Northwest and
Alaska
Fisheries Center

National Marine
Fisheries Service

U.S. DEPARTMENT OF COMMERCE

NWAFC PROCESSED REPORT 83-05

Fish Attraction to Baits and Effects of Currents on the Distribution of Smell from Baits

May 1983

FISH ATTRACTION TO BAITS

AND EFFECTS OF CURRENTS ON THE

DISTRIBUTION OF SMELL FROM BAITS

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May 1983

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ABSTRACT

Fish are attracted to baits mainly by olfactory stimuli (smell). Past studies show that most olfactory attracted fish swim against the current, and that currents near the bottom distribute the smell from the baits. The emission of attractive olfactory stimulants from the bait decreases rapidly with time so that within an hour about 40% of the total soluable proteins (which are main stimulants) may have dissipated. The interactions between changing leaching rate of smell, current speed and direction in relation to the line, and mixing of the smell fields from adjacent baits is expected to be relatively complex. A numerical model has been designed to study these interactions.

The formulas used in the model are described, and the model is reproduced, in the Appendix. The model was used to compute smell pattern developments with time with different current speeds and directions in relation to the line of baits. Hook (bait) spacing influences the strength of the smell field as does the direction of current in relation to the line of baits. The smell field in a rotary current is greatly determined by the current direction at the time of the setting of the long line.

To validate the computed distributions of smell, current measurements at very close intervals near the bottom are required (5, 10, 20, and 40 cm from the bottom). Furthermore there is a need to know the lowest smell concentrations at which fish react in various conditions and commence the search for bait (attraction threshold).

1. INTRODUCTION

Research in the last few decades has confirmed that in most fish distant location of food is by olfactory stimuli (smell) (e.g., Atema 1980). The attracting smell from baited fishing gear (long lines, pots) is distributed by currents and their associated turbulence. Thus, the long line catch might be affected by currents (e.g., speed and direction in relation to line direction). This distribution of smell with currents can be studied with numerical methods of advection as used in Hydrodynamical Numerical (HN) models. These numerical studies might also indicate the necessity of measurements for validation.

The rate of emission of smells from baits decreases with time as the baits are leached out (Solemdal and Tilseth 1978). The interaction between changing leaching rate and changing currents (e.g., tidal currents) is expected to result in complex smell distribution patterns in space and time (smell fields), which would affect the attraction of fish to the bait.

This paper reviews the mechanism of fish attraction by smell emitted from baits, and describes the methods and results of a study of the distribution patterns of smell as affected by different near bottom currents. The results are expected to find some application in long line and baited trap fisheries, indicating such factors as the effect of varying the height of bait above bottom, optimizing the direction of long line setting in relation to current, and what might be the optimum soak time. Above all, the studies with the model should indicate what additional research and measurements must be conducted.

2. FISH ATTRACTION BY BAITED GEARS AND DISTRIBUTION OF SMELL FROM BAITS

In fishing with any kind of baited gear, the primary purpose of the bait is to attract fish to the location of the gear, and, subsequently, to entice them to enter the trap or to bite the hook. The bait, therefore, has to emit stimuli which are attractive to the target fish, at levels of intensity sufficient to induce the fish to search for the source of smell.

The bait also has to remain intact (i.e., stay on the hook) and continue to emit stimuli for a period long enough to permit the attracted fish to find the bait.

In the near field, where the process of capture takes place, vision may also be of great importance, but attraction beyond a few meters is probably nearly always based on olfactory stimuli (e.g., Kleerekoper 1969). For certain species of fish with less developed olfactory organs, however, chance foraging also will be of significance in their feeding behavior (Pipping 1926, 1927).

Bait attraction

In the following we shall assume that olfactory stimuli alone are causing the far field attraction of a bait. Since fish have been found to be able to detect chemicals at extremely low levels of concentration (Atema 1980), we shall further assume that the presence of a bait stimulus in the water inhabited by a fish will always be detected.

The bait scent or smell, however, has to compete with the large array of other stimuli to which the fish is subjected at the time. The reaction to the awareness of a new smell will, therefore, be dependent on its relative attractiveness to the fish, which may be a function of many factors, such as physiological state, food and feeding conditions, previous diet, time of season or day, etc. (e.g., Fernö et. al. 1981, Solemdal et. al. 1983). The level of intensity of the bait smell will be important. Probably it must exceed a certain threshold before the fish reacts by starting to search for the bait, and it is conceivable that this reaction threshold may be modified by the duration of stimulation.

In conventional cut long line bait (e.g., herring, mackerel, squid), water soluable proteins have been found to be attractive olfactory stimulants. These are rather quickly dissolved and dissipated in the water, some experiments indicating emission rates of as much as 40% of the total contents of soluable proteins being dissolved within an hour at normal ambient sea water temperature (Solemdal and Tilseth 1978).

The bait stimuli is not emitted at a constant intensity, but rather at a quickly (in the matter of minutes) increasing and, thereafter, gradually decaying rate. Most likely, the emission has already culminated by the time the long line or pot has sunk to the bottom in offshore fishing.

For baits placed on the sea bed, the stimuli are dissipated by the movements of water close to the bottom. UW-TV observations of fishing gear suggest that near bottom currents are weak but variable, both in velocity and direction, even when there is a clear main direction of water transport. We may, therefore, assume that the stimuli from a point source on the sea bed are dissipated downstream along the bottom within an arc, of say 20-40°. Horizontal velocities very near the bottom are probably seldom above a few cm/sec in relevant fishing locations, which is well below endurance swimming speeds for the species and sizes of fish caught by baited fishing gears.

Vertical dissipation of bait stimuli is probably mainly caused by near bottom turbulence.

Because of the quck decay in stimuli emission rate at very slow bottom current velocities (and/or at small arcs of dissipation), the emission decay rate may exceed the rate of stimuli intensity decrease caused by geometrical spreading. In such cases, fish attracted by the bait at a distance would swim into decreasing stimuli intensities whichever direction they are heading. While steep intensity gradients and distinct chemical trails provide sufficient information for localization, the gradients in the stimuli farfield of a baited gear are normally so weak that other non-chemical cues are required for localization of the baits (Kleerekoper et. al. 1975). Knowledge and understanding of the mechanisms in food localization of fish are as yet rather incomplete, but it is believed that fish are able to sense the direction of water movement and locate the source by swimming upstream when aroused by smell stimuli (Atema 1980).

The number of fish attracted to the bait will be a function of fish density, area of attraction, and the variability in attraction rate within this area. The total number of fish attracted to the bait, when plotted against soak time will, therefore, form a sigmoid curve, ascending slowly during the early part of the soak, then at a gradually steeper rate which falls off again as the rate of attraction decreases.

The time required for the stimuli to be dispersed below the attraction level plus that required for the most distant attracted fish to get to the bait, is the maximum soak time required to attract fish. Unless fish from outside move into the stimuli area, any further soak time will be non-productive, even if the bait is still emitting stimuli.

3. EFFECTS OF CURRENTS ON THE DISTRIBUTION OF SMELL FROM BAITS

3.1 The numerical model

Molecular diffusion in the water is very slow and, therefore, the main mechanism for the distribution of smell from bait is current and turbulence (eddy diffusion) associated with it.

The currents near the bottom are weak, but the current speed increases rapidly with distance from the bottom (Figure 1). This increase with height above the bottom depends on the roughness of the bottom and current speed in the water mass above. The increase of current speed with increasing distance from the bottom would affect the distribution of smell from bait which is hung at different heights above the bottom (e.g., in traps). Unfortunately no current measurements in very short distances over the bottom (few cm) are at hand at present.

Over the continental shelf, and especially in shallower waters, tidal currents dominate. These currents can be diurnal or semidiurnal; the change of direction and speeds is usually ellipse-like. In water shallower than about 30 meters, wave motion (particle movement in below-surface layers due to waves) can reach the bottom and affect the distribution of smell from baits. The easiest way to study the complexities of smell distribution from bait is with a numerical model with spatial resolution.

In the present study the distribution of smell from bait was simulated with a numerical model where different speeds, directions, and different source strengths were prescribed.

Experiments show that the amount of smell emitted from the bait decreases rapidly with time. This decrease was simulated with Formula 1.

$$S_t = \frac{1}{at+1} S_o \qquad (1)$$

where S_t is the strength of the smell at the source at time t, S_o is the initial strength and a is a numerical constant. Two different values were assigned to a and the results are shown in Figure 2.

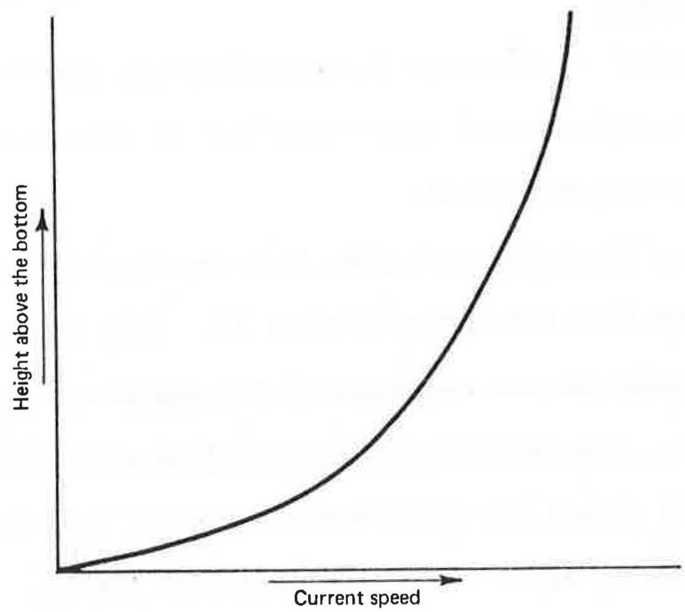

Figure 1.--Schematic profile of current speed near bottom.

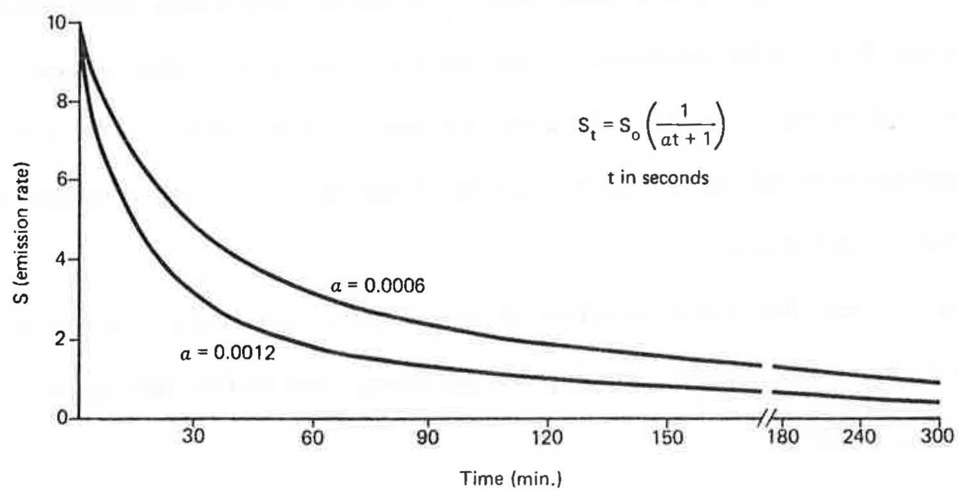

Figure 2.--Simulated decrease of smell emission from bait with two different decay constants.

In smell distribution simulation experiments, the amount of smell at any given time was released either at a single point to study its distribution in detail, or in a row of points 2 to 8 meters apart to simulate baited hooks in a long line with different hook spacing.

The current speed was simulated with prescribed u and v components and horizontal turbulence was simulated with the fluctuations of these components. The unidirectional flow was simulated with Formulas 2 and 3.

$$U = U_b + U_a \cos(\alpha_1 t) \tag{2}$$

$$V = V_b \cos(\alpha_1 t + \kappa_1) \tag{3}$$

where U_b and V_b are prescribed u and v components of the current, U_a is the magnitude of fluctuation of u component and V_b is a small fraction of U_b (13% in the programme in Appendix, this fraction growing with increasing U_b). The V_b component is for the simulation of horizontal eddy diffusion of smell due to fluctuations in current. If main current direction is desired in v direction, the Formulas 2 and 3 change position. α_1 is the phase of current fluctuation (changing either 1 or 2 degrees per second (6 or 3 minute periods)); t is time in seconds, and κ_1 is phase lag (e.g., 45°).

A rotating tidal current was simulated with Formulas 4 and 5.

$$U = U_b \cos(\alpha_2 t + \kappa_2) \tag{4}$$

$$V = V_b \cos(\alpha_2 t + \kappa_3) \tag{5}$$

where α_2 is 0.008 degrees per second, κ_2 is 90° and κ_3 is 180°.

The advection of smell was computed with an "upcurrent differentiation" method. First, the gradient of smell (S_v of S_u) in upcurrent direction was computed:

U positive:

$$S_u = (S_{n,m} - S_{n,m-1})/d \tag{6}$$

U negative:

$$S_u = S_{n,m} - S_{n,m+1})/d \tag{7}$$

where n and m are the coordinates of grid points and d is grid size (in cm).

The computation of the gradient of S in v direction (S_v) is analogous to Formulas 6 and 7.

The concentration of S in any grid point was thereafter computed:

$$S_{n,m} = S_{n,m} - (t_d|U|S_u) - (t_d|V|S_v) \tag{8}$$

where t_d is length of time step (in seconds) and U and V are corresponding components of currents.

Additional horizontal diffusion was computed with a smoother:

$$S_{n,m} = \alpha_3 S_{n,m} + \beta(S_{n+1,m} + S_{n-1,m} + S_{n,m+1} + S_{n,m-1}) \tag{9}$$

where α_3 was 0.80 and $\beta = (1 - \alpha_3)/4$.

The conservancy of the diffusion and transport formulas was computed after each smoothing.

The grid distance was selected either as 1, 2, or 4 meters and the corresponding time step used was either 30 or 60 seconds, depending on grid size.

In some runs, the vertical height or thickness of the smell distribution layer was made to thicken with distance from the bait (simulating vertical eddy diffusion), and the amount of smell (S) was distributed in this thickening layer, resulting in lower concentrations with distance from source.

3.2 Distribution of smell from single bait

Some results of the computations with the above described model are discussed below with reference to current speed and its direction in relation to the direction of the long line. The initial strength of smell emission was arbitrarily selected at 10 units in the first 30 seconds. The emission decreases with time as shown in Figure 2. Figure 3 shows the distribution of "smell field" after 1 and 2 hours of soak time, with a constant current speed of 0.2 cm/sec. After two hours, the "nominal field strength 10" (the contour of the 10 units of "smell") has reached 22 meters from the bait, and the width of the "10 field" is about 12 meters.

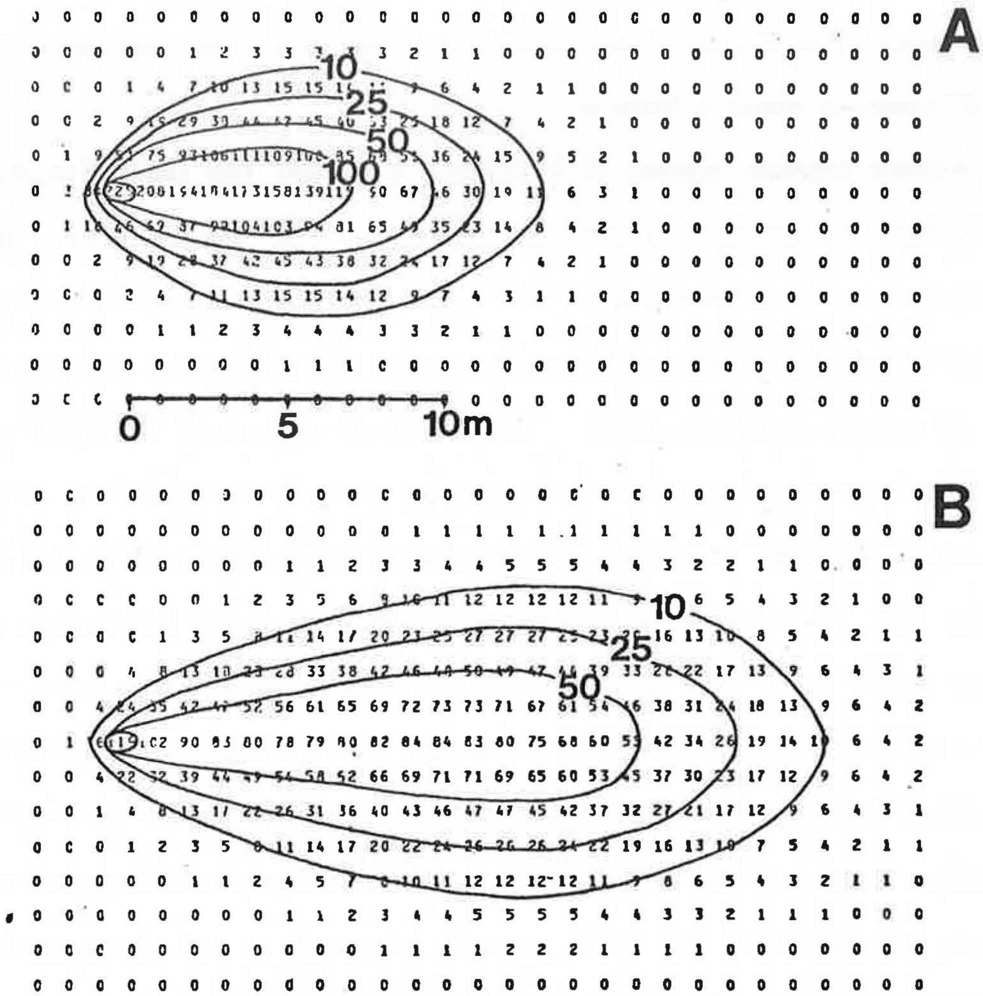

Figure 3.--Distribution of smell from a bait with current speed of 0.2 cm/sec; laminar flow; A - after 1 hour soaking, B - after 2 hours soaking. (10 units of smell emitted in every 30 seconds.)

With a current speed of 0.6 cm/sec (Fig. 4) the length of the "10 field" is about 32 meters after one hour and its width about 6 meters (Fig. 4A). After two hours, the maximum width of the "10 field" remains about the same, but the length is now about 43 meters from the bait, with lower concentrations in between the bait and this higher concentration area. This feature is caused by the rapid decrease of smell emission with time (Fig. 2). The maximum width of the "10 field" remains about 6 meters.

With higher current speeds (1.4 cm/sec, Fig. 5A) the smell field gets longer and wider, but its concentrations lower (observe the increased grid distance in these computations). The width of the field increases slower than its length (i.e., the "10 field" width with current speed of 1.4 cm/sec is at maximum 12 meters at about 55 meters from the bait). The width of the smell field is an important factor in estimation of optimum hook spacing as it determines the strength of the smell field by overlap of fields from adjacent baits (Figs. 8 to 20). After two hours (Fig. 5B), the center of secondary maximum is about 105 meters from the bait. The smell field strength between this secondary maximum and at the bait is only slightly more than half the strength of the secondary maximum.

The occurrence of the higher concentration of smell away from the bait raises the questions whether fish can find the hook (bait) and are attracted to it in such cases, and how does the smell stimuli existing in the environment (e.g., benthos) interact with the search for the bait?

Rotary tidal currents prevail on the continental shelf. Therefore, computations of the distribution of smell from a single bait were made with rotary current (rotation period 12 hours). At time 0 the current was running to east (right) with U = 0.65 cm/sec. Figure 6 shows the smell distribution after 2 hours and Figure 7 after 3 hours. Due to the rotational effect, the smell field becomes c-shaped, with higher concentrations some distance from the bait, resulting from the decreasing emission rate of the smell.

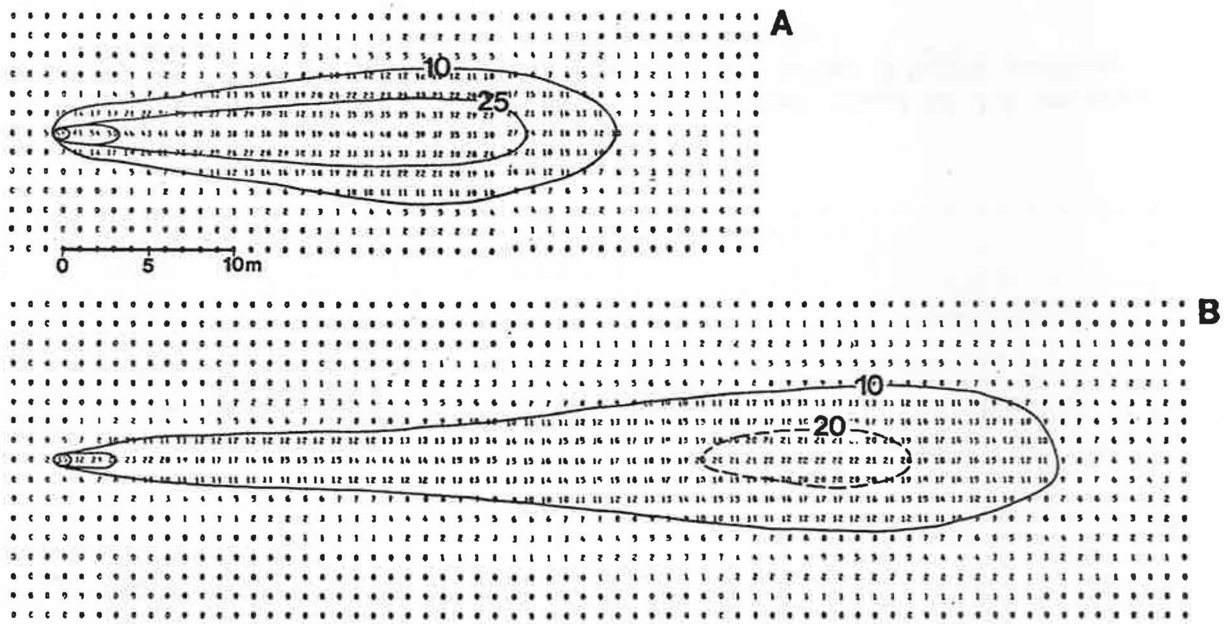

Figure 4.--Distribution of smell from a bait with current speed of 0.6 cm/sec; laminar flow; A - after 1 hour soaking, B - after 2 hours soaking. (10 units of smell emitted in every 30 seconds.)

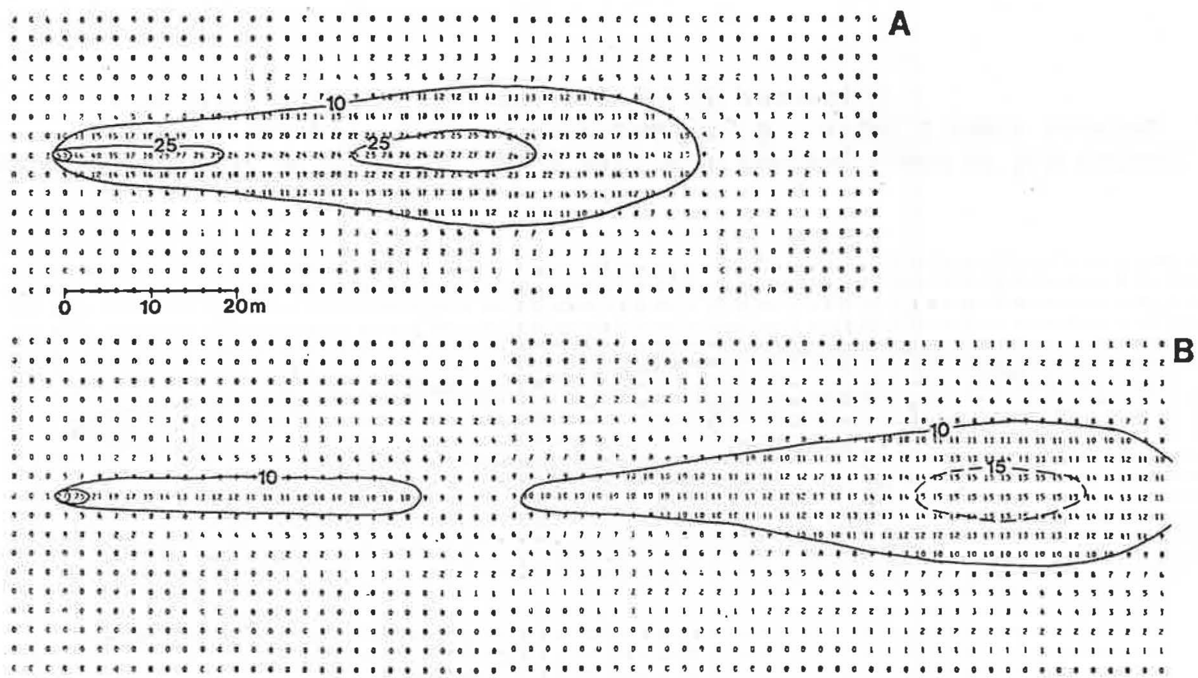

Figure 5.--Distribution of smell from a bait with current speed of 1.4 cm/sec; laminar flow; A - after 1 hour soaking; B - after 2 hours soaking. (10 units of smell emitted in every 30 seconds.)

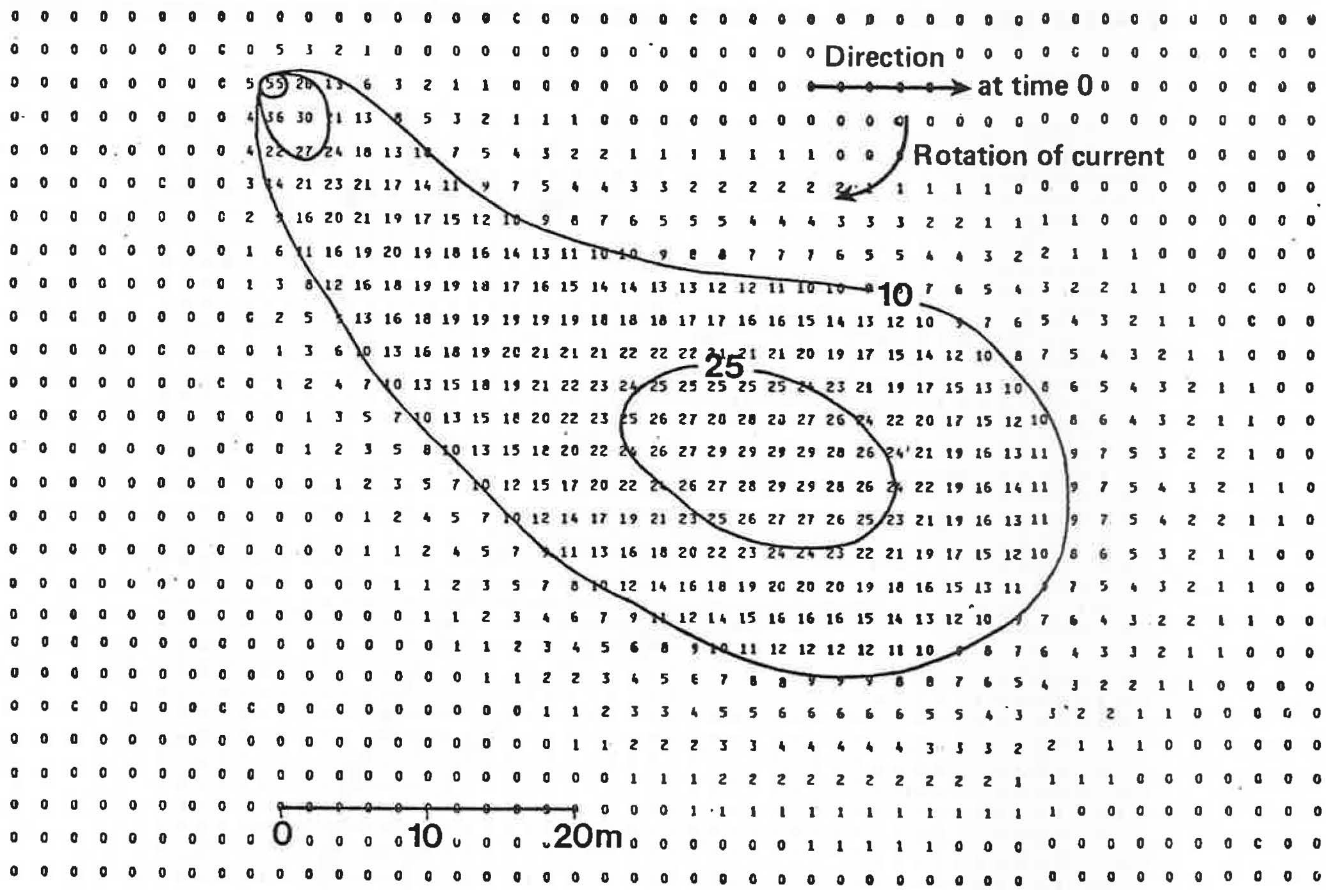

Figure 6.--Smell field in a rotary current after 2 hours (initial flow to the right, 0.65 cm/sec, full rotation in 12 hours).

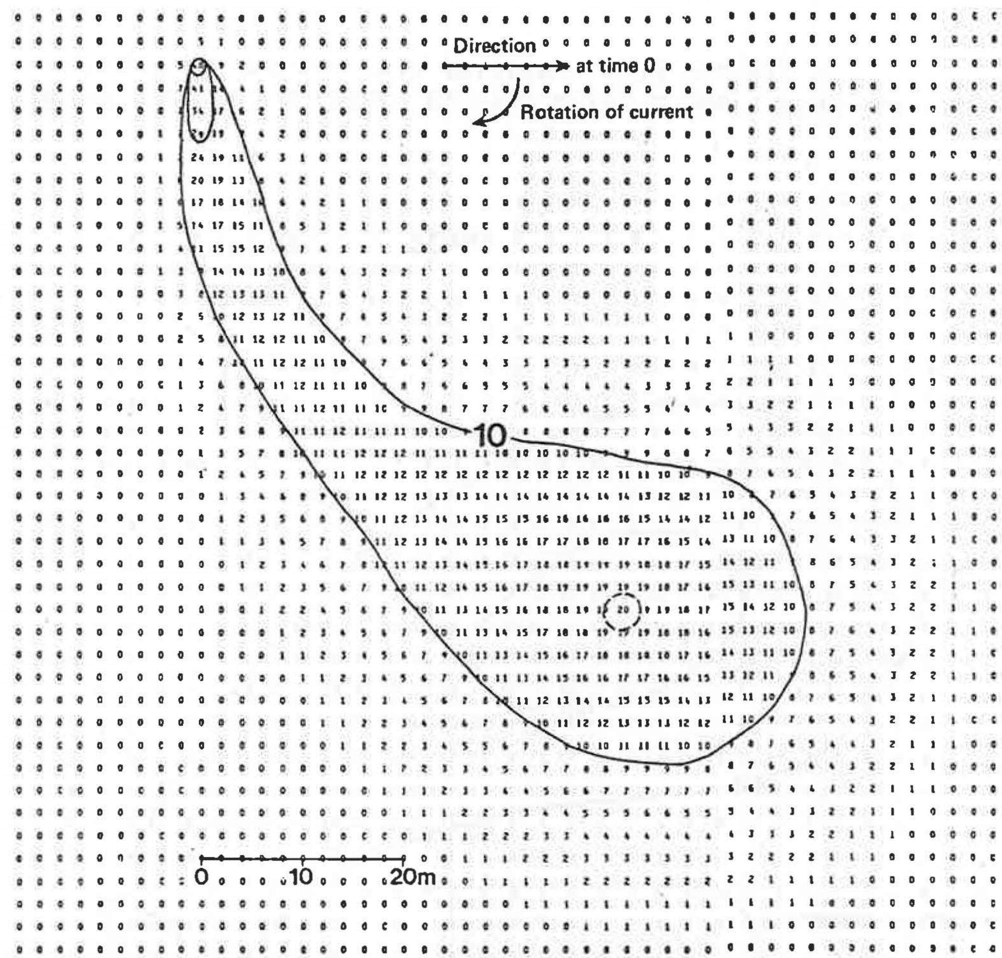

Figure 7.--Smell field in a rotary current (same as in Figure 10) after 3 hours.

3.3 Distribution of smell from a line of baits in unidirectional current

As the smell field expands laterally downcurrent due to turbulence (eddy diffusion), it is expected that the smell fields from individual baits would overlap. Computer runs with 6 and 11 baited hooks in a line with 2 and 4 meters hook spacing were made, in which an 0.6 cm/sec current was perpendicular to the line. Figure 8 shows the resulting smell field after 1 hour from 6 baited hooks 4 meters apart. The second maximum smell field concentration is about 20 meters downcurrent of the baits and is somewhat stronger than the field from a single bait (Fig. 4A). The smell field from a line of baits 2 meters apart after one hour soak time in 0.6 cm/sec currents is given in Figure 9. Although the second maximum of the smell field is at the same distance from the hooks as in Figure 8 (ca. 20 meters downcurrent), its strength is about twice that in Figure 8. Thus, closer spacing of hooks might better attract fish to the bait by creating a stronger smell field.

After two hours soaking time (Figures 10 and 11), the center of the maximum smell field is about 45 meters downcurrent in both bait spacings. The smell field between this maximum and the baits is about one-third of the strength of the maximum field strength. The field strength with 2 meters hook spacing is about twice as strong as that with 4 meters spacing.

The results of the computations of smell fields presented in Figures 3 to 11 were made assuming laminar flow (no turbulent eddy exchange in vertical direction). In nature, the flow is likely to be turbulent also in a vertical direction to some degree, and the layer in which the smell is distributed near the bottom will increase in thickness with the distance from the bait which decreases concentrations of smell. Some outputs from the computations with increasing layer thickness are shown in Figure 12, with other conditions (current speed and bait spacing) being the same as in Figure 10. Comparing Figure 12 with Figure 10, we can notice that

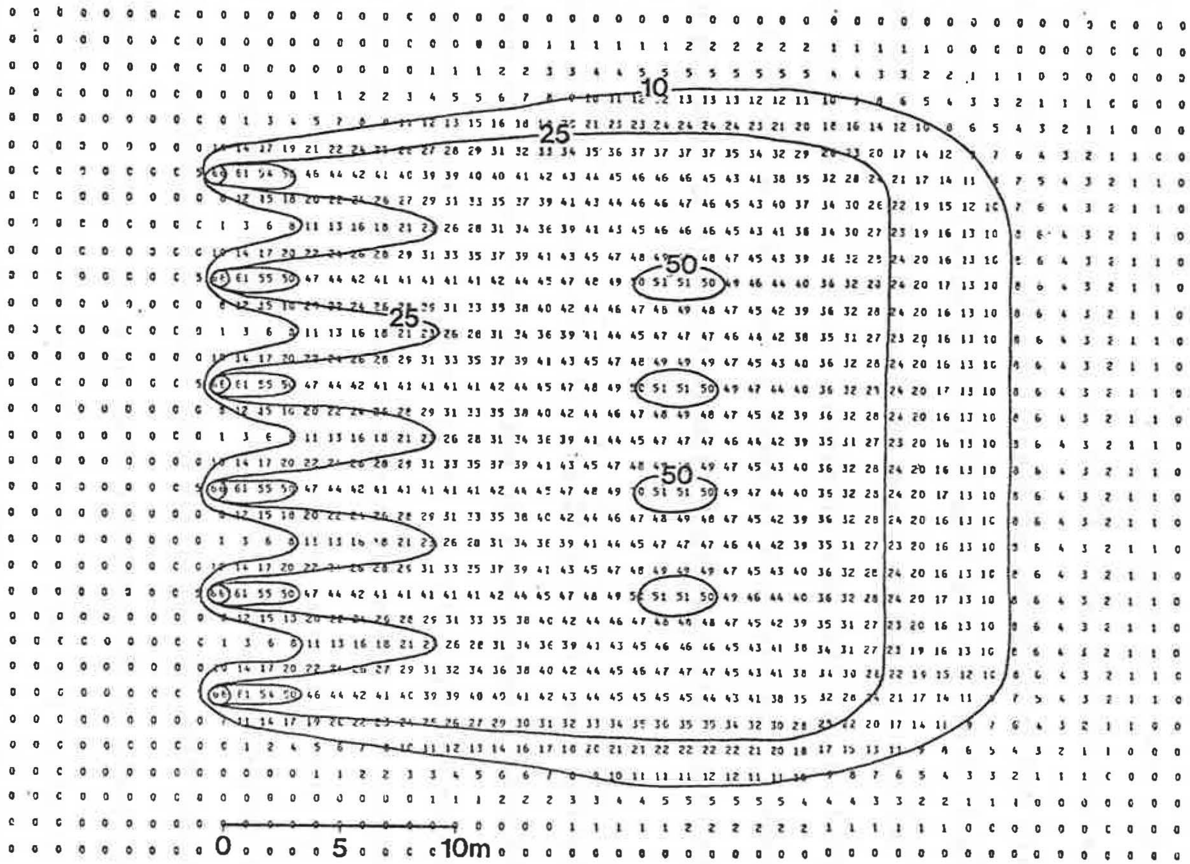

Figure 8.--Smell field from a line of 6 baited hooks, 4 meters apart, after 1 hour. 0.6 cm/sec, laminar flow.

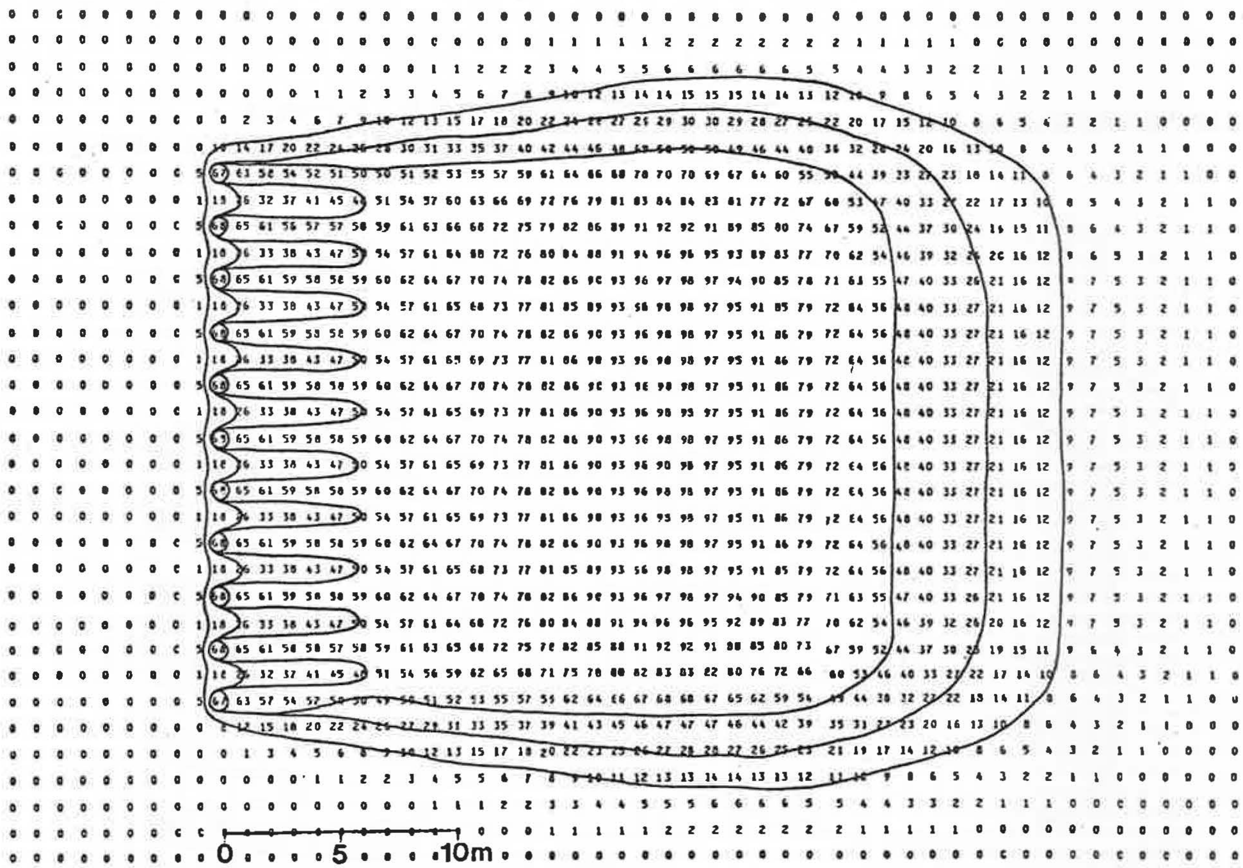

Figure 9.--Smell field from a line of 11 baited hooks, 2 meters apart, after 1 hour. 0.6 cm/sec, laminar flow.

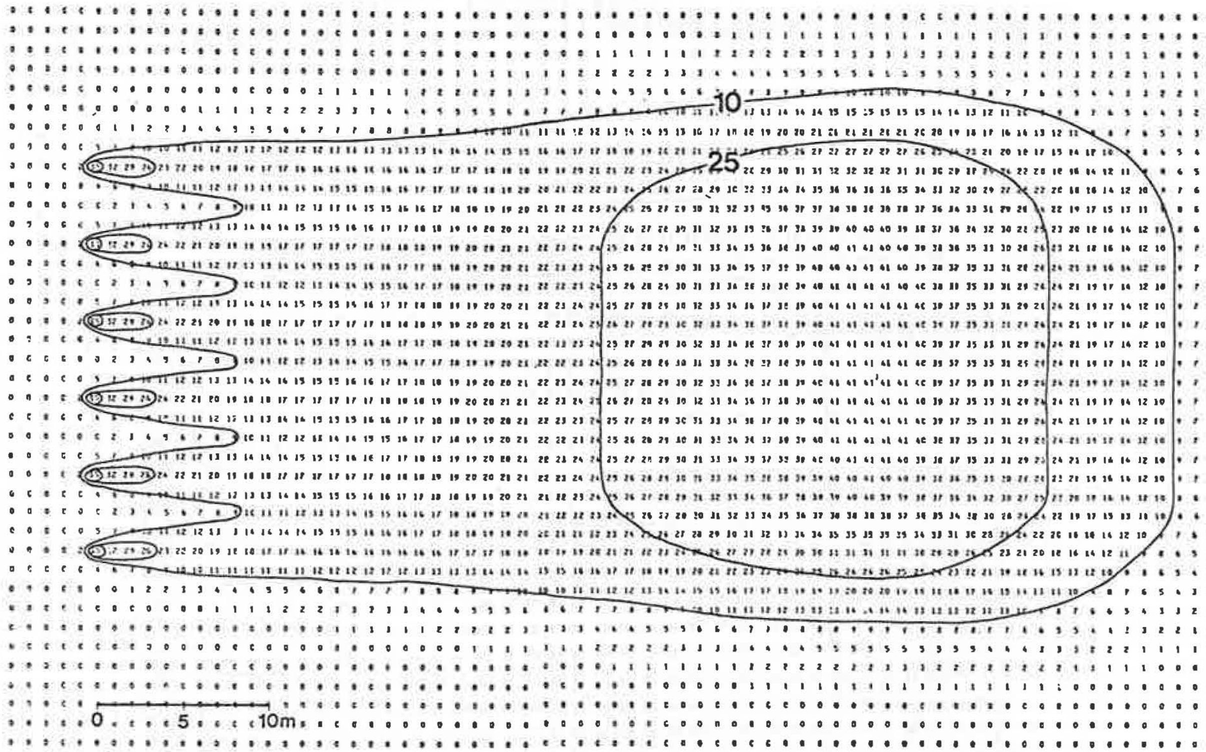

Figure 10--Smell field from a line of 6 baited hooks, 4 meters apart, after 2 hours. 0.6 cm/sec, laminar flow.

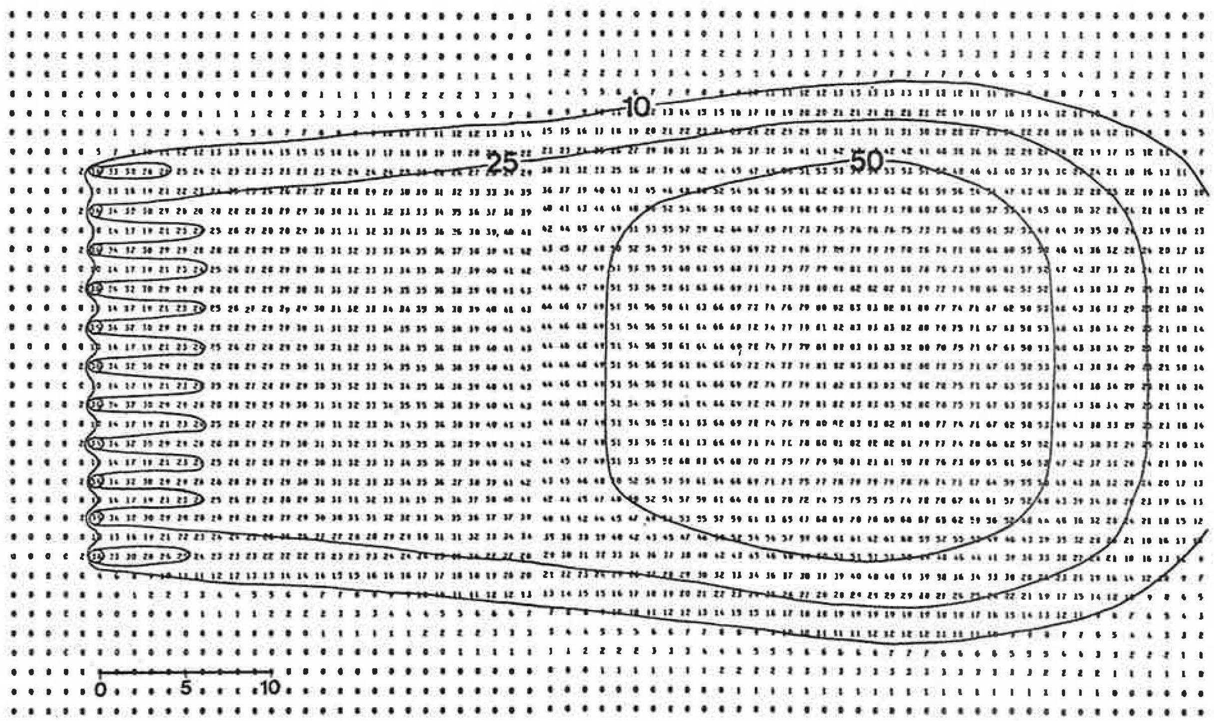

Figure 11--Smell field from a line of 11 baited hooks, 2 meters apart, after 2 hours. 0.6 cm/sec, laminar flow.

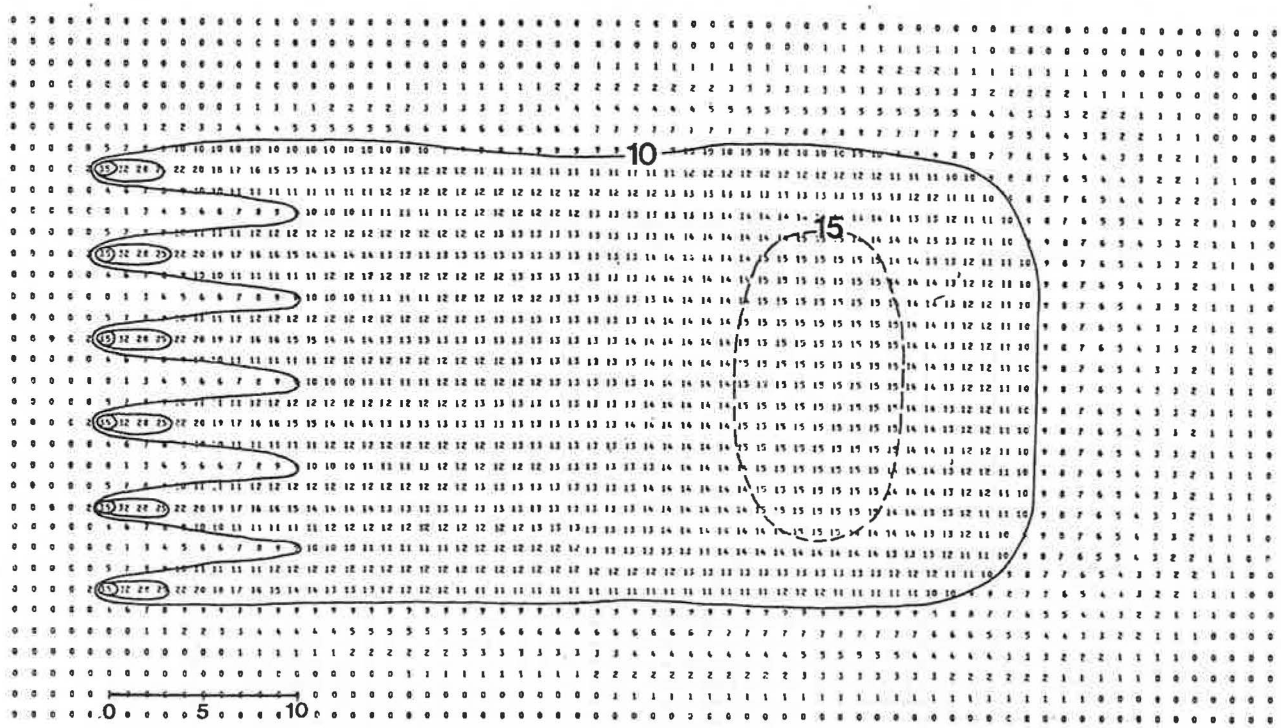

Figure 12--Smell field from a line of 6 baited hooks, 4 meters apart, after 2 hours; 0.6 cm/sec, layer thickness increasing with distance from the hooks.

the second concentration in Figure 12 has nearly disappeared as the result of increased thickness of the layer with distance from bait, and the field strength is rather uniform betwden bait and about 45 meters from it in Figure 12. The "10 smell unit" concentration field has also shortened as a result of thickening of the smell-containing layer.

3.4 Distribution of smell from a line of baits in rotary current

The distribution of smell field from a line of 6 baited hook, 8 meters apart, in a rotating current (initial current to the right, U=0.65 c/sec, clockwise rotation) is shown in hourly intervals in Figs. 13 to 16. At the prescribed current speed, the center of the second maximum in smell field starts to develop in about an hour 16 meters from the hooks (Fig. 13). After two hours, the center of this maximum is about 34 meters from the hooks and the field nearer to the hooks has considerably lower intensity (Fig. 14). After three hours, this "maximum field" has about the same intensity, but is at about 42 meters from the hooks (Fig. 15). The near field of smell has decreased to about half of the value at the smell maximum. After three hours, the current is parallel to the line of hooks, and the concentration of smell starts to build up there due to overlap. After four hours, concentration of smell has built up along and near the line of baits (Fig. 16). However, there remains a secondary maximum of smell at about 35 meters from this line at this time which would move slowly toward the line of baits during the next two hours.

In a second set of numerical experiments (rotary current with the same velocity and the same hook spacing as in Figs. 13 to 16), the current at time 0 was parallel to the line of hooks and turned clockwise (Figs. 17 to 20). After one hour soaking time, the higher concentration of smell is to the left of the line (Fig. 17). The concentrations are two and a half times as high as those in corresponding Figure 13 when the current was initially running perpendicular to the line. These high concentrations are the result of overlap

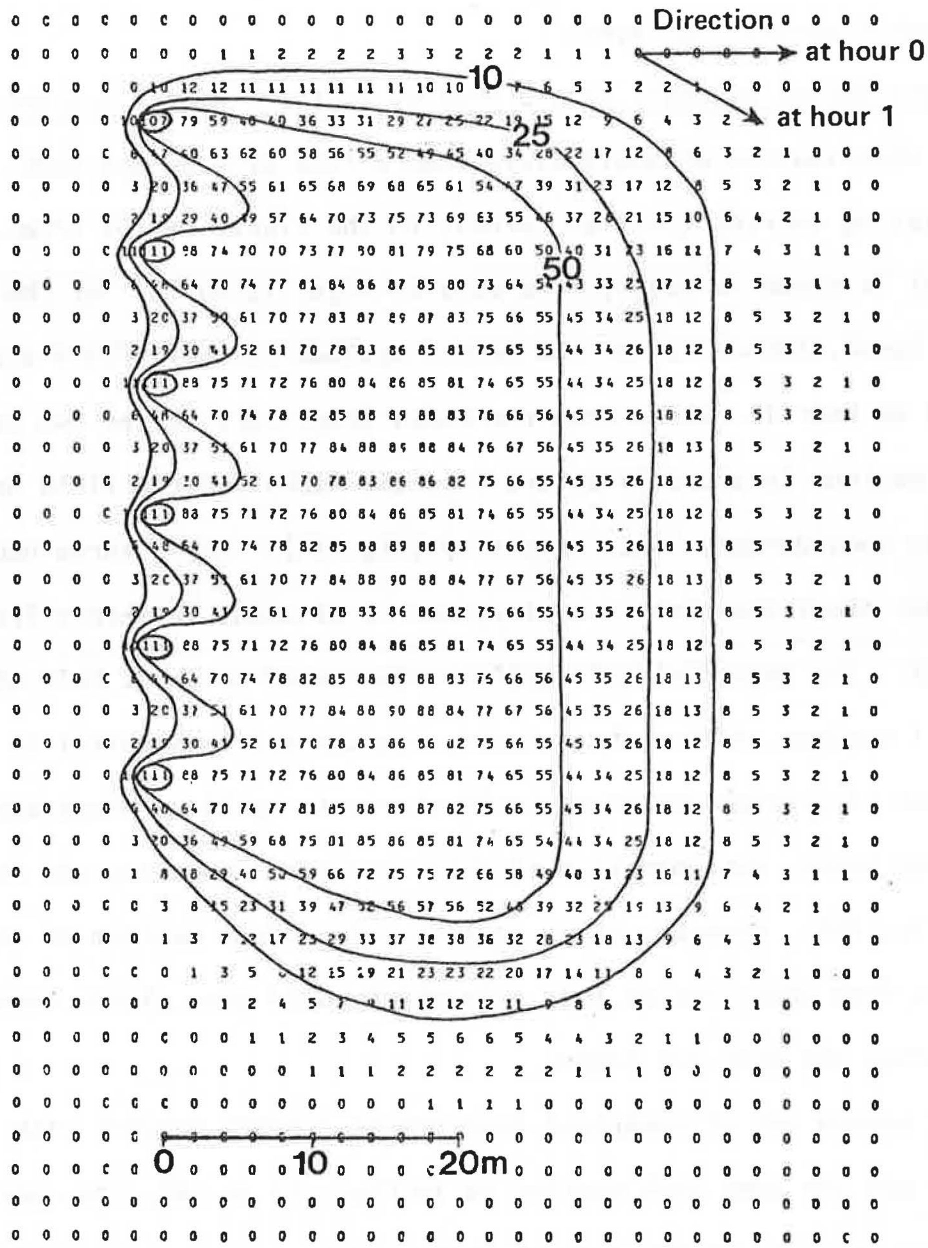

Figure 13--Smell field from a line of 6 baited hooks, 4 meters apart, in a rotary current, after 1 hour, (initial current perpendicular to the line, 0.65 cm/sec, turning clockwise).

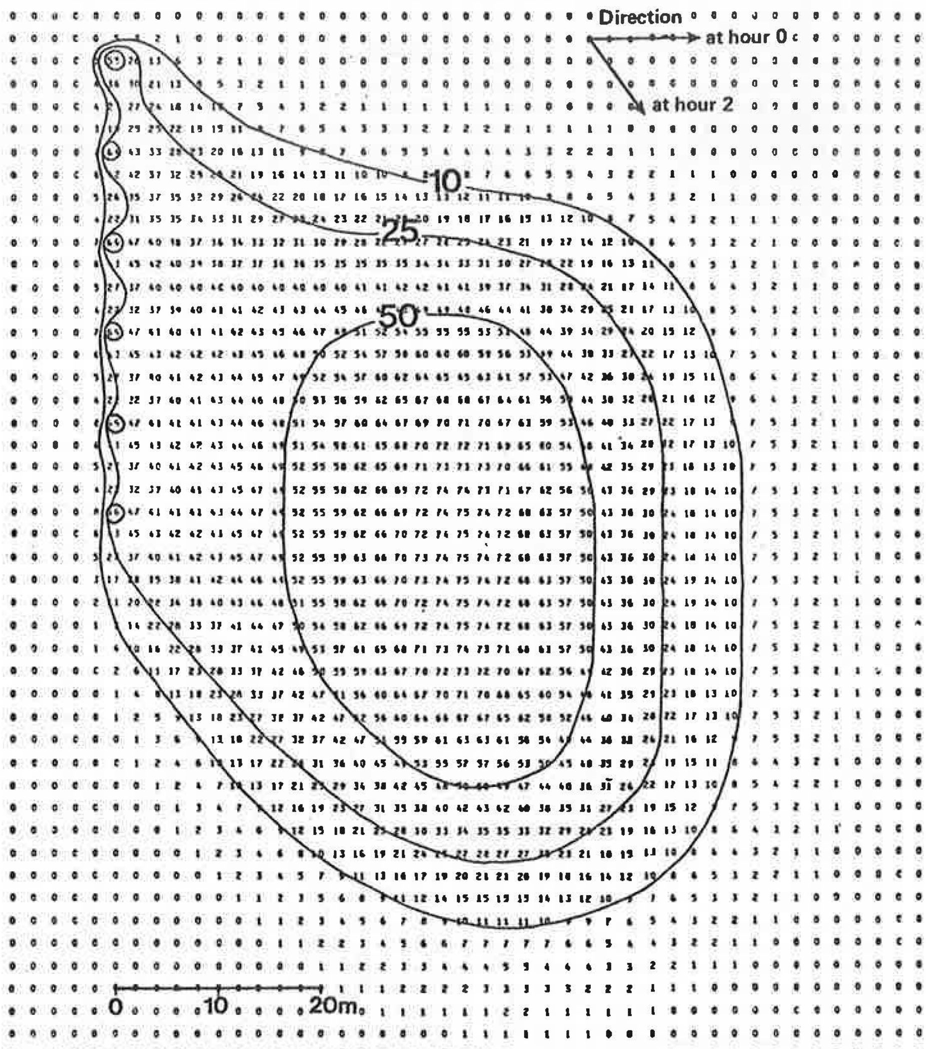

Figure 14--Smell field in a rotary current (as in Fig. 13) after 2 hours.

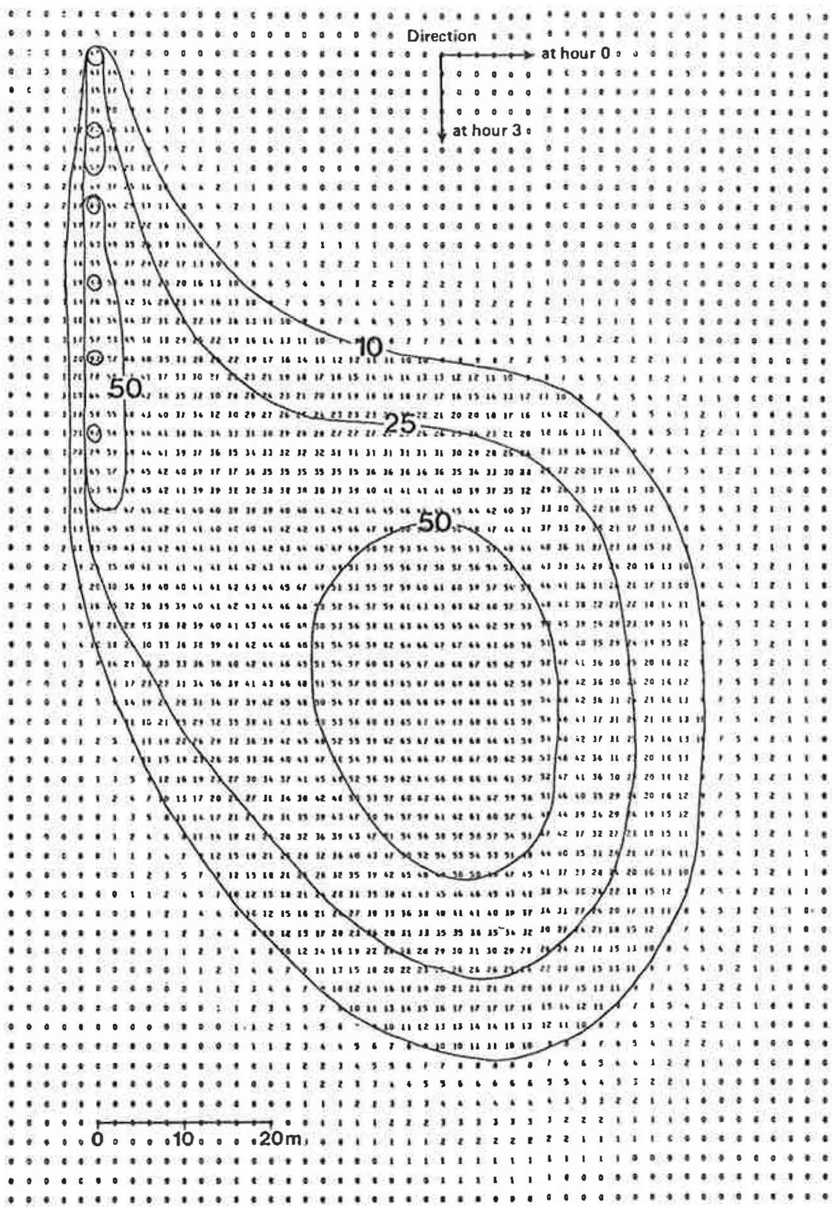

Figure 15--Smell field in a rotary current (as in Fig. 13) after 3 hours.

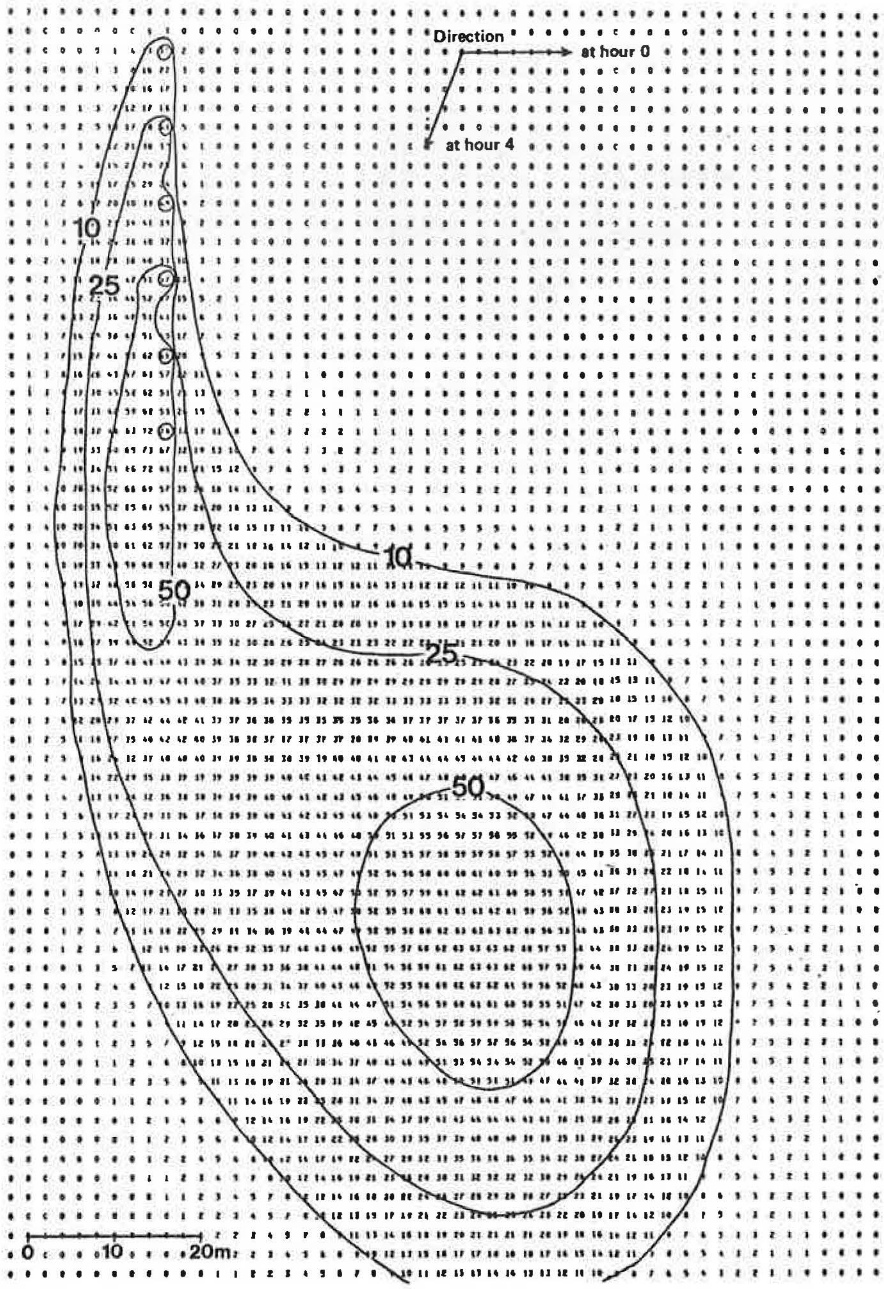

Figure 16--Smell field in a rotary current (as in Fig. 13) after 4 hours.

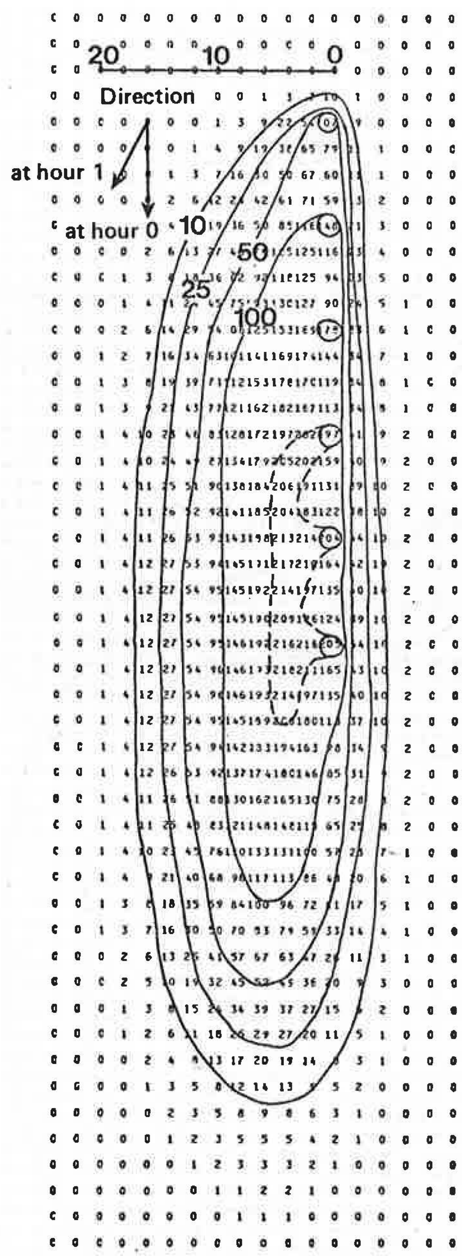

Figure 17--Smell field from a line of 6 baited hooks, 4 meters apart, in a rotary current, after 1 hour, (initial current longitudinal to the line, 0.65 cm/sec turning clockwise).

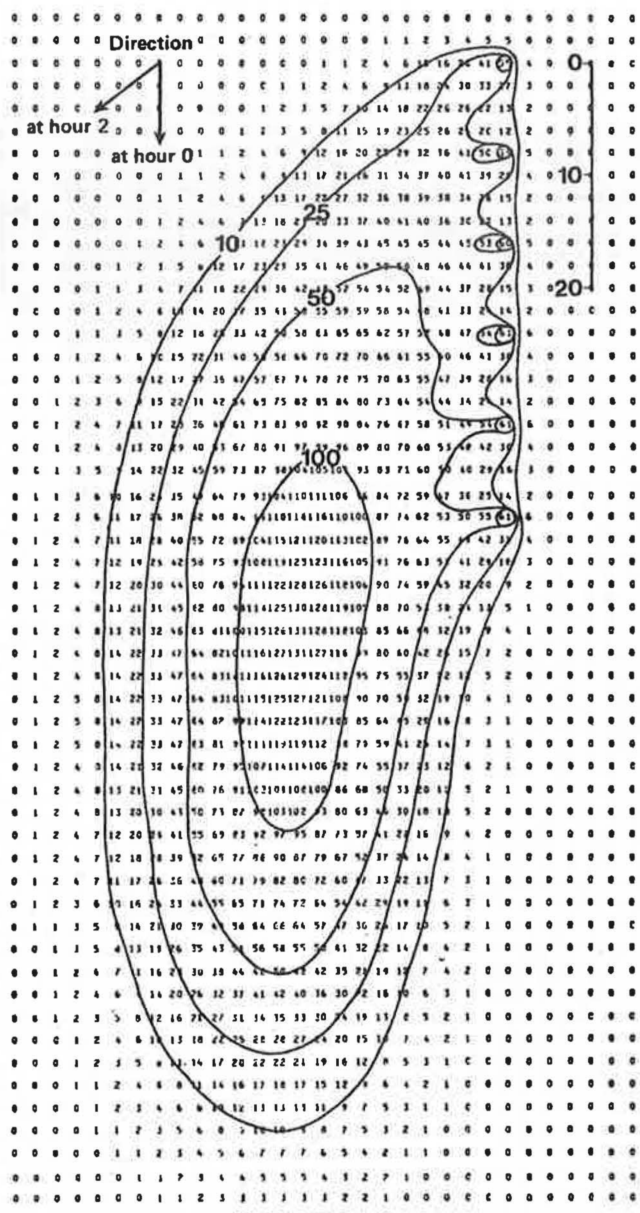

Figure 18--Smell field in a rotary current (as in Figure 17) after 2 hours.

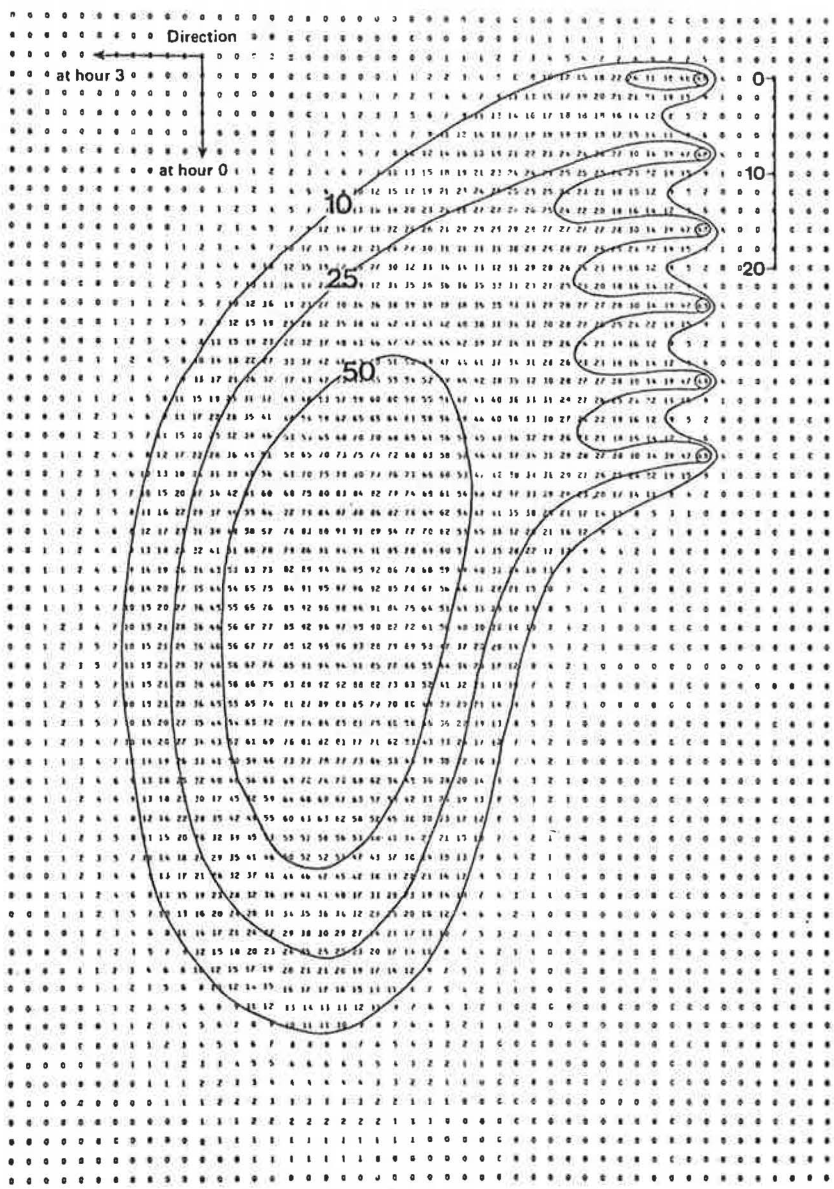

Figure 19--Smell field in a rotary current (as in Figure 17) after 3 hours.

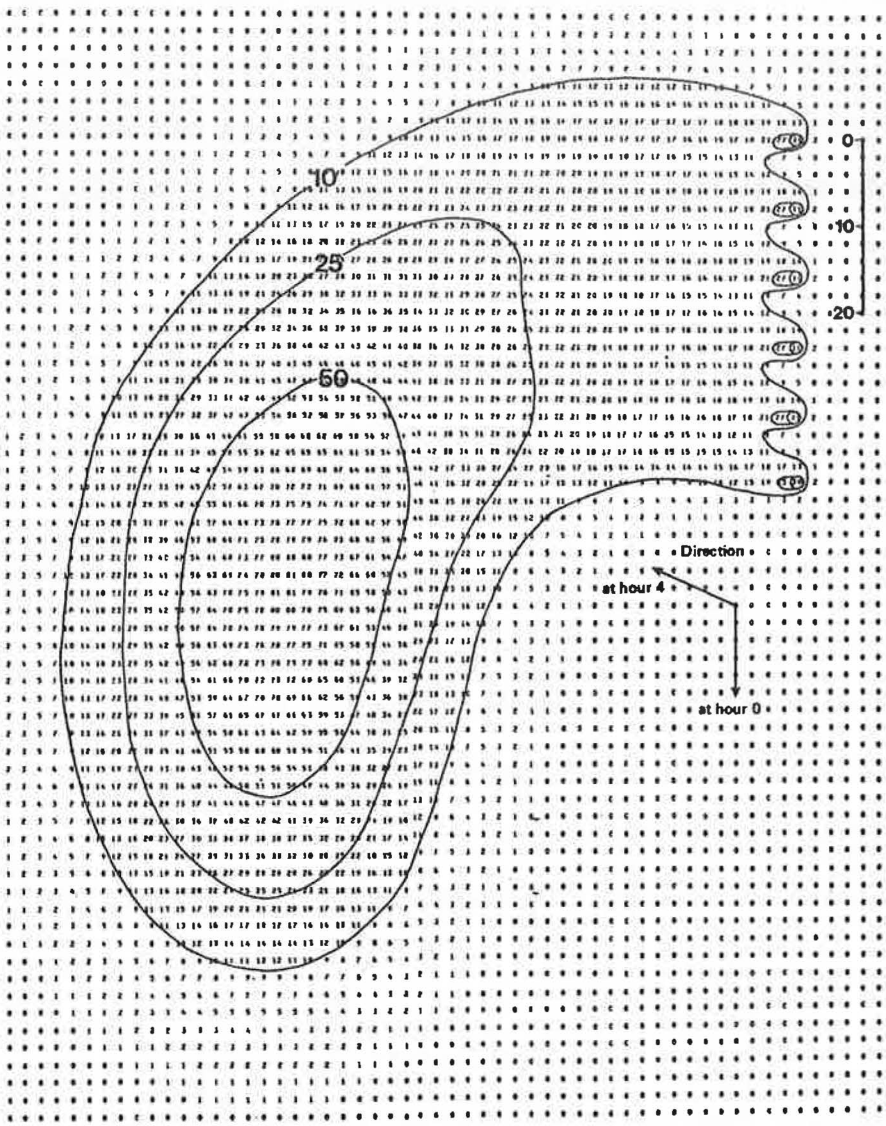

Figure 20--Smell field in a rotary current (as in Figure 17) after 4 hours.

of smell fields from several baits. After two hours, the center of high concentration of smell has moved farther to the left and is about 20 meters from the line (Fig. 18). After three hours of soak time (Fig. 19), the center of the field of maximum smell is about 38 meters from the line, the concentrations being about one-third higher than on corresponding Figure 15. After four hours (Fig. 20), the concentration field has moved farther away from the line. However, the smell concentrations between the baits and the high concentration field are about one-fourth of the high concentrations, and are considerably lower (about half) than in Figure 16.

Properly designed experimental fishing is required to determine which of the setting times in respect to tidal currents (i.e., initial current perpendicular or longitudinal to the line) is more beneficial for attracting the fish to the bait and influencing the catch. In cases where the current was initially perpendicular to the current, the secondary maximim smell field at some distance from the line is weaker than in cases where the current was in the same direction with the line during the setting. However, in the former case, another higher concentration of smell forms after about three hours of setting along the long line when the tidal current has become parallel to it. This higher smell concentration at the baits might be beneficial in helping the fish find the bait.

4. CONCLUSIONS

Olfactory stimuli from the baits (smells) are the main means of distant attracting of fish to the bait. The reaction threshold of the fish to different stimuli (smells) is at present not well known.

Water soluable proteins have been found to be the attractive olfactory stimulants of long line baits. These proteins are rapidly leached from the bait (in the first few hours).

In an unidirectional steady current, perpendicular to the line of baits, a smell field maximum forms within an hour at some distance from the bait; this distance depends on current speed. The smell concentrations between this maximum and the bait are considerably lower than the smell maximum. This condition is caused by the rapid decrease of the amount of smell emitted by the bait per unit time. If the layer in which smell is distributed thickens with the increase of the distance from the bait, the concentrations in the "maximum smell field" become lower. In long lining, the smell field strength increases with the decrease of hook spacing, caused by overlap of smell from adjacent baits.

In rotary (tidal) current, considerable differences occur in the strength of the smell field and in the distance of the smell field maximum from the line, depending on the direction of the current during the setting of the line. The strongest smell field is achieved if the current runs parallel to the line during the setting. On the other hand, when the line is set across the current, relatively high stimuli intensities near the line are maintained for a longer period.

These numerical simulations indicate the need for several empirical studies: First, we need to measure current speeds at close distances above the bottom. Second, we need to know the approximate strengths of smell from different baits which excite fish to search for the bait under varying conditions, (i.e., the attraction threshold values of bait smell), and how this is modified by other environmental smell stimuli from natural food (e.g., from benthic animals).

Furthermore, several other conclusions on the distribution of smell field obtained in this numerical study require experimental verification, especially the effect of turbulence near the bottom and the corresponding increase in the thickness of the layer in which the smell is distributed. Fishing experiments with different line directions in relation to current direction during the setting time, would also be desirable, provided the dirunal feeding cycles, which might interact with these experiments, are taken into consideration.

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Appendix I

SIMULATION MODEL PHEROM FOR COMPUTATION

OF DISTRIBUTION OF SMELL FROM BAIT

The formulas used in the simulation are described in the text. The input parameters to the model and symbols used therein are given in the following list.

The program allows several options for running, which are set with indices in the beginning of the program. Thereafter various auxiliary constants are set.

The current speed (u and v components) are prescribed in four different sets, which can be chosen with the indices KU and KR. The initially prescribed current speeds can be augmented at the end of the program so that results are given for four different sets of speeds in one run.

The selectable current direction sets are: 1) perpendicular to the line (KU=1), parallel to the line (KU=2), at 45° angle to the line (KU=3), and a rotating semidiurnal tidal current (KR=2). The initial current speeds are described with U(UI) and V(VI) components, and the currents are allowed to fluctuate in speeds with a fluctuation amplitude of 25% of prescribed current speed and with a 3-minute period of fluctuation (FAF = 2° per second). Furthermore, a slow fluctuating cross-current is prescribed for the current perpendicular and longitudinal to the line, the fluctuation of which is offset from the main component by 45° (TCAP). The rotary current changes direction 0.008° per second.

The grid size is defined either as 1 meter (GR=1), or 2 meters (GR=2). The smell from the hooks (usually in column 15) is emitted either from one hook only (KL=1) or from 6 hooks in a line (KL=2) (also 11 hooks used).

The advection of the smell is computed with "upcurrent differentiation" method (see text), whereafter a diffusion is applied (as a smoother) and the conservation of the smell is checked (no time decay is allowed except a decay of leaching from the bait).

An option to compute the change of concentrations due to increasing thickness of the turbulent layer from the source (bait) is given next in the program. In the program listing given here, the layer is allowed to thicken 15% per 10 meters.

The concentration fields are printed in prescribed time intervals. At the end of computations (3 hours real time), the speeds are augmented and the program repeated.

The two appended subroutines are for diffusion (smoothing) and for printing of outputs.

LIST OF INPUT PARAMETERS AND SYMBOLS USED IN THE MODEL

1. Control parameters

KA - "Layer thickness" index; 1 - laminar flow; 2 - layer thickness increasing with distance from bait.

KF - Current fluctuation index; 1 - period 3 min., FAF = 2°/sec; 2 - period 6 min., FAF = 1°/sec.

KG - Grid size index; 1 - grid size 1 m; 2 - grid size 2 m. (Note: DL is grid size; if current speed is >1 cm/sec, grid size is raised to 2 m).

KL - Single bait or line index; 1 - single bait; 2 - line of 6 or 11 baits in line.

KR - Unidirectional or rotating current index; 1 - unidirection; 2 - rotating tidal current. (Only one quarter of rotation is computed.)

KT - Time step index; 1 - 30 sec.; 2 - 60 sec. (Note: the frequency of the call for smoothing (IAC) and output printing (IPR) are time step dependent.)

KU - Current direction index; 1 - U direction; 2 - V direction; 3 - current at 45° angle to line.

2. Symbols for inputs and computed parameters (* denotes inputs)

*ADO - Phase speed of the rotation of current (0.008 deg/sec).

*AE - Smell decay factor (a) (0.0012).

*AKADI - Phase lag of the rotation in radians (90 deg. lag).

ALP - Phase speed parameter in radians.

*ALPHA - Smoothing parameters.

*APARP - Phase lag of the rotation in radians (180 deg. lag).

AROT - Phase speed of rotation in radians.

BET	- (1 - ALPHA)/4.
*CON	- Conversion factor from degrees to radians (0.0174533).
*CTR	- Parameter for computation of increase of layer thickness from bait (0.015) (input after statement 60).
DIS	- Intermediate for computation of distance from bait.
*DL	- Grid size, cm.
*FAF	- Current fluctuation period parameter (degrees per second).
*IAC	- Parameter determining the interval of time steps when smoothing (diffusion) subroutine is called.
*IPR	- Parameter determining the interval of time steps when output (printing) subroutine is called.
IS(N,M)	- Integer value of S (for printing).
ITC	- Time step counter for smoother.
ITOP	- Time step counter for output.
*KS	- Counter for the number of different current speeds computed in one run (input in statement 72).
M	- Grid index (M direction, i.e., rows).
*ME	- Number of grid points in row.
N	- Grid index (N direction, i.e., columns).
*NE	- Number of grid points in column.
PF(N,M)	- Field for computation of concentrations due to increased "layer thickness".
RRC	- Factor of concentration decrease due to increase of layer thickness.
S(N,M)	- Smell concentration field.
SH	- Intermediate, smell gradient in u direction.

*SO	- Initial strength of smell.
SUA	- Intermediate for summation (smell before advection).
SUS	- Intermediate for summation (smell after advection).
SV	- Intermediate, smell gradient in v direction.
T	- Time counter (summation).
*TCAP	- Phase lag in radians.
*TD	- Time step, in seconds.
*TF	- End of computations in seconds.
*TURC	- A parameter for simulation of turbulent diffusion (0.13).
U	- U component of the current
UA	- Magnitude of the fluctuation of U component.
*UI	- U component of the current (prescribed)(cm/sec).
U1	- Intermediate (SUA/SUS).
V	- V component of the current.
VA	- Magnitude of the fluctuation of V component.
*VI	- V component of the current (prescribed) (cm/sec).
VALE	- S value "left" (S(N,M-1)).
VALO	- S value "below" (S(N+1,M)).
VARI	- S value "right" (S(N,M+1))
VAUP	- S value "up" (S(N-1,M))

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P R O G / H O O K Y / 1   O N   D I S K

```
FILE  6(KIND=PRINTER)
FILE  66(KIND=PRINTER)
C     PROGRAM PHEROM

      DIMENSION S(75,80),PF(75,80)
C     XXXXXX
C     INDICES
C     KG-GRID SIZE 1-1M;2-2M
C     KT-TIME STEP 1-30 SEC. 2-60 SEC.
C     KF-FLUCTUATION PARAMETER (FA);PERIOD 3 MIN,KF=1,FA=2.
C        6 MIN,KF=2,FA=1.
C     KL-SINGLE BAIT OR LONG LINE; 1-SINGLE; 2-6 HOOKS
C     KA-LAMINAR FLOW OR INCREASING LAYER  1-LAMINAR; 2-INCREASING LAYER
C     KU-UNIDIRECTIONAL              CURRENT 1-UNIDIRECTIONAL,U-DIRECTION
C        2-UNIDIRECTIONAL V-DIRECTION, 3-UNIDIRECTIONAL AT 45 DEG. ANGEL
C     KR-UNIDIRECTIONAL OR ROTATING, 1-UNIDIRECTIONAL, 2-ROTATING
C     KS-SPEED COUNTER FOR 4 DIFERENT SPEEDS
C     XXXXXX
C     RUN 66
      KG=1
      KT=1
      KF=1
      KL=2
      KA=1
      KU=1
      KR=1
C     XXXXXX
      AE=0.0012
C     OTHER VALUES 0.0012,0.0006,0.0003
      IF(KG-1)1,1,2
    1 DL=100.
      GO TO 3
    2 DL=200.
    3 IF(KT-1)4,4,5
    4 TD=30.
      IAC=6
      IPR=40
      GO TO 6
    5 TD=60.
      IAC=3
      IPR=20
    6 IF(KF-1)7,7,8
    7 FAF=2.
      GO TO 9
    8 FAF=1.
    9 CON=0.0174533
      ALPHA=0.80
      ALP=FAF*CON
      TCAP=45.*CON
      SC=10.
      TF=10800.
      KS=1
      KKK=0
      TURC=0.13
C     XXXXXX
```

```
C     CURRENT SPEED INPUT
      IF(KR-1)12,12,16
   12 IF(KU-2)13,14,15
   13 UI=0.2
      VI=UI*TURC
      UA=0.25*UI
      VA=0.25*VI
      GO TC 18
   14 VI=-0.2
      UI=VI*(-TURC)
      UA=0.25*UI
      VA=0.25*VI
      GC TC 18
   15 UI=0.14
      VI=-0.14
      UA=0.25*UI
      VA=0.25*VI
      GO TC 18
   16 UI=0.65
      VI=0.65
      UA=0.25*UI
      VA=0.25*VI
      ADC=0.008
      AROT=ADC*CON
      AKADI=90.*CON
      APARP=180.*CON
      DL=200.
      TF=14400.
      GC TC 18
C     XXXXXX
   18 T=0.
      ITC=0
      ITCP=0
C     XXXXXX
      DC 11 N=1,75
      DO 11 M=1,80
      S(N,M)=0.
   11 CONTINUE
C     XXXXXX
   10 ITC=ITC+1.
      ITCP=ITCP+1
   20 IF(KR-1)41,41,47
   41 IF(KU-2)42,43,44
   42 U=UI+UA*CCS(ALP*T)
      V=VI*COS(ALP*T+TCAP)
      GO TC 49
   43 V=VI+VA*CCS(ALP*T)
      U=UI*COS(ALP*T+TCAP)
      GC TO 49
   44 U=UI+UA*CCS(ALP*T)
      V=VI+VA*CCS(ALP*T+TCAP)
      GC TO 49
   47 U=UI*COS(AROT*T+AKADI)
      V=VI*COS(AROT*T+APARP)
   49 CONTINUE
C     10 UNITS CF PHERCMON ADDEC EACH TIME STEP (SO=10.)
   25 S(10,15)=S(10,15)+SO*(1./((AE*T)+1.))
C     XXXXXX
      GC TC 251
C     XXXXXX
```

```
252 IF(KL-1)27,27,26
 26 S(14,15)=S(14,15)+SO*(1./((AE*T)+1.))
    S(18,15)=S(18,15)+SO*(1./((AE*T)+1.))
    S(22,15)=S(22,15)+SO*(1./((AE*T)+1.))
    S(26,15)=S(26,15)+SO*(1./((AE*T)+1.))
    S(30,15)=S(30,15)+SO*(1./((AE*T)+1.))
    GO TO 27
251 S(12,15)=S(12,15)+SO*(1./((AE*T)+1.))
    S(14,15)=S(14,15)+SO*(1./((AE*T)+1.))
    S(16,15)=S(16,15)+SO*(1./((AE*T)+1.))
    S(18,15)=S(18,15)+SO*(1./((AE*T)+1.))
    S(20,15)=S(20,15)+SO*(1./((AE*T)+1.))
    S(22,15)=S(22,15)+SO*(1./((AE*T)+1.))
    S(24,15)=S(24,15)+SO*(1./((AE*T)+1.))
    S(26,15)=S(26,15)+SO*(1./((AE*T)+1.))
    S(28,15)=S(28,15)+SO*(1./((AE*T)+1.))
    S(30,15)=S(30,15)+SO*(1./((AE*T)+1.))
 27 SUS=0.
    SUA=0.
 30 DO 50 N=2,74
    DO 50 M=2,79
    SUA=SUA+S(N,M)
    IF(U)32,31,31
 31 SH=(S(N,M)-S(N,M-1))/DL
    GO TO 33
 32 SH=(S(N,M)-S(N,M+1))/DL
 33 IF(V)34,36,36
 34 SV=(S(N,M)-S(N-1,M))/DL
    GO TO 35
 36 SV=(S(N,M)-S(N+1,M))/DL
 35 S(N,M)=S(N,M)-(TD*ABS(U)*SH)-(TD*ABS(V)*SV)
    SUS=SUS+S(N,M)
 50 CONTINUE
    IF(ITC-IAC)80,55,80
 55 CALL SILITA(S,ALPHA)
    U1=SUA/SUS
    DO 60 N=1,75
    DO 60 M=1,80
    S(N,M)=S(N,M)*U1
 60 CONTINUE
C      EFFECTS OF INCREASING LAYER THICKNESS,APPROXIMATE
C      FACTOR -CTR REFERRES TO METERS FROM SOURCE
    CTR=0.015
    IF(KA-1)81,81,61
 61 DO 131 N=1,75
    DO 131 M=1,80
    PF(N,M)=S(N,M)
131 CONTINUE
    IF(KR-1)62,62,69
 62 IF(KU-2)63,62,69
 63 DO 64 N=1,75
    DO 64 M=1,80
    DIS=(M-15)*0.01*DL
    IF(DIS)51,51,52
 51 RRC=1.
    GO TO 53
 52 RRC=(1.-(CTR*DIS))
 53 PF(N,M)=PF(N,M)*RRC
 64 CONTINUE
    GO TO 81
```

```
 65 DO 66 N=1,75
    DO 66 M=1,80
    DIS=(N-10)*0.01*DL
    IF(DIS)54,54,56
 54 RRC=1.
    GO TC 57
 56 RRC=(1.-(CTR*DIS))
 57 PF(N,M)=PF(N,M)*RRC
 66 CONTINUE
    GO TC 81
 67 DO 68 N=1,75
    DO 68 M=1,80
    IF(M-15)58,58,59
 58 RRC=1.
    GC TO 82
 59 IF(N-10)58,58,83
 83 DIS=SQRT((M-15)**2.+(N-10)**2.)*0.01*DL
    RRC=(1.-(CTR*DIS))
 82 PF(N,M)=PF(N,M)*RRC
 68 CONTINUE
    GO TO 81
 69 DO 84 N=1,75
    DO 84 M=1,80
    IF(M-15)86,86,87
 86 RRC=1.
    GO TC 88
 87 DIS=(M-15)*0.01*DL
    RRC=(1.-(0.5*CTR*DIS))
 88 PF(N,M)=PF(N,M)*RRC
    IF(N-25)89,89,91
 89 RRC=1.
    GC TO 94
 91 DIS=(N-25)*0.01*DL
    RRC=(1.-(C.5*CTR*DIS))
 94 PF(N,M)=PF(N,M)*RRC
 84 CONTINUE
 81 ITC=0.
 80 IF(ITCP-IPR)90,85,90
 85 IF(KA-1)122,122,121
121 CALL PRIFMS(PF,T,U,V,UI,VI,TD,DL,KA)
    GC TO 123
122 CALL PRIFMS(S,T,U,V,UI,VI,TD,DL,KA)
123 ITOP=0
 90 T=T+TD
    IF(T-TF)10,71,71
 71 KS=KS+1
    TURC=TURC+0.05
    IF(KR-1)72,72,100
 72 IF(KS-5)73,100,100
 73 IF(KU-2)74,75,76
 74 UI=UI+0.4
    VI=UI*TURC
    UA=0.25*UI
    VA=0.25*VI
    IF(UI-1.05)111,110,110
110 DL=800.
111 GO TC 18
 75 VI=-C.4
    UI=VI*(-TURC)
    UA=0.25*UI
```

```
      VA=0.25*VI
      IF(VI-1.05)113,112,112
  112 DL=200.
  113 GO TO 18
   76 UI=UI+0.3
      VI=VI-0.3
      UA=0.25*UI
      VA=0.25*VI
      IF(UI-1.05)115,114,114
  114 DL=200.
  115 GO TO 18
  100 STOP
      END
```

```
      SUBROUTINE SILITA (S,ALPHA)
      DIMENSION S(75,80)
      NE=75
      ME=80
      BET=(1.-ALPHA)/4.
      DO 123 N=2,74
      DO 123 M=2,79
  103 IF(1-N)105,107,105
  105 VAUP=S(N-1,M)
      GO TO 108
  107 VAUP=S(N,M)
  108 IF(NE-N)110,112,110
  110 VALO=S(N+1,M)
      GO TO 113
  112 VALO=S(N,M)
  113 IF(1-M)115,116,115
  115 VALE=S(N,M-1)
      GO TO 117
  116 VALE=S(N,M)
  117 IF(ME-M)119,121,119
  119 VARI=S(N,M+1)
      GO TO 122
  121 VARI=S(N,M)
  122 S(N,M)=ALPHA*S(N,M)+BET*(VAUP+VALO+VALE+VARI)
  123 CONTINUE
      RETURN
      END
```