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THE DAILY FOOD INTAKE OF YOUNG SOLES (*SOLEA SOLEA* L.) IN RELATION TO THEIR SIZE AND THE WATER TEMPERATURE.

by

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ABSTRACT.

Daily food intake of young soles, from 6 to 30 cm length, was measured in the laboratory at five constant temperatures from 10 to 26°C. The daily consumption (C) was correlated with length (L, cm) and weight (W, g) of the fish, which resulted in the following exponential relationships with temperature (T, °C) :

$$C = 0.000011\ e^{0.35\ T}.L^{(3.20-0.0096T-0.0026T^2)}$$
$$C = 0.006\ e^{0.18T}.W^{(1.12-0.013T-0.00055T^2)}$$

It appears that the daily food consumption of small soles is maximal at high temperatures (26°C for 10 cm fish). With increasing size of the fish the temperature for maximum feeding shifts to lower values (16°C for a 50 cm fish). The daily food consumption expressed as percentage of the metabolic weight of the fish ($C = \%\ W^{0.8}$) appears to be independant of fish size at about 16°C. Higher temperatures are more favourable for the smaller fish, lower temperatures for the larger fish. This may explain why young soles need coastal nurseries with a high summer temperature and a rich food supply, while the adult fish find optimum conditions at lower temperatures offshore.

RESUME.

La consommation quotidienne en nourriture de jeunes soles, de 6 à 30 cm de long, a été mesurée au laboratoire, à 5 températures constantes, de 10 à 26°C. Cette consommation quotidienne (C) a été reliée à la longueur (L, cm) et au poids (W, g) des poissons, fournissant avec la température (T, °C) les relations exponentielles suivantes :

$$C = 0.000011\ e^{0.35\ T}.L^{(3.20-0.0096T-0.0026T^2)}$$
$$C = 0.006\ e^{0.18T}.W^{(1.12-0.013T-0.00055T^2)}$$

Il apparaît que la consommation quotidienne de petites soles est maximale à de hautes températures (26°C pour un poisson de 10 cm). Lorsque la taille du poisson augmente, la température de consommation maximale glisse vers des valeurs plus basses (16°C pour un poisson de 50 cm). La consommation de nourriture quotidienne, exprimée en pourcentage du poids métabolique du poisson ($C = \%\ W^{0.8}$) se montre indépendante de sa taille aux environs de 16°C. Des températures plus élevées sont plus favorables à des poissons plus petits, des températures plus basses à des poissons plus grands. Cela peut expliquer pourquoi les jeunes soles ont besoin de nurseries côtières, avec une température estivale élevée, et une nourriture abondante, tandis que l'adulte trouve des conditions optimales à des températures plus basses, au large.

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INTRODUCTION.

The soles in the North Sea spawn in spring (April, May, June) in coastal waters at temperatures of 8-16° C. The pelagic eggs and larvae are carried with the residual tidal currents along the coast and the young soles settle after metamorphosis in coastal waters and estuaries (FLÜCHTER, 1970 ; ROSENTHAL, 1966 ; RILEY, 1974). The "demersal young fish surveys" of the Netherlands Institute for Fisheries Research (R.I.V.O., Ijmuiden) have shown that the Wadden Sea, the Rhine estuary and the adjacent shallow North Sea coastal area are an important nursery for several North Sea fish species, particularly for plaice and sole (ZIJLSTRA, 1972 ; BECKER and POSTMA, 1974). Estimates of the annual abundance, over many years, of young soles and plaice in the German coastal North Sea and Wadden Sea (TIEWS, 1971) indicated that considerable yearly fluctuations in abundance occur. These fluctuations are generally indicative of subsequent recruitment of yearclasses to the North Sea stock (RAUCK and ZIJLSTRA, 1976). It is therefore of great interest to know which factors and processes determine growth and survival of young flatfish in the coastal nurseries.

From monthly trawling surveys in 1962 and 1964 appeared that young soles spend only the summers of their first two years in the coastal nurseries (CREUTZBERG and FONDS, 1971 ; FONDS, 1975). They do not grow in winter (October to April) and leave the shallow coastal areas in autumn (November, December) when the water temperature decreases below 10° C, to return again in spring (March, April) when the temperature rises again (the cold adapted fish return already at water temperatures of 3-4° C).

During 1973-1974 the maximum growth rate of young soles was estimated at different constant temperatures and salinities (FONDS, 1975). During 1975-1976 the combined effect of temperature and food supply on growth, condition and survival of young (O-group) soles was studied by FONDS and SAKSENA (in prep.). During these investigations the maximum daily food intake of soles of different size was estimated at various temperatures. It appeared that for soles an interesting correlation exists between the daily food consumption, size of the fish and water temperature. This particular part of the work on soles is presented here because it may be of interest for mariculture projects. Moreover, the results may give an explanation for the distribution of soles in their natural environment : the juveniles inhabiting coastal areas whereas the mature fish are found in the open sea.

METHODS.

Young soles were kept in perforated plastic crates (55 x 40 x 30 cm deep) suspended in eight large constant temperature sea water tanks (250 x 65 x 55 cm deep), with running sea water and airsupply. Each crate was usually stocked with 1 to 4 fish of equal size, each tank contained 4 crates with soles of different sizes from 6 to 25 cm, while the largest fish (approx. 30 cm) were kept free in the large tanks, in the space underneath the crates. The different tanks were maintained at constant temperatures of 10, 14, 18, 22, 26° C, and the soles were acclimated several weeks before the start of the feeding experiments. Chopped fresh

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musselmeat was given daily as the only food (we owe many thanks to Dr. DRINKWAARD (1972) and Mr. VLEUGEL from the Experimental Mussel Station on Texel for the regular supply of fresh mussels).

Measurements of daily food intake of the soles were carried out from 28.10 to 3.12.75 at 14, 18, 22° C, and again from 20.01 to 6.02.1976 at 10, 14, 18, 22, 26° C. The fish were given every morning a weighed excess amount of musselmeat, and the remaining musselmeat was collected and weighed back the next morning before offering the next meal. The mussel was chopped and washed with seawater, and left to drip dry for at least 15 minutes before the rations were weighed off. The daily food intake of the soles was corrected for the decrease in the amount of musselmeat during 24 hours (about 15 %), as measured in separate controls.

The measurements were usually carried out during 1 or 2 weeks, and the soles were carefully measured and weighed at the start and the end of each period to estimate growth and food conversion. A few fish which refused to eat properly, probably due to disease, and some fish which jumped out of the crates were omitted from the calculations.

RESULTS.

The mean daily food intake of the soles in the different crates was calculated as grams musselmeat per fish per day and plotted against the size of the fish for each temperature (figure 1). The data suggest an exponential relation between daily food consumption and mean size or weight of the fish at each temperature, which appears from the linear regression

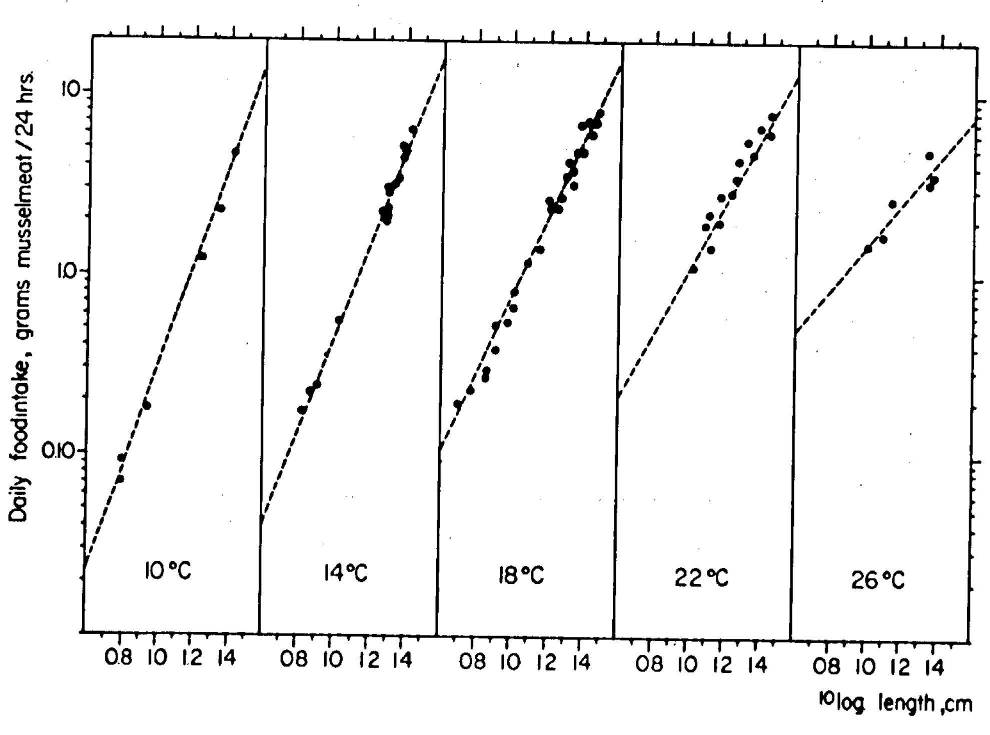

FIGURE 1 : *The linear correlation of log daily food consumption with log length of the soles, at 5 constant temperatures.*

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of log food consumption (C, gram/fish/day) against log length (L, cm, figure 1) or log weight (W, grams, figure 2). This relation can be described by the general equations $C = a\ L^b$ or $C = a\ W^b$ where a and b are constants (table 1). However, it appears that both a and b change with temperature. The best fit of a with temperature was obtained by the linear regression of temperature against $ln\ a$, hence a semi log correlation with the following equation :

$$ln\ a = ln\ k_1 + k_2 T \qquad a = k_1 e^{k_2 T}$$

where k_1 and k_2 are constants and T is the temperature in °C. The relation of the exponent b with temperature can be described satisfactorily with a simple linear correlation, especially in the range from 10° to 22° C ($b = k_1 - k_2 T$). A still better fit over the whole temperature range (10 → 26° C) was obtained with a second degree trend $b = k_1 - k_2 T - k_3 T^2$ ($k_{1,2,3}$ are constants, T is the temperature in °C).

For each temperature the daily food consumption (C) was calculated for soles with a size of 10, 20, 30, 40, 50 cm total length (figure 3 a) and for soles with a weight of 10 g. (∿ 10 cm), 100 g. (∿ 22 cm) and 1000 g. (∿ 47 cm). (The length (L) weight (W) relationship of the fish used for the experiments was approximately $W = 0.0075\ L^{3.066}$).

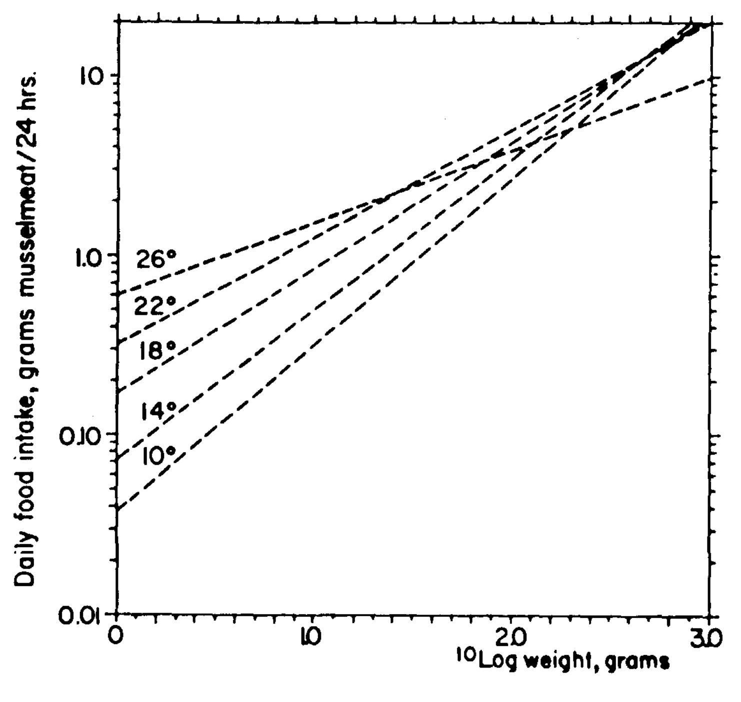

FIGURE 2 : *Linear correlation of log daily food consumption with log fish weight. Same data as in figure 1.*

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Temperature °C	Relation of C with L	Correlation coefficient r	Number of measurements (n)
10°	$C = 0.000377\ L^{2.853}$	0.9994	5
14°	$C = 0.00132\ L^{2.543}$	0.996	16
18°	$C = 0.00565\ L^{2.143}$	0.993	21
22°	$C = 0.0187\ L^{1.797}$	0.94	15
26°	$C = 0.1035\ L^{1.170}$	0.93	6
10 ÷ 22° (n = 4)	$C = 0.000014e^{0.33T} . L^{3.76 - 0.089T}$ (r = 0.999) (r = 0.999)		
10 ÷ 26° (n = 5)	$C = 0.000011e^{0.35t} . L^{(3.20 - 0.0096T - 0.0026\ T^2)}$ (r = 0.998) (r = 0.998)		
Temperature °C	**Relation of C with W**	**Correlation coefficient r**	**Number of measurements (n)**
10°	$C = 0.0349\ W^{0.938}$	0.9998	5
14°	$C = 0.0732\ W^{0.840}$	0.997	16
18°	$C = 0.1784\ W^{0.687}$	0.992	21
22°	$C = 0.3264\ W^{0.589}$	0.96	15
26°	$C = 0.6179\ W^{0.402}$	0.91	6
10 ÷ 22° (n = 4)	$C = 0.0053e^{0.19T} . W^{1.24 - 0.030T}$ (r = 0.997) (r = 0.996)		
10 ÷ 26° (n = 5)	$C = 0.0060e^{0.18T} . W^{(1.12 - 0.013T - 0.00055T^2}$ (r = 0.997) (r = 0.997)		

TABLE 1 : *The relation of daily food consumption (C, gram wet weight musselmeat per 24 hrs) with length (L, cm) and wet weight (W, gram) of soles at different temperatures (T, °C).*

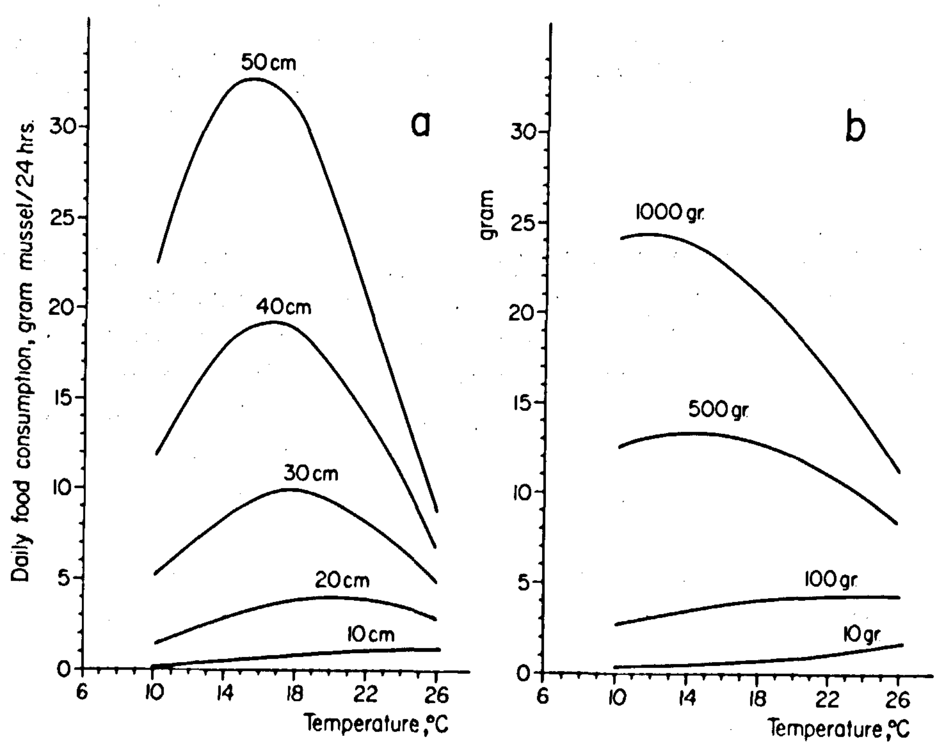

FIGURE 3 : *The calculated daily food consumption (C_{max}) for soles from 10 to 50 cm length (a), or from 10 to 1000 gram weight (b), in relation to temperature.*

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Finally, the calculated daily food consumptions were expressed in percentages of the weight of the fish (C as % W, figure 4a) and as percentages of the metabolic weight of the fish (C as % $W^{0.8}$, figure 4b), where the metabolic weight refers to respiratory metabolism related to $W^{0.8}$ ($R = aW^{0.8}$, WINBERG, 1960). Measurements of respiration of young soles indicated that oxygen uptake R in µgrat/fish/hr follows approximately the equation
$R = 2.e^{0.1T(°C)}.W^{0.8}$.

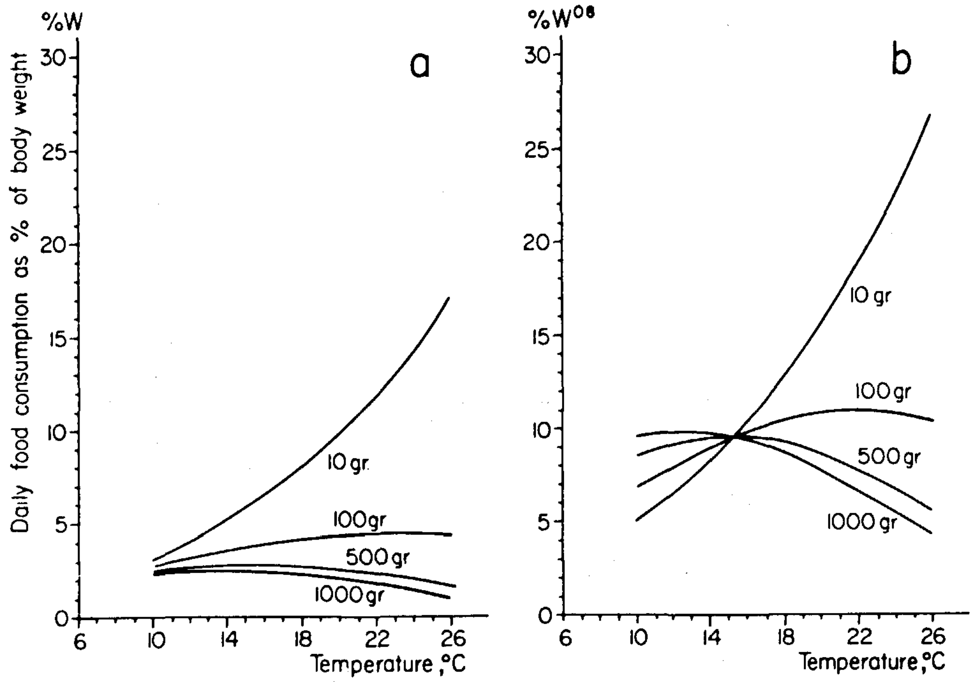

FIGURE 4 : *The influence of temperature on daily food consumption (C_{max}) when C_{max} is expressed as a percentage of fishweight (a), or a percentage of metabolic weight (b, %W expon. 0.8) of fish from 10-1000 gram.*

DISCUSSION.

ELLIOTT (1975, 1976) measured the maximum daily food consumption (D_{max}) of trout (*Salmo trutta* L.) in relation to temperature (T, °C) and the weight of the fish (W, gram). He found the relationship $D_T = Ae^{b_2 T}.W^{b_1}$, where A, b_1 and b_2 are constants. The weight coefficient $A.e^{b_2}$ is very similar to the weight coefficient for daily food consumption of soles. However, the weight exponent b_1 was approximately 0.76 for the trout and independant of temperature. As a consequence the optimum temperature for growth and feeding of trout is about 13°C, independant of the size of the fish.

Due to the change of the weight exponent with temperature for daily food consumption of soles, smaller soles show a maximum daily food intake at high temperatures (26° C) whereas the large fish show maximum feeding at low temperatures (14-16° C), as shown in figure 3. The daily food intake of the large soles is always higher compared to the small soles, but the opposite appears if food intake is expressed in % of body weight (W, figure 4a) : the small soles eat relatively more (≥ 15 % W/ day) as compared to the large soles, 2-4 % W/day

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(PANDIAN, 1975, gives an amount of 5 to 2 % W/day as daily food consumption of dabs (*Limanda limanda*) from 1 to 150 gram weight respectively).

When daily food consumption (*C*) is expressed as a percentage of the metabolic weight of the fish ($C = \%\ W^{0.8}$), a remarkable relationship appears with temperature (figure 4b). At 16° C the food intake is the same proportion of the metabolic weight (about 10 % $W^{0.8}$) independant of the size of the fish. At lower temperature consumption is higher for the larger fish, at higher temperatures consumption is higher for the smaller fish. When food consumption is related to metabolism, the soles appear to be in a kind of equilibrium at 16° C. Higher temperatures are more favourable for the smaller fish which eat relatively more, whereas lower temperature are more favourable for the larger soles. This may explain why the young soles need warm shallow coastal waters and a rich food supply, while the adult soles find optimum conditions for growth at greater depth in the North Sea offshore.

A similar temperature effect may be found for the plaice, which shows a similar change in habitat from shallow coastal waters to cooler deeper waters during growth. It will be very interesting to compare the energy balance (ELLIOTT, 1976) of sole, plaice, turbot, etc... with more stationary fish species like flounder, dab, dwarfsole, etc...

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