A model for the relationship between catch and soak time in baited fish traps

Per SUNDBERG (1)

ABSTRACT

A model is proposed which shows how catch is related to soak time, duration of bait smell and escapement rates in baited fish traps. The model predicts that a) *there is a certain soak time that maximizes the number of fish in the trap,* b) *this number will increase with increasing smell persistence of the bait, and* c) *this number will increase with decreasing escapement rate from the trap. Increasing smell persistence of bait and decreasing escapement rate from the trap will force the peak in number of fish towards longer soak times. A practical implication of the model is that the soak time that maximizes the number of fish is not necessarily the most profitable soak time for a trap fishery.*

KEY WORDS : Fish trap — Catch — Soak time — Relationship.

RÉSUMÉ

UN MODÈLE POUR L'ÉTUDE DE LA RELATION ENTRE LA PRISE ET LE TEMPS D'IMMERSION DE PIÈGES À POISSONS

Il est proposé un modèle qui montre comment la prise est reliée au temps d'immersion, à la durée de persistance de l'odeur de l'appât et au taux d'échappement des poissons, dans des pièges appâtés. Le modèle prévoit que : a) *il y a une durée d'immersion pour laquelle la prise est maximale,* b) *cette prise croît avec la persistance de l'odeur de l'appât,* c) *cette prise croît lorsque décroît le taux d'échappement du piège. Croissance de la persistance de l'odeur et décroissance de l'échappement tendent à inciter à des immersions prolongées des pièges. Une implication pratique du modèle est que le temps d'immersion qui fournit une capture maximale n'est pas nécessairement celui qui procure le profit maximal au pêcheur.*

MOTS-CLÉS : Piège à poissons — Capture — Temps d'immersion — Relations.

INTRODUCTION

A substantial part of the continental and island shelves in the tropics is not available to fishing by nets or trawling because of coral reefs. Instead fishing is done mainly with spears, hooks and traps. The traps are normally set baited, soaked for a certain period of time, hauled, emptied and then reset.

This paper presents a model for how the catch varies with time in baited fish traps for different escapement rates and duration times of bait smell. It is based on the assumption that a fish which senses the smell of the bait will enter the trap with a certain probability. The chance of encountering the smell zone is directly proportional to the size of the zone of smell and decreases with time since the bait will deteriorate. The model explains why the catch rate changes over time in terms of simple encounter and escapement probabilities. The model predicts that a certain soak time maximizes the catch and that

(1) *Research and Surveys Branch, Fisheries Division, Department of Primary Industry, P.O. Box 417, Konedobu, Papua New Guinea; present address: University of Göteborg, Department of Zoology, P.O. Box 250 59, S-400 31 Göteborg, Sweden.*

this soak time, together with the number of fish in the trap, depends on the persistence of the bait's smell and on how effective the trap is in retaining fish. The comparison of the predictions of the model with data from trapping in the Caribbean (MUNRO, 1974) shows that the model describes and explains the relationships between catch and soak time well, despite its simplicity.

2. THE MODEL

The bait will immediately start to emit various chemical compounds when the trap is set, and this will attract fish and other animals to a degree which depends on the type of bait and species involved. The actual pattern for how the smell of the bait is spread into the surrounding water is highly complicated and mainly dictated by currents, but also to a minor degree by diffusion (OKUBO, 1980). The crucial point for the development of the model presented here, however, is that the smell of the bait reaches a maximum distance from the trap at a certain time, and that the emission of attractants thereafter diminishes with time. This will continuously reduce the distance the bait can be smelled from the trap, until the bait is completely exhausted. The real pattern for how this smell is spread from the trap when set has not, for simplicity of the model, been taken into consideration. It has instead been assumed that a fish is able to detect a certain threshold of smell, and that this threshold concentration reaches its maximum distance from the trap instantaneously as it is set. It is further assumed that the boundary of this threshold concentration is spread equally fast in all directions, thereby forming a half sphere of smell, with radius r, above or equivalent to the threshold concentration. The bait will immediately start to deteriorate whereby the emission of smell will decrease and this is turn has the effect that the radius r will also decrease. The volume of this half sphere of smell will be:

$$V = 1/2\{(4/3).\pi.r^3\} \tag{1}$$

It is of course unrealistic to assume that a circular sphere of smell will be formed around the trap. There are two major factors that determine the actual pattern for how this cloud is dispersed, and these are currents and horizontal stratification of the water due to salinity and temperature differences between layers. These are factors that certainly have to be considered in practical fishing (for example where to set the trap in relation to the target population of fish) but does not really concern the theoretical exercise presented here. The only impact these factors will have on the model is that the volume expression in equation (1) tend to be much more complicated. The model, however, aim to detect some of the factors that determine the behaviour of fish traps and the simplification of the spreading of bait smell does not alter the qualitative outcomes of it.

It is furthermore assumed that a fish enters the trap with a certain probability, α, when it detects this threshold of smell. Or, in the case when the bait is completely exhausted, comes in close contact with the actual trap. This is once again a simplification of a much more complicated situation, and even if lobsters (MCLEESE, 1970) as well as other invertebrates (HANCOCK, 1974) are known to be attracted to baited traps by food odours carried by water currents, many other factors will attract fish to enter a trap. Denote entering the trap A, and the event of encountering the half sphere of smell, or the trap, B. The probability of entering the trap once it has been encountered can then be written as the conditional probability $p(A|B) = \alpha$. If furthermore, the probability for event B is $p(B) = \beta$, the overall probability for a fish both to encounter the half sphere of smell (or trap) and to enter the trap is $p(A \Lambda B) = p(A|B).\, p(B) = \alpha.\beta$ since events A and B are dependent.

It is reasonable to assume that it is competely a matter of chance if a fish will encounter the sphere of odours or not. This infers that the probability β is Poisson-distributed and thus directly proportional to the volume where V is given by (1), $\beta\alpha \propto V$. The expected number of fish entering a trap per unit time is hence a fraction, $\alpha.\beta$ of the total number of fish available N_{tot}. Since, however, the emission of odours from the bait will decrese with time t, so will the maximum distance from the trap the threshold smell can be felt decrease too. Assume the smell concentration change over time is proportional to the concentration, then:

$$-\,d(SC)\,/\,dt = c.SC$$

$$SC = SC_0.EXP(-\,c.t) \tag{2}$$

where SC_0 is the initial smell concentration and c a constant determining the speed of bait deterioration. Experiments by MACKIE *et al.* (1980) on artifical bait and the change in the rate of release of amino acids over time supports the assumption of an exponential decline in smell concentration. Hence given the above assumptions, the radius of the half sphere of smell will decrease exponentially since volume is a function of the radius r according to:

$$r = RT\{1 + K.EXP(-\,c.t)\} \tag{3}$$

The decrease in the volume of the half sphere of smell will then be found by inserting (3) in (1):

$$V = 1/2\{(4/3).\pi.[RT(1 + K.EXP(-\,c.t))]^3\} \tag{4}$$

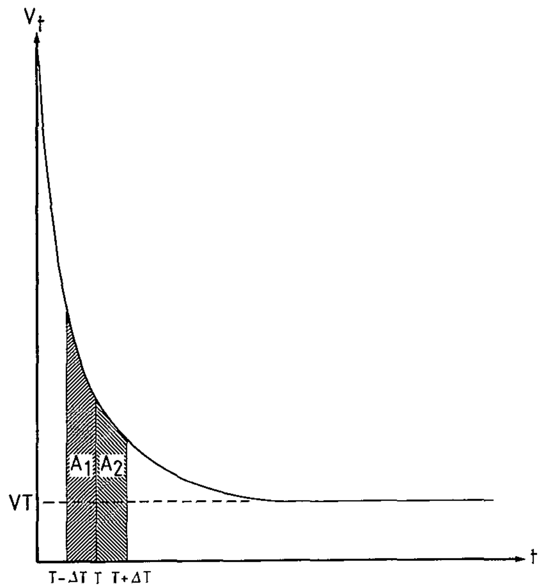

FIG. 1. — Decrease in volume (V) (equation 4) of smell, above or equivalent to threshold concentration, from the bait as a function of time *(t)*. During the time period T — ΔT to T, the probability of encountering the half sphere of smell is proportional to area A_1. During the period T to T + ΔT, this probability is proportional to area A_2. VT is the volume of trap, assumed to have the shape of a half sphere

Décroissance du volume (V) (équation 4) odorant d'un appât, supérieur ou égal au seuil de concentration, en fonction du temps (t). *Du temps T — ΔT à T, la probabilité de rencontrer la demi-sphère odorante est proportionnelle à l'aire A_2. VT est le volume du piège, supposé hémisphérique*

where RT is the radius of the trap (also assumed to have the shape of a half sphere), and *K* a general constant. As the smell of the bait subsides, the volume containing smell at, or above, threshold concentration decreases according to (4) until the bait is completely exhausted. The only volume remaining after that is the one of the actuel trap, and it is assumed that a fish will enter the trap with the same probability α as above, even though there is no bait left. It is realistic to assume that this will happen (MUNRO, 1974), but the probability is likely to be much lower in most instances. The value, α, has however been kept for simplicity and although the results would have been different in their details if a more realistic lower value, had been used, the qualitative conclusions would still have been the same.

Since the probability of encountering the half sphere of smell is assumed to be entirely due to pure chance, and hence directly proportional to the size of this cloud of smell, the number of fish encountering it will decrease with time. For the time period T — ΔT to T (Fig. 1), the probability if hitting the half sphere is proportional to area A_1, and for the period T to T + ΔT, area A_2.

The number of fish in a trap at a given time is not only determined by the number that entered it, but also by the number of fish that managed to escape. It is assumed that escapment, as well as encountering, is a purely random process and hence also Poisson-distributed. If the probability to escape from the trap is designated γ, then for a given unit of time $T_0 + \Delta T$, $\gamma . N_{T_0+\Delta T}$ will escape, where $N_{T_0+\Delta T}$ denotes the number of fish that entered during time $T_0 + \Delta T$. The number left at time T_1 (the time reached after adding a unit of time, ΔT, to T_0) of those caught during this period is thus $(1 - \gamma)\, N_{T_0+\Delta T}$.

From probabilities for encountering and escapement, the model which will describe how the number of fish in a trap will change over time, can be stated:

$$N_{T_2} = N_{T_1} + N_{T_1+\Delta T}$$

$$N_{T_2} = N_{T_0+\Delta T}(1 - \gamma) + N_{T_1+\Delta T} \qquad (5)$$

$$N_{T_2} = \{(\int_{T_0}^{T_1} V . dt) . (1 - \gamma) + \int_{T_1}^{T_2} V . dt\} . \alpha . \beta . N_{tot} \qquad (6)$$

Or, in words, the number of fish in the trap at time T_2 are those left at time T_1 (i.e. of the fish that entered during $T_0 + \Delta T$), plus those that entered during $T_1 + \Delta T$. There is a time-lag between entering and escapement, that is, each fish is in the trap for a least a certain period of time. Thus, the model is described in discrete steps for simplicity, but in practice small values of ΔT will turn equation (5) into a continous process, equation (6).

It has been assumed for simplicity that $N_{TOT} \gg N$ in the trap which probably is a reasonable assumption if the effective range of the bait is large. Even if the total number of fish available is significantly reduced, this will not alter the main qualitative outcomes of the model and it will only flatten the curve and shift the position of the peak.

3. RESULTS, AND A PRACTICAL IMPLICATION OF THE MODEL

The predictions of the model for different γ (escapement rates) and *c* values (bait efficiencies) are shown in Figure 2. The model fairly accurately depicts the situation in a real trap fishery, as can be seen from comparison with the data from MUNRO (1974), which are displayed in Figure 3. Both curves in Figure 3 are based on averages, in the case of 3:1 from observations of eight traps, and in 3:II of

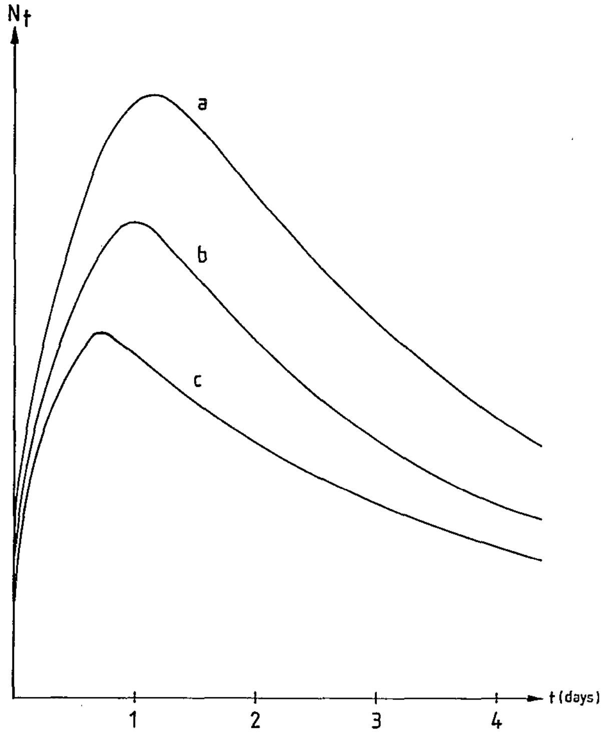

FIG. 2. — The number of fish (N_t) in the trap as a function of soak time t. This graph can be viewed as either the bait efficiency is held constant and the escapement rates varied such that $a = \gamma_1$, $b = \gamma_2$, $c = \gamma_3$, where $\gamma_1 < \gamma_2 < \gamma_3$, or the escapement rate is held constant and bait efficiency is altered so that $a = c_1$, $b = c_2$, $c = c_3$ where $c_1 < c_2 < c_3$. A more efficient bait is the one that keeps the smell a longer time and hence has a lower c-value in equations 3 and 4. A lower escapement rate means that the trap is better in retaining the caught fish

Nombre de poissons (N_t) dans le piège en fonction du temps t d'immersion. Ce graphe peut être interprété, soit en considérant l'efficacité de l'appât comme une constante et les taux d'échappement variables (avec $a = \gamma_1$, $b = \gamma_2$, $c = \gamma_3$ et $\gamma_1 < \gamma_2 < \gamma_3$), soit en considérant le temps d'échappement comme constant et l'efficacité de l'appât variant (avec $a = c_1$, $b = c_2$, $c = c_3$ et $c_1 < c_2 < c_3$). Un appât est d'autant plus efficace qu'il conserve son odeur un temps plus long et a, pour conséquent, un c plus faible dans les équations 3 et 4. Un taux d'échappement plus bas signifie que le piège retient mieux les poissons capturés

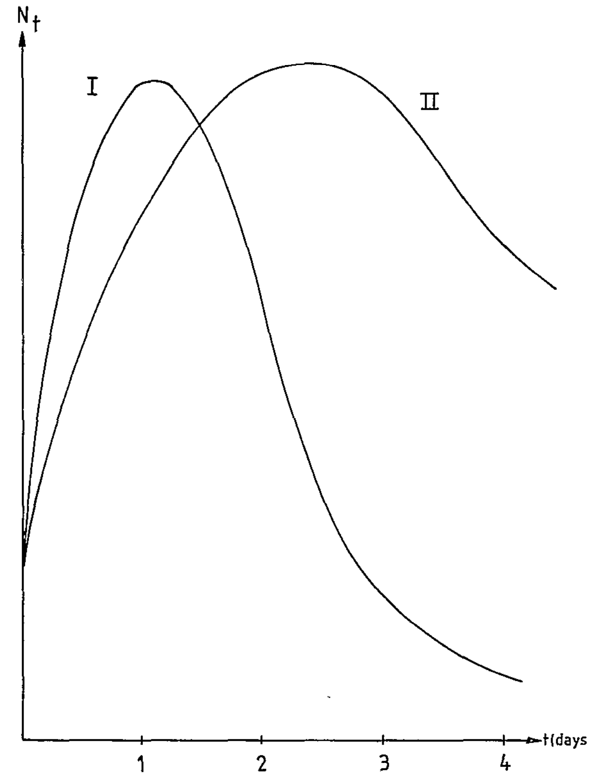

FIG. 3. — Mean number of fish (I) and mean weight of catch (II), as a function of soak time for traps from Port Royal reefs in Jamaica (I), and from around Saba Banks, Lesser Antilles (II) (MUNRO, 1974)

Nombre moyen de poissons (I) et poids moyen des captures (II), en fonction du temps d'immersion des pièges, sur les récifs Port Royal à la Jamaïque (I) et aux abords des Saba Banks, dans les Petites Antilles, (MUNRO, *1974*)

53 traps. In the case of curve I, bait remained in the traps for between one and four days, and was exhausted after an average of 2.5 days; the peak in the catch is at one day in situation I. The different shapes of the two curves derived from Munro may be due to the fact that 3:I shows the numbers of fish, whilst II is the weight of the fish. This difference in shape would be the result if small fish enter the trap to start with, followed by larger specimens. But the different curve shapes could also be explained by differences in bait efficiencies, site characteristics, and fish species involved. Both curves, however, verify the main predictions of the model, viz there is a certain soak time that maximizes the number of fish in the trap.

Does the catch maximizing soak time coincide with the soak time that maximizes profit? The following simple example will show that this does not have to be the case. Consider a fisherman able to handle a maximum of 100 traps per day. Table I shows how many traps he can operate for different soak times, and the cost per trap and haul if it assumed that the fishing season spans over 100 days. Now, if we assume that the curves in Figure 3 can be interpreted as income, we can superimpose the cost per haul and trap function from Table I, and the distance between these curves will be the net income (not considering other costs). This is done in Figure 4 for two costs for a trap, 200 and 300

TABLE I

A simple analysis showing (Fig. 4) that the soak time that maximizes the catch does not have to be the most profitable soak time. The assumptions are a fisherman able to operate 100 traps per day during the fishing season, assumed to span over 100 days. There is thus 10 000 hauls per season for one fisherman. Two costs for one trap are compared: (1) 300 monetary units, (2) 200 monetary units

Une analyse simple montrant (fig. 4) que le temps d'immersion qui conduit à une prise maximale n'est pas celui qui procure le meilleur profit. On fait l'hypothèse que le pêcheur est capable de mettre en œuvre 100 pièges par jour pendant la saison de pêche, estimée à 100 jours. Il y a, par conséquent, 10 000 poses par saison et par pêcheur. Deux coûts de piège sont comparés : (1) 300 unités de monnaie, (2) 200 unités de monnaie

soak time in days	number of traps operative	cost		cost per trap and haul	
		1	2	1	2
1/2	50	1,5000	1,0000	1.5	1.0
1	100	3,0000	2,0000	3.0	2.0
2	200	6,0000	4,0000	6.0	4.0
3	300	9,0000	6,0000	9.0	6.0
4	400	12,0000	8,0000	12.0	8.0

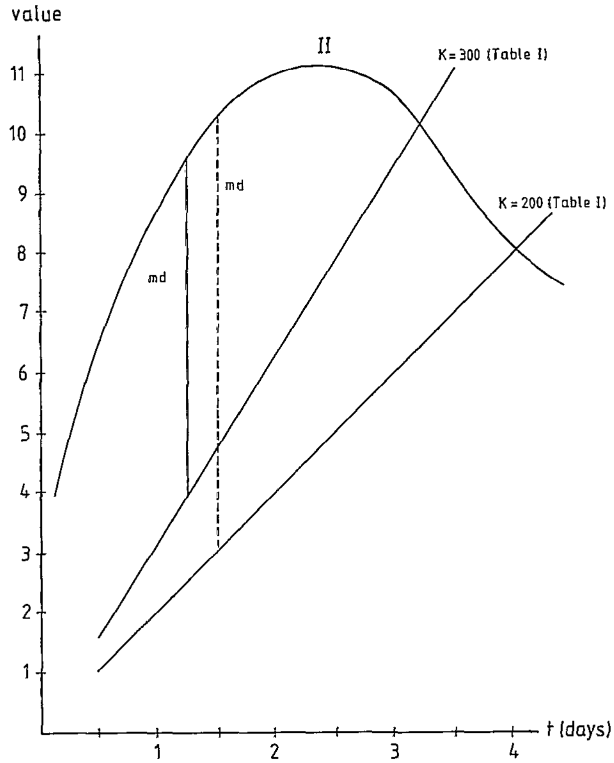

FIG. 4. — A combination of income per soak time *(t)* (curve II from Fig. 3) and cost per trap and haul as a function of soak time (the two straight lines, data from Table I). The difference in value (the y-axis) between the curve and each of the two straight lines indicates the profit for each soak time. Maximum profit does not coincide with maximum catch. *K* stands for cost of a trap (that, together with value, are expressed in monetary units), *md* for maximum difference

Relation entre le revenu en fonction du temps (t) *(courbe II de la fig. 3) et le coût par piège et relevage en fonction du temps d'immersion (les deux droites sont tracées d'après les données du tableau I). La différence de valeur, lue sur l'axe des y, entre la courbe et chacune des droites correspond au profit pour chaque temps d'immersion. Le profit maximal ne coïncide pas avec la capture maximale. K représente le coût d'un piège (exprimé, comme les profits, en unités de monnaie),* md *étant la différence maximale*

monetary units, in combination with curve II from Figure 3. The maximum difference between income and cost are displayed for the two cost function, and clearly it happens at soak times shorter than the one maximizing the catch. This analysis could be further extended by allowing for vessel running costs, distance from harbour and fishing ground, etc. It show, though, that it is not enough to maximize catch when study the feasability of a trap fishery.

DISCUSSION

The model developed here takes into account the two parameters which trap fishermen are concerned with in general (MILLER, 1980), namely the attractive power of the bait, and the design that prevents the catch from escaping. The model certainly is a simplification of a much more complicated situation of why and how fish (or other aquatic animals) enter a trap (BENNET, 1974), but its performance in comparison with actual data shows that it reflects the real situation, if not perfectly well, at least reasonably well.

The model here is based upon the assumption that the bait will emit attractants which forms a cloud of smell around the trap. Effectively this cloud acts as an enlargement of the trap and thus increases the probability for a fish to find it. Bait, however, is not a prerequisite for a fish to enter a trap. MUNRO *et al.* (1971) actually find unbaited traps to be 15 percent more effective in catching fish, considering the number of specimens, although heavier weight was caught by baited traps. This could be an effect of smaller fishes using traps as habitats. WOLF and GHISLETT (1974) found that unbaited traps caught little or nothing in deeper waters and concluded that bait is a more necessary attraction in deep waters than in shallow. Another explanation could be that fish size inccreases with depth (SUNDBERG and RICHARDS, 1984), and that there are no or few fish in deep waters small enough to seek such habitats.

There must be several factors which are important in determining the ingress rate, and one, for example, is that smaller fish probably attract larger and hence increase the ingress rate above what could be expected from the bait alone. There are also intra-specific interaction and HIGH and ELLIS (1970) report for example how specimens of several species swam frantically back and forth outside the trap when other of their species were caught. They swam around the trap bumping the walls with their snouts until they found a tunnel and enterred. Another factor, which will decrease the ingress rate, is the saturation effect (BEVERTON and HOLT, 1957). This effect was cogently demonstrated by MILLER (1979) in the case of crab traps, and has also been noticed for fish traps (MUNRO, 1974). Both these factors could of course be incorporated into the model, but it would probably be difficult to express them quantitatively in a sensible and realistic way.

The pattern with a certain soak time that gives the highest number of fish in the trap can be deduced from several papers dealing with the relationship between soak time and catch, even though none of these papers explicitly state the conclusions reached in this paper. Such papers are for example SKUD (1979) and FOGARTY and BORDEN (1980) on soak time and catch per pot in the lobster fishery, together with the theoretical account of this problem in AUSTIN (1977). No model, however, has been proposed hitherto that tries to explain the causal relationship between soak time and catch, although there are several of descriptive nature. Even if the situation is properly modelled in MUNRO (1974), his model is descriptive and does not explain how the relationship is reached. The effects of bait deterioration and escapement rates have, however, been extensively discussed (SKUD, 1979 and references therein) in relation to the decrease in catch over time, but only in a heuristic way.

REFERENCES

AUSTIN (C. B.), 1977. — Incorporating soak time into measurement of fishing effort in trap fisheries. *Fish. Bull. U.S.*, 75 : 213-218.

BENNET (D. B.), 1974. — The effects of pot immersion time on catches of crabs, *Cancer pagurus* L. and lobsters, *Homarus gammarus* (L.). *J. Cons. int. Explor. Mer*, 35 : 332-336.

BEVERTON (R. J. H.) and HOLT (S. J.), 1957. — On the dynamics of exploited fish populations. *Fishery Invest. Lond.*, Ser. 2, 19, 533 p.

FOGARTY (M. J.) and BORDEN (D. V. D.), 1980. — Effects of trap venting on gear selectivity in the inshore Rhode Island american lobster, *Homarus americanus*, fishery. *Fish. Bull. U.S.*, 77 : 925-933.

HANCOCK (D. A.), 1974. — Attraction and avoidance in marine invertebrates — their possible role in developing an artificial bait. *J. Cons. int. Explor. Mer*, 38 : 220-225.

HIGH (W. L.) and ELLIS (J. E.), 1973. — Underwater observations of fish behaviour in traps. Helgoländer wiss. *Meeresunters.*, 24 : 341-347.

MACKIE (A. M.), GRANT (P. T.), SHELTON (R. G. J.), HEPPER (B. T.) and WALNE (P. R.), 1980. — The relative efficiences of natural and artificial bait for the lobster, *Homarus gammarus*: laboratory and field trials. *J. Cons. int. Explor. Mer*, 39 : 123-129.

MCLEESE (D. W.), 1970. — Detection of dissolved substances by the american lobster *(Homarus americanus)* and olfactory attraction between lobsters. *J. Fish. Res. Bd Can.*, 27 : 1371-1378.

MILLER (R. J.), 1979. — Saturation of crab traps: reduced entry and escapement. *J. Cons. int. Explor. Mer*, 38 : 338-345.

MILLER (R. J.), 1980. — Design criteria for crab traps. *J. Cons. int. Explor. Mer*, 39 : 140-147.

MUNRO (J. L.), 1974. — The mode of operation of Antillean fish traps and the relationships between ingress, escapement, catch and soak. *J. Cons. int. Explor. Mer*, 38 : 337-350.

MUNRO (J. L.), REESON (P. H.) and GAUT (V. C.), 1971. — Dynamic factors affecting the performance of the Antillean fish trap. Gulf Caribb. Fish. Inst., Proc. 23rd. Ann. Sess. : 184-194.

OKUBO (A.), 1980. — Diffusion and ecological problems: mathematical models. Springer Verlag, Berlin, Heidelberg, 254 p.

SKUD (B. E.), 1979. — Soak time and the catch per pot in an offshore fishery for lobsters *(Homarus americanus)*. *Rapp. P.-v. Réun. Cons. int. Explor. Mer*, 175 : 190-196.

SUNDBERG (P.) and RICHARDS (A.), 1984. — Deep-sea bottom handline fishing in Papua New Guinea. A pilot study. *Papua New Guinea Journal of Agriculture, Forestry and Fisheries*, 33 : 55-62.

WOLF (R. S.) and GHISLETT (G. R.), 1974. — Trap fishing explorations for snappers and related species in Caribbean and adjacent waters. *Mar. Fish. Rev.*, 36 : 49-61.