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Factors Affecting Catch of Long Lines, Evaluated with a Simulation Model of Long Line Fishing

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EVALUATED WITH A
SIMULATION MODEL OF LONG LINE FISHING

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ABSTRACT

Catch rates of long lines are affected by numerous technical, biological, and environmental factors. The rate of bait loss, which is one of the important catch determinants, is influenced not only by the nature of the bait, but also by invertebrate predation, by the motivation of the fish, and by consequent multiple attacks on bait, resulting in bait loss. The distribution of smell from the bait to attract the fish is influenced by currents. Among the important technical factors affecting the catch rates are type of line material, hook type, and spacing of hooks. All factors affecting long line catches are assembled into a complex conceptual model of long line fishing (Figure 1).

Available quantitative knowledge about these factors is evaluated and a numerical model is designed for simulation of long line fishing. The numerical formulations of this model are presented and the model is reproduced in the appendix. The main purposes of the simulation model are to study the sensitivity of different parameters on the catch rate, to guide and prioritize technological developments as well as applied fisheries research on long line fishing, and to suggest improvements in the interpretation of present catch per unit effort in long line fisheries.

Some general conclusions from the use of this model are: that the rate of bait loss from various causes in a few hours after the setting largely determines the ultimate catch; that after a few hours of soak time the catch increases only slightly, approaching the escape rate; and that the catch rate is a complex function of fish density and reaches a "saturation level" at higher fish densities. The setting time of the day in relation to the daily feeding periods of fish also has considerable influence on the catch rate.

Methods for estimation of fish density from catch rate are discussed, and suggestions for further studies are presented.

1. INTRODUCTION

Published reports directly relevant to the theory of long line fishing are scarce, and they are mostly restricted to studies of how one, or a few, chosen gear and/or operation parameters affect catch rate, the overall purpose frequently being to refine CPUE estimates as indices of fish density.

Comprehensive reviews of relevant long line literature were given by Skud and Hamley (1978) and by Bjordal (1981). More recent works (e.g., Bjordal 1982, Fernö et. al. 1981), as well as the general experience of long line fishermen, confirm that long line catch is affected by a number of interacting parameters, e.g., length of line, hook spacing, soak time, bait type and quality, hook type and size, material, dimension and rigging of line; as well as environmental factors such as velocity and direction of water movement, abundance and distribution/behavior of natural prey and competing predators; and, not least, the behavior, density and state of feeding, sexual development, etc. of the target fish themselves.

Specific knowledge of feeding and foraging behavior of most commercial fish harvested with long lines is very incomplete and fragmentary. Accordingly, any concept of how such behavior interacts and affects long line capture has to be largely based on the existing general knowledge of chemical sensing and feeding behavior in fishes.

A comprehensive review of this field of research was presented by Atema (1980) from which is specifically noted: Olfaction is the dominant sense for

distant prey detection, but for near field location, taste and vision are also of major significance, while in most fishes internal (mouth) taste alone determines the palatability and eventual ingestion of the prey. Some chemicals may stimulate both smell and taste organs, but cause very different behavioral responses.

Experience (learning) can modify innate food odor preferences in a positive ("ingestive conditioning", "specific appetite") or in negative ("bait shyness") direction.

The present study is an attempt to establish a comprehensive theory, via a conceptual model, and to design a numerical simulation of interactions in the fish capture processes of long lining, taking into account not only gear parameters, but also variables relating to the environment and to the target fish. Relevant data have been extracted from a number of sources, some of which have not previously been published, and the concept and development of the model draws to a large extent on unpublished observations and experiences in different commercial long line fisheries.

The main objective of the study has been to elucidate interactions and factors of the fishing gear per se, the target species, and the ambient environment that affect the processes of fish capture with baited long lines.

Accordingly, and also for the sake of simplicity, most operational aspects of long lining were not included in the model, e.g., choice of fishing location, gear shooting and hauling particulars.

Similarly, the model was made monospecific and therefore disregards the effects of competition between different kinds of fish that occur to varying degrees in many long line fisheries.

While many of the catch-affecting conditions and technical details of long line fishing vary from one target species to another, this report deals with long line fishing in general. The combinations and values of the parameters applied in the numerical simulations, therefore, may not be strictly relevant to any particular, existing long line fishery. Nevertheless, the simulation model will serve two main purposes:

- 1) To determine quantitatively the effects of various parameters affecting long line catch and to develop and test the quantitative relations between the affecting parameters.
- 2) To identify the most essential factors affecting the catch and consequently to prioritize and guide future research to fill gaps of knowledge, and to guide technical developments.

2. FACTORS AND INTERACTIONS DETERMINING LONG LINE CATCH

The conceptual model of factors and interactions in long line fish capture is presented in graphical form in Fig. 1.

Naturally, the starting point is the bait (1), the primary purpose of which is to attract fish to the location of the gear, and, subsequently, to entice them to bite the hook. The bait, therefore, has to emit stimuli which are attractive to the target fish, and of sufficient strength or intensity to induce the fish to search for the stimuli source. Also, the bait has to remain intact (i.e., stay on the hook) and continue adequate stimuli emission for a duration long enough to permit the attracted fish to find the bait and attack it.

When a bait becomes immersed, the active stimuli components are being dissolved and dispersed in the surrounding water. The time pattern, or rate of stimuli emission (6), for natural cut bait (e.g., mackerel) is known to show a quick rise, followed by a gradual attenuation (Solemald and Tilseth 1978). Evidently the emission intensity and rate of attenuation are important bait parameters, and these are mainly determined by the bait type and quality (e.g., freshness, preservation, etc.).

Commercial long line gear is made up of a large number of baited hooks, which, in the case of most demersal operations, are set in a straight line. The baits will then constitute a linearly extended array of chemical stimuli emitters, the dimension and configuration of which are given by the length and orientation (i.e., the direction of shooting the gear) of the main line (32), and by the distance between the baits, the nominal hook spacing (31).

The stimuli components emitted from this array are dispersed in the surrounding water, the rate and pattern of dispersion being determined by the speed and direction of water movement (7). Accordingly, the stimuli intensity

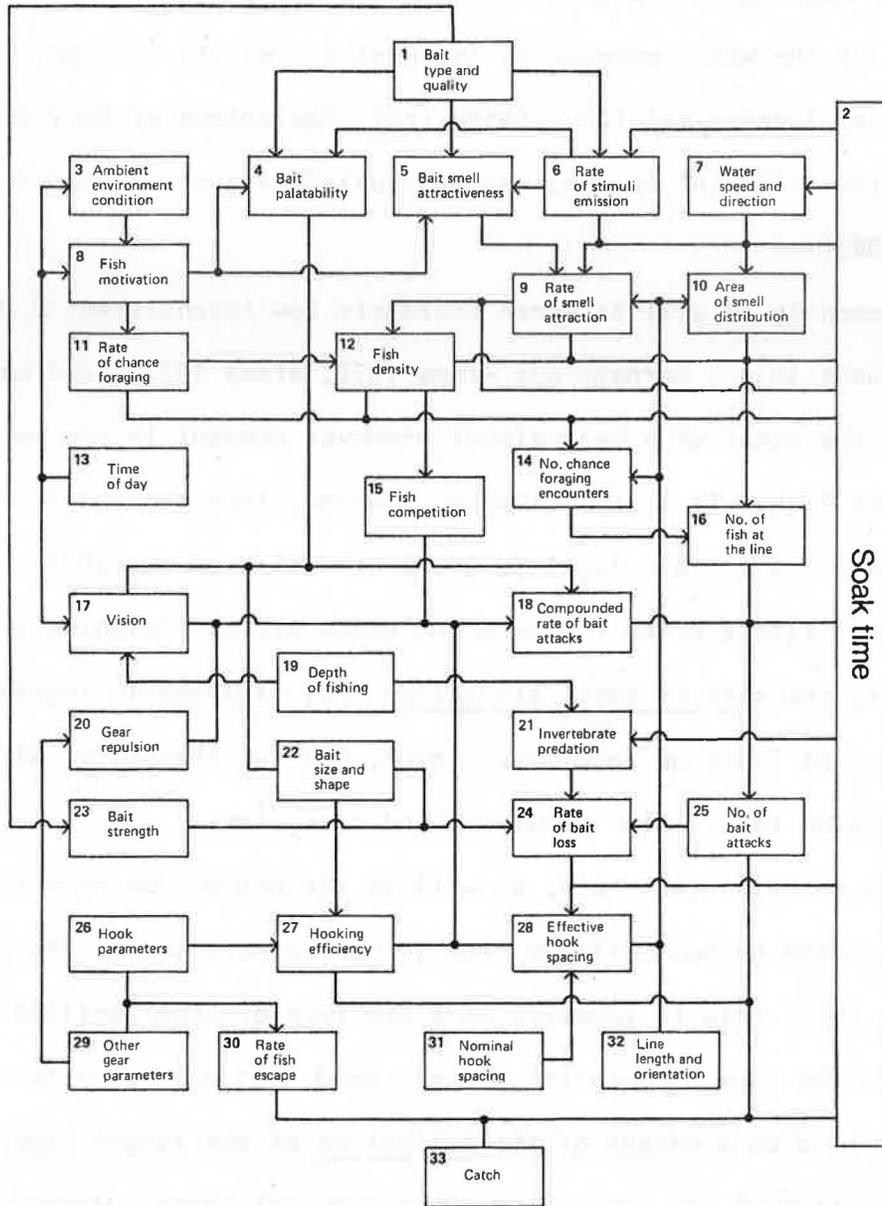


Figure 1.--A conceptual model of factors and interactions affecting long line catch.

distribution in time and space, the area of smell distribution (10), is a function of the magnitudes and patterns of bait stimuli emission along the long line, and of the water movements, integrated over the relevant period of bait immersion (soak time) (2). (Numerical simulations of bait smell distribution with different currents are presented in another report (Olsen and Laevastu 1983)).

Fish are known to be able to sense extremely low intensities of dissolved chemical compounds (e.g., Bardach and Atema 1971, Atema 1977), and may well be able to detect the scent of a bait almost whenever present in the waters inhabited by the fish. It is conceivable, however, that the intensity of bait smell must be above a certain level to arouse the fish to search for the source. The proportion of fish alerted to the scent which are sufficiently aroused to search for bait, the rate of smell attraction (9), is probably increasing with smell intensity, at least up to a given level, and is, therefore, also a function of stimuli emission rate, water movement, and soak time.

The stimuli reaction threshold, as well as the attraction rate is, however, primarily determined by how well the fish likes the bait smell, the smell attractiveness (5). This is inherent with the type of smell emitted and, therefore, with the type and quality of bait used, but the net effective attractiveness is also a matter of the motivation of the target fish (8) itself (which is a function of its hungriness, physiological stage, diurnal feeding phase, previous diet and experience, etc., e.g., Takagi 1971, Solemdal et. al. 1983), and of the ambient environmental condition (13) (density, quality, and distribution of natural prey, predator competition, temperature, light, turbidity, etc.).

The number of fish attracted to the long line by smell is a function of smell distribution, fish density (12) (within the smell distribution area), rate of attraction, and soak time.

Evidently the distribution of fish density within the area of smell distribution is modified over time by fish attraction. Fish will gradually concentrate near the long line and be thinned out in the peripheral areas of smell distribution above the attraction threshold, unless this thinning is compensated for by immigration.

Fish may, however, encounter a baited line by chance foraging in addition to olfactorially aroused and guided search. Possibly for fish with little developed olfactory organs (Pipping 1926, 1927), chance foraging is also a significant method of finding their prey.

The probability of bait encounter by chance foraging is directly related to the speed, duration, and range of foraging movements of the fish, the rate of chance foraging (11) (e.g., Curio 1976). This parameter, which is modified by fish state and ambient environmental conditions, affects fish density. It is conceivable, therefore, that, in general, chance foraging is less agile and far reaching at high fish densities (with abundant prey) than when fish are hungry and scattered.

Foraging bait encounter is, of course, also a function of bait density (effective hook spacing (28)), which is dependent on the magnitude of bait loss. This, integrated over time, for the whole length of line, with fish density and rate of foraging, gives the number of chance foraging encounters (14) which, added to that of those attracted by smell, totals the number of fish at the line (16), i.e., within a distance of the baits that ensures location by vision and/or other senses.

Experimental tank as well as free field observations, confirm that not all fish in the near field of a baited long line will in fact attack the baits (Fernö et. al. 1977). The vigour and rate of attack are determined by a complexity of factors. Bait palatability (4) is of primary and direct importance. This quality is determined by the bait taste and texture (and possibly also smell), as modified or affected by fish state and ambient environment.

Variations in bait size and probably also shape (22) may enhance or lessen the bait palatability (Johannesen 1982), the optimal bait dimension being determined by species, size, and state of the fish, as well as by environmental factors (e.g., temperature, McKenzie (1938)).

Similarly, fish attack the baits more vigorously when there is competition and/or some fish have already become hooked on nearby hooks (Solemdal and Tilseth 1978). Accordingly, fish density, through fish competition (15) also, at least up to a certain level, affects the rate of bait attack.

On the other hand, some characteristics of the fishing gear itself appear to have repulsive effects on the fish. Thus, it is an old established fact that thin, fine lines fish best, and it is now well confirmed that line visibility is a key factor in gear repulsion (2) (e.g., Huse 1979).

Consequently, this effect on the rate of bait attack, as well as those of bait size and fish competition, are directly related to vision (17), and, therefore, also to time of day (3) (and year), fishing depth (19), and water turbidity.

Not all fish attacking a baited hook become hooked, and those that do not may make repeated attacks. The rates of repeats are affected by the same factors as that of the initial attack, but since the negative ones, especially gear

repulsion, become of progressively greater importance through the experience gained by the fish from each unsuccessful bait attack (i.e., where no bait is stolen), the rates of repeats will diminish, the degree of attenuation probably being largely determined by gear repulsion. Also, the probabilities of repeated attacks are clearly affected by the chance of becoming hooked, the hooking efficiency (27), and by the density of hooks still having bait (effective hook spacing) (28).

The compounded rate of bait attacks (18) equals the sum of all the attenuated rates from the initial attack to the last repeat. This quantity integrated over soak time with the number of fish at the line and the number of effective hooks (length of line x effective hook spacing), gives the total number of bait attacks (25).

The average distance between hooks with baits on, the effective hook spacing, which at the time of shooting equals the nominal hook spacing (31) of the gear, increases during the soak as a result of bait loss and hooks being occupied by hooked fish.

The rate of bait loss (24) is a function of multiple attacks by fish and of invertebrate predation (21), both being modified by the strength of the bait to withstand attacks. Bait strength is of course mainly determined by the type and quality of the bait, but the size and shape of the bait are conceivably also of importance.

Experience in some long line fisheries suggests that invertebrate predation decreases with fishing and would, therefore, be a function of soak time. It is also known to vary with fishing depth (Skud and Hamley 1978), probably as a result of depth related changes in the abundance and species composition of invertebrates.

The end result of fishing, the catch (33) of fish in numbers, is the product of number of bait attacks and hooking efficiency, less the number of fish that subsequently manage to get off the hooks.

Bait size and shape, in combination with hook size, clearly affect hooking efficiency (Johannesen 1982), as do various other hook parameters (shape, wire thickness, sharpness, etc.), some of which are species selective (Bjorda1 1982).

Hook parameters (e.g., size, bending/breaking resistance) impact the rate of fish escape (30), as is the case also with other gear parameters (29). It is noted that often hook and gear parameters that reduce the chance of hooked fish escaping also reduce the hooking probability and/or the rate of bait attack (e.g., size of hook, thickness of wire, strength of gangion).

3. SIMULATION MODEL OF LONG LINE FISHING

3.1 Purpose and principles of the simulation

The conceptual model of the long line fishing (Figure 1), was used as the basis for design of a numerical (quantitative) simulation (model) for long line fishing.

The basic principle of a natural system simulation is to attempt to reproduce (simulate) quantitatively the processes in the system, based on available knowledge. The quantitative results of the processes can be variable in space and time, depending on the state of influencing factors in this system. Consequently, the simulation must be based on known and measurable influencing parameters for which quantitative data is available, and/or utilizing parameters which can be derived from other parameters (and measurements) at hand.

The simulation must be time dependent in most cases.

Proven theory should be used whenever possible, provided it has been validated with quantitative empirical data. Often good theory with mathematical formulation is available; however, parameters used in the theory and formulation are not always measurable or the mathematical formula cannot be solved numerically to reproduce desired results. In this case, empirical formulas must be developed.

The simulation formulation presented below contains mostly empirical expressions (formulas of convenience) which attempt to reproduce known condition.

3.2 Input parameters

The input parameters are listed and briefly discussed below in an arbitrary order. It is not possible to rank them by order of importance (effects), as this can vary from one type of fishery to another.

The simulation is time (t) dependent with a computational time step (t_d) of 10 minutes. At time 0, 100 baited hooks are assumed to be present ($B_0 = 100$). The actual time of day for setting the line is applied in the simulation of diurnal variation of fish motivation.

Hook spacing (d) can influence the catch in a number of ways, some of which enhance the catch, whereas others may work in the opposite direction:

- a) The number of fish at the line (in the nearfield) per hook increases with increased hook spacing.
- b) Higher bait densities (smaller hook spacing) give higher smell field intensities and more homogenous smell distribution. This might affect attraction rate as well as smell distribution area.
- c) The chance of foraging encounters is proportional to bait density.
- d) At large hook spacings fish may not readily find a new bait to attack when one is occupied or consumed. Similarly, at high fish densities at the line, saturation occurs quicker at low bait densities. Superimposed on this there may also be a slight increase in invertebrate bait predation with increased hook spacing as reported by Skud & Hamley 1978).

Consequently, the relative increase in fish density per hook resulting from increased hook spacing, is partly counterbalanced by inferior smell distribution, increased bait predation, and by reduced foraging encounters and multiple bait attacks.

Hook spacing is prescribed in the model as distance in meters between the hooks. However, in computation of bait loss due to invertebrate predation, a hook distance factor (d_e) is introduced (values 0.7 to 1.1; 0.85 in computed examples of Figures 2 to 7).

Depth of water (H) can affect the catch. There are two established effects of depth on catch: First, light penetration is a function of depth and all factors affecting bait attack which are dependent on vision would, therefore, be functions of depth. Quantitative observations on the depth functions of these factors are lacking. Second, the composition and density of invertebrate bait predators varies with depth. Data of Skud (1978) show greater bait losses at higher depths. However, the average catch rate also increased with depth in the same experiments.

In the computation of bait loss due to invertebrate predation, the following variations in depth factor were applied: depth <50m, $H=0.85$; 59 to 100m, $H=1$; >100m, $H=1.15$. In model runs presented here, the value used was 1.

Current speed (c) near the bottom (or at depth of the bait) determines the distribution of smell from the bait and thus the area of attraction of fish to the bait. The effect of current is a function of time and is described in detail in another report (Olsen and Laevastu 1983). Current speed is introduced into the model as very near bottom current speed in cm/sec (0.5 to 1.5). In addition, an index of current direction (v) at the time of long line setting, is introduced (values 0.2 - current longitudinal to line; 9.5 - current perpendicular to the line; 0.35 used in examples on Figures 2 to 7). This index requires further field experiments (e.g., determination of which initial setting in relation to current results in higher catch) (see further Olsen and Laevastu 1983).

There are several properties of the bait which affect the catch, therefore three different bait parameters are introduced into the model. A bait attractiveness index (p) (bait type) is used in computation of "effective fish

density" (1 to 3; 1.5 used in examples). A bait strength factor (s) is included in computation of bait loss due to invertebrate predation, as well as in computation of bait loss due to multiple attacks by fish; and a bait palatability exponent (k) is used in the computation of bait loss due to multiple attacks (0.4 to 0.8; 0.62 used in examples).

Bait size is also known to affect the catch. The effect is different for different size of fish and might also vary from species to species. No separate parameter is used here for bait size; it can be taken into consideration in estimating other properties of the bait listed above.

Hook type (size, shape) is considered in estimating the hooking rate per attack (h) (0.1 to 0.3; 0.2 and 0.3 used in examples). Although the effect of hook type on escape rate is not yet known, a parameter (y) is provided in the computation of the latter (1 to 3; 2 in examples). It is possible that a hook can be effective in initial hooking of fish, but the escape from this hook might be easier than from hooks which are less effective in initial capture. Further experimental work on this subject is desirable, as these parameters may also vary from species to species.

The type of line (l) (whether spun, monofilament, etc.) is known to affect catch greatly. An index of line type, with values of 0.8 to 2.5 is suitable for the formulations in our model (1.5 used in examples).

A fish motivation index (f) is provided for computation of effective fish density (0.5 to 0.9; 0.75 in examples). This index, which incorporates also the effects of ambient environmental stimuli, could be used to simulate differences in catch rates of similar target species (e.g., cod, haddock, or sablefish). Its major application is, however, to reflect the regular diurnal rhythm in the feeding behavior of the fish (see Chapter 3.3).

A rate parameter of probability of fish making repeated attacks (Q) is required for computation of bait loss due to multiple attacks. This parameter is a function of bait palatability (0.4 to 0.75; 0.52 in the examples), as affected by fish competition, gear repulsion, bait size and shape, and by hooking efficiency and effective bait density.

Rate parameters are required for computation of the rate of bait loss due to invertebrate predation (b). The values of 0.015 to 0.05 for ten minute time steps, i.e., 2 to 5.5 percent of baits lost within 10 minutes seems reasonable, (0.02 and 0.03 were used in the example). This rate changes with time. Some experimental data on the rate of bait loss is available (e.g., Skud & Hamley 1978, High and Olsen 1982). It depends on various factors, such as expected density of invertebrate predators, bait type, hook spacing, depth of water, etc.

The rate of escape (a) of fish from hooks is a time dependent complex exponent (see below the computation formulas for escape rate).

3.3 Process formulas (derived composite parameters)

Catch rates (and bait losses) in long line fishing are dependent on fish density - either fish foraging in the location of the long line or moving (migrating) through the location of the baited line. Therefore, a need exists to estimate fish density or relative abundance of fish in the vicinity of the long line.

Curio (1976) has presented a predation theory. The main conclusion of his theory is that bait encounter is a function of the square root of fish density and is inversely proportional to hook spacing.

The actual (real) fish density is unknown and unmeasurable in most cases. For the purposes of the present simulation, we define a relative effective fish density

(E) as fish in the near field of baited hooks that are likely to attack these baits. It does not matter in our simulation whether the fish are quasi-resident or migrating through the area where the long line is set.

The relative fish density (effective fish density) is constructed to be a function of a prescribed (estimated) fish density (D) with reference to 100 baited hooks, and is, therefore, also a function of hook spacing (d) (length of the line). In our present example, three different values have been prescribed to D - 2, 4, and 6.

The effective fish density is assumed to also be a function of soaking time, based on two considerations: First, in the case of a "resident" population, fish present in the area near the long line might get caught or satiated with bait. Second, a population migrating near a long line will discover fewer baits if the line has been soaked for some hours and baits have been lost. Furthermore, the bait smell distribution area is a function of soak time and intensity subsides with time.

The bait smell field (area) which is a function of current speed (c) in the depth of the bait, initial current direction in relation to the direction of line (v), and the decay of the emission of smell from the bait with time, also affects the effective fish density. Furthermore, the effective fish density is considered also to be a function of bait type (attractiveness) (p).

The effective fish density is also dependent on the foraging behavior of target species and is, therefore, affected by the feeding and physiological state of the fish (i.e., fishery on feeding prespawning, spawning, or post-spawning fish). Therefore, a fish motivation index is introduced into the computation procedure which would allow various adjustments to be made.

The composite, empirical effective fish density (E) computation formula (1) has been derived at by numerical tuning:

$$E_t = D_{ad} L_{ad} e^R \quad (1)$$

where D_{ad} is the time-adjusted prescribed density:

$$D_{ad} = D^{0.62} (t_d^{0.14}/1.7) \quad (2)$$

L_{ad} is the hook space and bit type and fish motivation factor:

$$L_{ad} = f_a d^{0.25} p^{0.5} \quad (3)$$

R is the smell area factor:

$$R = v c - (0.021 t_d c) \quad (4)$$

As we have defined the effective fish density in terms of fish being interested in attacking the bait, it is reasonable to adjust the effective fish density to the diurnal variations in the feeding periods. The adjustment is done with a harmonic formula (5) for the fish motivation index:

$$f_a = f + mf (\cos \alpha t + \kappa) \quad (5)$$

f_a is the fish motivation index as adjusted to time of day, f is the basic fish motivation index, m is the magnitude of its semidiurnal fluctuation (0 to 1; 0.6 in the examples), α is phase speed of the fluctuation (0.5 degrees per minute in semidiurnal cycle), t is time in minutes from the setting time, κ is setting time in relation to feeding cycle. If we assume that the maximum feeding occurs at 6 a.m. and 6 p.m., then $\kappa = 0^\circ$. With κ we can simulate also line setting time in relation to feeding cycle: $\kappa = 0^\circ$, setting time 6 a.m. (or 6 p.m.); $\kappa = 90^\circ$ - setting time 9 a.m. (or 9 p.m.); $\kappa = 180^\circ$ - noon or midnight, and $\kappa = 270^\circ$ - 3 a.m. (or 3 p.m.).

Bait loss due to invertebrate predation in time step t (B_b) is computed with Formula 6 (this bait loss can include also bait loss caused by fish other than the target species):

$$B_b = B_{t-1} e^n \quad (6)$$

where B_{t-1} is the number of baited hooks at the end of time step $t-1$, and the exponent n is:

$$n = b_c + (0.18 b_c t_d^{0.30}) \quad (7)$$

and $b_c = b s d_\ell H \quad (8)$

where d_ℓ is a hook spacing factor (values 0.7 to 1.1; 0.85 in examples). This hook spacing factor will cause the bait loss due to invertebrate predation to increase slightly with hook spacing (i.e., there are fewer predators per bait at closer hook spacing). Besides experimental evidence for this, an argument can be raised that the predators present in the vicinity of long line (crabs, starfish, snails, amphipods and isopods) could be reaching near saturation when more bait per unit predator is available in smaller areas, which is the case with shorter lines with the same number of hooks. H is a "depth factor", and is not well understood. In examples computed in this paper, it is assumed to be 1.

The predation by invertebrates on bait possibly decreases with time (Skud 1978). The time factor (t_d) in Formula 7 simulated the effect of predator saturation as well as the decrease of smell emission from bait which might attract predators.

s in Formula 8 is a bait strength parameter (1 in the presented example). The range and variation of this parameter is poorly known.

There is no firm proof available for either assumption above (except slight evidence of higher bait loss with increasing depth and hook spacing), and both factors can be excluded from computations without affecting the essential results.

The bait loss exponent (n) decreases with time, thus the rate of bait loss also decreases. The number of baits left at the end of the time step (B_t) is found by subtracting the losses due to multiple attacks and due to hooking.

$$B_t = B_c - A_b \tag{9}$$

A small initial bait loss during the setting (4%) is subtracted in the first time step.

The bait loss due to hooking is computed together with bait loss due to multiple attacks (A_b), as the former is a direct function of the latter.

A fish entering the nearfield of a baited hook, within which it can directly locate the bait by vision and/or other senses, may start attacking the bait one or more times with any one of the results:

1. the fish is hooked;
2. the fish manages to steal the bait without being hooked and (a) either leaves the area, or (b) attacks another bait;
3. the fish leaves the area while the bait is still (at least partially) intact.

Assuming that the probability of the fish becoming hooked during any single attack on the bait (h) will remain constant, while the probability of the fish making attacks (q) is variable, possibly decreasing by each subsequent attack, and that the bait on an average will withstand a certain number (s) of attacks before being removed from the hook, the following relations are conceivable (C_i being the probability of a fish becoming hooked when making the i th attack):

$$\left. \begin{aligned} C_1 &= q_0 h \\ C_2 &= q_0 q_1 (1-h) h \\ C_3 &= q_0 q_1 q_2 (1-h)^2 h \\ C_n &= q_0 q_1 q_2 \dots q_n (1-h)^{(n-1)} h \end{aligned} \right\} \tag{10}$$

$$\sum_{i=1}^n C_i = Q h = q_0 h [1 + q_1 (1-h) + q_1 q_2 (1-h)^2 + \dots + q_1 q_2 \dots q_n (1-h)^{(n-1)}] \tag{11}$$

when q_0, q_1, q_2, \dots are the probabilities of making 1st, 2nd, 3rd attacks, etc.

The total hooking probability is thus the product of the total number of attacks (q), and the hooking probability of one attack (h).

The number of baits lost by fish predation for every fish hooked is given by:

$$P_f = \frac{1}{Q h s} + 1 - \frac{1}{s} \quad (12)$$

If we define rate of attraction as that relevant to fish which are not only attracted to a bait, but also do a first attack on the bait, the proportion q_0 will be 1 and may, therefore, be deleted. The subsequent probabilities of attack, q_1, q_2, q_3 , etc. are, however, also a function of "bait shyness", and are, therefore different, but interrelated. The probability ($\frac{1}{s}$) of a bait being taken by the fish during an attack is a function of bait firmness (bait strength (s)), and probably also of baiting method and bait size and shape.

It might be assumed that when fish are very hungry and the bait is palatable, the same high proportion of fish present in the near field will continue to make repeated attacks, i.e., $q_1 = q_2 = q_3$, etc.

$$Q = [1 + q(1-h) + q^2(1-h)^2 + \dots + q^{(n-1)}(1-h)^{(n-1)}] = \frac{1}{1 - q(1-h)} \quad (13)$$

However, in most cases the rate of repeated bait attacks probably decays because the fish is learning to avoid the line:

$$q_{n+1} = q_n f(n+1) \quad (14)$$

if the decay is facultative, i.e.,

$$q_{n+1} = q_n \frac{k}{n+1} \quad (15)$$

$$Q = [1 + q_0 k(1-h) + \frac{[q_0 k(1-h)]^2}{2!} + \frac{[q_0 k(1-h)]^3}{3!} + \dots] = e^{q_0 k(1-h)} \quad (16)$$

Some likely values for the parameters in the above formulas have been obtained from in situ experiments using underwater TV cameras. Although the number of attacks can be easily observed, due to limited field of view it is not easy to determine whether these are all repeated attacks or attacks by other fish moving

into the area. Furthermore, it has not been well determined how many attacks result in bait loss without hooking. Further investigations are required in this subject. Examination of stomach contents of hooked fish could shed light on how many baits are eaten before hooking occurs.

The value for h has been found to be between 0.1 and 0.3. It is also dependent on bait size and hook type. The value of k is between 0.6 and 1 if we consider all attacks, but considering the attacks resulting in bait loss only, its value might be between 0.4 and 0.8. In our formulation below, k is made to present bait type. The value of q_1 is between 0.4 and 0.9.

In our model we are mainly concerned with numbers hooked (H_b) and with bait loss by multiple attacks (A_b). The latter is computed for each 10 minute time step with Formula 17:

$$A_b = E_c e^{q k (1-h)} B_t / N_o U \quad (17)$$

where:

$$U = \ell d^{0.32} \quad (18)$$

q is the probability of fish making repeated attacks (0.4 to 0.75; 0.52 in examples in Figures 2 to 7); k is related to bait type (palatability) (0.4 to 0.8; 0.62 in our examples), and h is hooking rate per attack.

It is known from the fishing experiments, as well as from underwater observations, that the rate of attack is greatly affected by the type of the line (ℓ) (line type index), e.g., monofilament lines do not repel fish as much as highly visible lines of multifilament materials (gear repulsion).

The bait loss due to multiple attacks is obviously dependent on the effective fish density (E_c) as adjusted to semidiurnal feeding rhythm, and also on the fraction of baited hooks left (B_t / N_o) at the given time step, as well as on hook distance (d) - both of the last factors affecting the "finding" of baited

hooks with a given fish density. There is also empirical evidence that increased hook spacing increases the catch rate (Skud 1978, Karlisen 1978).

Numbers hooked (H_b) is computed from the number of multiple attacks resulting in bait loss (A_b), from hooking rate parameter (h) (discussed above), and includes bait strength factor(s) which indicate the ability of bait to withstand multiple attacks:

$$H_b = h A_b s \quad (19)$$

Before computing the total catch (C_h) by summing the number of fish which remain hooked from hookings in each time step, we need to compute the rate of escape of hooked fish. This escape rate is a function of time, i.e., decreasing with time, either because of fish getting tired and/or dying on the hook. Furthermore, it might be a function of a hook parameter (i.e., the ability of the hook to retain the fish, either because of its size or special shape). In halibut long line (High and Olsen 1982), escape rate was found to vary from 5 to 50% and was on the average 20% after 5 hours of soak time.

The number of fish remaining hooked at each time step (F_t) from hooking in previous time steps (H_b) is:

$$F_t = H_b e^i \quad (20)$$

where:

$$i = -a + (a g t_d) + (g_c y) \quad (21)$$

a is escape rate (0.03 to 0.06; 0.045 in examples); g is escape rate change (decrease) (0.008), y is hook type parameter (1 to 3; 2 in examples); and g_c is a constant which has an identical value to g . It is possible that the hook type parameter (y) used in the escape formula can vary in an opposite direction from the hook type consideration in determining hooking rate (h). The latter parameters are technical considerations which need experimental data.

The total catch after the soak time t is:

$$C_h(t) = \sum_0^t F_t \quad (22)$$

The computer program in FORTRAN is given in Appendix 1.

3.4 Sensitivity of the simulation model

The types of sensitivity analyses commonly used in single-formula models are not applicable to more complex simulations. The sensitivity of various input parameters is tested and adjusted in the design stage of the simulation. The bases for these adjustments are the known empirical relations (data). The real sensitivity study of the simulations becomes the study of the time-dependent behavior of the system.

"Sensitivity considerations" pertain to the uncertainties in input data, thus indicating where additional studies are desirable. Our study indicates that more empirical measurements are required on the rates of bait losses through invertebrate predation and multiple attacks by fish, and factors affecting this loss, such as the properties of baits and hooks. Further data are required on escape rates, and especially on hooking rates with different types of hooks, baits, and target species. Hooking rate and bait loss by multiple attacks are among the most important input parameters affecting catch rates.

The effects of currents on the attraction of fish through distribution of smell from baits has been studied with another simulation (Olsen and Laevastu 1983) where hook spacing effects are also included.

The use of the simulation has shown that the long line catch is greatly affected by time dependent relations, which are not easily apparent through simple considerations. These time dependent factors are: soaking time, time of long line setting in relation to diurnal feeding cycle of fish, rate of bait loss, rate of hooking, and effective fish density. Some quantitative results on these subjects are given in the next chapter.

4. RESULTS FROM NUMERICAL EXPERIMENTS

The simulation model described above can serve a multitude of purposes, such as determining where technical development and operational practices improve catch rates of long lines. Above all, the simulation will guide and rationalize further research to achieve these ends.

The simulation (or rather its input parameters) must be tuned to particular target species subject to long line fishing (e.g., halibut, cod, or sablefish). This detailed tuning has not been made to the simulation described in Appendix 1; rather the simulation was initially used to study some general factors affecting all long line fishing. In the following, only a few general results are pointed out as examples for the use of the simulation.

Figure 2 shows bait loss and catch with time at three different initial fish densities, with some specific input parameters. Some obvious conclusions can be drawn from this figure:

- 1) The bait loss during the first few hours of soaking greatly determines the total catch. Thus, any measure which can reduce this early bait loss will increase the total catch.
- 2) After about 2 to 3 hours of soak time, the catch increases only slightly. The subsequent catch (after about 3 hours of soak time) is relatively larger if fish density is low. (Experimental evidence from halibut longlining also showed that about 50% of fish were hooked in the first 2 hours and only 10% after 6 hours of soaking (High and Olsen 1982)).
- 3) Catch (rate) is not a linear function of fish density; the rate decreases with increasing fish density. It appears that a saturation of gear is reached at high fish densities.

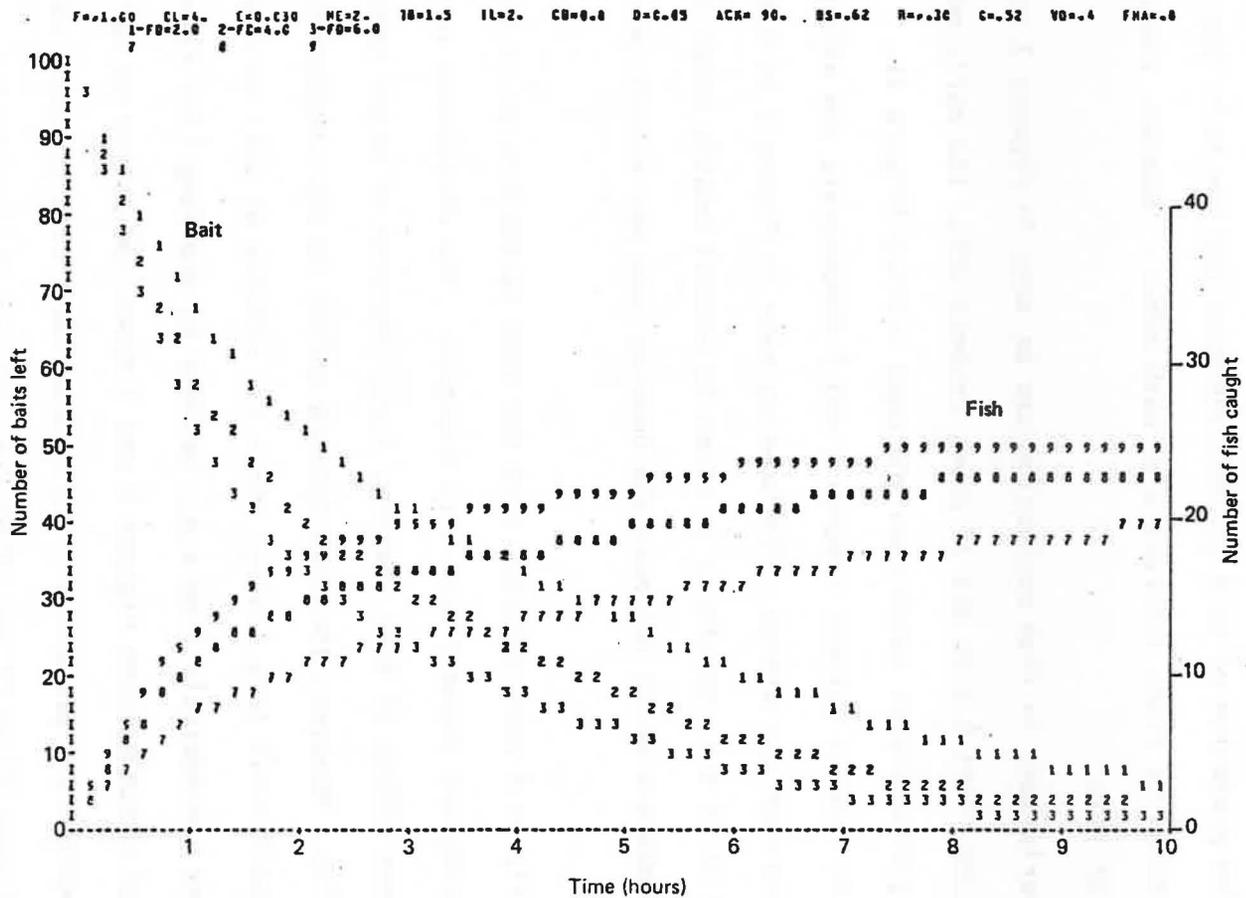


Figure 2.--Bait loss and long line catch of fish with time at three different "effective fish densities" (2,4, and 6). Setting time 9 a.m. (Bait loss exponent = 0.03, hook spacing = 4 m, hooking rate = 0.3).

The high bait loss in the first few hours of soaking is not only caused by invertebrate predation, but also by multiple attacks by fish. If the hooking rate per attack decreases, bait loss by attacks remains unchanged, but total catch decreases. The predation of bait by invertebrates and the bait loss through multiple attacks by fish, interact with each other. However, the latter results in hooking of fish.

The effect of variations in fish motivation can be seen in Figures 3 and 4 which refer to setting times 6 a.m. and 12 noon, respectively, the early morning setting (Figure 3) giving higher catch than the noon setting (Figure 4).

The difference in catches between Figures 2 and 5 demonstrate the effect of the change of hooking rate per attack. The hooking rate in Figure 2 is 0.3., whereas in Figure 5 it is 0.2, resulting in close to proportionally lower catch. Thus, any technical measure which improves the hooking rate per attack, would increase the catch.

The catches in Figure 6 were computed with the same parameters as in Figure 2, except the hook spacing was changed from 4 to 6 meters. The difference in catch demonstrates the known effect of hook spacing, i.e., increase of catch rate with increased hook spacing. However, the hook spacing effect in the simulation must be tuned to a particular long lining, since its effects as well as practices of hook spacing, vary considerably from e.g., halibut to cod long line fisheries.

The difference of catch between Figures 2 and 7 shows the effect on bait loss by change in invertebrate predation. The initial bait loss exponent was decreased from 3% (Figure 2) to 2% per 10 minutes (Figure 7), resulting in slightly higher catch of fish.

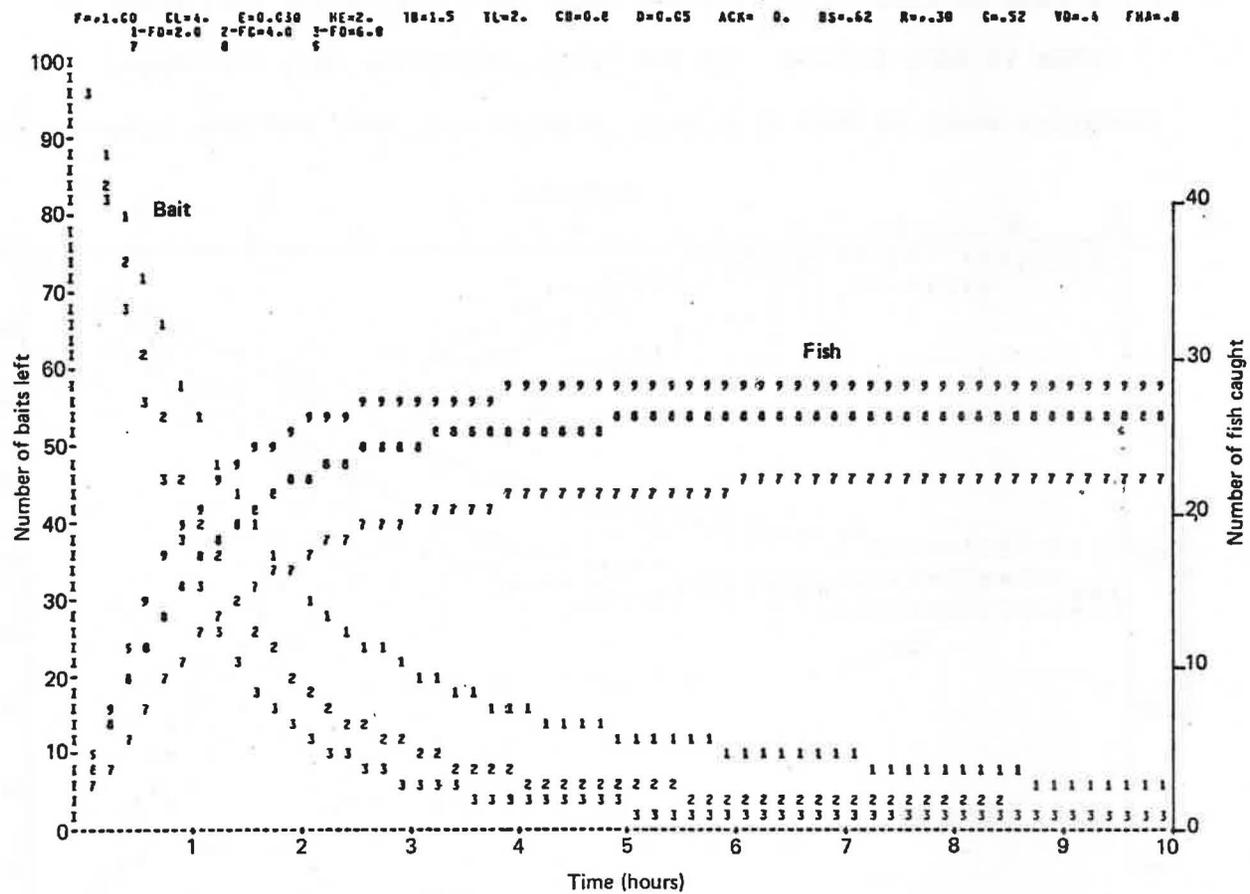


Figure 3.--Bait loss and long line catch of fish with time at three different "effective fish densities" (2,4, and 6). Setting time 6 a.m. (Bait loss exponent = 0.03, hook spacing = 4 m, hooking rate = 0.3).

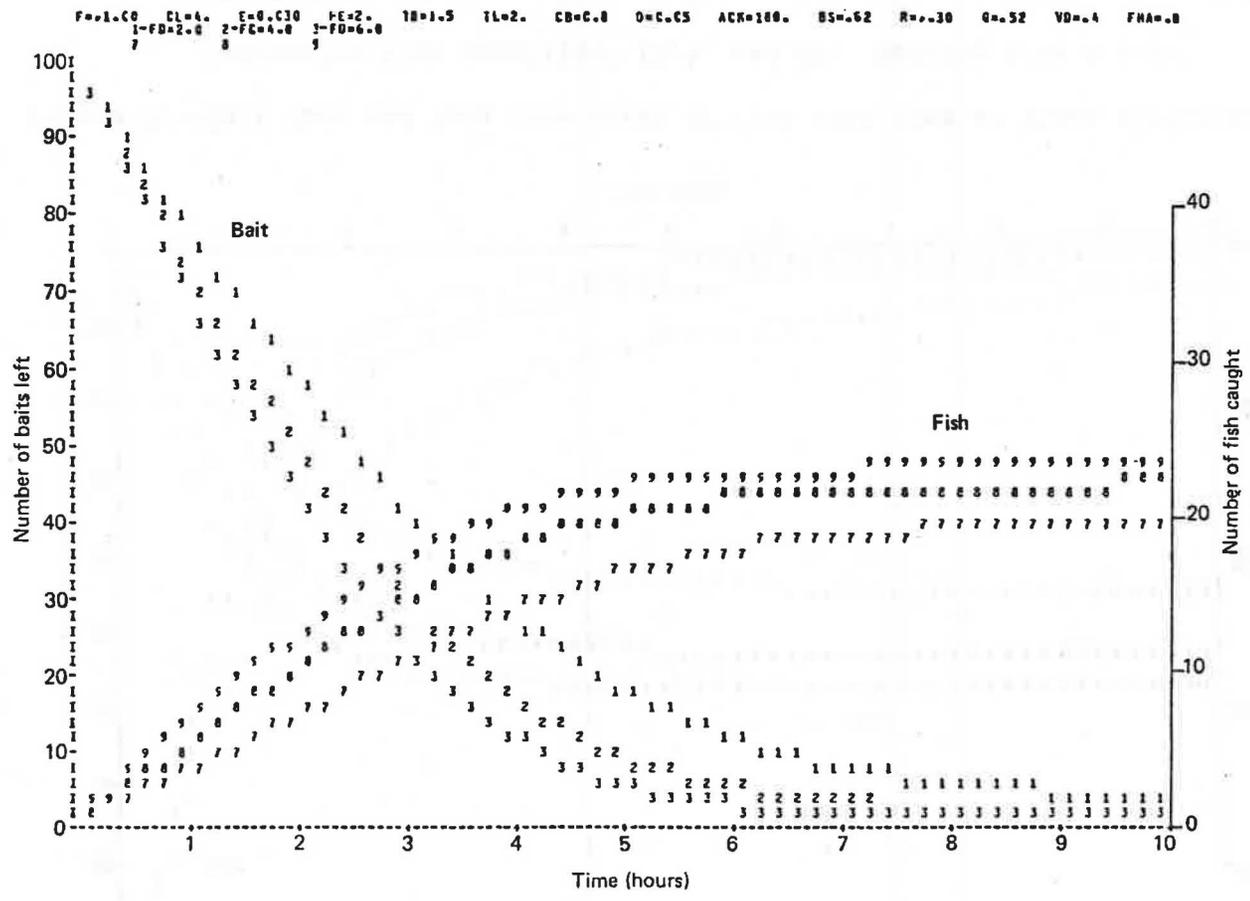


Figure 4.--Bait loss and lone line catch of fish with time at three different "effective fish densities" (2,4, and 6). Setting time at noon. (Bait loss exponent = 0.03, hook spacing = 4 m, hooking rate = 0.3).

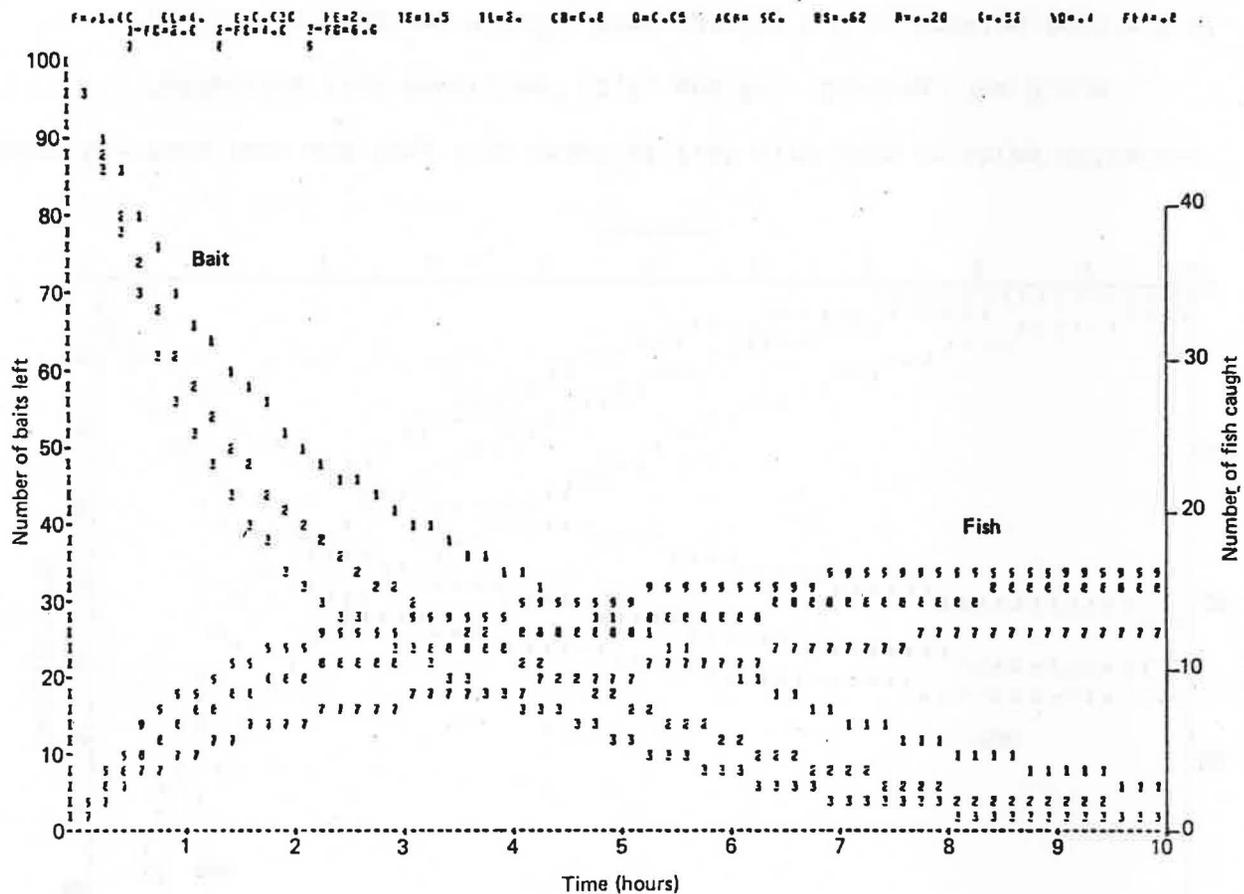


Figure 5.--Bait loss and long line catch of fish with time at three different "effective fish densities" (2,4, and 6). Setting time 9 a.m. (Bait loss exponent = 0.03, hook spacing = 4 m, hooking rate = 0.2).

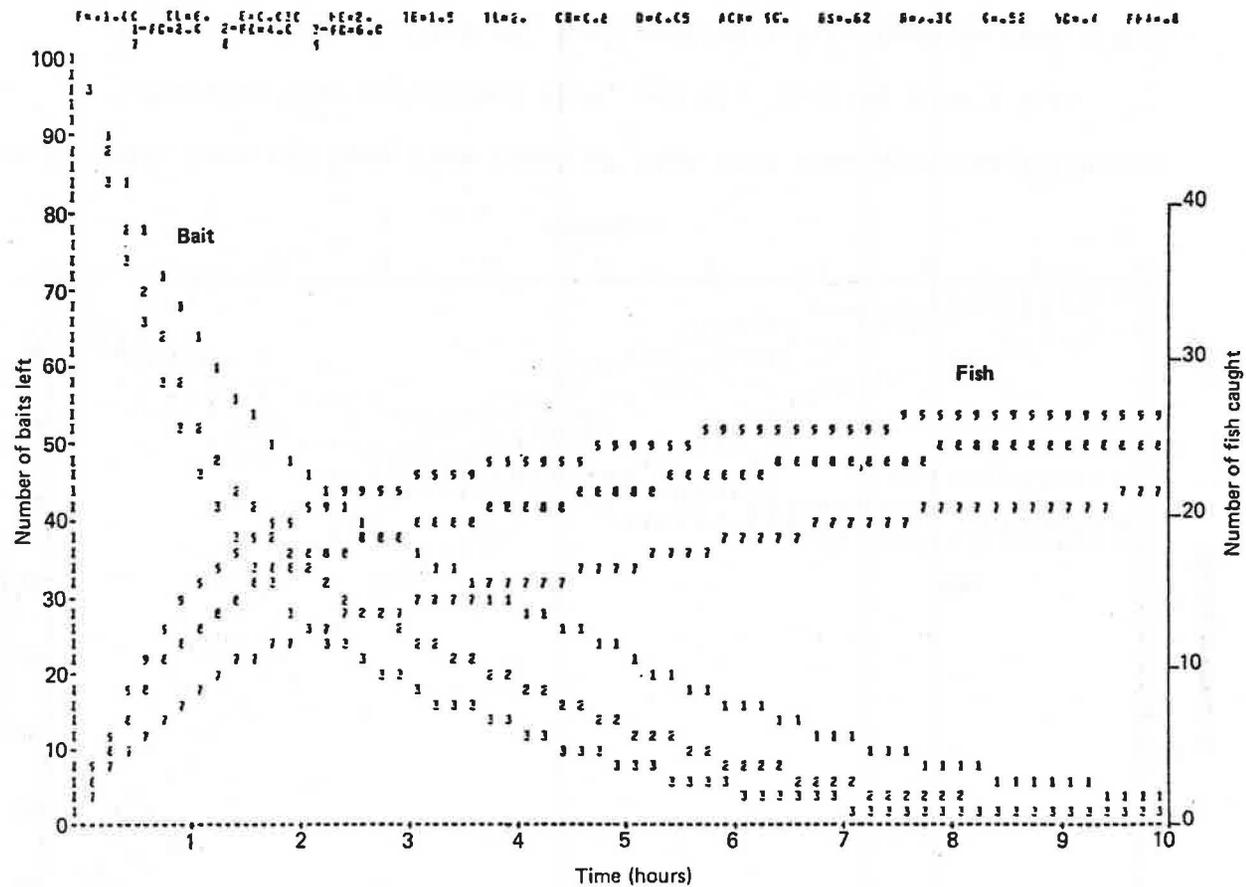


Figure 6.--Bait loss and long line catch of fish with time at three different
 "effective fish densities" (2,4, and 6). Setting time 9 a.m.
 (Bait loss exponent = 0.03, hook spacing = .6 m, hooking rate = 0.3).

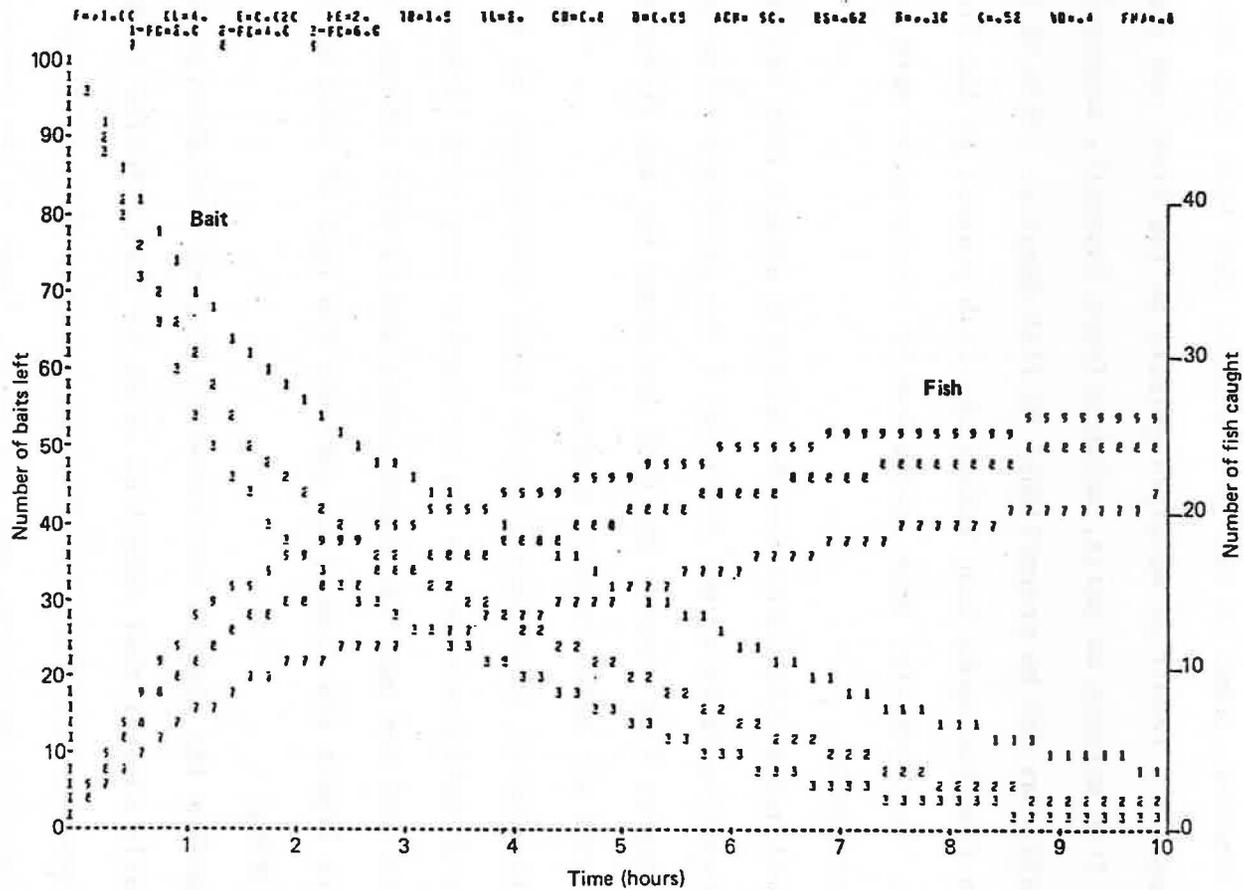


Figure 7.--Bait loss and long line catch of fish with time at three different "effective fish densities" (2,4, and 6). Setting time 9 a.m.
 (Bait loss exponent = 0.02, hook spacing = 4 m, hooking rate = 0.3).

5. LONG LINE CATCH AND FISH DENSITY

As reviewed by Skud and Hamley (1978), previous authors have pointed out that hooking and bait loss may significantly affect CPUE in long line fishing, and various methods for making adjustments for these effects have been proposed.

None of these, however, seems to take into account that bait loss due to fish predation is mainly a result of multiple attacks by the fish, and that the compounded rate of fish attacks on baits, which differs (normally exceeds) from the hooking rate, may not be proportional to fish density. This is because baits may be stolen from the hooks long before the fish present at the line are satiated or hooked. Consequently, gear saturation is likely to be more pronounced than previously anticipated.

The present study has demonstrated how the multiple attack rate may be affected by a number of interacting factors, and in Figure 8 the resulting relationships between initial effective fish density and CPUE are shown for two different hooking rates, but with all other factors constant.

While the combination of input parameters in these simulations, as stated earlier, may not be directly relevant to any particular long line fishery, and the process formulas used are open for improvements and further tunings, the curves shown by this figure are thought to indicate the type of relationships that do exist in long lining.

As such they confirm the assumed non-linearity between fish density and CPUE, and they clearly suggest that long line catch is less affected by density changes when fish are abundant than when they are scarce. This relative insensibility at high fish densities, and vice versa, leads to the interesting conclusion that longlines are particularly efficient for catching fish when fish are scattered, i.e., at low stock densities.

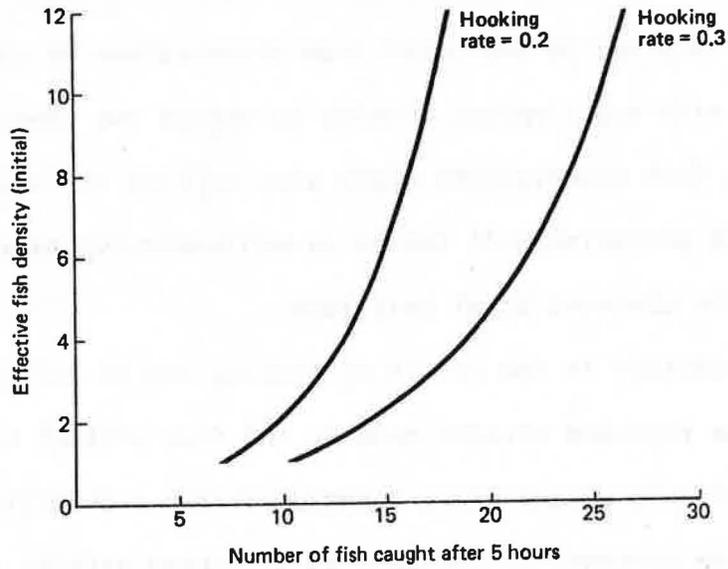


Figure 8.--Catch with long line (100 hooks) after 3 hours soak time with different "effective fish densities". Setting time 9 a.m. (Hooking rates = 0.2 and 0.3.)

A further important implication is that for a seasonal fishery, where the fishing effort is distributed in space and time over a variety of fish densities, the simple arithmetic mean of the fleet's individual catch rates does not necessarily equal the catch rate corresponding to that of the average fish density.

It would thus seem that for purposes of resources management as well as for fishing technology, development of better quantitative knowledge of the relation between long line catch and fish abundance is most desirable. Evidently the most serious gaps in present knowledge relate to bait loss and hooking rate.

Total bait loss rate may be evaluated from observations on commercial long line vessels paired with experimental fishing to extend the range of soaktimes and fish densities. Such observations might also suffice for separating invertebrate and fish predation bait losses by extrapolations towards zero fish density (catch) of the observed total bait loss.

The fish bait predation is the result of hooking and of baits being stolen in the process of the repeated attacks made by the fish without becoming hooked. This bait loss by multiple attacks is a function of the probabilities or rates of repeat attacks, the strength of the bait to withstand attacks and remain on the hook, and of the individual, single attack hooking rate.

The latter two parameters may be considered independent of the density and feeding motivation of the fish present at the line. Separate assessments of their approximate values may, therefore, be made by laboratory and/or field experiments. The multiple attack rates are, however, clearly fish dependent and therefore have to be estimated from data relating to the fish actually caught.

If it can be assumed that the numbers of baits found in the stomachs of long line caught fish are equal or nearly proportional to those of the baits

consumed by the fish prior to hooking, frequency distributions of long line baits in the fish stomachs may provide the additional information required to enumerate the multiple attacks.

This concludes the requirements for establishing a CPUE relative fish density relationship which is tuned to the particular conditions of the relevant fishery.

6. CONCLUSIONS AND SUGGESTIONS FOR FURTHER STUDY AND DEVELOPMENT OF THE MODEL

The review of available literature made it clear that we lack reliable data (measurements) of many parameters which affect the catch of long lines. Moreover, the results of some past experiments are uncertain, because many factors which affect the catch varied in the experiments or were not reported properly. The model presented in this paper can guide future experiments, indicating which parameters need to be measured and which should be kept constant during the experiments. In particular a need exists for better quantification of the following factors:

- a) Bait loss caused by invertebrate predation during the first few hours of soaking, by season, time of the day, and depths of fishing.
- b) Hooking rate per attack by species, bait type, and by hook type and size.
- c) Escape rates by species, seasons, fishing depth, and hook type.
- d) Diurnal rhythm of feeding (and the related rate of hook attacks) by species season and soak time.

Additional species specific data are also desirable with regard to:

- e) Effects of hook spacing on bait loss and catches.
- f) Effects of bait type and strength on bait losses and catches.

The research needs in respect to currents near the bottom and the related problems of distribution of smell from baits, are described in another paper (Olsen and Laevastu 1983).

In addition the outlined, tentative methods for estimating relative fish density from long line catches need further experimental studies.

Additional meaningful numerical experiments with the simulation can be conducted after it has been adapted to any particular (specific) fishery.

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APPENDIX I

LONG LINE FISHING SIMULATION PROGRAMME (HOORATE)

The long line fishing simulation programme uses the formulas described in the text of this paper. The programme is written in FORTRAN II and, therefore, can be easily converted to BASIC to run on microcomputers.

The programme is designed in rather general form, so that it can be adapted to any particular long line fishing by changing mainly the input parameters. Although emphasis in this programme is on determination of total catch (rate), it can be (and has been) used for the study of different technical, biological, and environmental factors on the long line catch.

The simulation is time dependent with a ten minute time step. Consequently, all coefficients are adapted to this time step. The input parameters and symbols are listed in Table 1. Input parameter values (and ranges of values) and symbols used in the model are given in Table 2. In this table the corresponding symbols used in the formulas in the text are also given.

The inputs to the model are introduced with individual statements in the beginning of the programme, making the reviewing of the programme easier. The initial values in first time step are set first and other derived parameters are computed once in each time step after statement 20. Computations are made in one run with three different inputted fish densities, and the essential results are printed (see example Table 2). At the end of the computations, the bait losses and catches corresponding to these three input fish densities, are plotted with a printer (see example in Figures 2 and 7 in the text). The printer plots list also the numerical values of the parameters used in the particular runs.

Table 1.--Symbols and input parameters, programme HOORATE

<u>Inputs</u>		
Symbol in formula	Symbol in programme	Description and range of values
a	D	Escape rate constant (0.03-0.06)
b	E	Bait loss exponent (0.02 to 0.05)
c	CS	Current speed near bottom (0.5; 0.8; 1.5)
d	DL	Hook distance (2, 4, 6, 8 m) (Must be indexed in fisheries with longer hook spacing.)
d_{ℓ}	DLF	Hook distance factor (0.85; 0.9; 1.1; 1.2)
D	FD	Initial fish density factor (2, 4, 6)
f	FHA	Fish motivation index
g	B	Escape rate change (0.008)
h	HR	Hooking rate per attack (0.2 to 0.4)
H	HF	Depth factor (<50m = 0.85; 50 to 100m = 1; >100m = 1.15)
k	BS	Bait palatability exponent (0.4 to 0.8)
ℓ	TL	Line type index (0.8 to 2.5)
m	EM	Magnitude of semidiurnal fluctuation of fish motivation
N_o	HI	Number of hooks (100)
p	TB	Bait attractiveness index (1 to 3)
Q	Q	Probability of repeated attacks (0.4 to 0.75)
S	SL	Initial bait loss (4)
s	HZ	Bait strength factor
t_d	TD	Time step counter (time step 10 minutes)
v	VD	Current direction index, at time of setting (0.2 - longitudinal, 0.5 - perpendicular)

Table 1 (cont'd).

y	HE	Hook type parameter (1 to 3)
α	AL	Phase speed of semidiurnal change of effective fish density (0.5 deg/min)
κ	ACK	Phase lags, regulating maximum feeding period (also of setting time) (0 to 360 deg.)
—	CONV	Factor for converting degrees to radians (0.0174533)

Outputs

A_b	BLA(t)	Bait loss due to multiple attacks and hooking
B_t	BN(t)	Number of baits left at the end of each time step
B_b	BNC(t)	Bait loss due to invertebrate predation
C_h	TRH(t)	Number of fish remaining hooked
E_c	EDA(t)	Effective fish density adjusted to feeding periods (time of day)
E_t	EFD(t)	"Effective fish density"
F_t	FNR(t)	Fish retained at the end of each time step (after escapement)
H_b	FN(T)	Hooking (rate) per time step
t	T(t)	Time in minutes

Other parameters

Symbol in formula	Symbol in programme	Description and range of values
	APN	Intermediate (in hooking rate computation)
R	ARA	Intermediate (area consideration)
	COF	Intermediate (time factor)
L _{ad}	DFS	Intermediate (hook space and type factor)
	EE	Intermediate (in bait loss by invertebrate predation)
	FMAG	Magnitude of semidiurnal change of fish density
	FFS	Intermediate (baited hooks)
	FSR	Intermediate (bait factors)
U	FTT	Intermediate (line type and hook spacing factor)
	K	Counter
	ND	Time step counters
i	PIC	Intermediate (escape loss exponent)
n	PL	Intermediate (bait loss exponent)
	STR	Intermediate (summation)
	TD	} Time step counters
	TDN	
	TDL	Intermediate (in bait loss by invertebrate predation)
	TIF	Intermediate (time factor)
	CBA(t), CBB(t), CBC(t)	Bait loss fields for plotting
	FLD	Plotting field
	HCA(t), HCB(t), HCC(t)	Hooked fish count for plotting

Table 2.--Examples of numerical outputs from the programme HOORATE.

Time, minutes	Bait left after invertebrate predation	Bait loss due to multiple attacks	Bait left at the end of time step	"Effective fish density"	Fish density adjusted to time of day	Hooking rate	Fish left after escape	Catch
TI	BAC	BLA	BN	EFD	EDA	NF	FNR	TRH
10.	96.00	4.34	96.00	1.53	1.52	1.30	1.27	1.30
20.	94.01	4.06	89.95	1.52	1.44	1.22	1.18	2.43
30.	88.19	3.68	84.30	1.65	1.47	1.16	1.13	3.58
40.	82.71	3.56	79.15	1.71	1.44	1.07	1.04	4.62
50.	77.69	3.21	74.48	1.74	1.38	0.96	0.94	5.56
60.	73.15	2.87	70.28	1.76	1.31	0.86	0.84	6.40
70.	69.05	2.55	66.50	1.77	1.24	0.77	0.75	7.14
80.	65.36	2.27	63.10	1.77	1.16	0.68	0.66	7.80
90.	62.04	2.01	60.02	1.77	1.09	0.60	0.59	8.39
100.	59.03	1.79	57.25	1.77	1.02	0.54	0.52	8.92
110.	56.32	1.59	54.73	1.76	0.95	0.48	0.47	9.38
120.	53.86	1.42	52.43	1.74	0.89	0.43	0.42	9.80
130.	51.61	1.28	50.33	1.73	0.83	0.38	0.37	10.17
140.	49.55	1.15	48.40	1.72	0.78	0.35	0.34	10.51
150.	47.66	1.05	46.61	1.70	0.74	0.32	0.31	10.82
160.	45.91	0.97	44.94	1.68	0.71	0.29	0.28	11.10
170.	44.28	0.90	43.38	1.66	0.68	0.27	0.26	11.36
180.	42.75	0.84	41.90	1.64	0.66	0.25	0.25	11.61
190.	41.30	0.80	40.50	1.62	0.65	0.24	0.23	11.84
200.	39.92	0.77	39.16	1.60	0.65	0.23	0.22	12.07
210.	38.60	0.74	37.86	1.58	0.65	0.22	0.22	12.29
220.	37.33	0.73	36.60	1.56	0.66	0.22	0.21	12.50


```

C   BLA(1)=EDA(1)*EXP(FSR)*TL*(DL**0.30)          000045
C   INITIAL NO FISH CALGHT                          000046
C   TRH(1)=FR*BLA(1)                                000047
C   FN(1)=TFH(1)                                     000047
C   INITIAL FISH ESCAPEMENT(RETENTION)              000047
C   FNR(1)=FN(1)*EXP(-D)                            000047
C   XXXXXX                                           000048
C   EFFECTIVE FISH DENSITY                           000049
20  ARA=VD*CS-(0.025*TD*CS)                          000050
C   COF=(TD**0.14)/1.7                               000051
C   DFS=FHA*SQRT(TB)*(DL**0.25)                     000052
C   EFD(ND+1)=DFS*FD**0.62*COF*EXP(ARA)             000054
C   FMAG=EM*EFD(ND+1)                                000054
C   ARUN=AL*T(ND)*CONV                               000054
C   EDA(ND+1)=EFD(ND+1)+FMAG*COS(ARUN+AMA)          000054
C   XXXXXX                                           000058
C   BAIT LOSS DUE TO INVERTEBRATE PREDATION         000059
C   EE=E*HF*DLF*HZ                                   000060
C   TIF=(TD**0.30)*0.18                             000061
C   PL=-EE+(TIF*EE)                                  000063
C   BNC(ND+1)=BN(ND)*EXP(PL)                         000065
C   XXXXXX                                           000066
C   BAIT LOSS DUE TO MULTIPLE ATTACK                000067
C   FFS=BN(ND)/HI                                    000067
C   FSR=G*BS*(1-HR)                                  000067
C   FTT=TL*(DL**0.32)*HZ                             000067
C   BLA(ND+1)=EDA(ND+1)*EXP(FSR)*FFS*FTT           000068
C   BNC(ND+1)=BNC(ND+1)-ELA(ND+1)                  000069
C   XXXXXX                                           000070
C   HOOKING (NUMBER HOOKED)                          000071
C   FN(ND+1)=FR*BLA(ND+1)                            000073
C   XXXXXX                                           000074
C   XXXXXX                                           000077
C   FISH ESCAPE FROM HOOKS                           000078
C   STR=C.                                           000079
C   IF(ND-1)43,43,41                                 000079
43  STR=FNR(1)                                       000079
C   GO TO 42                                          000079
41  DC 40 N=1,ND                                     000080
C   TDN=N                                             000081
C   PIC=-D+(D*B*TDN)+(B*HE)                          000082
C   FNR(N)=FN(N)*EXP(PIC)                            000083
C   STR=STR+FNR(N)                                    000084
40  CCNTINUE                                         000085
42  PIC=-D+(D*B*TD)+(B*HE)                           000086
C   FNR(ND+1)=FN(ND+1)*EXP(PIC)                     000087
C   XXXXXX                                           000088
C   TOTAL NO FISH REMAIN HOOKED                      000089
C   TRH(ND+1)=STR+FNR(ND+1)                          000090
C   XXXXXX                                           000091
C   ND=ND+1                                           000092
C   TC=ND                                             000093
C   T(ND)=T(ND-1)+10.                                000094
C   IF(ND-60)20,50,50                                000095
C   XXXXXX                                           000095
C   PRINTING                                          000095
C   50 PRINT 51                                       000096
51  FORMAT(//6X,2HTI,7X,3HBNC,7X,3HBLA,7X,2HBN,8X,3HEFD,7X,3HEDA,7X,2
C   2HNF,8X,3HFNR,7X,3HTRH,/)                        000098
C   PRINT 52,(T(N),BNC(N),BLA(N),BN(N),EFD(N),EDA(N),FN(N),FNR(N),TRH( 000099

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2N),N=1,60)
52 FORMAT(5X,F4.0,4X,F6.2,5X,F6.2,4X,F6.2,4X,F6.2,4X,F6.2,4X,F6.2,4X,F6.2,4X)
   2,F6.2,4X,F6.2)
   IF(K-2)53,54,55
C     XXXXXX
C     SAVING FIELD FOR PLOTTING
53 DO 59 N=1,60
   CBA(N)=BA(N)
   HCA(N)=TRH(N)
   BN(N)=0.
   TRH(N)=0.
59 CONTINUE
   K=K+1
   FD=4.
   ND=1
   TD=ND
   GO TO 9
54 DO 58 N=1,60
   CEB(N)=BA(N)
   HCB(N)=TRH(N)
   BN(N)=0.
   TRH(N)=0.
58 CONTINUE
   K=K+1
   FD=6.
   ND=1
   TD=ND
   GO TO 9
55 DO 57 N=1,60
   CBC(N)=BA(N)
   HCC(N)=TRH(N)
57 CONTINUE
60 FD=9999999.
C     XXXXXX
C     PLOTTING
   PRINT 65,HF,DL,E,HE,IB,TL,CS,D,ACK,BS,HR,C,VD,FHA
65 FORMAT(1H1,5X,3HF=,F4.2,3X,3HDL=,F2.0,3X,2HE=,F5.3,3X,3HHE=
   2,F2.0,3X,3HTB=,F3.1,3X,3HTL=,F2.0,3X,3HCB=,F3.1,3X,2HD=,F4.
   32,3X,4HACK=,F4.0,3X,3HBS=,F3.2,3X,3HR=,F3.2,3X,2HQ=,F3.2,3X,3HVD=,
   4F2.1,3X,4HFHA=,F2.1)
   PRINT 66
66 FORMAT(12),8H1-FD=2.0,2X,8H2-FD=4.0,2X,8H3-FD=6.0)
   PRINT 67
67 FORMAT(12),1H7,9X,1H8,9X,1H9)
   NI=52
   MI=125
   IBLANK=1H
   IN=1HI
   IF=1H-
   IA=1H+
   DO 10 J=1,NI
   DO 10 K=1,MI
   FLO(J,K)=IBLANK
10 CONTINUE
   DO 11 J=1,51
11 FLO(J,4)=IN
   FLO(1,1)=1H1
   FLO(1,2)=1H0
   FLO(1,3)=1H0
   DO 12 J=6,51,5

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	FLD(J,3)=1H0	0C0143
	FLD(J,4)=IP	0C0144
12	CCONTINUE	0C0144
	FLD(6,2)=1H9	0C0144
	FLD(11,2)=1H8	0C0144
	FLD(16,2)=1H7	0C0144
	FLD(21,2)=1H6	0C0144
	FLD(26,2)=1H5	0C0144
	FLD(31,2)=1H4	0C0144
	FLD(36,2)=1H3	0C0144
	FLD(41,2)=1H2	0C0144
	FLD(46,2)=1H1	0C0144
	DC 13 K=5,MI	0C0145
13	FLD(51,K)=IP	0C0146
	DC 14 K=17,MI,12	0C0147
14	FLD(51,K)=IA	0C0148
	FLD(52,17)=1H1	0C0149
	FLD(52,29)=1H2	0C0149
	FLD(52,41)=1H3	0C0149
	FLD(52,53)=1H4	0C0149
	FLD(52,65)=1H5	0C0149
	FLD(52,77)=1H6	0C0150
	FLD(52,89)=1H7	0C0150
	FLD(52,101)=1H8	0C0150
	FLD(52,113)=1H9	0C0150
	FLD(52,124)=1H1	0C0150
	FLD(52,125)=1H0	0C0151
	IX=1H1	0C0154
	IY=1H2	0C0155
	IZ=1H3	0C0156
	IS=1H7	0C0157
	IT=1H8	0C0158
	IU=1H9	0C0159
	DC 70 N=1,60	0C0160
	I=INT(51.-CBA(N)/2.)	0C0161
	J=2*N+4	0C0162
	IF(I-1)71,71,72	0C0163
71	I=1	0C0164
72	IF(I-50)74,74,73	0C0165
73	I=50	0C0166
74	FLD(I,J)=IX	0C0167
70	CCONTINUE	0C0168
	DC 75 N=1,60	0C0169
	I=INT(51.-HCA(N))	0C0170
	J=2*N+4	0C0171
	IF(I-1)76,76,77	0C0172
76	I=1	0C0173
77	IF(I-50)79,79,78	0C0174
78	I=50	0C0175
79	FLO(I,J)=IS	0C0176
75	CCONTINUE	0C0177
	DC 80 N=1,60	0C0178
	I=INT(51.-CBB(N)/2.)	0C0179
	J=2*N+4	0C0180
	IF(I-1)81,81,82	0C0181
81	I=1	0C0182
82	IF(I-50)84,84,83	0C0183
83	I=50	0C0184
84	FLD(I,J)=IY	0C0185
80	CCONTINUE	0C0186

DC 85 N=1,60	000187
I=INT(51.-HCB(N))	000188
J=2*N+4	000189
IF(I-1)86,86,87	000190
86 I=1	000191
87 IF(I-50)89,89,88	000192
88 I=50	000193
89 FLD(I,J)=I7	000194
85 CCNTINUE	000195
DC 90 N=1,60	000196
I=INT(51.-CBC(N)/2.)	000197
J=2*N+4	000198
IF(I-1)91,91,92	000199
91 I=1	000200
92 IF(I-50)94,94,93	000201
93 I=50	000202
94 FLD(I,J)=I2	000203
90 CCNTINUE	000204
DC 95 N=1,60	000205
I=INT(51.-HCC(N))	000206
J=2*N+4	000207
IF(I-1)96,96,97	000208
96 I=1	000209
97 IF(I-50)99,99,98	000210
98 I=50	000211
99 FLD(I,J)=IU	000212
95 CCNTINUE	000213
PRINT 101,(MI,(FLD(J,K),K=1,MI),J=1,NI)	000214
101 FCRMAT(2X,*A1)	000215
PRINT 102	000216
102 FCRMAT(60X,"HOURS")	000217
RETURN	000218
END	000219

