WÄRTSILÄ

This paper not to be cited without prior reference to the author

International Council for
the Exploration of the Sea

C.M. 1980/B.30
Fish Capture Committee

Ref: Biological Oceanography
Committee

Assesment of Antarctic krill catch rates using computer modelling

by M.T. Törmä

Oy Wärtsilä Ab Turku Shipyards
Laivurinkatu 1
20810 Turku 81
Finland

Abstract

This paper describes a computer model which can be used for analyzing the catch rates of Antarctic krill. The distribution of krill patches is taken as a cumulative density function thus giving easily the trawling distances. Using the value of krill on deck as a parameter the profit and efficiency of the trawling can be analyzed. The optimum daily catching rates can be calculated when neglecting minor patches.

Résumè

Ce document décrit un modèle d'ordinateur qui peut être utilisé pour l'analyse des taux de prises d' "Antactic krill". La distribution des bancs d' "Antartic krill" est considérée comme une fonction de densité cumulée tout en donnant facilement les distances à parcourir. En utilisant la qualité de l' "Antartic krill" à bord comme paramètre, on peut analyser le profit et l'efficacité de la pêche. Le taux maximum des prises quotidiennes peut être calculé en négligeant les bancs peu importants.

1. GENERAL

When designing a factory trawler for catching and processing krill, one naturally must be aware on the nature of the catching process: daily trawling and searching times, the influences of the distributions of krill patches and densities to the total result. Because the statistics of commercial catching rates are small for the time being, so the situation must be estimated. One method is to use computer modelling, and analyse the effect of different parameter variations to the final results. The purpose of this report is to describe the method used when designing the Wärtsilä krill vessel. The values used here are based on ref. /1./ and Japanese investigations during 1972-79.

2. THEORY FOR TRAWLING MODEL

Cumulative function of krill density

Assume the krill patches are located within an avarage distance of $\bar{x}$ with different sizes L_i and thicknesses d_i. The trawling path can be described as in fig. 1. When the trawl is taken full we have the equation:

$$\Delta S = \int_{t_1}^{t_2} \varrho(x)\; A \cdot V \cdot dt = A \int_{x_1}^{x_2} \varrho(x)\; dx \qquad (1.)$$

where $\varrho(x)$ = krill density (kg/m^3)

A = trawl opening (m^2)

V = trawling speed (m/s)

ΔS = maximum allowed amount of krill in trawl (kg)

t_1, t_2 = trawling period (s)

x_1, x_2 = trawling interval (m)

We can define the cumulative function for krill as:

$$R\,(x) = \int_{0}^{x} \varrho\,(x)\; dx \qquad kg/m^2 \qquad (2.)$$

Using R (x) in (1.) we obtain:

$$\Delta S/A = R\,(x_2) - R\,(x_1)$$

$$\Rightarrow R\,(x_2) = R(x_1) + \Delta S/A \qquad (3.)$$

If R (x), ΔS, A and the end point of previous trawling-interval x_1 are known, then we get from (3.) the end point of the present trawling interval x_2.

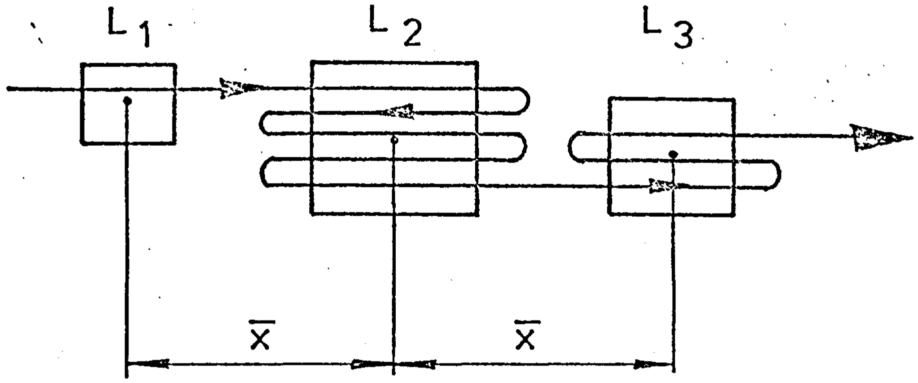

FIG. 1

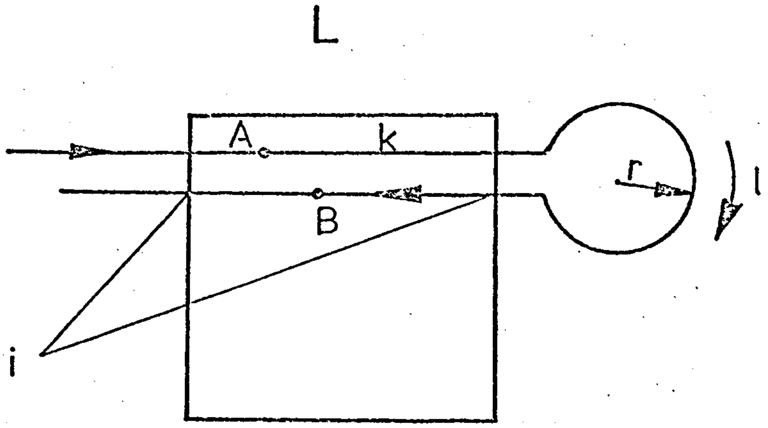

FIG. 2

Cumulative function of a krill patch

Next we can examine one of the krill patches, fig. 2. Then we have:

L = side length of a square-shaped patch (m)

k = k^{th} trawling time in a certain patch,

A = start point of k^{th} trawling,

B = end point of k^{th} trawling,

i = index of the crossing times through the patch

r = the turning radius of the trawling device (m),

l = distance outside the patch $\approx 2\pi r \approx 6\ r$ (m)

If the trawl is not full when the patch is crossed, so it follows after the vessel during the round turn and is possibly filled up on the next crossing.

The krill density $\varrho(x) = \varrho$ is constant inside the patch and outside $\varrho \equiv 0$.

When the patch is crossed through as shown in fig. 2, the krill density and cumulative functions are as in fig. 3.

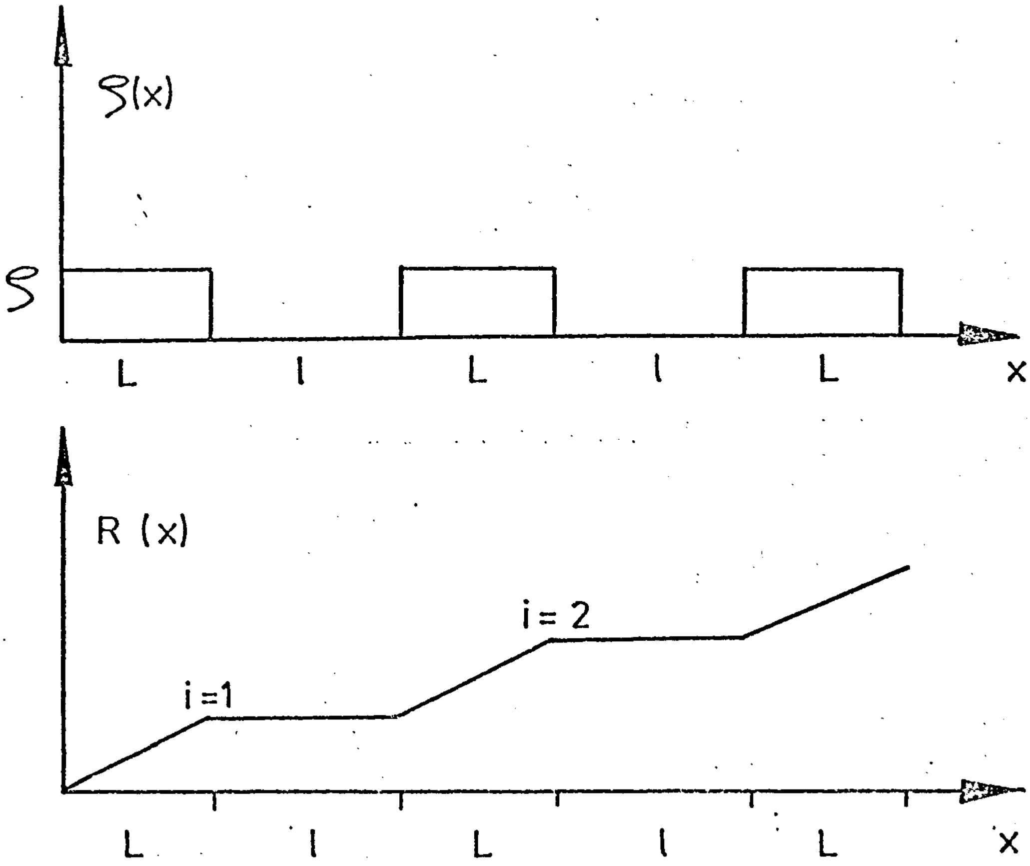

FIG. 3

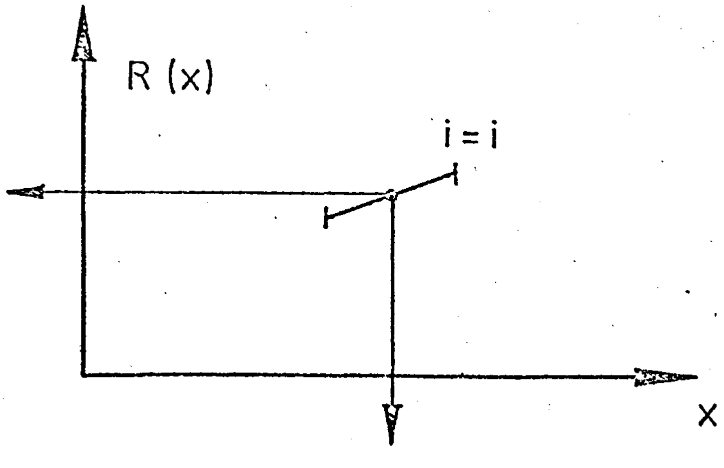

FIG. 4

The cumulative function is made according to the following rule:

R	x	number of crossing times
ϱL	L	1
ϱL	$L + l$	
$2\varrho L$	$2L + l$	2
...	...	...
$i\varrho L$	$iL + (i-1)l$	i
$i\varrho L$	$iL + il$	

If we take any rising part of $R(x)$ as in fig. 4., so we have in general:

$$R(x) = \varrho L(i-1) + \varrho(x-x_a) \qquad (4.)$$

$$x_a = (i-1)\cdot(L+l)$$

where $x_a < x < x_a + L$.

Number of trawling times / crossing times

Using (3.) k times for successive trawlings, we obtain:

$$R(x_k) = k \cdot \Delta S/A \qquad (5.)$$

where k = number of trawling time

x_k = distance of the end point of k^{th} trawling interval from origo.

In (5.) the right part is known, and thus the corresponding x_k is obtained from (4.):

$$R(x_k) = \varrho L(i-1) + \varrho(x-x_a) = k \quad S/A \qquad (6.)$$

where i is taken from equation:

$$k \,\Delta\, S/A > \varrho L(i-1) \quad \text{or:}$$

$$\Rightarrow i = 1 + \mathrm{INT}\left[k \frac{\Delta S}{\varrho AL}\right]. \qquad (7.)$$

Equation (7.) gives the function between crossing times (i-1) and trawlings (k). The distance x_k, which is equal to the distance trawled, is obtained from (6.):

$$\begin{aligned} m = x_k &= x_a + k \frac{\Delta S}{\varrho A} - L(i-1) \\ &= (i-1) \cdot (L+1) + \mathrm{Res} \qquad (8.) \end{aligned}$$

where the residual distance is:

$$\mathrm{Res} = k \frac{\Delta S}{\varrho A} - L\,(i-1). \qquad (9.)$$

Maximum number of trawling times

If k is relatively large, so approximately from (7.) and (8.):

$$i-1 \approx k \frac{\Delta S}{\varrho AL} \qquad (10.)$$

$$m \approx (i-1) \cdot (L+1) \approx k \frac{\Delta S}{\varrho A} \left(1+\frac{1}{L}\right).$$

The distance trawled in the patch is

$$m_p \cong (i-1)\cdot L \approx k \frac{\Delta S}{\rho A} . \qquad (11.)$$

The trawled volume in the patch is:

$$V_p \approx (i-1)\cdot LA \approx k \frac{\Delta S}{\rho} \qquad (12.)$$

Using emptying coefficient f:

$$f = \frac{V_p}{V} = \frac{\text{trawled volume}}{\text{patch's total volume}}$$

we obtain the upper limit for trawling times k:

$$V_p = k \cdot \frac{\Delta S}{\rho} \sim f\ V$$

$$\Rightarrow k_{max} \sim f \frac{\rho V}{\Delta S} . \qquad (13.)$$

In equation (13.):

ρV = mass of krill in patch

ΔS = catch / trawling

and thus the emptying coefficient f is also the relative krill mass taken from the patch. The total volume of the patch is taken as

$$V = L^2 d . \qquad (14.)$$

Trawling time in a patch

If we are trawling k times in the patch, so the total trawling time is:

$$T_p = \frac{m}{V} + k \Delta T \qquad (15.)$$

where m = trawling distance from (10.)

V = trawling speed

ΔT = time for hauling, emptying and shooting the trawl.

Profit from trawling

Assume that the profit from trawling is taken according to the value of krill on deck and on the other hand the volume of the fuel used. Thus the profit after k trawlings is:

$$H_p = h_1 k \Delta S - h_2 \gamma P \frac{m}{V} \qquad (16.)$$

where h_1 = value of krill on deck ($/kg)

h_2 = price of fuel ($/kg)

γ = fuel consumption coefficient (kg/Ws)

P = power used in trawling (W)

m/v = trawling time (s)

Using an estimate for P as:

$$P = \lambda A V^3 \qquad (17.)$$

where λ = trawl shape coefficient $W/m^2 \frac{m^2}{s^2}$

A = trawl opening area m^2

V = trawling speed m/s

The shape coefficient is obtained, when P, A and V are known for one speed V.

The profit is thus:

$$H_p = h_1 k \Delta S - h_2 \gamma \lambda A V^2 m. \qquad (18.)$$

Transition time and costs

Assuming the average distance between patches is $\bar{x}$, we obtain the total transition time as:

$$T_S = \bar{N} \bar{x} / \bar{V} \qquad (19.)$$

where $\bar{N} + 1$ = number of patches

$\bar{x}$ = average distance between patches (m)

$\bar{V}$ = transition speed (m/s)

Corresponding total costs are:

$$K_s = h_2 \bar{\gamma} \bar{P} \bar{x} \bar{N} / \bar{V} \qquad (20.)$$

where γ = fuel consumption coefficient at transition power (kg/Ws)

$\bar{P}$ = transition power (W)

COMPUTER MODELLING

Trawling model

The model for trawling path through patches as in fig. 1. is obtained when summing up profits from different patches (18.) and taking into account the transition costs (20.)

The total profit is thus:

$$H = - K_s + h_1 \Delta S \sum k_v - h_2 \gamma \lambda A \sum m_v V_v^2 . \qquad (21.)$$

The total time is obtained by summing up (15.) and the transient time (19.):

$$T = T_s + \Delta T \sum k_v + \sum m_v / V_v \qquad (22.)$$

where V = index for summa, $v = 1 \ldots N$,

N = number of patches.

The parameters k_v, m_v and V_v in the model should be chosen such that the efficiency

$$\eta = \frac{H}{T} = \text{max !} \qquad (23.)$$

We define following coefficients:

$$a_1 = \frac{K_s}{h_1 \Delta S} = \frac{h_2 \bar{\gamma} \bar{P} (N-1) \bar{x} / \bar{V}}{h_1 \Delta S}$$

$$b_1 = \frac{h_2 \gamma \lambda A}{h_1 \Delta S}$$

$$(24.)$$

$$a_2 = \frac{T_s}{\Delta T} = \frac{(N-1) \bar{x}}{\bar{V} \Delta T}$$

$$b_2 = 1/\Delta T$$

All values in (24.) are calculated from the input data. We obtain thus:

$$H = h_1 \Delta S \; (-a_1 + \sum k_v - b_1 \sum m_v V_v^{\,2}) \qquad (25.)$$

$$T = \Delta T \; (a_2 + \sum k_v + b_2 \sum m_v / V_v)$$

Equation (23.) is sufficient to determine the trawling parameters, as will be seen.

Optimum speed

To find out the optimum speed we have:

$$\frac{\partial}{\partial V_v} \cdot \left(\frac{H}{T}\right) = 0 \Rightarrow T \frac{\partial H}{\partial V_v} = H \frac{\partial T}{\partial V_v} \, .$$

From (25.) we get:

$$\frac{\partial H}{\partial V_v} = h_1 \Delta S \; (- b_1 \, m_v \, . \, 2 \, V_v) \qquad (26.)$$

$$\frac{\partial T}{\partial V_v} = \Delta T \; (-b_2 m_v V_v^{\,-2})$$

and thus the optimum condition gives:

$$V_v = V_o = \sqrt[3]{\frac{1}{2} \, \frac{H}{T} \, \frac{\Delta T}{h_1 \Delta S} \, \frac{b_2}{b_1}} \, . \qquad (27.)$$

The result is that trawling speed for all patches is the same = optimum speed V_o. The optimum speed is calculated iteratively from (25.) and (27.). If it exceeds the maximum speed according to the power:

$$V_{max} = \sqrt[3]{P_{max} \, / \, (\lambda A)} \, , \qquad (28.)$$

then the trawling speed is $V = V_m$.

Optimum number of trawling times

As was shown in previous part, the trawling speed V_v in patches is equal = V, so that the following values can be used:

$$c_1 = V_v^2 b_1 = V^2 b_1$$
$$c_2 = b_2/V_v = b_2/V. \tag{29.}$$

The efficiency η is written using (25.) as:

$$\eta = \eta_o \frac{-a_1 + \sum k_v - c_1 \sum m_v}{a_2 + \sum k_v + c_2 \sum m_v} \tag{30.}$$

where $\eta_o = \frac{h_1 \Delta S}{\Delta T}$.

The trawling distance m_v in patch v is obtained from (7.), (8.) and (9.) when $k = k_v$. The corresponding approximation (10.) is:

$$m_v \approx k_v \frac{\Delta S}{\varrho A} (1 + \frac{1}{L_v}). \tag{31.}$$

The number of trawlings k_v varies between:

$$k_v = 0 \ldots k_{v_{max}}$$

where $k_{v_{max}} \cong f \frac{\varrho^d}{\Delta S} L_v^2$. (32.)

To determine the optimum value for number of trawlings k_v an increase of +1 is given. Thus from (31.):

$$\Delta m_v \approx \frac{\Delta S}{\varrho A} (1 + \frac{1}{L_v}) . \tag{33.}$$

and from (30.) we obtain:

$$\eta + \eta_v = \eta_o \frac{-a_1+1-c_1\Delta m_v+\sum k_v-c_1\sum m_v}{a_2+1+c_2\Delta m_v+\sum k_v+c_2\sum m_v} \qquad (34.)$$

Change Δm_v is positive and so according to (34.) it decreases the efficiency. Further, according to (33.), Δm_v is that larger the smaller L_v is. Then the result will be that small patches decrease the resulting efficiency.

To find out the optimum one can do as follows:

- in the first step each patch has maximum value of k_v (from (32.).
- starting from the smallest patch, k_v is decreased always by one. Simultaneously the efficiency η is calculated from (30.) and (7.) - (9.).
- when the efficiency begins to decrease, the procedure is stopped. This situation is the optimum.

3. RESULTS AND CONCLUSIONS

The vessel data are obtained from /2./. The size of krill patches varies from 0 to 200 metres. The distribution of sizes is taken from /1./. Following values are used as parameters

- trawl opening area	$A = 400\ m^2$
- amount of krill per haul	$S = 10$ tons
- trawl handling time	$T = 30$ min
- turning radius	$r = 200$ m
- krill density in patch	$\rho = 0.15\ kg/m^3$
- average distance between patches	$\bar{x} = 5000$ m

These values are varied between 0.5 to 1.5 times the original values and the corresponding optimum efficiency and krill catching rate are calculated. The results are shown in fig. 5. As the conclusions the following comments can be made:

- Using the data from /1./ a catching rate of abt. 260 tons per 24 hours can be expected.
- The trawl handling time and the amount of krill per haul have the biggest influence on the catching rate.
- The method used here can be used for analyzing the effects of various parameters on krill catching rate. The information obtained can be used for developing the krill catching vessels. However, the input data must be based on sufficient amount of measurement during several years.

4. REFERENCES

/1./ Hirayama N., Sakutaro Y., et al. Stok assesment of Antarctic krill by records of fish finder, Transactions of the Tokyo University of Fisheries, No. 3., pp 71-81, Nov. 1979

/2./ Wärtsilä Krill Vessel, P-2077, booklet, Wärtsilä Turku Shipyards, 1980.

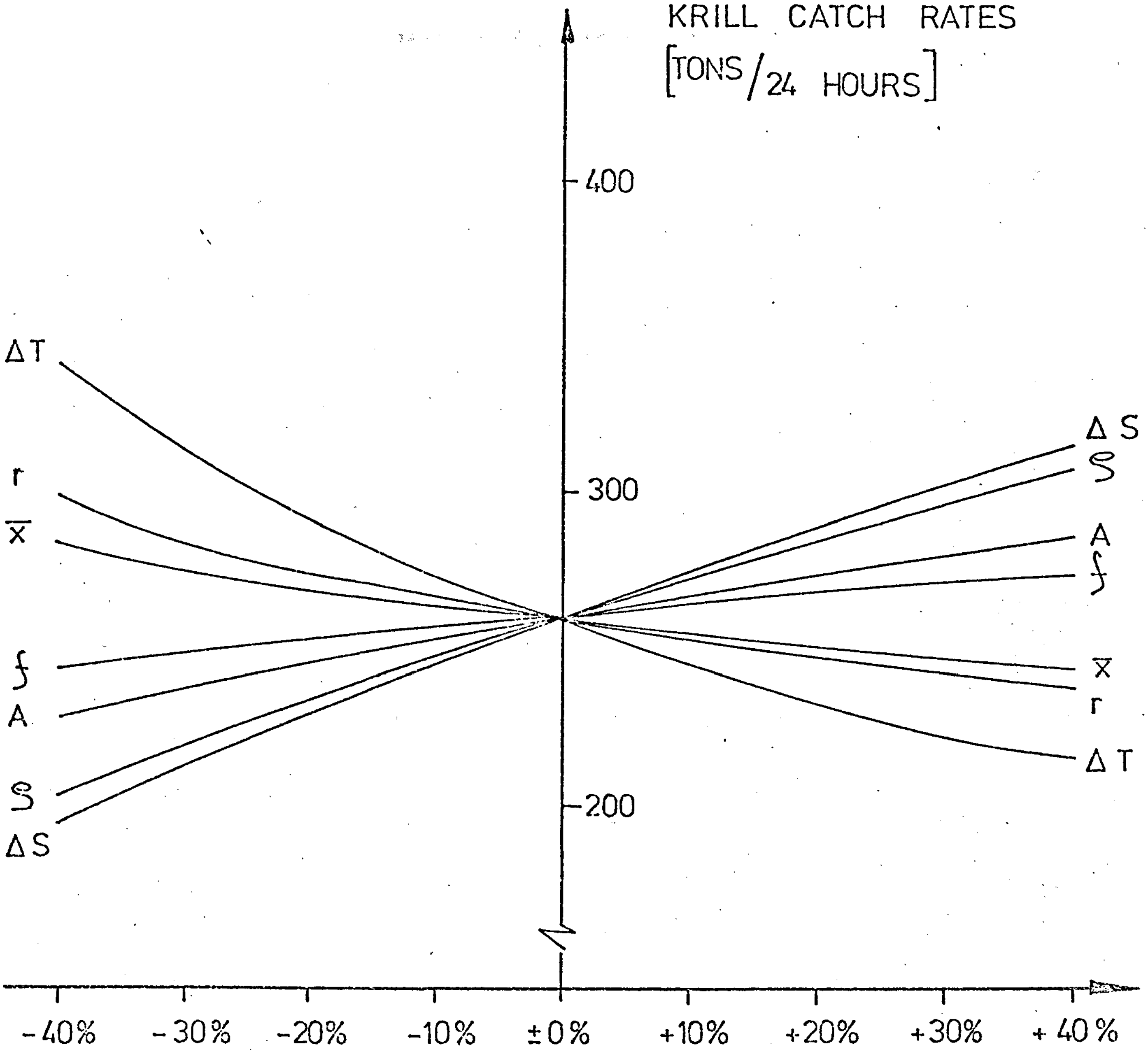

FIG. 5

Influence of various parameters on the krill catch rate

ΔT = trawl handling time

r = radius of turning

$\bar{x}$ = average distance between patches

f = emptying coefficient

A = trawl opening area

ϱ = krill density

$\Delta\varrho$ = amount of krill catch per haul