptic and spatial withdrawal of the one of these two beta species, which loses out in the social competition, that it does not reach maximum expansion of its home range until after the 20th day of removal trapping, by which time most of the α_1, α_2 and β_1 individuals have been removed.

5. General comments

The above formulations resulted from the analysis and interpretation of large masses of mostly unpublished data from many investigators. An appreciation of the types of community structures which develop among small mammals is essential to study of experimentally induced mass movements.

III. The general conceptualization underlying the experimental initiation of a directed mass movement

A spatial distribution of members of single or multiple species communities, according to the principles described above, requires that there have evolved means of communication whereby each individual can determine the whereabouts of each of his associates for a radial distance of at least three sigma, and probably for as much as six sigma (more likely the latter). Sigma here is in terms of the alpha members of the alpha species. This means that with such a sigma distance approximating 50 to 60 feet, each individual is able to maintain an approximate knowledge of its associates over an area of six to ten acres. The only communication system that can fulfill the demands of this formulation is that of vocalization and audition. It also demands that vocalizations occur in "waves." That is for a while all individuals are quiet. Then one individual begins a "burst" of signals. Each burst consists of 7-19 separate signals with each signal lasting 2-3 secondsand a somewhat longer interval between signals. By the time the first individual ceases signalling all others within his ken will also have signalled. Furthermore such signalling should "sweep" through the environment so that such a "wave" of signals will enable individuals in one location to affect others at a greater distance than possible by direct perception of an emitted signal. Granted, such a system is quite hypothetical, but observed data require that something approximating it be true; so we shall proceed as if this formulation is correct in essential details.

Now we may ask, "What are the basic principles to which the individual conforms." In the first place, on the average, the intensity and frequency of signals impinging on the individual from all directions must be identical. It will adjust its movements to maintain this condition. If, perchance, on one trip out from its home it encounters signals in higher than average frequency, it will on its next trip move in a roughly opposite direction from home. In doing so the animal may in effect be avoiding excessive stimuli, but it is acting as if it is attempting to equalize the intensity or frequency of stimuli in all directions. This represents the primary principle of orientation in space which may be manipulated to induce a directed mass movement.

A second principle involves the attempt of each individual to maximize the distance from his nearest neighbors. Conformity to this principle leads to a uniform distribution of home range in the initial phase of spatial distribution of members of the alpha species.

Now consider an extensive habitat in which over it the community of small mammals is bound by a web of communication as described. Toward its center mark off a circle having a radius of about twelve sigma, that is about 600 feet. Within this distribute several hundred traps. Within about 30 days most of the residents of all species will have been removed. Then consider the situation in which animals residing just peripheral to this trapped-out area will be. They will find themselves able to detect the presence of the normal number of associates away from the depleted area, while toward it there will exist a void of signals. Their normal adjustment being to move so as to equalize the intensity of signals impinging upon them from all directions, they will, as a consequence, start shifting toward the depleted area. In time this shifting will take them beyond the normal limits of their prior home range and into the depleted area. This action will expose them to the traps left set in the central area, and so they also will be removed.

We have evidence that the width of the band inhabited by animals initially moving in is equivalent, approximately, to six home range sigma, or roughly 300 feet. Within this band the constellations of associates of the alpha species, which form during the second phase of structuring of the community, form closer ties among groups of seven to nineteen animals (average 12). At first just a few individuals move in; then gradually, as the effect of the deficit of signals in the central depleted area overcomes the attachment of the group to their homes, a larger number each day moves in. Then there is a gradual diminishing of in-migrants as those living farthest away in the band, along with those having the greatest attachment to their homes, also become involved in the process. The end effect is of a wave of in-migrants into the central area of trapping. The input of such a wave from a 6-sigma width peripheral band requires several days; the duration in part being determined by how effective the traps are in removing invaders.

But as the inhabitants from the first peripheral band move inward, those living in the next adjacent outward band of equal width will find themselves in the same circumstance of being able to detect a greater intensity or frequency of signals in an outward direction than toward the central area, where traps are maintained set. In this way there will become established a "chain-reaction" whereby many successive waves are simultaneously moving toward the central area.

Certain spatial aspects of the situation introduce complexities, which may modify the process. Consider a central area of 6-sigma radius (300 ft.), and assign the encompassed area as having a relative area of 1.0. Then a band of equal width (i.e., 6-sigma) about it will have a relative area of 3.0. In like fashion a series of such concentric bands will form a series having relative areas respectively of 1 : 3 : 5 : 7 : 9 : 11, 13, 15, etc. These will represent the relative number of animals in the first 8 bands. To the extent that number of animals is proportional to area it is easy to calculate changes in relative density. At the end of the first wave 3 animals will have entered band 1 for every one previously living there; while in the second band 1.67 animals will have entered for every one living there previously. Table 1 provides data on 8 bands through 10 successive Periods of movement. Each Period encompasses the number of days required for the animals living in one band to move inward into the next band in so long as removal of invaders into the centralmost band or bands continues.

Examination of Table 1 reveals that as the process of inward movement continues the relative density inward increases much more rapidly than outward. Figure I, which contrasts relative density during Periods 1, 4, 7 and 10 clearly demonstrates this consequence. By the end of the 10th Period (one wave of invaders enters the area of removal trapping each period) the innermost band has had entered it during this period 21 times the number originally inhabiting it, while during the same time the 8th band has had only 2.33 times the invaders as original inhabitants.

If we consider the central area where traps are maintained to cover Bands 1 and 2, and which have prior to Period one removed all residents from this area as well as adjacent Band 3, then the total relative density removed prior to any invasion will be 9 (i.e., 1 + 3 + 5, the relative number of inhabitants of Bands 1, 2 and 3). By the end of Period 10 all residents through Band 13 will have invaded the central two bands and have been caught. The sum of the relative number of inhabitants of Bands 4 through 13 is 160. Thus the residents to invader will have the ratio of 9 : 160 or 1 : 17.8.

This latter paragraph is merely an insertion to reveal an end state result. However, the line of logic continues, leading to some possible consequences of the differential densities, with the central area being high and decreasing outward. When animals from all bands move inward, each is in effect moving toward a region of higher density, although the immediate impetus for directional movement stems from the void represented by the next adjacent inward band moving inward. If one more distant band gets slightly out of phase with the whole system by migrating slightly more rapidly than the next innermost one, such animals will find themselves in the paradoxical position of arriving into a region of higher density by continuing to perform a response which had led them into a lower density area. This might cause them to slow down. However, I have experimental evidence (some of which is included in my paper, A "Behavioral Sink"), which shows that when density reaches 3-5 times optimal levels, many responses, which at lower densities would be given while the animal was alone, now occur in the presence of others. These others become secondary reinforcing stimuli. In time presence of others becomes a requisite condition for giving the response. At this stage animals seek locations where the probability of being with others will be maximized.

In terms of the induced migrations, whenever during it the density of a band gets in the range of 3-5 times normal there arises the probability of a need for social proximity to others developing into a strong secondarily acquired drive. At this time one may expect the members of 2-3 adjacent bands to become compacted and move inward as a single rather than separate waves.

In any case as the animals move inward they are persistently rewarded for moving in a given direction, inward toward the trapping area. We may think of the reward as the escape from signals of animals moving in behind them. However, we may conceptualize the reward, the fact remains that the one constant factor in the behavior of these animals is directed movement. Any continuing behavior, however rewarded, has the property of reoccurring for some time in the absence of the conditions causing its original repetition. With no reinforcement of the behavior by the rewards originally associated with its expression, its frequency gradually diminishes until the behavior is no longer exhibited. The duration of the period of decline or extinction varies.

If an experimentally induced movement could be maintained for a sufficiently long time, probably of the order of two-three months, I suspect that the period of extinction would persist for two to four weeks thereafter, even though the practice of removal trapping were no longer continued in the central area. In the case of initiation of such a movement in the center of a continuous habitat, persistence of movement requires that animals arriving at the center and crossing it continue in the face of others from the opposite direction. I feel sure that under such circumstances there would result a great milling about with a more rapid extinction of the behavior and an eventual establishment of randomly directed movement but with a gradual diffusion outward toward areas of lower density where eventually the animals would again settle down and establish organized communities.

However, if the trapped area were established as a semicircle at an ecological or physiographic edge of the habitat results should be quite different. I am here thinking of the edge of the habitat being at a lake or sea shore or where a more lush vegetation borders a desert of ice or near barren soil (the latter being, for example, an extensive plowed area). Given such a situation and with removal practice continued for 90 days and then terminated I would expect something like the following at the cessation of trapping: Animals would arrive at the edge of the habitat. There they would encounter a condition that they would not normally enter such as barren land, ice or water. However, the behavior of moving would have become so well established that after a few moments hesitation each animal will move out into the undesirable space. Once having committed itself to moving in the strange habitat no further decisions are required. Such action may lead to death unless continued movement can be maintained until reaching the opposite side of the undesirable habitat and unless adequate resources of food and shelter occur on this opposite side.

If what I have said so far proves correct in essential details, it is obvious that such experimentation might be adapted for certain types of control of density. Of equal, if not greater importance, would be that such research would enable development of insight into problems related to phenomena involved in panic reactions and accommodation to mass disaster situations.

IV. An example of an induced movement

Despite all the circumstantial evidence and logic which suggests the feasibility of experimentally inducing a directed mass migratory movement, there yet remains only one actual experiment. As a result of preliminary studies and theorizing the U. S. Army made a grant to the New York State College of Forestry for the execution of a large scale study under the immediate supervision of Dr. Wm. L. Webb.

In essence this consisted of laying a circular trap line enclosing a 30 acre tract surrounded by extensive similar forest habitat. Along this line a trap was placed every 5 feet. The notion was that once the many fewer traps placed within the circle had removed the residents, the close spacing of traps along the peripheral line would suffice to capture all invaders as they encountered the line. Unfortunately this peripheral line of traps proved ineffective to that extent, with the consequence that animals accumulated in the center in greater numbers than the few traps there were able to remove them rapidly. An attempt was also made to trace movements inward by invaders by line trapping along three one-mile long radii from the central area. Unfortunately 50% of the animals captured each night died from exposure. This apparently set up "convexion" currents toward the radii, which "held" animals near the point of first contact with these trap-lines until at a later capture they also died from exposure. Even so many animals maintained their induced movement (between the radii) toward and into the central area, where ultimately they also were captured. Considering only the dominant species, the mouse <u>Clethrionomys</u>, the results were as follows: Most of the residents were captured during the first 21 days of removal trapping. There followed four successive waves of invaders; each wave encompassed 15 days:

	Observed	Expected
Residents:	107	107
1st Wave:	88	96
2nd Wave:	111	107
3rd Wave:	138	135
4th Wave:	165	163
Total	609	608

Assume that each group of invaders originally inhabited one of four bands of width w, and that the residents inhabited an area encompassed by the circular trap line plus an adjacent band of width w. Then we may calculate w and the distance of the successive bands from which invaders originated.

The radius from the center of the area being trapped to the trapline was 562 feet. Thus, the area sampled during the first 20 days equals $\pi(562 + w)^2$. Since each wave of invaders is presumed to represent a band of equal width, w, then the entire area sampled during the entire 80 days equals $\pi(562 + 5w)^2$. One hundred and seven mice were taken from the central area, and 608 from the total area. Thus, to the extent that number of mice is proportional to the area they inhabit, 5.626 as many mice inhabited the total area as the central area. It follows that:

$$5.626\,[\pi(562 + w)^2] = \pi(562 + 5w)^2$$

Thus $w = 302$ feet

Radii to the limits of the central area and the four successive bands become 864, 1166, 1468, 1770, and 2072 feet. A w of 302 feet represents the approximate diameter of home range (i.e., radius = 3σ of the bivariate normal distribution) for this species found in other studies by Dr. Earl Patric for this habitat.

Despite the many shortcomings of this study, the fact remains that depletion trapping in a central area did induce a directed mass movement. Without going into the details of the shortcomings of this study I must add that without having executed this study it would have been impossible to develop the plans included here which I hope, in the main, avoid the complicating factors experienced there.

V. Suggested experimental procedures

1. General comment:

Any effort to explore this general problem entails a major effort both in time and personnel. In time 4-6 months must be allowed for. In personnel it will take 6-12 individuals. Several thousand animals will be trapped and all traps must be serviced every day for at least the 90-day continuous removal period. We are dealing with a phenomenon of the behavioral physics of populations in which many "atoms" or units, the individual animals, are required for appropriate analysis. I emphasize this point because the biological study of populations infrequently has utilized such a mass effort.

2. The half-octagon layout (Fig. 2)

a. General comment

Utilization of this layout (a simpler form of a half-circle layout) presupposes an environment is available along which there is an ecological or physiographic barrier. Furthermore, this barrier between an inhabited and an at least nearly uninhabited area must form a relatively straight line for a distance of at least 1600 feet. The reason for this will become apparent as the discussion proceeds. Furthermore the habitat should be at least a mile in depth and extend for at least a mile to the left and right from the center point, P, of the inner trapping plot. In other words the minimum habitat required is a two square mile plot.

b. Details of the half-octagon plot (Fig. 2)

Establish the center point (P on Fig. 2) one hundred feet inside the study habitat. Survey a straight line parallel to the boundary for a distance of 975 feet in both directions from P. The ends of these survey lines form points A_1 and A_2, the anchor points of the A half-octagon trap line. Then starting at P locate the anchor points G_1 and G_2, each 75 feet from P. The interval between all other adjacent anchor points is 150 feet. With these 14 anchor points fixed, locate the corners of the concentric half octagons. Place clearly visible posts at the center point, P, all 14 anchor points, and the 21 corners of the concentric half-octagons.

The lines determined by these points represent the trap lines. Along these, stations are to be located every ten feet. See Table 2. Location of 1127 stations along these lines is quite a task. Stakes can be placed at each station. However, an equally satisfactory procedure is to wind cord or wire about a reel having a ten-foot circumference (1.59 ft. radius). Soaking the reel with paint along one side of its circumference will automatically mark the wire or cord at 10-foot intervals.

At each station place two traps. Each station (or the traps there) is to be marked with its line and number. Traps should be placed in a standard fashion at the station marker. Place the two traps (designated as 1 and 2) at a station in the following fashion. Place the "2" trap two feet in an outward direction from the marker and at a right angle to the line. Similarly place the "1" trap two feet in an inward direction from the marker and at a right angle to the line. Preferably each trap should be attached to the station marker with a string.

Having the two traps so located provides information on direction of movement. During the period of removal of the resident population equal numbers of animals should be caught in traps 1 and 2 (except for along line A where more animals should be taken in the 2 positions since the traps on the B line compete with those on the A line for animals living between A and B, while no such competition with the A line exists with regard to animals living peripheral to it). As soon as invasion begins animals on the average should approach the No. 2 positioned traps before the No. 1 ones. Such data will provide further documentation of the reality of the invasion.

c. Habitat preferences

Having two traps at each station can provide additional information of preferences for moving through the habitat. Consider an animal moving through the environment in a roughly straight line. As it travels it will find the environment to one side of its route more desirable than on the other. To the extent that such preferences exist the actual route of travel during invasion will be an irregular zig-zag one. Determination of such preferences requires description of the micro-habitat about each station. The area about the station to be described must initially be an arbitrary one. I suggest a 4x8 foot "quadrat" in which the traps lie two feet from each side. Each investigator must assess which indicators are most likely to be relevant. No comment will be made here on determining microhabitat preference.

d. The probability of capture during invasion

Due to the similarity with which traps are set along all lines there must be some average probability of an animal being caught as it crosses a line. Consider the case when 300[1/] animals cross the A line during a single day. This is roughly one animal per station, or one animal per two traps. The trapping system will certainly become quite inefficient when many more than this contact the A line during a single day.

Given a probability of 0.1 (see Table III-A for details) only 30 animals will be taken in line A. This leaves 270 arriving at line B where 27 are caught, etc., to line G, through which 143 pass toward the center point, P. Obviously if such a low probability exists invasion will soon terminate due to animals "piling up" at P. Other inefficiencies of a system of trapping with such a low probability of capture are reflected by stations per animal, and relative density (number of animals in a half circle of 150 foot radius, which is essentially the area falling within 75 feet on either side of line G. If this area is denoted as 1.0, then beginning with line G, the areas within 75 feet of the "concentric" lines G to A form the ratio series 1 : 3 : 5 : 7 : 9 : 11 : 13.) As the surviving animals move inward the number of stations per animal declines. This means that animals will be interfering with each other with regard to the opportunity to be caught. Since both traps at some stations will contain trapped animals, later arrivals will find no opportunity of being caught. This situation further lowers the probability of capture and aggravates

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1/ To place this number of 300 in perspective consider the following. There are 10 animals per acre. Each line has exposed to it those animals living within 75 feet on either side. The G line, the innermost, has an exposure area of $\pi r^2/2$, where r = 150 ft. This 8.1 acre area contains 8.1 animals. The successive band-areas about the other six trap-lines contain animals in the numbers shown in Table II. In actuality the outer line will likely capture considerably more than 105 animals because, there being no competition from other lines farther out, there will be exposed to it animals living for considerably more than 75 feet. If invasion begins on day 21 of removal trapping and if invasion proceeds at a rate of travel of 43 ft. per day (see Tables IV and V) those animals inhabiting the 14th band from the edge of the trapped area will invade before the end of 90 days. If during the 7-day period during which the residents of the 14th band invade the half-octagon, one third enter on some one day, 292 will enter on that day. Thus conditions are not likely to be encountered at which more than 300 animals will enter during any one day.

the increasing density developing toward the center point P of the trapping area. Due to the decreasing area adjacent to successively more inward trap lines, the relative density slightly, then markedly, increases from outer to inner lines despite animals being trapped as they progress inwards. Thus, if the probability of being caught while crossing a line is of the order of 0.1, animals will so rapidly concentrate toward the center as to inhibit the invasion.

With a probability of 0.25 (Table III-B) of being trapped upon passing through a trap line, this pattern of setting traps reaches a borderline of effectiveress. Competition of animals for traps, in terms of stations per animal, becomes relatively constant across lines. Furthermore, density very slightly decreases through the areas adjacent to the first few bands progressing inward. In addition only 13% of each day's invaders reaches the center.

With attainment of a probability of capture of 0.3 (Table III-C) the system of traps becomes fairly effective. Density becomes more noticeably reduced from the outer to inward bands. And by the time a probability of 0.5 (Table III-D) is reached the system of traps becomes quite effective. For the experimental initiation of an invasion the probability of capture while animals are crossing a trap line must be at least between 0.3 and 0.5. We have no way of knowing beforehand what probability of capture will result from the suggested pattern of setting traps interacting with the behavior of the animals to be studied.

One must conduct a study and from the results determine the probability of capture. Let us suppose that trapping has been conducted for 30 days and essentially all residents removed. Then there will begin invasion on following days of trapping. Prepare a sum of total captures for each line over some extended period of trapping, perhaps from days 31-60. Let these sums be represented by b_1, b_2, b_3, b_4, b_5, b_6, and b_7 for lines A to G respectively.

Let p = probability of being captured on encountering a trap line during invasion.

$$
\begin{aligned}
\text{Then } p &= (b_1 - b_2)/b_1 \\
&= (b_2 - b_3)/b_2 \\
&= (b_3 - b_4)/b_3 \\
&= (b_4 - b_5)/b_4 \\
&= (b_5 - b_6)/b_5 \\
&= (b_6 - b_7)/b_6
\end{aligned}
$$

Each of these equations provides an estimate of p. The last two are likely to prove unreliable due to concentration of animals toward the center which may cause some reverse migration.

Let B_1, B_2, B_3, B_4, B_5, B_6, and B_7 represent the number of animals arriving at each trap line from A through G respectively over the time span for which p is calculated.

Then

$$B_1 = b_1 / p$$

$$B_2 = b_2 / p$$

etc. to B_7

Of these B values B_1 is the most important for it represents the number of animals invading the trapped area. B_1 can be calculated for each day. B_1 as a function of time provides the best picture of the course of the invasion. There exists the possibility that p will decline as invasion continues as a consequence of a gradually developing "perceptual blindness" to meaningful stimuli.

3. <u>The drift-fence and pit-traps</u>

Even if all invading animals move toward the central point, P, some will manage to pass through all trap lines unless the probability of capture on encountering a trap line considerably exceeds 0.5. Capturing these animals requires a technique insuring that few animals getting through the system of concentric trap lines will escape. Dr. Walter E. Howard has developed a procedure likely to prove of use in this situation. He utilizes fences of hardware cloth along which there are sunk pit-traps containing denatured alcohol covered with a half inch layer of one part hexane and two parts light mineral oil. Animals which encounter the fence become diverted from their line of travel and run along the fence until they encounter a pit-trap and fall in. The contained fluid preserves the captured animals for several months.

Any screen not exceeding a mesh diameter of 1/4 inch is likely to prove acceptable. Solid metal is to be avoided since vocalizations of the invading animals would be reflected off it and might inhibit the directed movement of invaders. Place nine pit-traps, T_1 to T_9, in the positions shown in Figure 2. V-shaped drift fences lead toward each pit-trap. The arms of each V measure approximately 157 ft., making a total of 2829 feet of drift fence. It is suggested that the fence extend 3 to 6 inches beneath the soil and that the upper six inches be bent over at right angles toward the fence. These precautions will reduce the number of individuals who might escape capture by digging under or climbing over the fence.

Howard used one gallon glass jugs for pit-traps. However, in the present type of experiment there exists the possibility of large numbers of animals encountering a pit-trap during one 24-hour period. For this reason larger traps should be used. Two to five gallon metal drums might be used successfully. In this case the liquid should reach a level below the edge so that an animal could not quite reach the surface by hanging down by its hind feet. The probability of the animals entering the pit-trap may be enhanced by covering the surface with small pieces of bouyant material which will give the surface the appearance of a solid non-liquid surface, but which are too small to assist the animals in keeping afloat and avoiding being drowned.

At each pit-trap, establishing maze-like wings to the drift-fence, as shown in Figure 3, will reduce the likelihood of animals avoiding capture in the pit-traps. Periodic removal of animals will be facilitated by inserting a wire basket which has a slightly smaller diameter than the pit-trap, and whose top edge lies below the surface of the contained liquid.

4. Theoretical results

The logistics of studying induced mass movements require careful planning. Posting data concerning captured subjects can in itself demand considerable effort. It is therefore desirable to gain some insight into the likely number of animals taken within 90 days in the snap-traps of the half-octagon and in the pit-traps. Such totals will be dependent upon density and rate of movement toward the half-octagonal area.

Density will likely vary between 2.5 and 10 animals per acre. Each wave of migrants will likely originate from a band of about 300 feet in width. At least four and probably not more than 10 waves will enter the half-octagonal area after the removal of the residents from it. The assumption is made that it will require 20 days to remove all residents, and that the remaining 70 days of removal trapping will cover the period of several waves of invaders, each originating from a band 300 feet farther out from the preceding one.

Table IV provides relevant data. With a low density of 2.5 per acre and with only four waves of invaders, 519 animals will be taken during the 90 days. At the opposite extreme, with 10 per acre and 10 waves of invaders, 6361 animals will be taken.

Even with 10 waves of invaders the average distance of movement is only of the order of 43 feet per day. If the rate of migration should double, the total numbers taken increases markedly. Furthermore, as discussed in Section VI-2, there is reason to believe that inward migration into the pit-traps will continue unabated for some time after cessation of snap-trapping. For example assume that there were seven waves of invaders to the termination of snap trapping, 90 days from its initiation, and that the migration persisted thereafter until 10 more waves of invaders had entered the pit traps. This means that residents of 21 bands of 300 feet width will have been captured. This gives:

Animals per acre	Total animals captured after 17 waves of invasion
2.5	3,570
5.0	7,140
10.0	14,280
20.0	28,560

Were the phenomenon to continue through 17 waves of invaders, inhabitants from 1376 acres surrounding the 52 acres, inhabited by animals immediately exposed to the traps of the half-octagon, will have been attracted into this tract. In other words residents to invaders will have the ratio 1:26.56.

5. The 9-unit moving trap-line plot

Daniel Brant (Small rodent populations near Berkeley, California: *Reithrodontomys*, *Peromyscus*, *Microtus*. Ph.D. Thesis, Museum of Vertebrate Zoology, University of California, Berkeley, California) introduced a new concept for studying home range. The concept demands that each capture or observation result from the encounter of a moving animal with a moving trap. At the time the animal encounters the trap, the trap is actually not moving. The trap moves in the sense that each day a particular group of traps is moved to a new location. The shifting of the traps from day to day to new locations traces a path. This path represents the movement of the traps and requires several days for completion. During such a period each encounter between animal and trap must take place at a different location from prior ones. Captures are unbiased by learning of locations. In the general area being studied a number of non-overlapping trap-paths of similar pattern are simultaneously being run. The points on any one path are so far removed from similar points on other paths in adjacent areas that very few traps are actually set at any one time within any particular animal's home range. This arrangement reduces the likelihood of traps interfering with normal home range movements, and thus reduces the likelihood of the calculated home range being smaller than the actual.

Brant based the locations of stations for setting traps on a system of points representing the intersection of rows and columns within which the same interval characterized that between rows and between columns. Such a pattern of points is easy to set out; but has the disadvantage of making points at some distances from calculated home rage centers more or less probable with reference to the space available at such radial distances. Such an undesirable consequence stemming from the locations of trapping stations will be avoided by a uniform distribution of points representing trapping stations. In such a system of points every point is the center of a hexagon formed by connecting the surrounding six equidistant nearest points to it, and connecting all such points forms a field of equilateral triangles. See Figure 4. I therefore recommend for home-range studies that trapping stations be represented by such a uniform distribution of points. This necessitates a change from Brant's procedure with regard to specifities, but maintains his basic philosophy. Further remarks about home range studies are given in Section V-7.

However, the present concern is with studying experimentally induced migratory movements. Even in this it is desirable in live-trapping to avoid the complications introduced by the opportunity of the same animal being captured at the same point on two successive days. For this reason I recommend the use of the modified moving trap line. It is designated as "The 9-unit moving trap-line plot."

Each such plot (Figure 4) consists of 27 points forming trapping stations. These 27 points are grouped into nine triangular units, designated as unit 1 to unit 9. In systematic fashion the stations of each unit are numbered 1 to 3 as shown on Figure 4. Set two live-traps within a 2.5 ft. radius of the station marker. During home-range studies place the traps within this radius wherever it is deemed most likely to capture animals. When using this method of live-trapping for the study of experimentally induced movements use the trap placements described in Section V-6.

Ten days are required to trace the moving trap-line path. On day 1 set the six traps at unit No. 1. On day 2 move the traps to unit No. 2. On day 3 move the traps to unit No. 3, . . . , until on day 10 traps are removed from unit No. 10. On day 10 move the traps back to the vicinity of unit No. 1. Place the traps in a pile, unset, at a convenient location, not at any of the stations of unit No. 1. It is advisable to allow an interval of 4 or 11 days before resetting traps. This gives the investigator a respite from his labors, but more important it gives the animals opportunity to recover from any ill effects associated with being trapped. Of equal importance, this intervening period removes the disturbance produced by the investigator tramping through the environment.

6. Use of the 9-unit plot to investigate induced mass movements

From the central point, P, of the half-octagon kill-trap pattern survey three straight lines passing through the corners of the half-octagon. These lines are to be numbered 1, 2 and 3 in a clockwise fashion as shown in Figures 2 and 5. At 1000, 2000, 3000, 4000, and 5000 feet from the edge of the half octagon place markers, numbered 1 to 5 respectively. These represent the mean coordinate point, M, (x = 115.5 ft., y = 100 ft) of each 9-unit plot. The x-axis of the plot is to lie perpendicular to the line.

Assuming that the first setting of the kill-traps of the half-octagon begins on a Monday, also set the six traps for each triangular unit No. 1 on that data, and remove them from unit No. 9 the Wednesday of the following week. During the next four days set no line traps. This absence of traps allows animals to recover from any ill effects of trapping or disturbances introduced by the trapper walking through the habitat. Then on the following Monday again start line trapping on the No. 1 triangles. Thus live trapping is initiated every other week. Locations of captures may be designated, for example, as 25321 which means capture on radial line 2, the fifth plot along the line, triangular unit No. 3 of that plot, corner (station) No. 2 of that triangle, and trap No. 1 of that station.

<u>Placement of traps at each station:</u> The two traps at a station are to be numbered 1 and 2. Place trap No. 1 two feet from the station marker toward the center point, P. Place trap No. 2 two feet from the marker away from center point, P. If the induced migration is highly directional there should result a preponderance of captures in the No. 2 traps for stations which capture one animal. Extreme precautions should be taken to reduce mortality resulting from animals being captured in traps. If necessary protect the traps with covers from rain and sun. Revisiting the traps at shorter intervals than 24 hours may be necessary. The average mortality per 24 hours should not exceed 5%. With any greater mortality than this, there will result local reductions of density sufficient to cause movements toward these smaller areas of reduced density, and thus introduce the possibility of interfering with the main induced movement.

As a control procedure 15 other 9-unit plots should be established with similar orientation to a point near the edge of the habitat. These are to be in an area far removed from the main study area. All 9-unit plots in the control area should be run on exactly the same days as on the experimental area so as to eliminate any possibility of weather producing differences in results.

For both control and experimental area, live trapping results should be quite similar for the first three periods of live trapping (i.e., beginning on the 1st, 3rd, and 5th weeks of kill-trapping on the experimental area). These results should assume the following general picture: Many unmarked animals will be taken the first Period of live trapping. The second period of live trapping fewer unmarked animals will be captured. By the third period most animals captured will already have been marked.

However, during the 4th period of trapping (the 7th week of kill-trapping on the experimental area) marked differences should characterize comparisons between live trapping on the control and experimental area. On the control areas only a very few unmarked animals will be captured. These will be normal wanderers, recently weaned animals, and a few others moving in to replace any deficit from mortality. In contrast on the experimental area some marked animals will have already left the vicinity of the 9-unit plots and started their journey toward the central depleted area. Their places will have been taken by unmarked animals, previously living farther out. For this reason a number of unmarked animals will be trapped in live traps during the fourth period of trapping on the experimental area.

By the 5th period of live trapping (the 9th-10th weeks of kill trapping) differences of results between control and experimental areas should have become marked. By that time some marked animals should be captured in kill traps and possibly a few marked animals may be taken in one 9-unit plot of the experimental area that were originally marked farther out.

I will not here engage in any further discussion of treatment of such results, but it is obvious that they will contribute to determinations of speed of travel and distance of the chain reaction of induced migration.

Note: For purposes of calculating distances moved, and rate of movement, all animals captured in any plot may be treated as having originated from the mean coordinate point, M, of that plot.

7. The 5x6 plot "quadrat" for studying home range

Studies of home range do not necessarily form an integral part of the study of induced mass movements. However, knowledge of home range in terms of the variability of the home range sigma distances and the distances between home range centers, would materially contribute to the understanding of the origin of induced mass movements. See: Calhoun, J. B. and Casby, J. U. Calculation of home range and density of small mammals. 1958, Public Health Monograph No. 55, 24 pp., U. S. Government Printing Office, Washington, D. C.

The quadrat study plot here recommended consists of 30 9-unit plots placed as shown in Figure 6. On day one the six traps of triangular unit No. 1 in each of the 30 plots are set. Similarly the traps in each plot are moved to the next higher numbered unit on successive days. Centers of triangular units simultaneously set will be 250 feet apart in the y-direction and 260 feet apart in the x-direction.

General statistics

(a) Area of quadrat: 39.54 acres

(b) Area of 62.5 ft. buffer zone: 7.17 acres

Animals with home range centers falling within this peripheral buffer zone are to be excluded from the analysis since their home range will likely lie partially outside the quadrat.

(c) Area of quadrat not including buffer zone = 32.37 acres

(d) 180 traps required (*i.e.*, 30 plots, 6 traps per plot)

(e) Daily walking distance in servicing quadrat = 4 miles

Home range centers and home range sigmas can reliably be calculated only for animals with two or more captures. The following theoretical results provide an insight into the magnitude of effort required:

Consider that there are 100 animals whose home range centers lie within the 32.4 acre non-buffer zone portion of the quadrat. On the average one animal is captured in each unit of six traps. This gives 30 captures per day or 270 for the nine days of tracing the paths of the moving trap lines. On the average each animal will be captured 2.7 times. 4x2.7 = 10.8. Therefore on the average it will require four 9-day periods (with 4-11 days between periods) to obtain adequate data. Analyses will be based upon over 1000 captures. Preferably the trapping should encompass five periods to insure that a larger proportion of the population will meet the minimum criterion of 10 captures.

Captures can be designated by plot, unit and station (*e.g.*, 23-6-2 means capture on plot 23, unit 6, station 2). I have prepared this procedure for studying home range so that data are amenable to machine analysis of all relevant equations given in the paper by Calhoun and Casby, 1958, cited above, as well as additional analyses suggested in my paper, The Social Use of Space. The computer programs for such analyses have not yet been written. Should there prove sufficient interest in the utilization of the procedures detailed here, I will see to it that a computer program is written up and made available.

Somewhat separate from the computer program itself is the preparation of data in a form suitable for transfer to IBM type punched machine-sort cards. The prime data are:

(a) Station designation and its x and y coordinates. There are 810 stations. Their numbers and coordinates represent one battery of data.

(b) Master card for each animal, by toe or tag number which identifies it. Included on this card may be such items as species, sex, date of first capture, relative age on first capture, and any other data concerning the animal anticipated to remain stable over the study period, and finally death date if it occurs during the study period.

(c) Daily record data: Number of animal, station of capture, and any other additional data deemed to be relevant.

(d) Microhabitat: The investigator may be interested in answering questions about the capture at or avoidance of stations within an animal's home range with regard to characteristics of the habitat near stations. Such study may be integrated into the over-all program by letting the station number-coordinate card be a master one with each remaining column designating a characteristic by either presence or absence or degree on a rating scale.

Where home range studies are conducted in conjunction with the study of induced migrations, they should take place at a separate location, but in a similar habitat.

VI. Primary objectives

1. Panic Related Phenomena

If an induced mass movement can be sustained for a sufficiently long time the experiences of each individual involved will be of an entirely different order than customary for the species. Prior to involvement in an induced mass movement each individual will have customarily made appropriate responses to a wide variety of stimuli, each of which was meaningful in terms of spatial and temporal aspects of their occurrence. They repeatedly encountered every aspect of their home range; routes between goals became known; signals emitted by neighbors impinged on each individual in a regular pattern, thus facilitating orientation. In other words, in the natural course of events the environment is both varied and predictable, permitting a wide variety of meaningful responses, each to a particular set of stimuli.

Once an animal is drawn into an induced mass movement few aspects of its environment remain constant and predictable. Its neighbors no longer move toward and away from it about their own home range centers as formerly. Each movement away from its former home range brings encounters with unfamiliar configurations of the environment. To be sure, similar types of stimuli are encountered, but they fail to permit the former degree of predictability with regard to consequences of responses. No longer are routes to safe retreats known; no longer are certain routes to sources of food known, no longer is it possible to maintain communication with recognizable other individuals.

Only one aspect of the environment remains predictable. Stimuli originating from other individuals remains of a lesser intensity and of a lesser frequency of occurrence from one direction than from all others. Movement in this direction tends to make uniform the intensity and frequency of stimuli in all directions. However, since all associates are making the same response, each individual soon finds itself in the same circumstance of less social stimuli being detected from the same direction. Thus there develops a sustained movement in a given direction. This movement in a given direction becomes the only constant type of response to a repeatedly present pattern of stimuli. Every other response, such as related to eating, drinking, or resting finds expression each time under a different set of stimuli. Thus there are no constant reinforcing stimuli for any behavior except the onward directed movement.

Under these circumstances onward movement will become the most persistent and predominant behavior. At any moment in time the shift from one behavior to another is influenced by the degree of which behaviors are rewarded or reinforced. Probability of reinforcement becomes increasingly greater for the behavior of onward directed movement than for any other. Thus if we could observe any individual during its travel in an induced mass movement, we would find it engaging in relatively long periods of movement in a given compass direction, interspersed with relatively brief periods of such activities as eating, drinking, grooming or sleeping. Relative is here used in reference to the duration of behaviors of animals living in an undisturbed static home range situation.

When one behavior alone in a large repertoire is persistently reinforced, it may be expected to persist for a long time even in the absence of the normal reinforcing stimuli. That is to say, such a behavior will have a long time course of diminution or extinction. Furthermore, it may be anticipated to be sustained even in the face of stimuli, which in the undisturbed animal, would have led to cessation of movement in a given direction. In part this will arise from reduced powers of discrimination. During the course of onward movement few stimuli will have had relevance to responses. Necessity of making discriminations will have been reduced. Thus when faced with a noxious stimulus, the animal will evince a reduced tendency to avoid ti.

With this general theoretical background two procedures for study present themselves. First we may study the induced mass movement as an ongoing process or, second, we can capture animals involved in the process and compare them under appropriate experimental conditions with other animals captured from an undisturbed community.

2. Study of the induced mass movement

Now suppose that through persisting removal in a half-octagon and drift-fence design for capturing invaders we have been able to maintain an induced mass movement for a fairly long period of time. Of course we do not know the duration of a "fairly long period of time." I can only suspect that it must be at least 70-90 days after the removal of all resident animals from the half-octagon area. This means that removal trapping must continue for 90-110 days from the time of initiating trapping.

Consider that trapping was terminated at the end of 90-110 days but that the drift fence was left in operation. If all the postulated changes in behavior had taken place, animals will continue to move toward the experimental area and into it until they contact the drift fence, whereupon they would move along it and into the pit-trap. On a theoretical basis this process should continue until the environment to its limit of a formerly continuous population had become essentially void of residents.

If invasion persisted during the time that only the drift-fence, pit-trap system of capturing invaders was in operation, and if the half-octagon had been placed toward the edge of the habitat bounding upon a habitat where conditions were unsuitable for the species involved, other studies are possible. By unsuitable habitat I refer primarily to such conditions as a large body of water, completely barren desert, a cliff, or a wide surface highway. The unsuitable habitat should be such as to permit easy observation of animals moving into or across its edge or surface.

Now suppose that animals after cessation of removal trapping have persisted in entering the pit-traps for an additional 15-25 day period. At the end of the time place covers over the nine pit-traps, and remove the drift fence for a distance of about 20 feet in either direction from each pit trap. This will leave nine discrete breaks in the drift-fence. If the induced mass movement has developed to the extent hypothesized, then invaders will converge upon the breaks in the barrier fence, pass through it, and enter the undesirable habitat. If this habitat be water the animals will continue swimming out into it in the direction of their original movement on land. If the body of water is too wide, they will all drown. If the body of water or other habitat is narrow, they will cross it, continue moving in the usual direction, but after a time gradually cease moving farther on if conditions reinforcing the behavior no longer persist, particularly if they move into suitable habitats where members of an otherwise undisturbed population live.

3. The study of disturbed animals

We must start with the situation where members of an induced mass movement have continued to enter pit-traps after cessation of trapping on the lines of the half-octagon. Given this state of affairs, we live-trap animals, which otherwise would have gone into the pit-trap; these will be called the experimentals. From an undisturbed area live-trap a comparable group of controls. A set of hypotheses may be stated for investigation.

(1) Discriminations are made less well by the experimentals.
(2) Learning by experimentals is poorer.
(3) All behavior except for locomotion are of shorter duration.
(4) Complex behaviors are more ineffectively executed by experimentals.

Items (1) and (2) in part overlap insofar as testing is concerned. Some suggested tests:

(a) Simple discrimination learning: Use a simple Y maze, that is, a single choice situation. The arms are to be neutral colored channels with vertical walls. Each terminates in a somewhat larger chamber. The starting box, arms, and end chambers are covered with glass or screen. Suspended above the apparatus are lights of sufficient intensity to be noxious. If the animal tested chooses the appropriate arm the light intensity drops to a level more desired by the animal. Regardless of the chamber arrived at the animal is forced to remain then by dropping a door at the end adjacent to the chamber. The subject is left in the chamber it arrives at for several minutes. Then it can be started in another of the series of trials in a set. Run several, possibly ten trials in each set before returning the animal to its cage where it was confined after capture. Let c.s. represent the stimulus condition. For example, prepare a plate the height and length of an arm. Shade or structure the surface different from that of the walls of the arms. Then the c.s. plate can be inserted in random order on sequential trials on the outside wall of the left or right arm of the Y. Run 5 sets of trials, with an hour between trials for several consecutive days. If the hypothesis is correct the controls will more rapidly approach perfection in a set of ten trials.

(b) Visual cliff test: For a number of mammals it has been shown that they tend to avoid jumping off of a platform. Prepare a box whose floor is 3 feet in diameter and whose walls are three feet high. Walls are to be painted white and the floor checkered black and white with the diameter of the squares approximating the body length of the species studied. On the top of a single pipe pedestal fix a platform the width of the animal's body and 12 inches long. The height of the platform should be adjustable by sliding the pipe through the floor. This means that the floor of the field must be elevated above the floor. Calibrate the field with recently caught control animals. Starting with the platform at 30 inches above the floor run series of subjects at successively lower levels until a point is reached where 50% of the subjects jump off the platform within some fixed span of time, less than 10 minutes. Then compare the performance of controls and experimentals at this or a slightly higher level. If the hypothesis is correct, more experimentals should jump off and in an average shorter time.

(c) Conditioned avoidance: The apparatus consists of a two-compartment box, with compartments identical and designated as A and B. The floors of each consists of bars through which a shock, the unconditioned stimulus, u.c., can be administered on either side separately. An opening between the two sides requires that the animal jump over or climb through. A buzzer or sound source serves as the conditioned stimulus, c.s. At the start the animal is placed in one compartment and after a period of time the u.c. given until the animal jumps to the opposite side, where no shock occurs at that time. Then after a period of time the u.c. is given to the animal in the compartment to which it had gone at the time of administering the last u.c. This process is continued until immediately upon administering the u.c. the animal jumps to the opposite side. Beginning at this phase the c.s. is presented a few seconds before the u.c. The number of trials required to jump to the opposite side immediately upon presentation of the c.s., which produces avoidance of receiving the u.c., serves as the measure of rapidity of developing a conditioned avoidance. If the hypothesis is correct the experimentals will require more trials.

(d) Alteration of duration of behavior: The objective here is to measure the durations of a long series of behaviors. By providing separate places where eating, drinking, running and sleeping may take place recording is facilitated. I have used an apparatus containing an activity wheel, W, a nest compartment, N, a lever, L, which when depressed provides a drop of water, and a treadle, T, which when stepped on means that the animal is under a hopper where it may feed. W and N are at opposite ends of a runway. T and L are at opposite ends of another runway. The two runways are at right angles to each other and cross at their centers, thus when the animal is at the intersection it has a choice of going to any one of the four places. Durations of continuous revolving of the wheel, depressions of the lever, remaining on the treadle or in the nest box are automatically recorded on an Esterline-Angus event tape recorder. If the hypothesis is correct the experimentals will spend much more time running in the wheel. On the other hand the durations of the other three behaviors (eating, drinking and sleeping) should be shorter.

(e) Execution of complex behaviors: The requirement for a complex behavior suitable for study is that it be elicited without additional training. Construction of nests and care of young by recently parturient females should serve as adequate behaviors. This assumes that near-term females will be available among both controls and experimentals. If the hypothesis is correct the experimentals will exhibit disorganized maternal behavior both with regard to nest construction and care of young.

VII. Induced Mass Movements as a Means of Population Control

Before any consideration of application, the phenomenon of induced mass movements must be established as being possible by executing the studies of Section V. Assuming that such a demonstration has been made, we may then ask what alterations of procedure might produce effective results with less effort.

Only where extensive tracts of land are involved can such a means of population control prove economically feasible. Replace traps with poisoned bait stations or distribute poisoned bait along the half-octagonal lines. Conduct no poisoning for several weaks in areas through which the effects of the central poisoning is anticipated to spread. Absence of such disturbance will permit development of more stable social-spatial relationships among members of the population. This stability will enhance the probability that poisoning in a central area will induce a mass migration. There remains the question of placement of the poisoned-bait half-octagonal plots. The usual drift-fence pit-traps form a component part of such a removal procedure.

Consider first the case where the habitat within which we wish to reduce density is a stable one in terms of the plant species. I am here thinking of a type of situation where rodents living in an extensive natural habitat serve as intermediate hosts for a disease transmissible to man. In this case drift-fence pit-trap and half octagon poisoned bait procedures of killing animals can be established at appropriate intervals along the periphery of such a habitat. I can only suspect that one such set every mile along the edge might be adequate. Even after termination of poisoning the drift-fence pit-traps might be left in place to continue a slower removal.

Secondly consider the case where extensive uniform agricultural land borders upon extensive natural habitats. Initially heavy infestations of rodents may characterize both habitats. The problem will be to reduce the populations in both habitats without producing the opposite effect from that desired, that is, without causing an invasion into the agricultural land. One half-octagonal pattern should be placed near the interface between the natural and the agricultural habitats. This is to be oriented so as to attract animals out of the agricultural land. Such an induced movement might cause some attraction of animals from the natural habitat. To insure the removal of such animals the drift-fence over the pit-traps should permit entrance into the pit-traps from either surface. However, such counter-movement from the natural habitat into the agricultural land should be actively prevented. To do this establish a second half-octagonal removal pattern within the natural habitat. Its center point, P, should lie along a line at right angles to the interface between the habitats. This line also passes through the center point P, of the setup at the interface. The half-octagonal setup should lie well within the natural habitat, at a distance equal to that which the earlier experiment with snap-traps revealed the effect to extend. It should be initiated sometime prior to initiating the setup at the interface. By so doing the two removal half-octagon patterns will act in concert in producing a movement out and away from the agricultural habitat.

In the case where a ravine or long narrow neck of natural habitat extends through the agricultural land placing a half octagon setup at its base may enable more effective drawing out of animals from the agricultural land. Where such a neck contacts a body of water, removal of the barrier fence following establishment of a well defined mass movement might result in a continuance of the phenomenon with all invaders entering the water and drowning.

Figure 7 schematically presents the theoretical consequences of simultaneously establishing eight such half-octagonal procedures for inducing mass movements. Arrows indicate general routes of movement.

Should such procedures prove effective in producing an initial marked reduction in population density, the final question pertains to maintaining a reduced population in the agricultural lands, maximally with no rodents at all present in the agricultural land. Such a state frequently does exist following plowing of extensive areas prior to planting and the growth of the crop to the point where it will support a rodent species capable of damaging the crop. Such animals which do damage crops must come from neighboring older growth crop land or from reservoirs of populations established in neighboring natural non-agricultural habitats. Thus ultimately the problem reduces itself to one of maintaining the populations in neighboring natural habitats at such a low level that for all practical purposes the pressures leading to natural invasion will be so low that there will be too few invaders to assure establishment of a reproducing population within the agricultural land.

Particular attention should be paid to reducing or eliminating populations within islands of natural habitat surrounded by agricultural land at those times when the surrounding agricultural land has recently been harvested and plowed. Other than for leaving the drift-fences in place within the adjacent extensive natural habitat following the half-octagon poison induced movements, I shall not further discuss appropriate procedures for maintaining low densities in such reservoir habitats. Suffice it to say, I am here emphasizing an about-face in the philosophy of rodent control re agricultural crops: Control densities in neighboring reservoir habitats and the damage to adjoining agricultural land will diminish to the point of economic insignificance.

Table I

Ratios of animals: area and relative densities as induced migration proceeds through time (Periods). See Figure 1.

Band:	1	2	3	4	5	6	7	8
Relative Area:	1	3	5	7	9	11	13	15
Period 1	3/1 3.00	5/3 1.67	7/5 1.40	9/7 1.28	11/9 1.22	13/11 1.18	15/13 1.15	17/15 1.13
Period 2	5/1 5.00	7/3 2.33	9/5 1.80	11/7 1.57	13/9 1.44	15/11 1.36	17/13 1.30	19/15 1.26
Period 3	7/1 7.00	9/3 3.00	11/5 2.20	13/7 1.85	15/9 1.66	17/11 1.54	19/13 1.46	21/15 1.40
Period 4	9/1 9.00	11/3 3.67	13/5 2.60	15/7 2.14	17/9 1.88	19/11 1.72	21/13 1.61	23/15 1.53
Period 5	11/1 11.00	13/3 4.33	15.5 3.00	17/7 2.42	19/9 2.11	21/11 1.90	23/13 1.76	25/15 1.66
Period 6	13/1 13.00	15/3 5.00	17/5 3.40	19/7 2.71	21/9 2.33	23/11 2.09	25/13 1.92	27/15 1.80
Period 7	15/1 15.00	17/3 5.66	19/5 3.80	21/7 3.00	23/9 2.55	25/11 2.27	27/13 2.07	28/15 1.93
Period 8	17/1 17.00	19/3 6.33	21/5 4.20	23/7 3.28	25/9 2.77	27/11 2.45	29/13 2.23	31/15 2.06
Period 9	19/1 19.00	21/3 7.00	23/5 4.60	25/7 3.57	27/9 3.00	29/11 2.63	31/13 2.38	33/15 2.20
Period 10	21/1 21.00	23/3 7.66	25/5 5.00	27/7 3.85	29/9 3.22	31/11 2.81	33/13 2.53	35/15 2.33

Table II

Theoretical trap-line statistics

Line	Approx. Length in feet	Stations per line	Traps per line	Acres per line 1/	Residents per line 2/
A	2960	297	594	10.55	105.5 3/
B	2507	252	504	8.92	89.2
C	2053	206	412	7.30	73.0
D	1600	161	322	5.68	56.8
E	1146	116	232	4.06	40.6
F	693	70	140	2.43	24.3
G	240	25	50	0.81	8.1
Total	11,199	1,127	2,254	39.75	397.5

1/ Within 75 ft. of each line.

2/ Calculated at 10 per acre.

3/ Actually more will be removed during initial removal trapping since animals living out to perhaps 225 feet will also be taken bringing the total captures on the A line up to 227, thus making a total of 519 residents captured.

Table III

The influence of probability, p, of being trapped on passing through a trap line on the removal of a "wave" of 300 animals entering the half-octagonal pattern of trap-lines.

R = Relative area about line
A = Animals arriving at line
S = Stations per line

Table IIIa; p = 0.1

Line	Relative Area R	Number of Animals: Arriving at line	Number of Animals: Killed on line	S/A	A/R 1/
A	13	300	30	0.99	23
B	11	270	27	0.93	25
C	9	243	24	0.85	27
D	7	219	22	0.74	31
E	5	197	20	0.59	39
F	3	177	18	0.41	59
G	1	159	16	0.16	159
Center, P		143			

1/ The relative unit of area of 1.0 is equivalent to that lying within the half circular area of radius = 150 feet about the center point, P. This is a 0.81 acre unit.

Table IIIb; p = 0.25

Line	R	Number of Animals		S/A	A/R
		Arriving	Killed		
A	13	300	75	0.99	23
B	11	225	56	1.12	20
C	9	169	42	1.22	19
D	7	127	32	1.27	18
E	5	95	24	1.22	19
F	3	71	18	0.99	24
G	1	53	13	0.47	53
Center, P.		40			

Table IIIc; p = 0.3

Line	R	Number of Animals		S/A	A/R
		Arriving	Killed		
A	13	300	100	0.99	23
B	11	200	67	1.26	18
C	9	133	44	1.55	15
D	7	89	30	1.81	13
E	5	59	20	1.97	12
F	3	39	13	1.79	13
G	1	26	9	0.96	26
Center, P.		17			

Table IIId; p = 0.5

Line	R	Number of Animals Arriving	Killed	S/A	A/R
A	13	300	150	0.99	23
B	11	150	75	1.68	14
C	9	75	37	2.75	8
D	7	38	19	4.24	5
E	5	19	9	6.10	4
F	3	10	5	7.00	3
G	1	5	2	5.00	5
Center P.		3			

Table IV

Theoretical captures in "central" half-octagon during an induced mass movement. (Accumulated totals in parentheses.)

Source	Origin (Bands)	Relative area	Acres 1/	Residents 10/acre	Residents 5/acre	Residents 2.5/acre	Radius in feet
Residents	1-4	16	51.9	519	260	130	1200
Wave 1	5	9	29.2	292 (811)	146 (406)	73 (203)	1500
2	6	11	35.7	357 (1168)	179 (584)	89 (292)	1800
3	7	13	42.2	422 (1590)	211 (795)	106 (398)	2100
4	8	15	48.7	487 (2077)	244 (1039)	122 (519)	2400
5	9	17	55.2	552 (2629)	276 (1315)	138 (657)	2700
6	10	19	61.7	617 (3246)	309 (1623)	154 (811)	3000
7	11	21	68.2	682 (3928)	341 (1964)	171 (982)	3300
8	12	23	74.6	746 (4674)	373 (2337)	187 (1168)	3600
9	13	25	81.1	811 (5485)	403 (2743)	201 (1371)	3900
10	14	27	87.6	876 (6361)	438 (3181)	269 (1590)	4200
Total		196	636.1	6361	3181	1590	

1/ Relative area x 3.24545

Table V

Theoretical mean rates of migration 1/

Waves in 70 days	Days to move 300 ft.	Ft/day	Maximum catch 2/ per day
4	17.50	17.1	162
5	14.00	21.4	184
6	11.67	25.7	206
7	10.00	30.0	227
8	8.75	34.3	249
9	7.78	38.6	270
10	7.00	42.9	292

1/ See discussion under Section Vd.

2/ Under the assumption that one third of each wave will arrive within half octagon during a one-day period and that there is a density of 10 animals per acre.

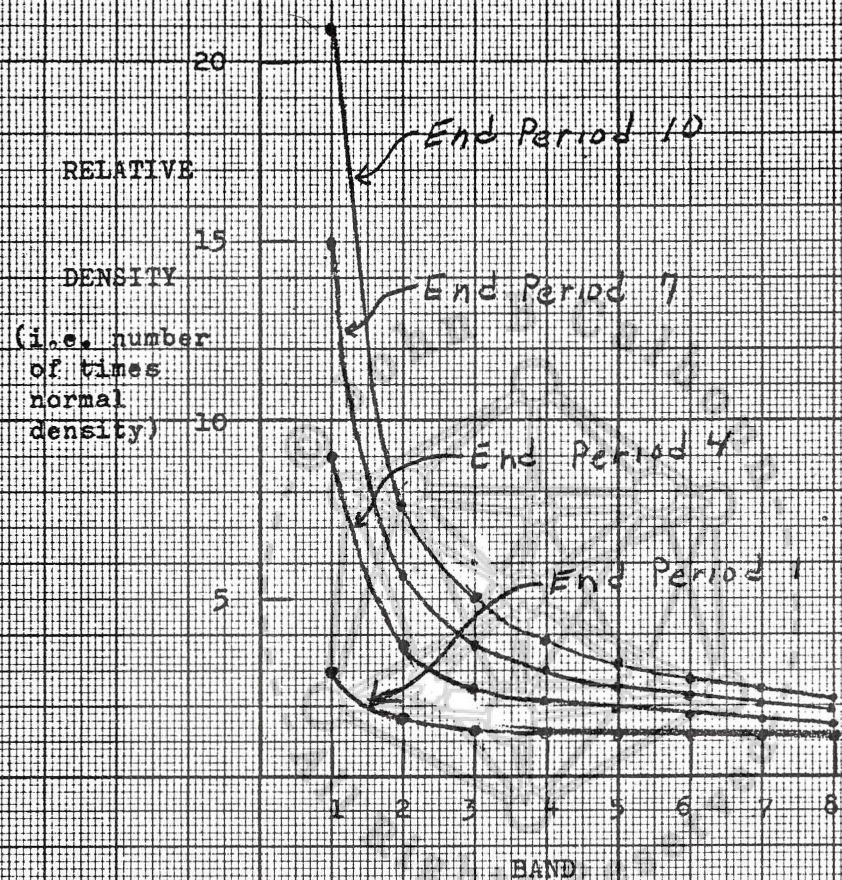
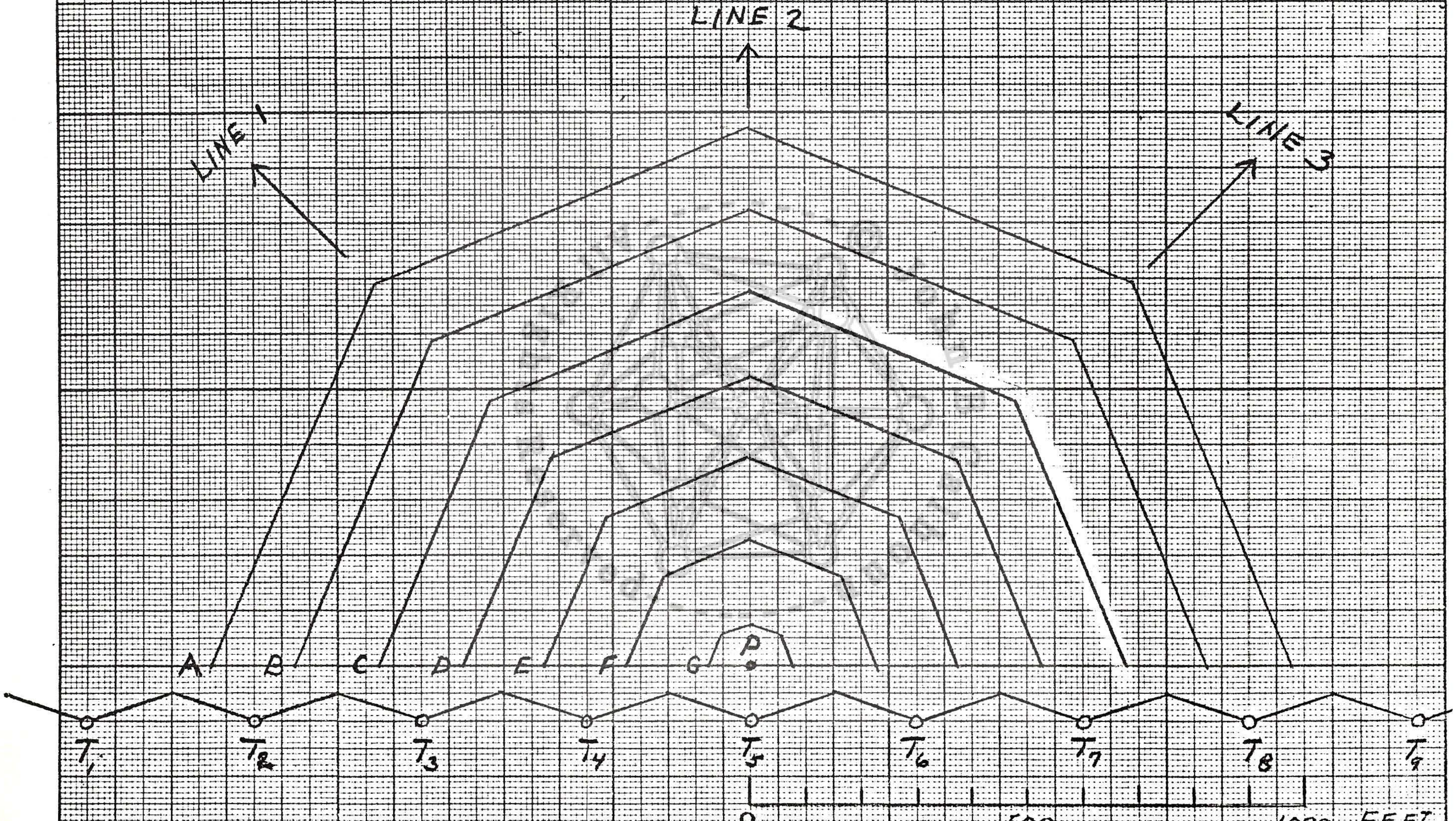

RELATIVE
DENSITY
(i.e. number of times normal density)
20
15
10
5
End Period 10
End Period 7
End Period 4
End Period 1
1
2
3
4
5
6
7
8
BAND

FIGURE 1



LINE 1
LINE 2
LINE 3
A
B
C
D
E
F
G
P
T_1
T_2
T_3
T_4
T_5
T_6
T_7
T_8
T_9
0
500
1000 FEET

FIGURE 2

MAZE ABOUT PIT-TRAP, T

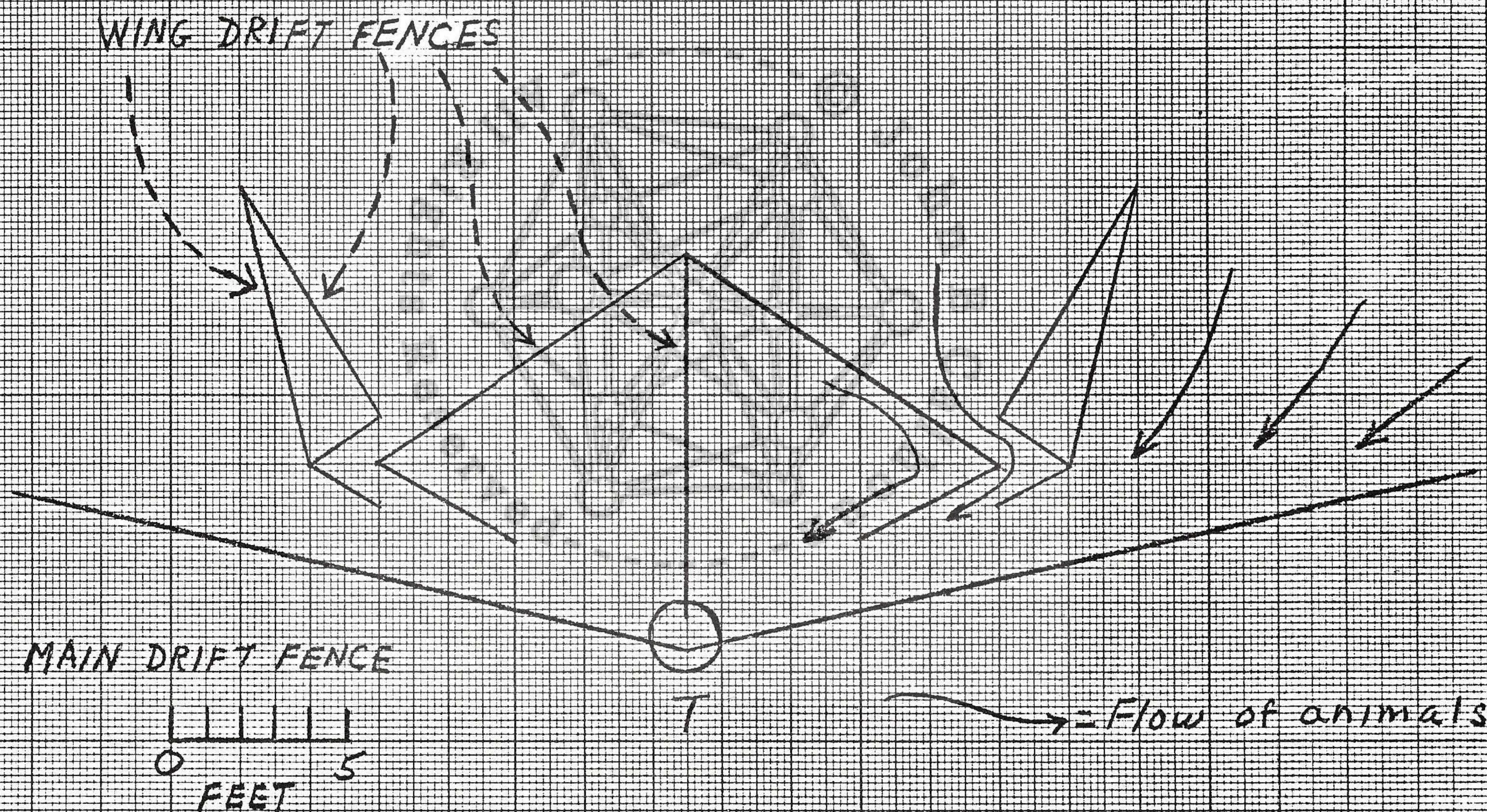
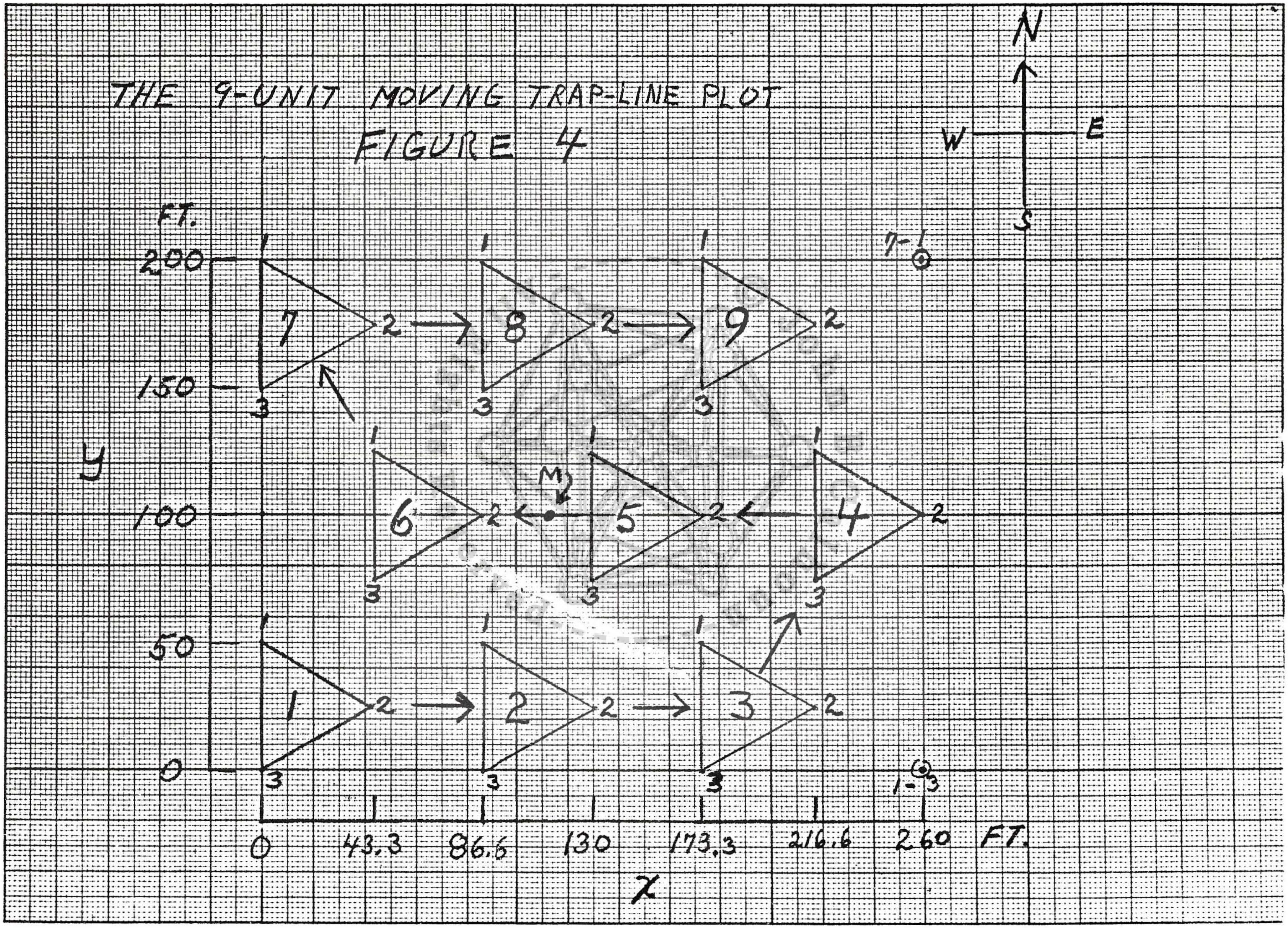


FIGURE 3

THE 9-UNIT MOVING TRAP-LINE PLOT

FIGURE 4



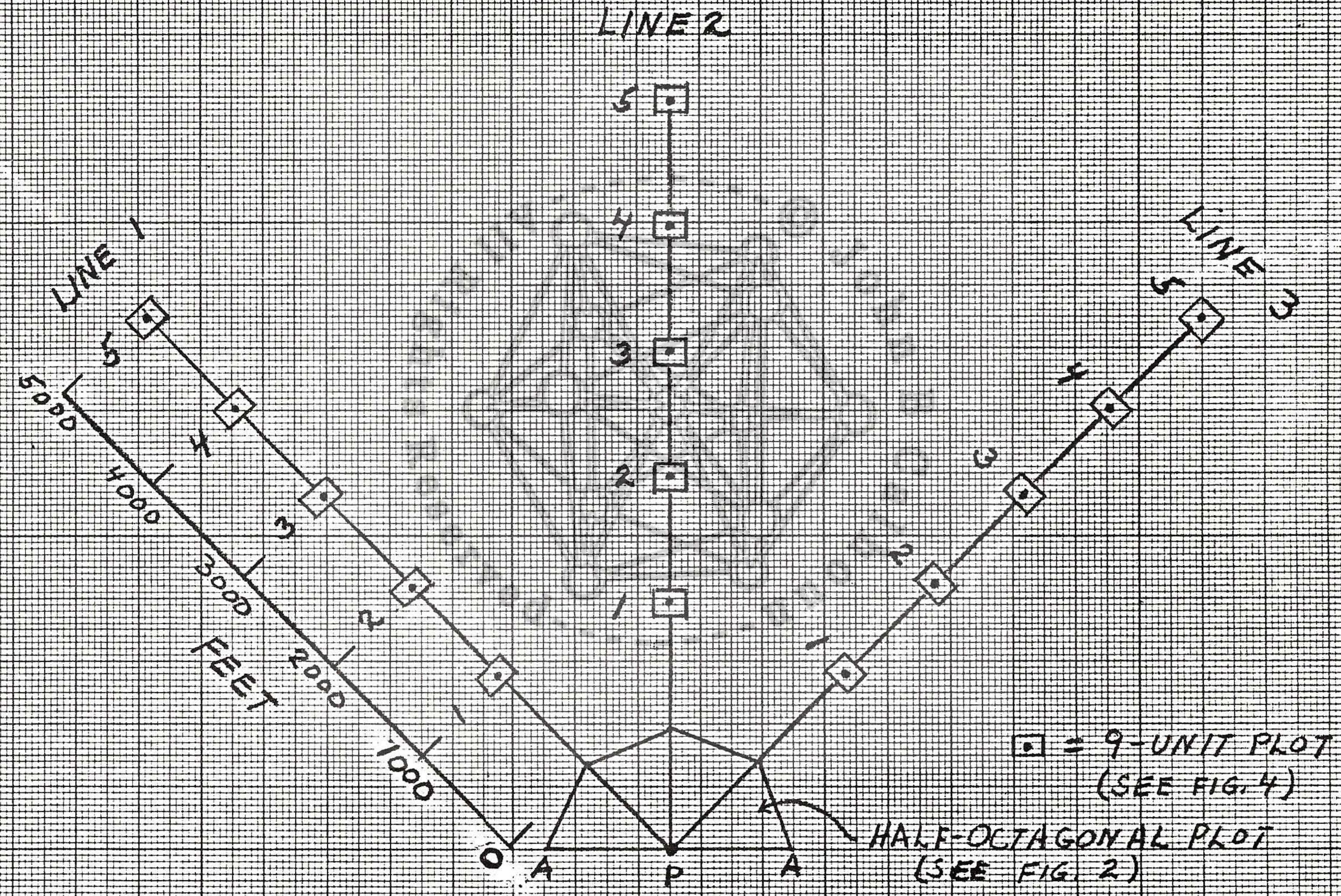
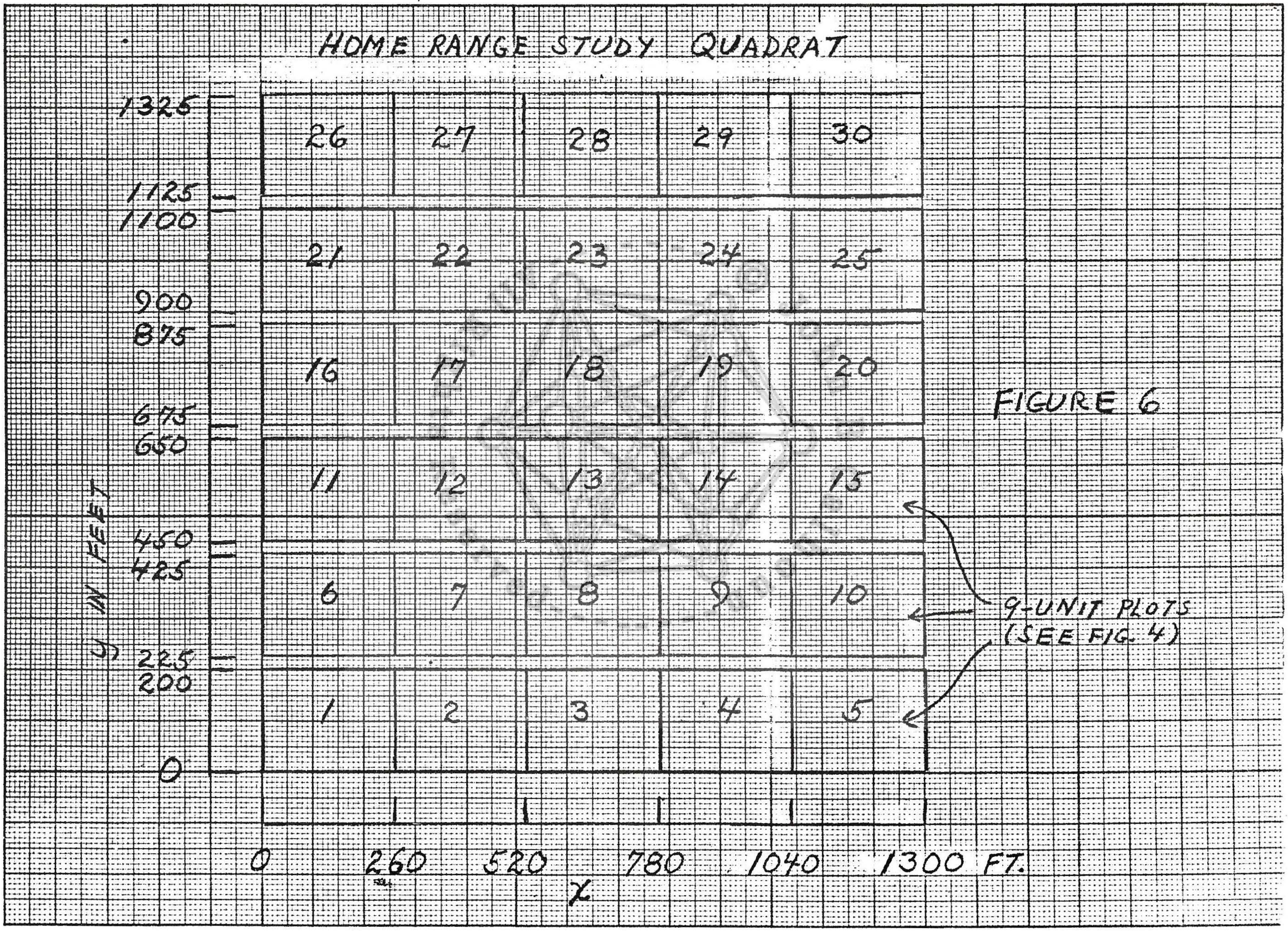

LINE 1
LINE 2
LINE 3
1
2
3
4
5
1000
2000
3000
4000
5000
FEET
O
A
P
A
= 9-UNIT PLOT
(SEE FIG. 4)
HALF-OCTAGONAL PLOT
(SEE FIG. 2)

FIGURE 5


HOME RANGE STUDY QUADRAT
26
27
28
29
30
21
22
23
24
25
16
17
18
19
20
11
12
13
14
15
6
7
8
9
10
1
2
3
4
5
1325
1125
1100
900
875
675
650
450
425
225
200
0
y IN FEET
0
260
520
780
1040
1300 FT.
x
9-UNIT PLOTS
(SEE FIG. 4)
FIGURE 6

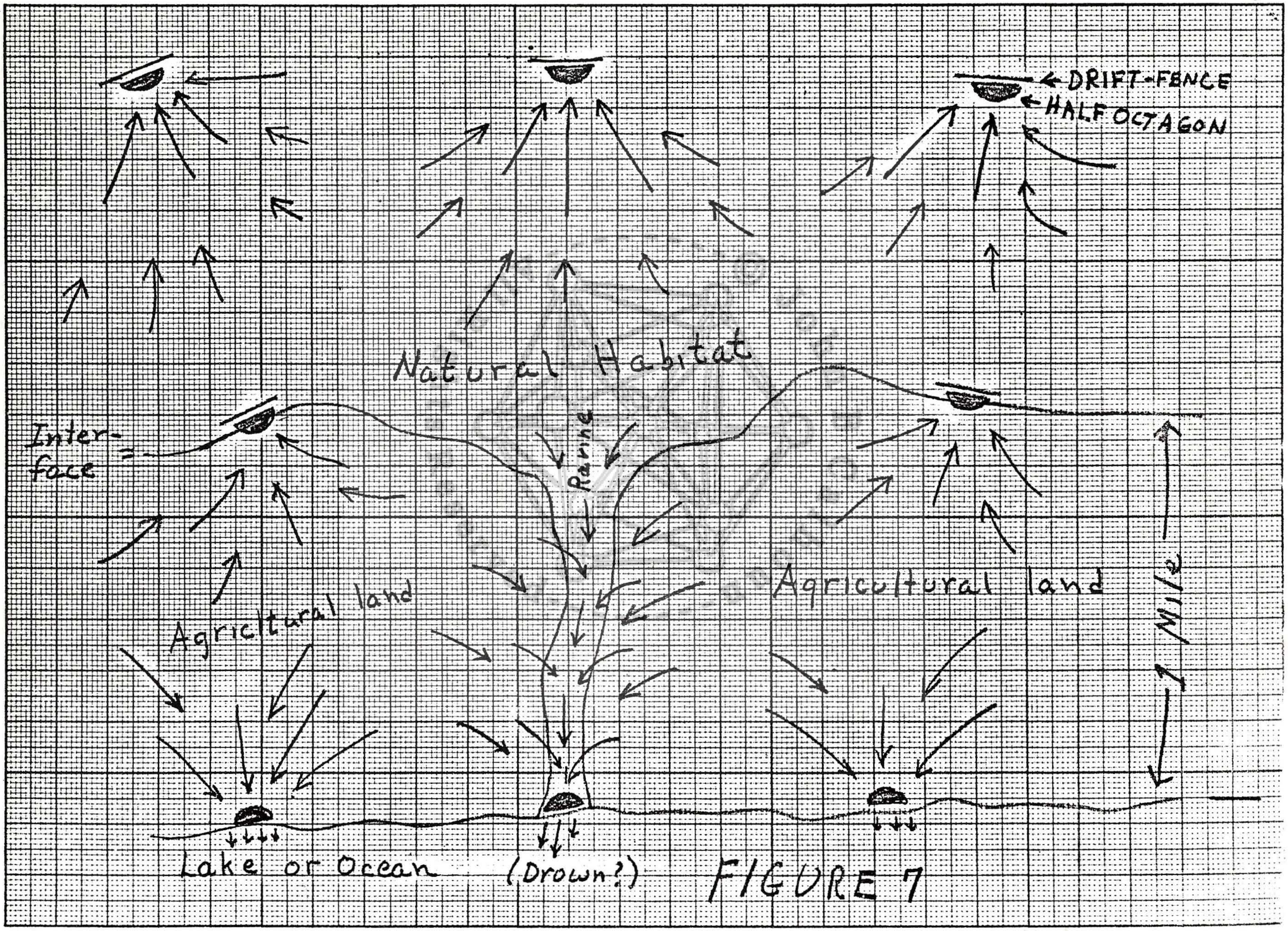

DRIFT-FENCE
HALF OCTAGON
Natural Habitat
Ravine
Inter-face
Agricltural land
Agricultural land
1 Mile
Lake or Ocean
(Drown?)

FIGURE 7