JAPANESE SKIPJACK STUDIES

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EXPLANATORY NOTE

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United States Department of the Interior
Oscar L. Chapman, Secretary
Fish and Wildlife Service
Albert M. Day, Director

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JAPANESE SKIPJACK STUDIES

Translated from the Japanese language by

W. G. Van Campen

Pacific Oceanic Fishery Investigations

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3/ From the Bulletin of the Japanese Society of Scientific Fisheries, Vol. 9, No. 6, pp. 231-236. March, 1941.

4/ From Bulletin of the Japanese Society of Scientific Fisheries, Vol. 9, No. 3, pp. 100-102. September 1940.

A Note on the Fisheries Condition of "Katuo" as a Function of Several Oceanographic Factors

Synopsis [in English]

Some tentative studies of the fishing conditions of "Katuo",* Euthynnus vagans (Lesson), as a function of several oceanographic elements, including surface temperature, are given here.

The fishing locality of "Katuo" moves from the region off Nozimazaki in May, passing off Tyôsi in June, to the region off Kinkwazan in July. The paths seem to follow the warm branches of currents, which are recognizable by the tongues of isotherms either at the surface or at the subsurface of 100m depth. The concentration of the shoals seems to be defined not only by the surface water temperature but also by the vertical distribution of vertical temperature gradient in the uppermost 100m layer. The paths also have close bearing to the migration of sardine shoals and to the distribution of copepoda, both being the natural food fauna for "Katuo".

In the sea-region south off Kagosima Pref, the catch of "Katuo" varies with salinity throughout the periods from March to September (Fig. 6). The value of transparency and of salinity giving the mode for the catch are shown in Figs. 5 and 7. [End of English synopsis]

With regard to the relation between the skipjack fishing situation and oceanographic conditions, a great number of reports have been published in the past on surface water temperature, the present author himself having published frequently on the subject in this journal, however, there has not yet been any thorough study of factors other than surface temperature. For the determination as a practical problem of the zone which connects the principal skipjack fishing grounds -- the apparent "fishway" -- the surface water temperature values alone do not suffice. Furthermore, in explaining the skipjack fishing situation in the Satsunan and Zunan areas there is much that cannot be understood from the water temperatures alone. Further there is the general problem of the relationship between oceanographic conditions and how well the skipjack take to the bait. If we try to make a start at solving the problems in such an area, we experience considerable difficulty because the threads of all of the factors are entangled and there is a paucity of data other than surface water temperatures. Nevertheless, feeling desirous of seizing a clue to the solution of these problems, I have made two or three preliminary investigations, the results of which are reported below.

First of all, if we consider the catch $\mathcal{N}$ as a function of several oceanographic factors, which are water temperature θ, temporal changes in water temperature $\dot{\theta}$, the gradients $\nabla\theta$ of water temperatures in a horizontal and a vertical direction, salinity $\mathcal{S}$, and transparency $\mathcal{D}$ we get the formula $\mathcal{N}=f(\theta, \dot{\theta}, \nabla\theta, \mathcal{S}, \mathcal{D}, \ldots)$. In the following let us consider cursorily some

* "Katuo," (Euthynnus vagans (Lesson)) = katsuo, skipjack (Katsuwonus pelamis of authors)

simple examples.

(1) $\mathcal{N} = f(\theta, \dot{\theta}, \nabla\theta)$. As a practical problem there is the forecasting of the locations of the skipjack fishing grounds, which every year in May, June, and July shift rapidly from the waters off Nojimazaki in Bōshū through the seas off Chōshi to the area off Kinkazan. Hitherto only superficial investigations depending on charts of surface water temperatures have been made, however, if we try examining the correlation between the positions of the fishing grounds and the distribution of the 19° - 22°C warm water zones (represented on the chart by the 20° isotherm) in each ten-day period of the four years from 1935 to 1939, we can see (Figure 1) that there is a rather close relationship between the movements of the fishing grounds and the form of the isotherms. The grounds which in May were stationary in the warm current system surrounding the edges of the cold water mass southeast of Nojimazaki, have shifted in June to the northward projecting peaks of the undulating line of the isotherms, which have moved to the north and northeast. In July there is further sharp* northward shift and two peaks in the isotherms are clearly apparent where there are two projecting branches of the warm current. As a consequence the fishing grounds are also split into two. At the same time the center of the fishing grounds shifts gradually from the coast to the offshore waters, where the main fishing grounds are located from the latter part of June to the early part of July. After the middle of July a conspicuous fishing ground appears off Kinkazan comparatively close to the coast. This means that the general outlines of the fishing grounds can be deduced from the water temperature θ, the distribution of the isotherms $\nabla\theta$, and the rate of change and consequent shifting of the isotherms $\dot{\theta}$, however, since there is a need for even more accurate forecasting of the "fishway", other factors must be taken into consideration. Now if we show (Figure 2) the locations of the appearance of feeding skipjack schools as studied by Mr. Gorozō Okamoto from the data of 1936, being able to assume a route of movement generally corresponding to the shifts in the main fishing grounds and to the deduced migration routes of marked skipjack, we car believe that the skipjack schools which move northward in the Northeastern area are on a feeding migration, following a path between places where natural foods (sardines, mysids) are abundant. Consequently it can be deduced that the movements of these schools of natural food animals also follow the branches of the warm currents.

(2) $\mathcal{N} = f(\theta, \nabla_z\theta)$. As is shown in Figure 3, the results of statistical studies indicate that in the Northeastern area in 1936 and 1937 both the number of fish taken and the frequency of catches reached their maximum value when the difference between the surface temperature (θ_0) and the temperature at the 100-meter level (θ_{100m}) was 10° - 16°C (θ_0 of 20° - 24°C). Furthermore, in late June and early July in the southern part of the Northeastern area another mode appeared where $\theta_{0m} = 22° - 23°C$ and $(\theta_{0m} - \theta_{100m}) = 2° - 4°C$. Figure 4 was made from charts of the distribution of water temperatures at the surface and the 100-meter level obtained through the

* With regard to this rapid shift in the isotherms and the positions of branches of the warm current, a close correlation can be seen with meteorological conditions preceding and following the start of the spring rainy season.

simultaneous oceanographic observations taken every year in August, and the approximate positions of the fishing grounds have been entered on the chart. From this it can be seen that the grounds lie within several hundred miles of the coast at places where the temperature difference between the upper and lower strata is comparatively great, and in the vicinity of projections of the warm current system at the 100-meter level (tending somewhat to center on the west side).

(3) $\mathcal{N} = f(\theta, \mathcal{S})$. If we consult the statistics to see the correlation between skipjack catch and salinity, we find, as shown in Figure 5, that the fish can be taken within a range of $\mathcal{S}$ of 33-35 ‰, however, the maximum catch frequency for both 1936 and 1937 appears where $\mathcal{S}$ is 34.6-34.8 ‰. In this regard, however, there are few data and accuracy is not high. There is a need for an investigation by areas and by seasons based on a larger volume of accurate data.

An interesting point to note here is the correlation, shown in Figure 6, between the temporal changes in the landings of skipjack $\mathcal{N}$ at Makurazaki in Satsunan for each ten-day period of the years from 1933 to 1937 and the changes in chlorinity $\mathcal{S}'$ taken by hygrometer at the Yakushima lighthouse. In this case the curve of $\mathcal{N}$ and the curve of $\mathcal{S}$ agree rather well in their general tendency during the period from the middle of March and the latter part of September, showing a true correlation, and the variations in maximal points of $\mathcal{N}$ and $\mathcal{S}$ from year to year come out in rather good agreement. Particularly well matched are the curves for the period of the decline of $\mathcal{N}$ and $\mathcal{S}$ from their maximum values.

The origin of this phenomenon is presumed to be the spreading of water of low chlorinity from the East China Sea system in the surface layer of the Kuroshio system in June, July, and August. Through the autumn and winter the $\mathcal{S}$ again increases and the temperature also reverts to its spring level, but the fact that $\mathcal{N}$ does not increase in proportion is probably due to the fact that it is not yet time for the schools, which were broken up during the summer, to reassemble and they are probably engaged in a migration related to their spawning season.

(4) $\mathcal{N} = f(\theta, \mathcal{D})$. If we attempt to examine the relation between the catch and transparency, we find, as shown in Figure 7, that the most fish are taken at transparencies of 14 - 28m and that the maximum catch frequency appears in the vicinity of 20m. The relationship of transparency to natural food, bait-taking, and catch will probably become gradually clearer in the future as more data are made available.

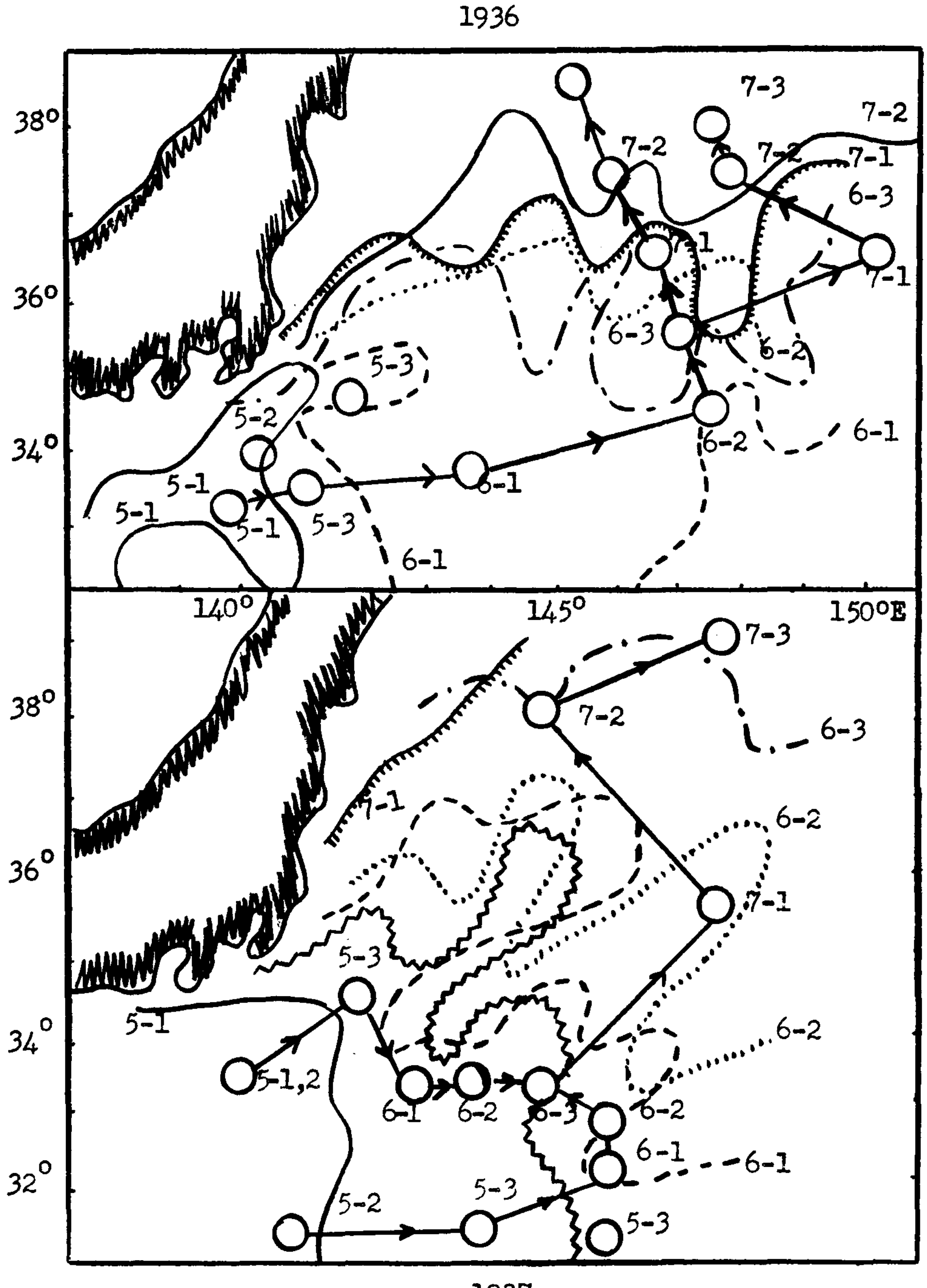

Figure 1a The small circles show the centers of skipjack fishing grounds; the solid lines, broken lines, and dotted lines represent the 20°C isotherm. The figures 7-1 indicate the first ten-day period of July, and so forth.

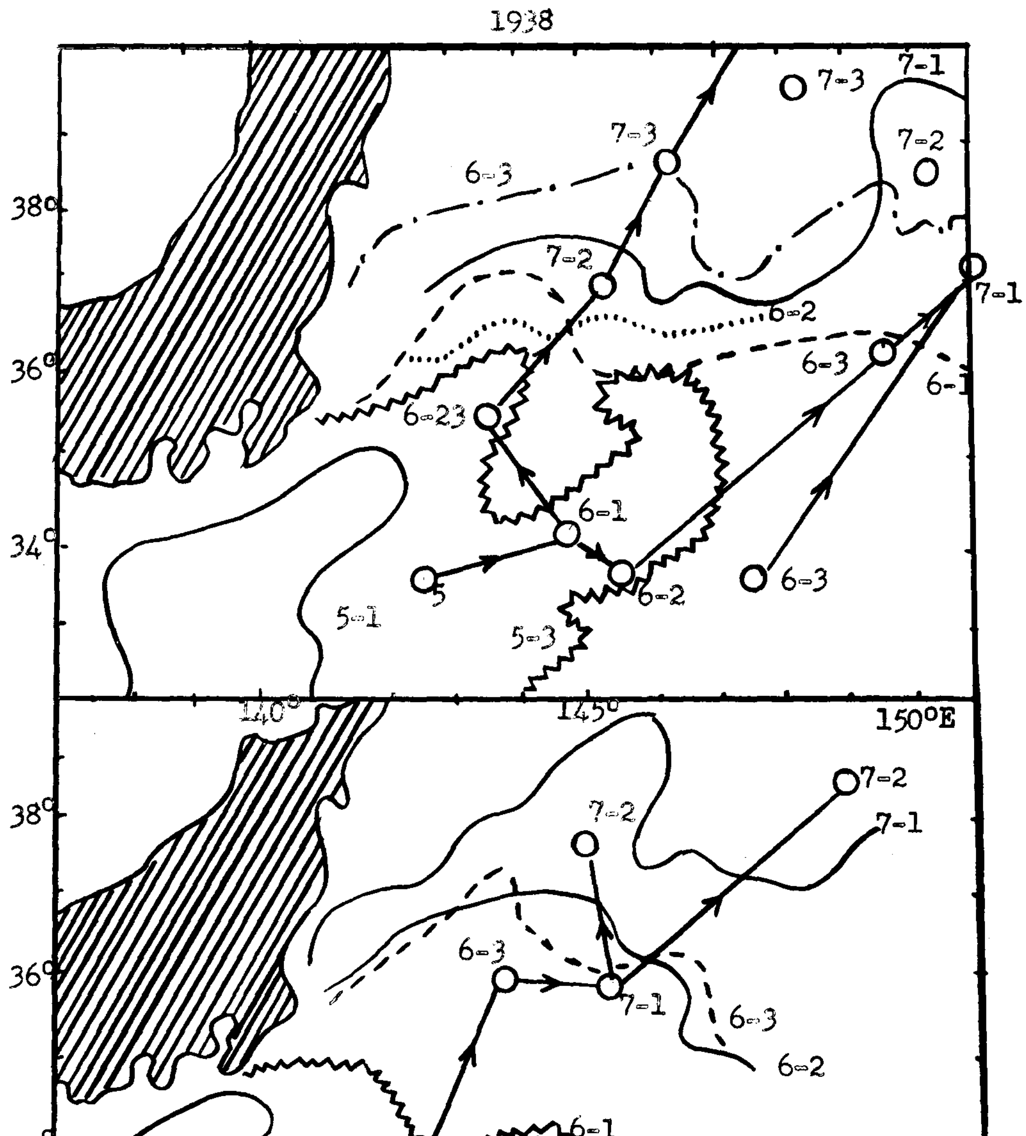

Figure 1b The small circles show the centers of skipjack fishing grounds, the solid lines, broken lines, and dotted lines represent the 20°C isotherm. The figures 7-1 indicate the first ten-day period of July, and so forth.

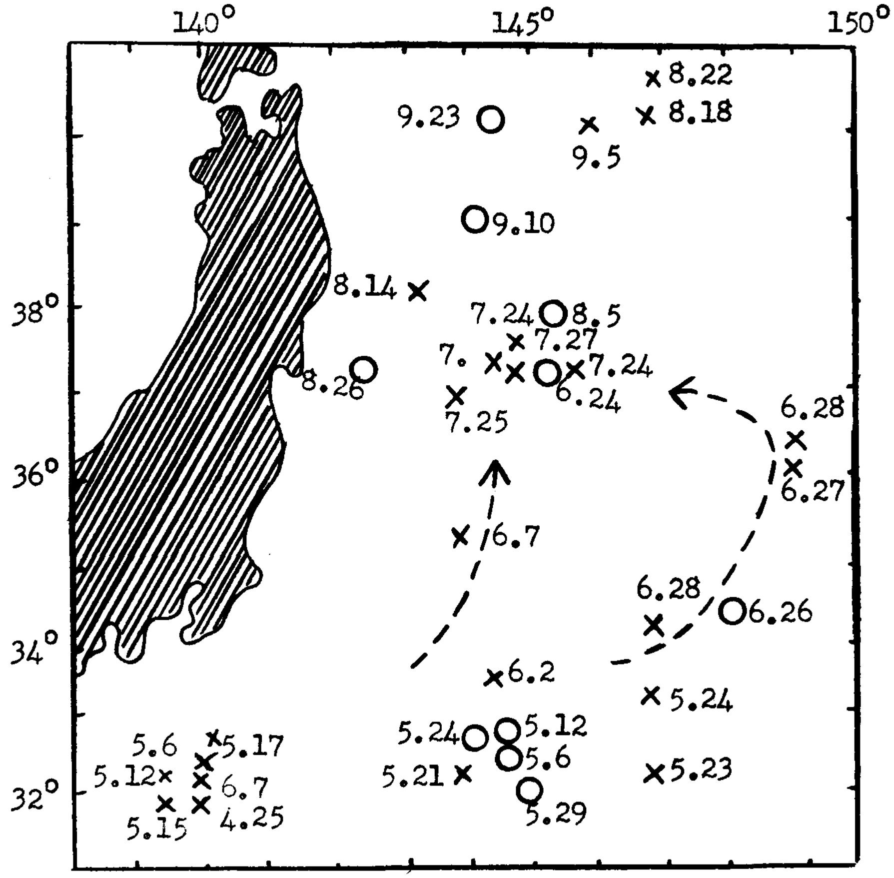

Figure 2 Positions at Which Feeding Schools of Skipjack Appeared in 1936 (According to Research Vessels and Special Fisheries Reporting Vessels). Circle indicates a school feeding on sardines; x indicates a school feeding on sardines or mysids; the numbers represent the date of appearance.

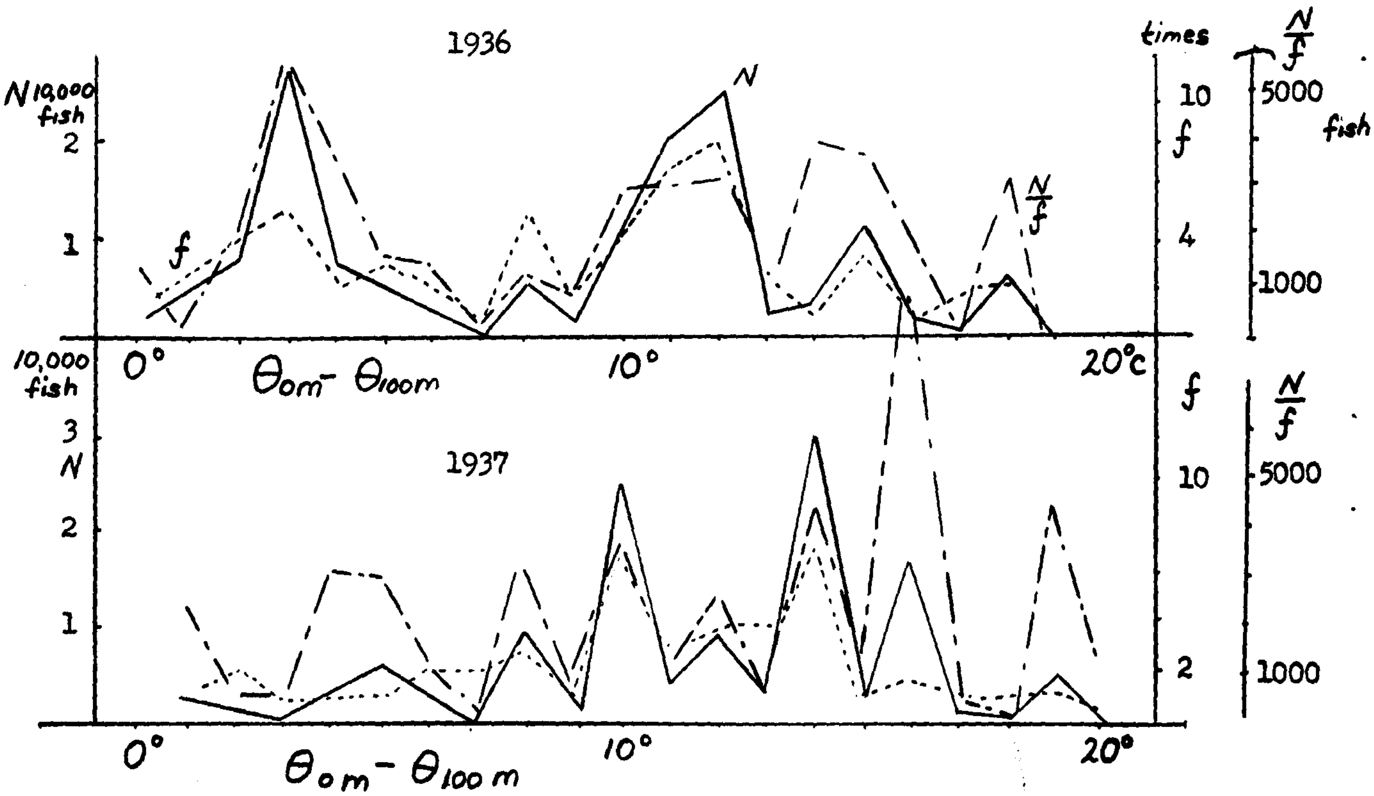

Figure 3 Skipjack Catch and Vertical Temperature Gradient (Difference Between Surface Temperature and Temperature at 100 Meters)

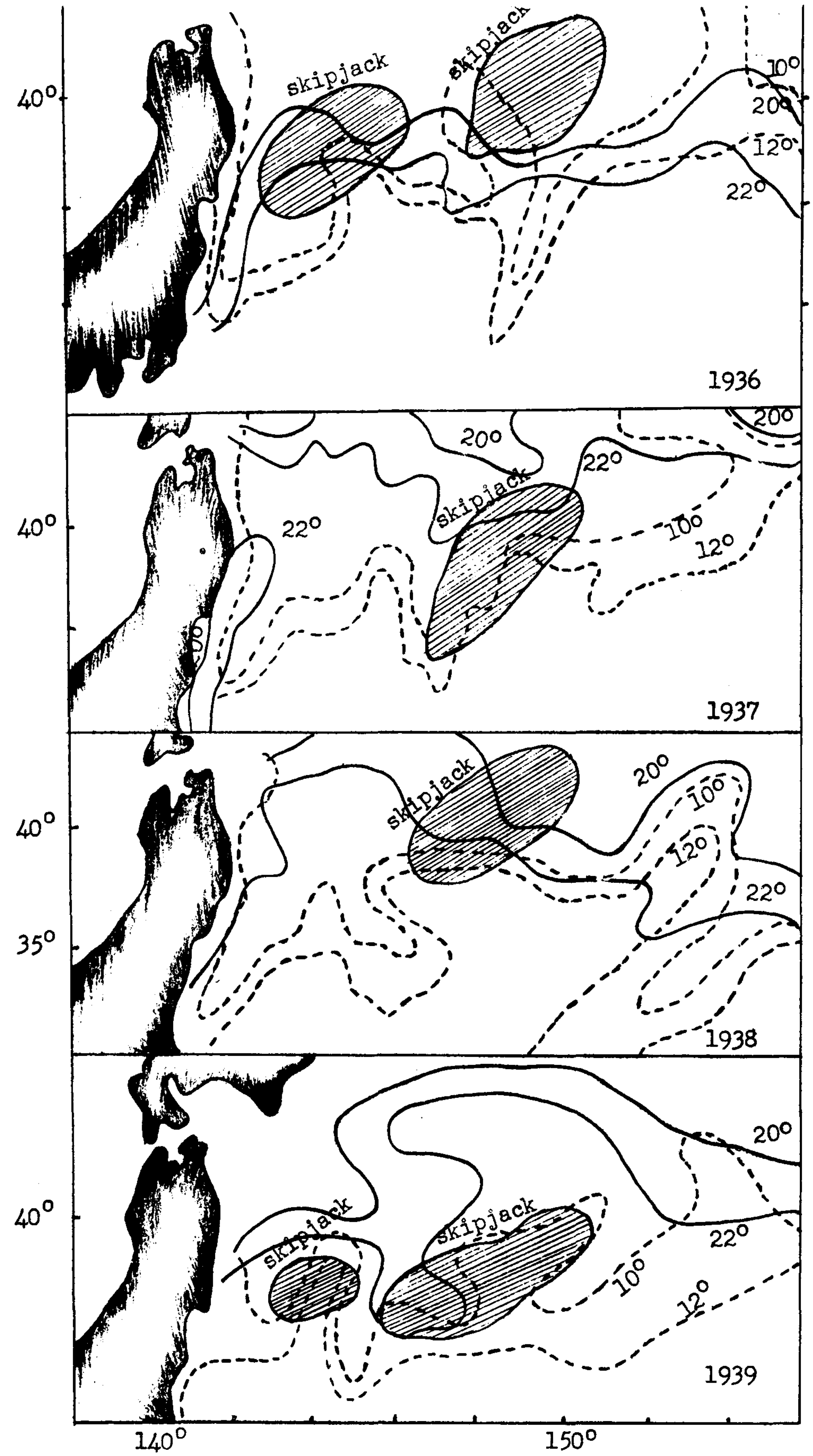

Figure 4 Distribution of Surface Temperatures (Solid Line) and Temperatures at the 100-Meter Level (Dotted Line) with Skipjack Fishing Grounds for August of Each Year (Diagonal Lines)

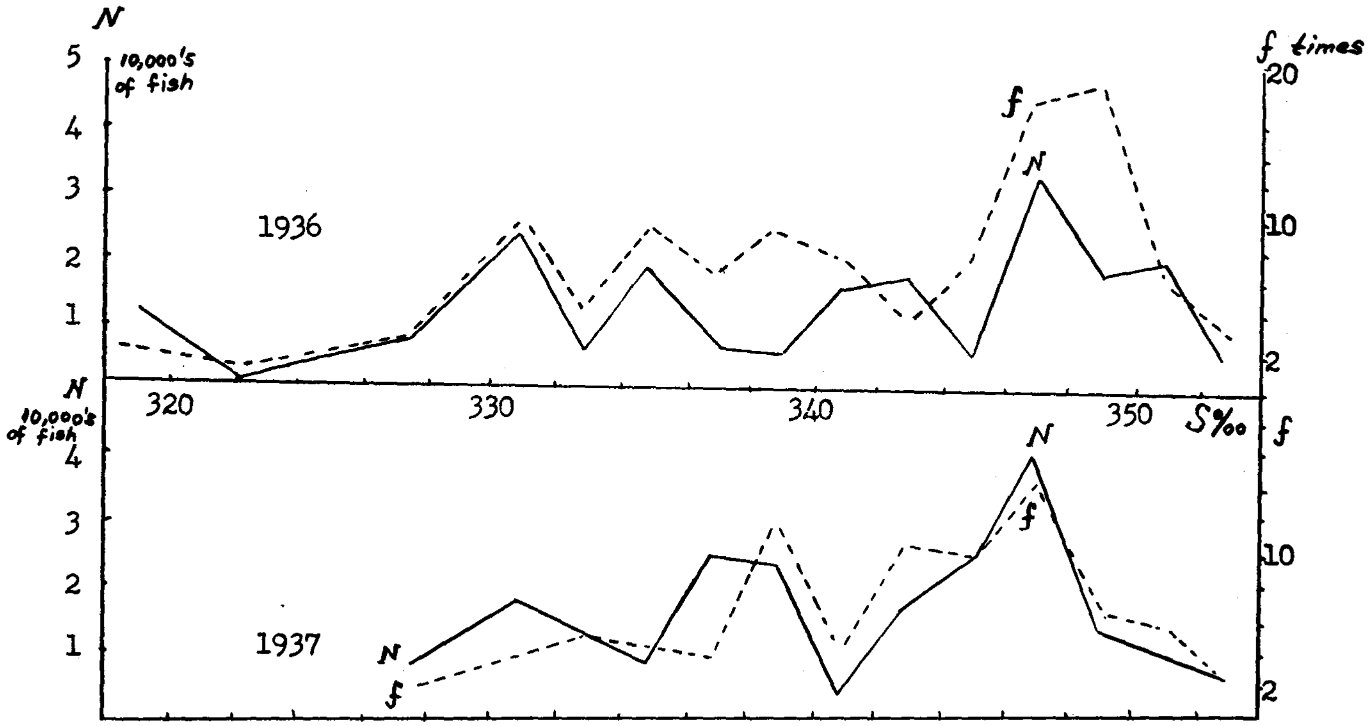

Figure 5 Chlorinity and Skipjack Catch

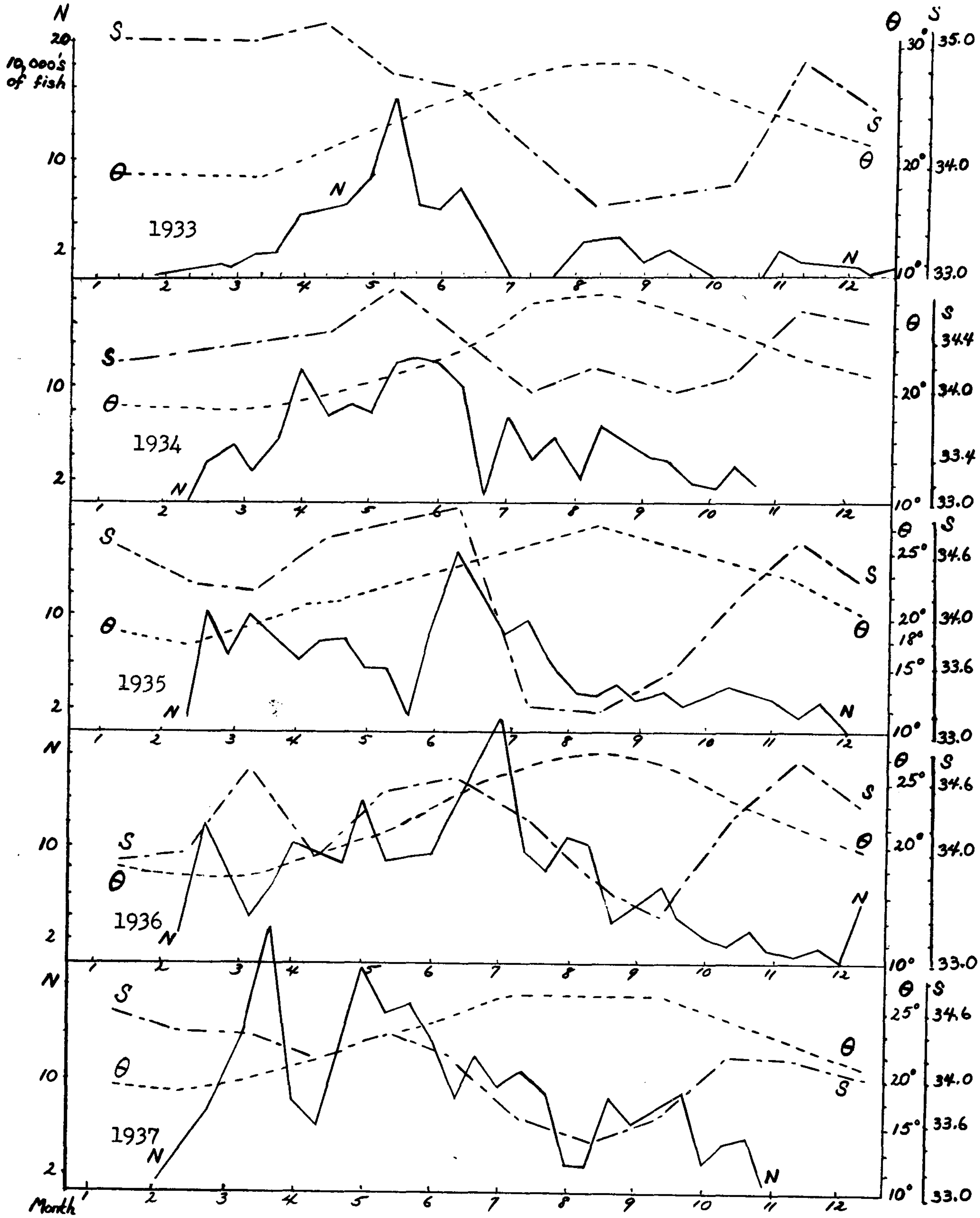

Figure 6 Temporal Changes in Skipjack Landings at Makurazaki and Monthly Changes in Temperature and Salinity and Yakushima

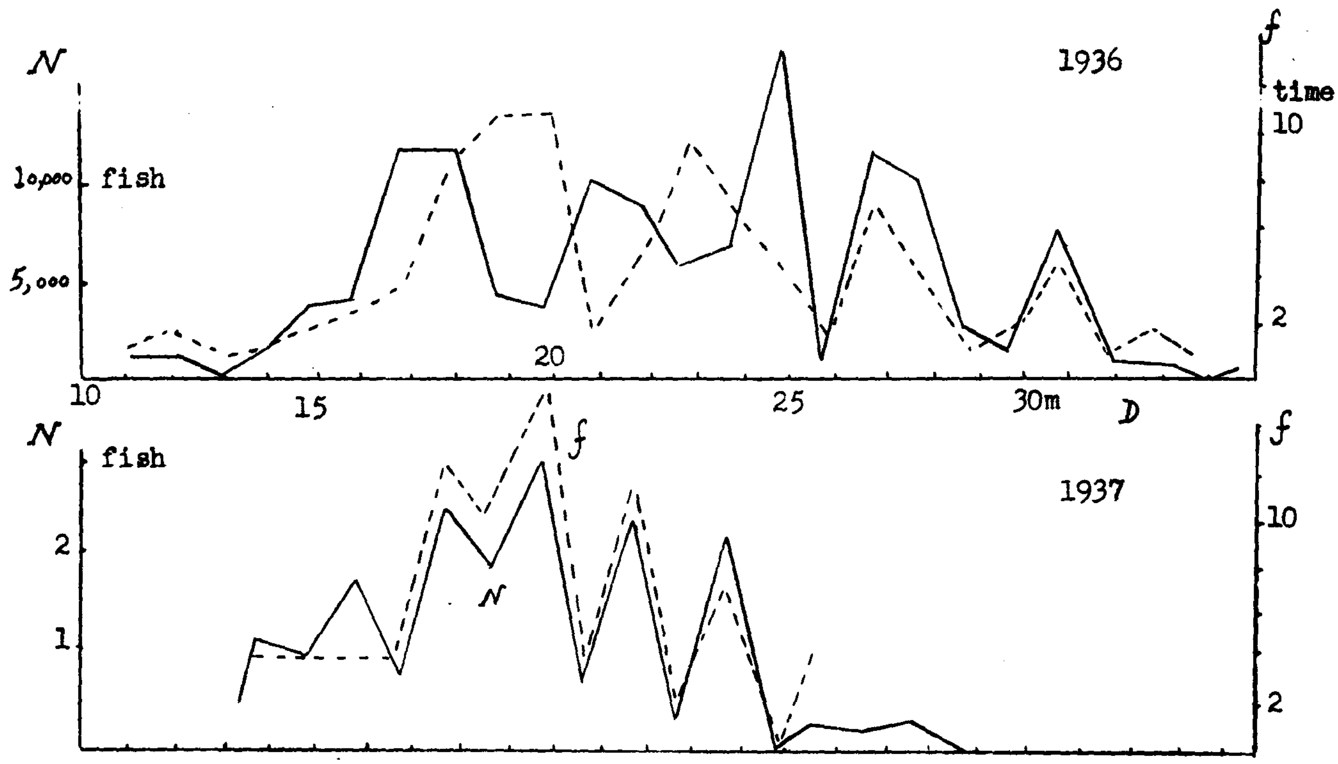

Figure 7 Sea Water Transparency and Skipjack Catch

The Time and Duration of Angling and the Catch of "Katsuo", *Euthynnus vagans* (Lesson)

Synopsis /in English/

Based on the data supplied from the fisheries-surveying boats, more than 50 in number, in the years from 1936 to 1939, the relations among the time of angling (t_0), the duration of angling (T) and the catch of Katsuo (n) were examined statistically.

Three maxima shown in the catch-curves (Fig.1), i.e. the principal one dominating early in the morning (5 - 9 h. a. m. about after the sunrise), which covers nearly the half of the total catch in a day, the secondary one falling about after the noon, and the tertiary one in the evening before the sunset, are noticed. Those maxima and the exponential decay indicated in the general trend of the catch curves (Fig.2) can be interpreted mainly as the results of the behaviour of the shoals of "Katsuo," subjected to their feeding habit, besides the disturbance of the shoals due to fishing, etc.

As regards to T, the dominant value of the catch corresponds to 10-40 minutes, and unto 80 minutes of T the catch increases with the increase of T, and then beyond 80 minutes the catch falls down rapidly. /end of English synopsis/

If we take t_0 as the time when the skipjack school is sighted and fishing is begun, T as the duration of fishing, and n as the number of fish taken in the unit time, then the total catch can be expressed as

$$N = \sum_{t = t_0}^{t = t_0+T} n\Delta t .$$

The relationship between fish catch and fishing time were investigated statistically from the data obtained from the research vessels of all of the fisheries experiment stations throughout the country and from about 50 skipjack fishing vessels especially designated to make reports on the fishing situation for the four years from 1936 to 1939, and the results are reported below.

(1) Relationship of t_0 time to catch n. Figure 1 shows in relation to t_0 the assembled totals of skipjack taken in each hour Δt, the number of catches made at that time, and the number of fish taken per catch. Looking at these graphs it can be seen that not many fish are taken up to about 4:00 a.m., but around the "false dawn" at about 5:00 the catch begins to increase rapidly. The first and principal peak in the catch curve appears between 5:00 and 9:00 a.m. and thereafter it falls off sharply, although a second small peak develops around noon to 1:00 p.m. (This is thought to correspond to what the skipjack fishermen of Shizuoka Prefecture call the "change of shadow.") The catch then continues to decrease steadily through the afternoon. A third peak corresponding to the time of day called "yumazume" appears to exist at around 4:00 to 6:00 p.m., but it is not very clear.

Now if we take N_1 as the number of fish caught during the forenoon,

$N_1 = \sum_{t_0 = 2h}^{t_0 = 11h} n\Delta t$, and if we take N_2 as the number captured during the afternoon, $N_2 = \sum_{t_0 = 12h}^{t_0 = 20h} n\Delta t$, however, the ratio N_2/N_1, between the two is 0.52 for 1936, 0.48 for 1937, 0.52 for 1938, and 0.54 for 1939, establishing approximately the relationship (1) for all four years[1].

$$N_1 = 2N_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

That is, in every year the catch during the forenoon was about twice the afternoon catch or 2/3 of the day's catch.

Now if we try calculating the total catch $N_1' = \sum_{t_0 = 5h}^{t_0 = 9h} n\Delta t$ in the first peak from 5:00 to 9:00 a.m., $N_1'/(N_1 + N_2)$ is 0.53 for 1936, 0.46 for 1937, 0.48 for 1938, and 0.51 for 1939, establishing the approximate relationship $2N_1' = N_1 + N_2$ or $N_1' = \frac{N}{2}$ ....(2) for all four years. That is, about half of the catch of an entire day (2 - 20h) is sighted and captured between 5:00 and 9:00 a.m. Now if we calculate N_1'/N_1 we get 0.8 for 1936, 0.7 for 1937, 0.7 for 1938, and 0.8 for 1939 which means that during the five hours from 5:00 to 9:00 a.m. there is captured 70 or 80 percent of the fish taken in the forenoon (the ten hours from 2:00 to 11:00).

From (1) and (2) we get the relationship (3).

$$\frac{N_1'}{N_1} = \frac{3}{4} = 0.75 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

(2) Relationship of t_0 and log n. If, in order to clarify the character of the catch curve described above, we plot the correlation between the log of the catch and t_0, a glance at Figure 2 will clearly show that at t_0 later than the 6:00 to 8:00 a.m. maximum of n the decrease is in almost a straight line except for the deviation caused by modes Nos. 2 and 3.

Accordingly for $t_0 > 6 - 8h \quad n = n_{max} e^{-\lambda t}$ ....(4)

Let us try considering for a bit why it is that we get this sort of a curve. One can think of four factors in this connection. (i) the factor (λ_1) of the disruption of the schooling of the fish due to diurnal changes in the mobility of the schools in relation to their food, (ii) the factor (λ_2) of the decrease in the schools due to the number of fish taken from them, (iii) the factor (λ_3) of the disruption and scattering of the schools due to fish, and (iv) the factor (λ_4) of the lowering of the operating efficiency of the fishermen with the passage of time due to fatigue (with regard both to their ability to sight fish and their ability to catch them). Therefore

(1) t_0 is the time when fishing begins, however, as will be seen in the following section, T may be considered to be on the order of 10 - 40 minutes. Therefore in this paper I have not taken this variation into account, but have considered for the purposes of the discussion that it is the median time. Thus where t_0 is given as 11h, the fishing time may generally be considered to have been between 11h and 12h.

it is thought that when day breaks and the sea becomes faintly lighted the schools suddenly begin to become active and seek food; thereafter until the time of n_{max} their biting becomes better in direct proportion as the light in the sea increases. Accordingly the catch increases sharply and reaches its maximum at t_0 = 6:00 - 8:00 a.m.[2] Thereafter, if we equate it with the passage of time, it falls off in roughly a regression line. It is thought that of λ_1, λ_2, λ_3, and λ_4, the main factor is λ_1 followed by λ_3, and that in general λ_2 and λ_4 do not show very marked values. Accordingly

$$n = n_{max} e^{-(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4)t} \fallingdotseq n_{max} e^{-\lambda_1 t} \quad \ldots\ldots\ldots\ldots (5)$$

Actually, as set forth in (1), the fish school and feed most actively in the early morning, and once their stomachs are filled their appetites decline, but around noon, for reasons connected with the time required for digestion, their appetites again increase and they become slightly active. It is presumed that another such phenomenon is exhibited in the evening just before sunset. Probably further study of what has been simply represented as λ_1 will reveal that it must be represented as a function showing three undulatory changes during the day.

(3) Examination of the relationship between T and the catch n. As can be seen in Figure 3, where the catch n is plotted against the time of duration of fishing T, the greatest total number of fish are taken and the greatest number of catches are made where T is one hour or less, with the maximum where T is 10 - 40 minutes. The n per time fished also increases in direct proportion to the increase of T where T is 80 minutes or less. Where T is greater than 80 minutes, however, neither the total number of fish taken nor the n per time fished show any increase. If we consider the catch for each 10 minutes of fishing, its value is very small where T is greater than 80 minutes. It is not yet clear how this T is related to such factors as the size of the school, and its swimming speed and movements with regard to the boat.

The correlation between the tide and the catch has been experienced and remarked upon by many fishermen, being particularly emphasized where fishing is carried on in the vicinity of islands, but I would like to leave this question to a later time because no quantitative study of it has as yet been completed.

In conclusion I wish to express my thanks to Mr. Takeo Maruyama for his assistance with the calculations and drawings for this study.

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(2) Mr. Yasuo Suehiro has reported that skipjack appear to bite somewhat better in the early morning than during the day. (Fisheries Experiment Station Report No.9, p. 99. 1938).

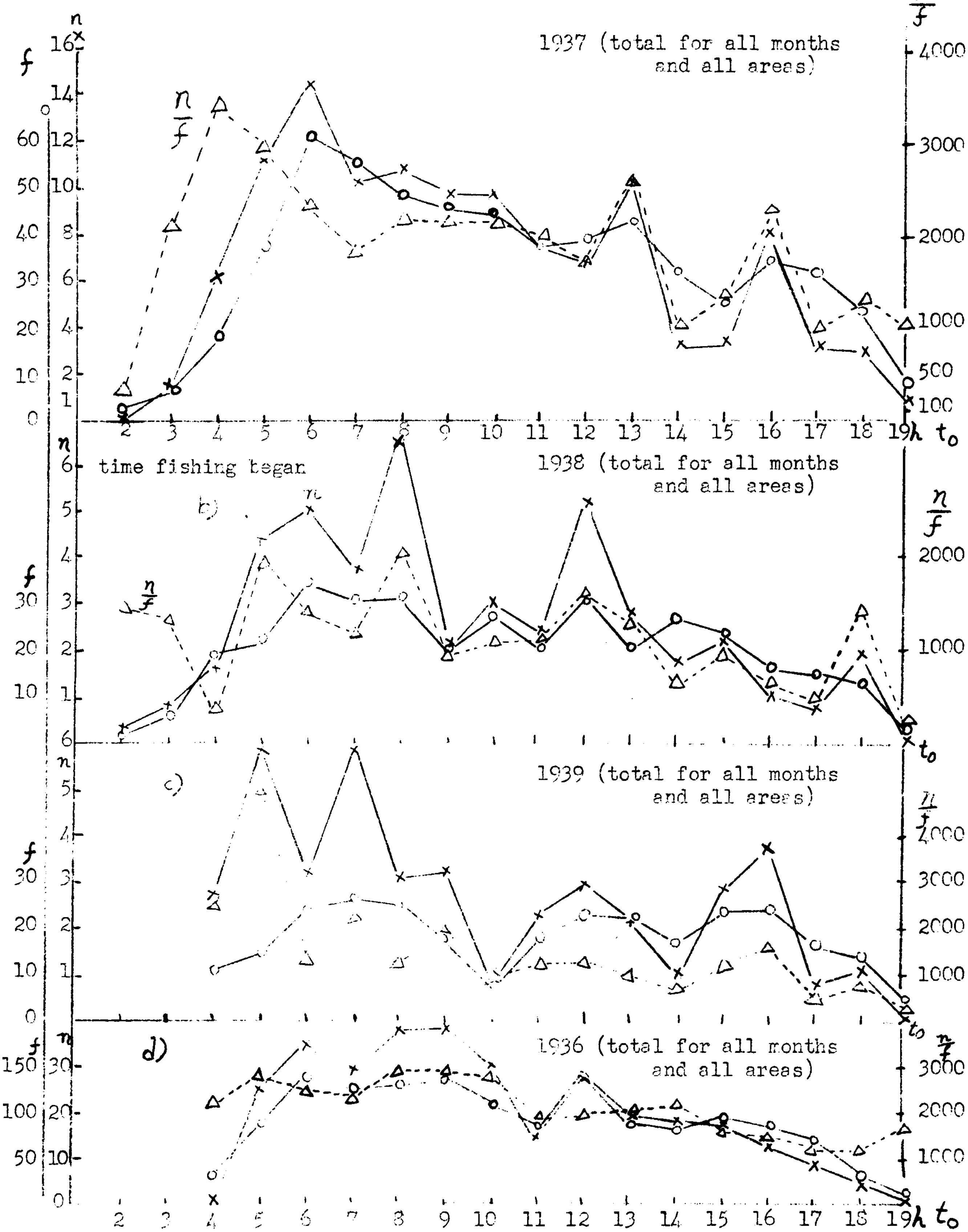

Figure 1

x total number of fish (units of 10,000) o times fished △ catch per time fished

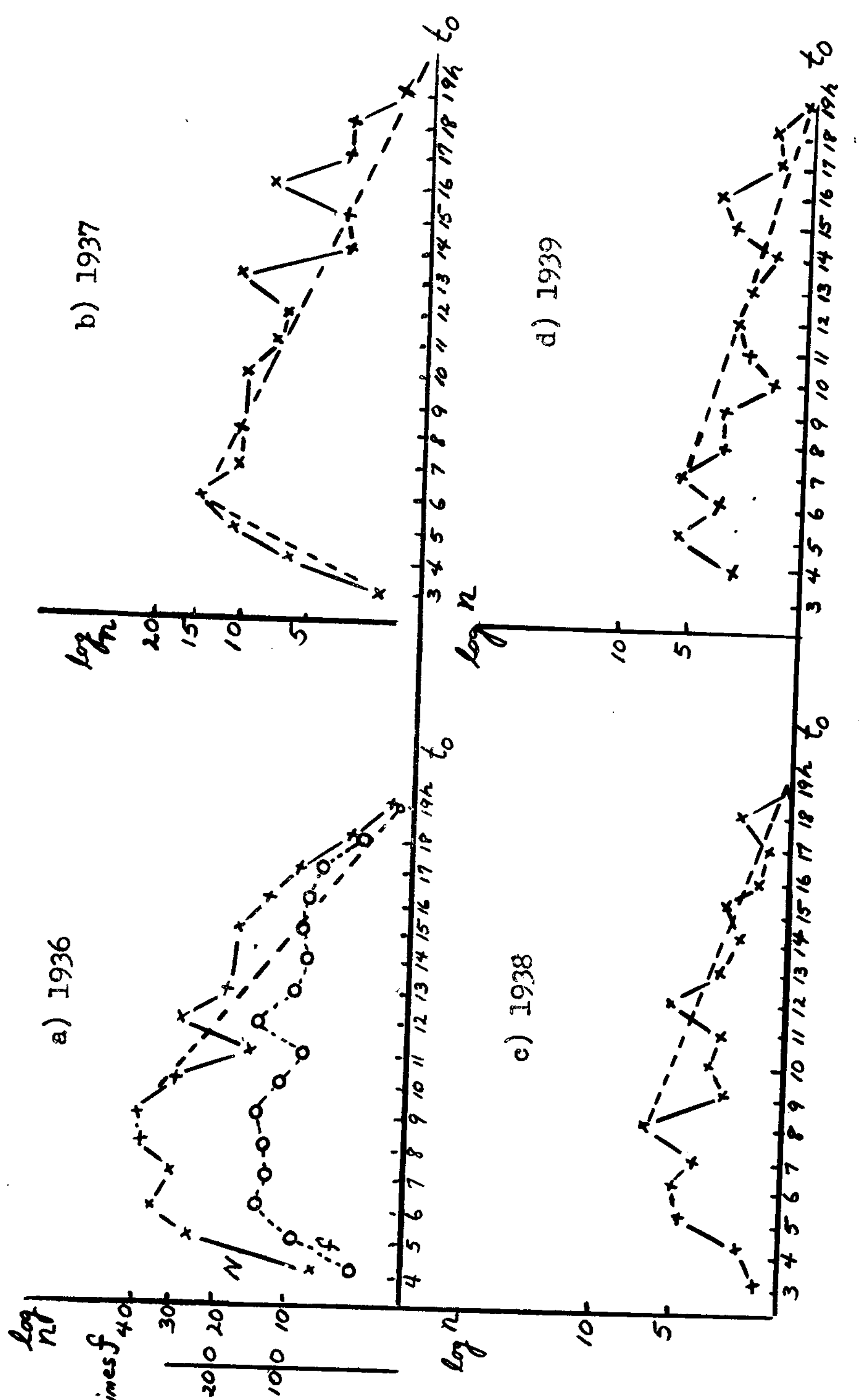

Figure 2

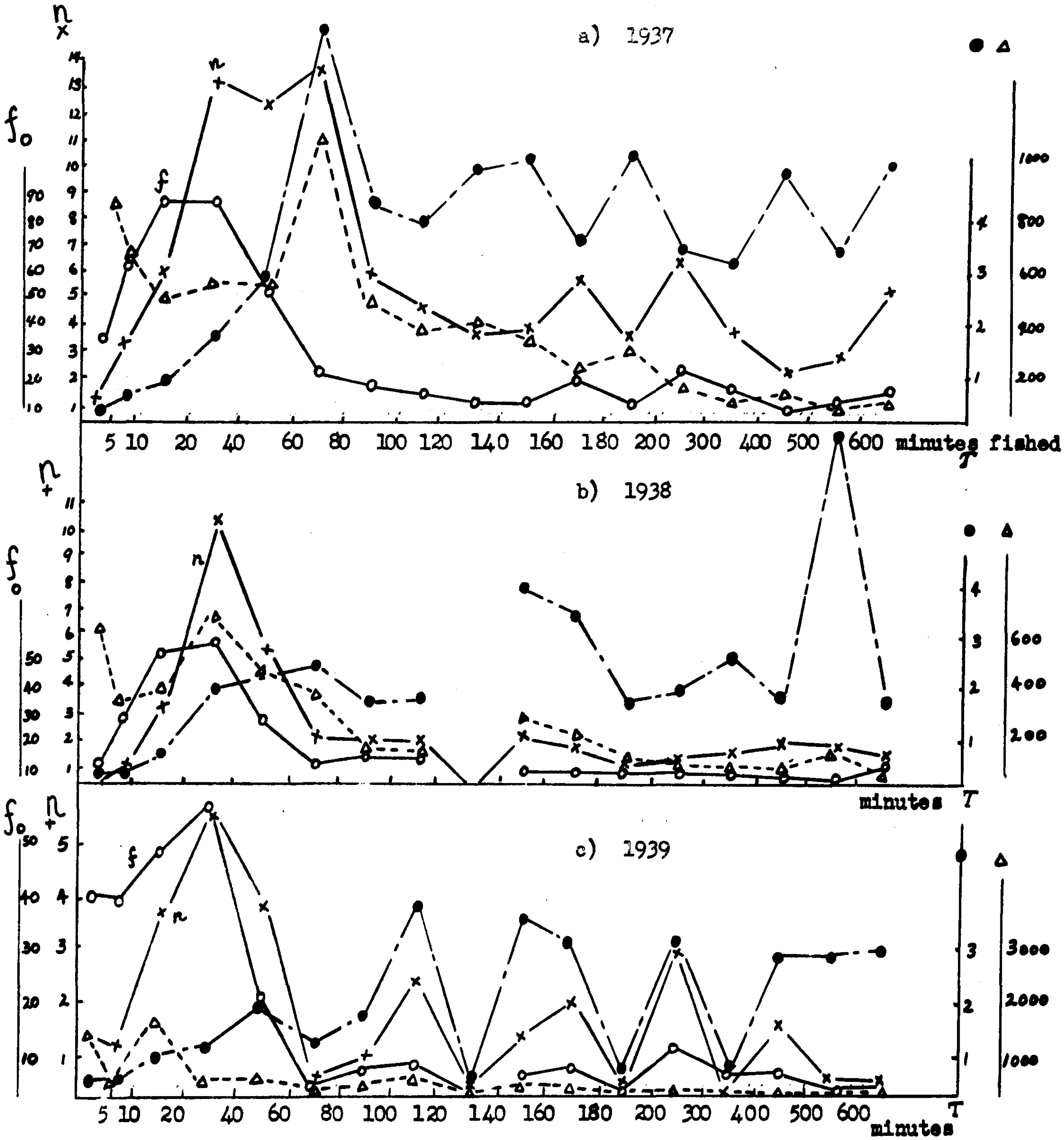

Figure 3

o number of times fished

x total number of fish taken (in 10,000's)

● number of fish taken per time fished (in 1,000's)

▲ number of fish taken per 10 minutes

The Body-temperature and the Bodily Features of "Katuo" and "Sanma"

Synopsis [in English]

The Body-temperature of "Katuo"* Θ, measured immediately after angled up on board of fishing vessels shows a linear relation to the water temperature (θ) at the fishing locality, as indicated in Fig. 1, and Θ is always 1°-3°C higher than θ, while the difference ($\Theta - \theta$) increases with θ (Fig. 2 - 4). The elements regarding to the features of fish-body for "Katuo" and "Sanma",** such as the body-weight (W), the total length (L), body-length (l), height (h), circumference (s), thickness (d), and density (ρ) were measured and the factor $K = W \times 10^3 / l^3$, the ellipticity of the cross section (c), the ratios, $\alpha = h/l$, $\beta = d/l$, s/l, s/h and the products, $\alpha\beta$, hd, etc. were computed. Then, the mutual relations among the factors were discussed (Fig. 5 - 11), with the empirical equations, which are almost represented in linear forms approximately. As a result of it, the relation $K \propto \alpha\beta$ was established. Also we find that the measurement of s is useful for the rapid inference of K or $\alpha\beta$. [end of English synopsis]

<u>Body temperature of skipjack</u>. Skipjack which are hooked and hauled out of the water die within a few minutes. Since it was desired to measure the body temperature as near as possible to the time when the fish was swimming alive in the water, fish were seized while they were still flopping about alive on the deck and the body temperature was measured by a rod-shaped thermometer inserted well inside the body through the vent. In some cases the temperature was taken immediately after the fish had died. The data obtained by the author in this way in May, 1936, aboard the fishing boat Kaijin Maru of Shizuoka Prefecture on a cruise in the Ogasawara area, and from troll-caught skipjack in May, 1940, aboard the Fisheries Experiment Station research vessel Sōyō Maru while cruising in the Kinan and Zunan areas are combined and shown in Figure 1, Figure 2, Figure 3, and Figure 4.

The body temperature of the skipjack (Θ) and the water temperature of the environment at the time show an almost linear relationship, which can be represented approximately by the following empirical formula.

$$\Theta = 0.9\,\theta + 4\,(^\circ C) \qquad \ldots\ldots (1)$$

The difference between the body temperature and the water temperature can be shown approximately by the empirical formulas (2) and (3).

$$\Theta - \theta = -0.15\,\theta - 5\,(^\circ C) \qquad \ldots\ldots (2)$$

$$\Theta - \theta = -0.14\,\Theta + 4.9\,(^\circ C) \qquad \ldots\ldots (3)$$

---

* <u>katuo</u> = skipjack, <u>Katsuwonus pelamis</u>

** <u>sanma</u> = saury, <u>Cololabis saira</u>

Figure 3 shows the frequency distribution of $\Theta - \theta$; out of 21 examples 62% are within the range of $+1^\circ - +2^\circ$, and 26% are within the range of $+2^\circ - +3^\circ$, values of $+1^\circ - +3^\circ$ thus occupying 88% of the total, while values of $0^\circ - +1^\circ$ are only 7% and those of $+3^\circ - +4^\circ$ are only 5%. Judging from these data, the body temperature of the skipjack rises with the water temperature, and always shows a difference of about $+2^\circ$ from its environment. Considered in more detail, a tendency could be perceived for this temperature differential to show greater values at lower body temperatures or lower water temperatures. As for differences in body temperature depending on the size of the fish, the data for May, 1940, show higher Θ for the smaller fish, but this is not clear for the earlier data. The idea that within the range of water temperatures which can be considered the so-called "suitable temperatures" the skipjack regulates its body temperature with respect to the surrounding water temperature proceeds naturally from the relationships of (1), (2), and (3) cited above. At the same time the fact that the body temperature of the fish is always higher than the water temperature means that heat is constantly being taken off into the sea water from the surface of the body of the fish. The fact that it is constant shows that, the heat energy[1] liberated being supplied within the body by the food taken in, this supply is almost constant. The amount of heat energy released from the whole body of a 2 kg fish is about 3,500 gr.cal., and where the water temperature or the body temperature is high, the amount is small, but where the water temperature or the body temperature is low the amount becomes comparatively great.

There are records of body temperatures taken on the catch from experimental tuna longline fishing by the research vessel Shōnan Maru of the fisheries experiment station of the Taiwan Government-General.[2] When these are shown graphically, as was done in the case of the skipjack, the results are as shown in Figure 5 a, b, c, and d. For the yellowfin tuna at water temperatures of $\theta\ 25^\circ - 27^\circ$ the body temperature can be shown by the approximate formula $\Theta = 1.1\,\theta - 1.3$, Θ being $1.2^\circ - 1.4^\circ C$ higher than θ. For the true marlin [*Tetrapturus mitsukurii*] at temperatures of $\theta\ 24^\circ - 27^\circ C$, $\Theta = 0.8\,\theta + 6.1$ and Θ is $0.7^\circ - 1.3^\circ$ (average $1^\circ C$) higher than θ. In the case of the big-eyed tuna at $\theta 23^\circ - 26^\circ$, $\Theta = 0.7\,\theta + 8.4$ and Θ is $0.6^\circ - 1.5^\circ$ (average $1^\circ C$) higher than θ. For white-tipped shark [*Carcharinus albimarginatus*] at $\theta\ 25^\circ - 28^\circ C$, $\Theta = 0.9\,\theta + 3.2$ and Θ is about 0.6° higher than θ. For the dolphin at $\theta 25^\circ - 28^\circ C$, $\Theta = 0.94\,\theta + 2.1$ and Θ is about 0.6° higher than θ. Thus not only the skipjack, but also the tunas have body temperatures $0.5^\circ - 1.5^\circ$ higher than the water temperature, and the white-tipped shark

(1) Hoshino, Saburō: On the Specific Heat of Fish Flesh. Journal of the Japanese Refrigeration Society, Vol.5, No.51, March 1930. According to this article the specific heat of fresh skipjack flesh is 0.882. Assuming that the specific heat of the live fish is of this order, for a difference of $2^\circ C$ between water temperature and body temperature the amount of heat released from the whole body of a 2 kg skipjack would be $2000 \times 2 \times 0.882 = 3528$ gr.cal.

(2) Taiwan Government-General Fisheries Experiment Station, Experimental Tuna Longlining in the Waters East of Formosa in 1936 (published in 1937), pp. 22-66.

and the dolphin have body temperatures 0.6° higher than the surrounding water. Studies in this field must be made more accurate through the addition of more measurement data.

In measuring the body temperature of saury, as in the case of sardines, the fish are small and therefore a rod-shaped thermometer is unsuitable. It is necessary to use a thermo-electric pile or an electrical resistance thermometer.

Form and body weight of fish. The form and locomotion of fish vary depending on the species, and they also differ according to the size and age of the fish. The pattern and speed of the movements of fish, and the resistance to their movements differ markedly depending on form, density, propulsive power, and the operation of the fins. The study of these problems probably will require mathematical researches based on aerodynamic experiments in a wind-tunnel or in a tank using models and real fish as well as actual measurements. What I wish to do here is to attempt an elementary examination of the essentials of the form and weight of the body of the fish from the records of actual measurements of skipjack and saury. Now when we make W the weight of the fish, l the body length, and ρ the density of all parts of the body

$$W = g\iiint \rho\, dx\, dy\, dz \qquad \text{(4)}$$

ρ differs in each part of the body and should be determined separately for each cross-section, however, considering the state of equilibrium of the body of the fish in the water, it is assumed that it has a roughly uniform value $\bar{\rho}$ which is approximately the density of the surrounding water. Then with the ratios of body height (h) and body width (d) to body length (l) expressed as α and β ($h = \alpha l, d = \beta l$), it is possible to make the substitutions $dx = dl$, $dy = \beta dl$, and $dz = \alpha dl$ for any part of the body, giving roughly

$$W = \mu g \bar{\rho} \cdot \alpha \beta l^3 \qquad \text{(5)}$$

Accordingly

$$K = \frac{W}{l^3} \times 10^3 = \mu' \bar{\rho} \alpha \beta \qquad \text{(6)}$$ [3]

As for the circumference s, if we take it as the circumference of a circle whose diameter is $\frac{h+d}{2}$

$$s = s' = \pi \frac{h+d}{2} \qquad \text{(7)}$$

If the cross-section is taken as an ellipse of which h is the long axis and d is the short axis, $c = \frac{h-d}{h}$ will be too small, so

$$s = s' + \Delta, \Delta = \frac{\pi h^2}{16} c^2 \qquad \text{(8)}$$

(3) Kimura, Kinosuke: The Fatness and Density of Fish. In Bulletin of the Japanese Society of Scientific Fisheries, Vol.6, No.2, pp.69-72. 1937. In this article Kimura defined the above-mentioned K as the condition factor, determined $\bar{\rho}$, W, and l for the sardine, and discussed K in detail.

In the following I will present the results of actual measurements of the various elements of the bodies of skipjack and saury.

(1) Bodily essentials of the skipjack. The measurement data are those taken by the author from 193 individuals aboard the Kaijin Maru in the Zunan-Ogasawara area on May 6-9, 1936, those taken by Mr. Gorozō Okamoto from 67 individuals aboard the Senshō Maru in the same area from May 28 to June 9 of the same year, and 8 individuals taken by trolling from the Sōyō Maru from May 3-26, 1940 and measured by the author with the aid of Mr. Takeo Maruyama, or a total of 268 individuals. If the data for all of these fish are assembled, the relationship(4) of W (gr) and l (cm) is as shown in Figure 6.

$$W = 0.205 l^{3.67} \qquad \text{.......................... (9)}$$

K is 17 - 30, and the relation between K and l is as shown in Figure 7, with a tendency for it to grow larger as l increases. From formula (9) it may be expected that $K \propto l^{0.67}$, however, if we try to find the correlation with l from the graph, it can be shown roughly by the following formula.

$$K = 0.4l + 4 \qquad \text{.......................... (10)}$$

The correlations between body height (h_2), body width (d_2), and total length (L) and l are as shown in Figure 8, and give approximately the following linear equations.

$$h_2 = 0.37l - 6 \text{ .... (11)}, \quad d_2 = 0.33l - 6.7 \text{ ... (12)}, \quad L = 1.08l \text{ .... (13)}$$

From Figure 9 the correlation between K and $\alpha\beta$ is approximately

$$K \doteqdot 387\alpha\beta + 3.2 \qquad \text{.......................... (14)}$$

The attempt was made to find $\bar{\rho}$ by submerging the fish in a vessel full of water and dividing the volume V shown by a measuring stick by W, but because there was much error in V, a value of 0.9 - 1.1 was obtained. When at equilibrium in the water, the density of the sea water being thought to be close to 1.02 - 1.03, it was assumed tentatively that $\bar{\rho} = 1$ giving $\mu \doteqdot 387$ from formula (8). The ellipticity of skipjack was $c = 0.2 - 0.3$. Using this and getting s by formula (8) gave results no different from those of formula (7), from which it was seen that it was satisfactory to consider it the circumference of a circle with a diameter of $\frac{h+d}{2}$.

(2) Bodily essentials of saury. From August 16 to September 6, 1940, aboard the Sōyō Maru while on a cruise in the coastal waters of Hokkaidō and the Kuriles the author collected at night 28 saury and, with the help of Mr. Nobuo Watanabe, measured them. On November 26 of the same year the

(4) In measuring W aboard ship a balance is more accurate than a spring scale. Some device is necessary to eliminate the effects of the swell and the engine vibration on the indicator needle. When l was measured with a roll-up tape there was an error of 0.2 cm. There is a good deal of error in measuring d so calipers should be used.

Sōyō Maru encountered a large school of saury and material from this catch was supplied by investigator Gorozō Okamoto so that the author was able to measure 60 of these fish on November 28. These results are assembled and shown in figures 10 and 11, and the following empirical formulas for saury of 14 - 39 cm body length have been obtained.

For fish of August-September and November $W = 0.00\,285\,l^{3.45}$ ......(15)
(the units here are gr for W and cm for l)
For fish of August-September $K = 0.13l + 1.6$ ......(16)

With respect to the K of the August fish (3.3 - 5.5), the K for the November fish is scattered between 3.5 and 5 and is roughly the same, but it is hard to recognize any regular correlation between K and l. The large saury with an l of 27 cm or over, in which K has a tendency to diminish regressively, are thought to be spent fish.

August-September	$h = 0.16l - 0.8$ ...(17)	November	$h = 0.13l - 0.2$ ... (17')
"	$d = 0.1\,l - 0.6$ ...(18)	"	$d = 0.07l$ .... (18')
"	$L = 1.1\,l$ ....(19)	"	$L = 1.12l$ .... (19')
"	$s = 0.4\,l - 1.7$....(20)	"	$s = 0.3l + 0.3$ ... (20')

Thus compared to the August-September saury of northern waters, those taken in late November in the southern area (near Nojimazaki) have a lesser body depth in relation to body length, and the breadth and circumference are also smaller so that it may be said that the fish are leaner, however, the ratio of body length to total length is roughly the same in both groups. Further, as shown in Figure 12

Both Aug.-Sept. and Nov. fish (leaving out two deviations)
$K = 0.23hd + 3.2$ ....(21)
Both Aug.-Sept. and Nov. fish (leaving out two deviations)
$K = 0.32s + 2.1$ ....(22)
Aug.-Sept. fish $K = 275\alpha\beta + 2.0$ ....(23)
November fish $K = 275\alpha\beta + 2.2$ ....(23')

If in formula (23) we let $\bar{\rho} \fallingdotseq 1$, then $\mu \fallingdotseq 275.$; and putting into formula (23') the $\bar{\rho} = 1.05$ derived from actual measurements, we get $\mu' \fallingdotseq 262.$*

For the correlation between l and $\alpha = h/l$ and $\beta = d/l$ in the August-September fish, $\alpha = 0.0027l + 0.073$ and $\beta = 0.002l + 0.025$ show a manner of increase with l which is scattered in the vicinity of a straight line. In the November fish, however, they appear to increase somewhat with l but the increase is not clearly marked. Also the correlation between s/h and l is not clear, and it appears to be scattered between 2.2 and 2.8 regardless of the l. The correlation between s/l and l is also obscure, however, a tendency can be detected for it to increase somewhat with l. The relationship between K and s/l can be shown as

* The actual measurement of $\bar{\rho}$ was done according to the same method used by Kimura (3) on sardines. Thanks are due to Mr. Kinosuke Kimura for much valuable advice and the loan of measuring instruments for taking this measurement.

Aug.-Sept. $K = 23.3 s/l - 3.4$ ... (24)   Nov. $K = 22.8 s/l - 2.5$ ... (24')

The oblateness c of the saury is greater than that of the skipjack, being $0.33 - 0.53$, so s can be generally shown by formula (7), but formula (8) will show it closer to the truth. If we look at the correlation of c with K and W, as shown in Figure 13, in the August and September fish there is a tendency for K to be larger as c is smaller. W, too, tends to increase, although the points are scattered, indicating that the fatter the fish are the rounder they are, however, the situation with regard to the November fish is not clear.

To summarize, in both the skipjack and the saury the condition factor K is mainly proportional to the product of α = body height/body length and β = body width/body length. It is thought that as α and β increase with the body length, the increase in the body height and the body width are proportionally greater than the increase in the body length and therefore the body of the fish becomes rounder and shows a tendency for the area of the cross-section, and consequently the volume of the body, the body weight, and K to increase. For that reason it was found that it is a practically effective method to measure s as a standard for K or $\alpha\beta$.
Finally, I wish to express my gratitude to Messrs. Gorozō Okamoto, Nobuo Watanabe, and Takeo Maruyama, who helped me with measurements or supplied data, and to the crews of the Sōyō Maru, the Kaijin Maru, and the Senkatsu Maru.

[TN: The thirteen figures illustrating this paper are scatter diagrams which cannot be traced from the microfilm projection with any degree of accuracy. They have therefore been omitted from this translation, only their descriptions being given below.

Figure 1 A scatter diagram of skipjack body temperature against water temperature for the Zunan and Ogasawara areas in May 1936 and May 1940.

Figure 2 A scatter diagram of body temperature (horizontal axis) against the difference between body temperature and water temperature (vertical axis).

Figure 3 A histogram of the frequency (vertical axis) of differences between body temperature and water temperature (horizontal axis).

Figure 4 A scatter diagram of the difference between body temperature and water temperature (vertical axis) and the water temperature (horizontal axis).

Figure 5a A scatter diagram of body temperature (vertical axis) against water temperature (horizontal axis) for 31 yellowfin tuna.

Figure 5b A scatter diagram of body temperature (vertical axis) against water temperature (horizontal axis) for 18 black marlin.

Figure 5c A scatter diagram of body temperature (vertical axis) against water temperature (horizontal axis) for 22 white-tipped shark.

Figure 5d A scatter diagram of body temperature (vertical axis) against water temperature (horizontal axis) for 108 dolphin.

Figure 6 A scatter diagram of log body weight against log body length for skipjack taken by the Kaijin Maru and Senkatsu Maru in May 1936 and the Sōyō Maru in May 1940.

Figure 7 A scatter diagram of K condition factor (vertical axis) against length in cm (horizontal axis).

Figure 8 A scatter diagram of body height (h) (left vertical axis) against body length (l) (horizontal axis) and total length (L) (inner right vertical axis) and head length (D) (outer right vertical axis).
Figure 9 A scatter diagram of condition factor (K) against $\alpha\beta$. ($h/l \cdot d/l$).
Figure 10 A scatter diagram of body weight in gr (vertical axis) against body length in cm (horizontal axis) for saury taken in November 1940 (o) and August-September 1940 (x) plotted on logarithmic graph paper.
Figure 11 A scatter diagram of body height (h), body circumference (S), body width (d), and condition factor (K) (all on the left vertical axis) against body length in cm (horizontal axis) and total length (L) in cm (right vertical axis). August-September fish are represented by a circle for h, an x for S, a circle with a dot for K, and an open triangle for d, and a circle with a dot for L. The November fish are represented by a cross for h, a circle with a dot for S, a dot for K, a filled-in triangle for d, and a dot for L.
Figure 12 Four scatter diagrams of K (vertical axes) plotted against $h_l d_l$, $S_l \alpha\beta$, and S/l.
Figure 13 Two scatter diagrams of condition factor (K) and body weight (W) plotted against the ellipticity of the cross-section (c).]

On the Weight Composition of Skipjack Schools in the Northeastern Sea Area

[English title and synopsis]

On the Composition of Shoals of "Katuo," Euthynnus vagans (Lesson), in the Northeastern Japanese Waters as Analysed by the Body-weight

Gorozô Okamoto

Based on the materials of the catch of "Katuo" landed at Kesennuma, Miyagi Pref. in 1939, which are grouped according to their dominant body-weights, an investigation was made on the composition of the fish. In Fig.2 four characteristic groups A, B, C, and D of the shoals are recognizable, which are in the ratios of 75:10:3:11 in the catch, and the increase in the body-weight of each group during the fishing-season seems to indicate the growth of the fish in the respective group. From the point of view of forecasting the yearly catch, however, more detailed and continual knowledge of the conditions such as migrations of the four groups are wanted in the future. [End of English synopsis]

In 1939 the total catch of skipjack from the Northeastern sea area, that is the waters north of a line drawn east from Nojimasaki in Chiba Prefecture and off the coasts of Tokiwa, Sanriku, and eastern Hokkaidō, amounted to 25 million fish or 56% of the total skipjack catch of the whole country. Of this 1/5 was landed at Kesennuma in Miyagi Prefecture. The present paper sets forth the results of an investigation of the sizes, based on data from radio broadcasts, of these 5 million fish landed at Kesennuma.

The number of skipjack caught at Kesennuma in the three years 1933, 1934, and 1935 was only about 2 million, but in 1936 it suddenly doubled. Succeeding years have continued to have heavy catches of 4.8 - 4.9 million fish, and this year's catch was on a level with the average of the catches of the past four years. As Figure 1 shows, the fishing grounds moved north from their position off the Bōsō provinces in the latter part of June to reach their northernmost limit about 50 miles south of Etorofu I. in the Kuriles in the last ten days of September, the fishing situation being in this respect also generally comparable to the average of the past four years.

Throughout the whole fishing season the smallest sized fish was 200 momme [1 momme = 0.1325 ounce] and the largest was 1,050 momme, large individuals of 2 - 3 kan [1 kan = 8.27 pounds], such as are taken in the Satsunan and Ogasawara areas, being completely absent.

In the last ten-day period of June when the first catches are made in this area, fish of 400 - 700 momme are taken and their mode, as shown in Figure 2, is at 450 - 500 momme. In the first and second ten-day periods of July this mode gradually advances to a heavier weight, and in the last ten-day period of July it is at 550 - 600 momme. For the sake of convenience these medium-sized skipjack are called Group A. From this time on Group B of fairly large fish of 750 - 800 momme appear in the catch. From the middle ten-day period of August on Group C consisting of small fish of 200 - 250 momme appear, and from about the first ten days of September Group D of medium-sized fish of 450 - 500 momme corresponding to the Group A of the third ten days of June appears in the catch. In all, four groups of fish of different weights can be detected. In about 100 days from the last ten days of June to the first ten days of September the fish of Group A increase in weight by 200 momme, and Group B shows a similar tendency, but after the last ten-day period of September both groups stayed within a fixed range and there was little change in weight. Thus it appears that while the schools are moving north the fish increase in weight, while after the schools turn south the gain in weight ceases. There is little gain in weight in Group C, which comes in the middle ten days of August, or in Group D, which comes in the first ten days of September, perhaps because it is already close to the time for turning southward. The proportions of each group taken throughout the whole fishing season are Group A 75%, Group B 10%, Group C 3%, and Group D 11%, which agrees with Uda's statement(1) that on the average 80% of the skipjack from the Northeastern sea area are medium-sized (500-1,000 momme).

As for the distribution of the various groups on the fishing grounds, Group A, which has moved north from the waters off Nojimasaki in the last ten days of June, is joined by Group B in the last ten days of July. In

(1) Uda, Michitaka. Bull. Jap. Soc. Sci. Fish. 7 (2), 1938.

the middle ten days of August Group C appears about 100 miles off Kinkazan, and in the first ten days of September it moves offshore and joins the mixed groups of A and B. At the same time Group D is added and from the first ten days of September to the end of the fishing season the ratio of each group in the mixed catch does not differ markedly either at the northern or southern limits of the fishing grounds, along the coast or at the offshore side, nor at the center of the grounds nor at their periphery, a nearly uniform ratio of mixture being maintained with the four groups thoroughly mixed in the northern section.

It cannot be deduced from the weight data alone whether these four different weight groups are due to differences in age or whether the migrating schools belong to different strains, but according to Aikawa[2] the skipjack schools of the Northeastern sea area are composed of a Satsunan strain and an Ogasawara strain, the former, with a condition factor of 24.0 - 24.4, making up about 80% of the total, while the latter has a condition factor of 18.0 - 18.8. Both groups are composed almost exclusively of fish in their fourth or fifth year. Another study of the skipjack of Palau waters[3] shows a range of sizes for each year class from fish of the year to those in their eighth year.

Now assuming that we are dealing with a strain of fish from the Zunan area and another from the Ogasawaras, if we reverse the formula[4] $f = \frac{w}{l^3} \times 1{,}000$ to get the body length from the weight and the condition factor, and deduce the age of each group, groups A and B, regardless of which strain they belong to, fall into the length categories of fourth-year fish for Group A and fifth-year fish for Group B. If Group C is assigned to the Satsunan strain, it is composed of second-year, and if to the Ogasawara strain, of third-year fish. Group D, whichever strain it may be assigned to, falls into the category of third-year fish. Even though groups C and D are treated as rather lean representatives of the Ogasawara strain, they cannot be regarded as fourth-year or fifth-year fish. It is considered that the four groups A, B, C, and D do not arise from differences in the strains from which they come, but rather that they show age classes.

Similar data are lacking for the southern areas outside of the Northeastern sea area and the weights of the whole catch are not clearly known, but the results of an investigation of the catches of about 50 vessels reporting on the fishing situation to the Central Fisheries Station show a weight composition for the schools like that given in Table 1. In general May and June are the peak season, and in the Zunan and Ogasawara areas a considerable catch continues to be made around July - October, the peak season in the Northeastern area, while an extremely small catch is made during the winter season of January - April and November - December.

(2) Aikawa, Hiroaki. Bull. Jap. Soc. Sci. Fish. 6 (1), 1937.

(3) Aikawa, Hiroaki. Bull. Jap. Soc. Sci. Fish. 7 (2), 1938.

(4) Kimura, Kinosuke. Bull. Jap. Soc. Sci. Fish. 6 (2), 1937.

In May and June in the waters off southern Japan, in the Zunan area, and off Nojimasaki as much as 85 - 89% of the catch is made up of medium skipjack of 350 - 550 *momme* which are thought to form the later Group A of the Northeastern area, agreeing pretty well with the weight composition of Northwestern waters, but in the Satsunan and Ogasawara areas the catch contains a mixture of all year-classes from young fish of about 250 *momme* to old fish of about 2 *kan* and over half of the catch is made up of big fish of 550 *momme* and over. During the period July - October, when the Northeastern area is having its peak season, no particular diminution in the number of medium skipjack is perceptible, and in the winter season large fish of 550 *momme* and above become markedly numerous.

It is, of course, not possible from body-weight data alone to determine the age or provenance of the schools, but it is presumed that in the waters of the Satsunan and Ogasawara islands the schools mainly composed of young fish of 350 *momme* and under and mature fish of 550 *momme* and over remain as sedentary fish, while the medium-sized fish of 350-550 *momme*, which are regarded as being of roughly the same age-class (fourth-year fish), come from somewhere to congregate off Shikoku, in the Kumano Nada, and off Zunan around May and June. These are presumed to be the fish which move north to the Northeastern sea area between July and October. It is thought that in order to forecast the skipjack fishing situation in the Northeastern sea area it is important to know not only the situation as regards the spawning and growth of the skipjack which are to form this group of medium-sized fish (fourth-year fish) but also the amount of third-year fish and the conditions which govern the migration of the fourth-year fish.

Finally I wish to express my gratitude to Dr. Uda for his guidance and encouragement and to the Kesennuma Land Radio Station for the data which was supplied me, and I hope to take in the future and in other sea areas as many fish measurements as possible.

Table 1 Weight Composition of Skipjack Schools in Southern Areas in Percentages (according to reporting vessels in 1939)

Area	Satsunan			Ogasawara			Southern Japan			Zunan			off Nojimasaki		
Weight (momme)	under 350	350-550	over 550	under 350	350-550	over 550	under 350	350-550	over 550	under 350	350-550	over 550	under 350	350-550	over 550
Jan-Apr	1.4	14.4	84.0		few			none			none			none	
May-Jun	5.5	23.2	71.3	13.8	39.2	47.0	10.4	85.5	4.0	6.4	85.8	7.8	2.8	88.6	8.6
Jul-Oct	1.7	25.3	73.0	20.3	23.4	56.3		few			few			none	
Nov-Dec	none	1.7	98.3		few			none			none			none	

[TN: 1 momme = 0.1325 ounce]

May-June is the peak season for the southern areas in general. July-October is the peak season for the northeastern sea area. In January-April and November-December there are no fish caught except in the Satsunan and Ogasawara areas.

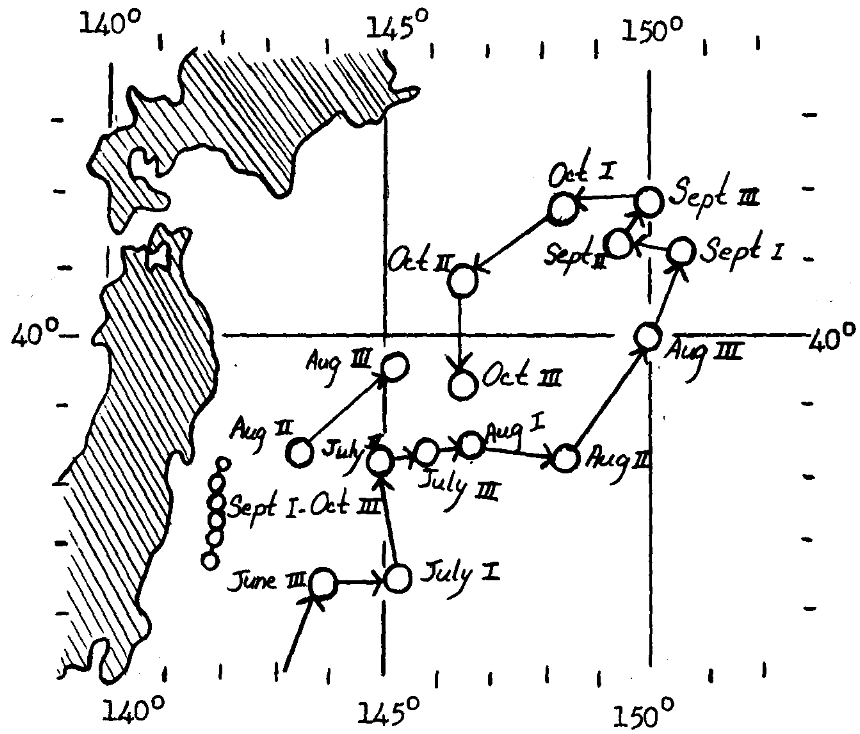

Figure 1 Movements of the center of the skipjack fishing_grounds in the Northeastern sea area in 1939. ⌊ TN:_Aug II means the second ten-day period of August.⌋

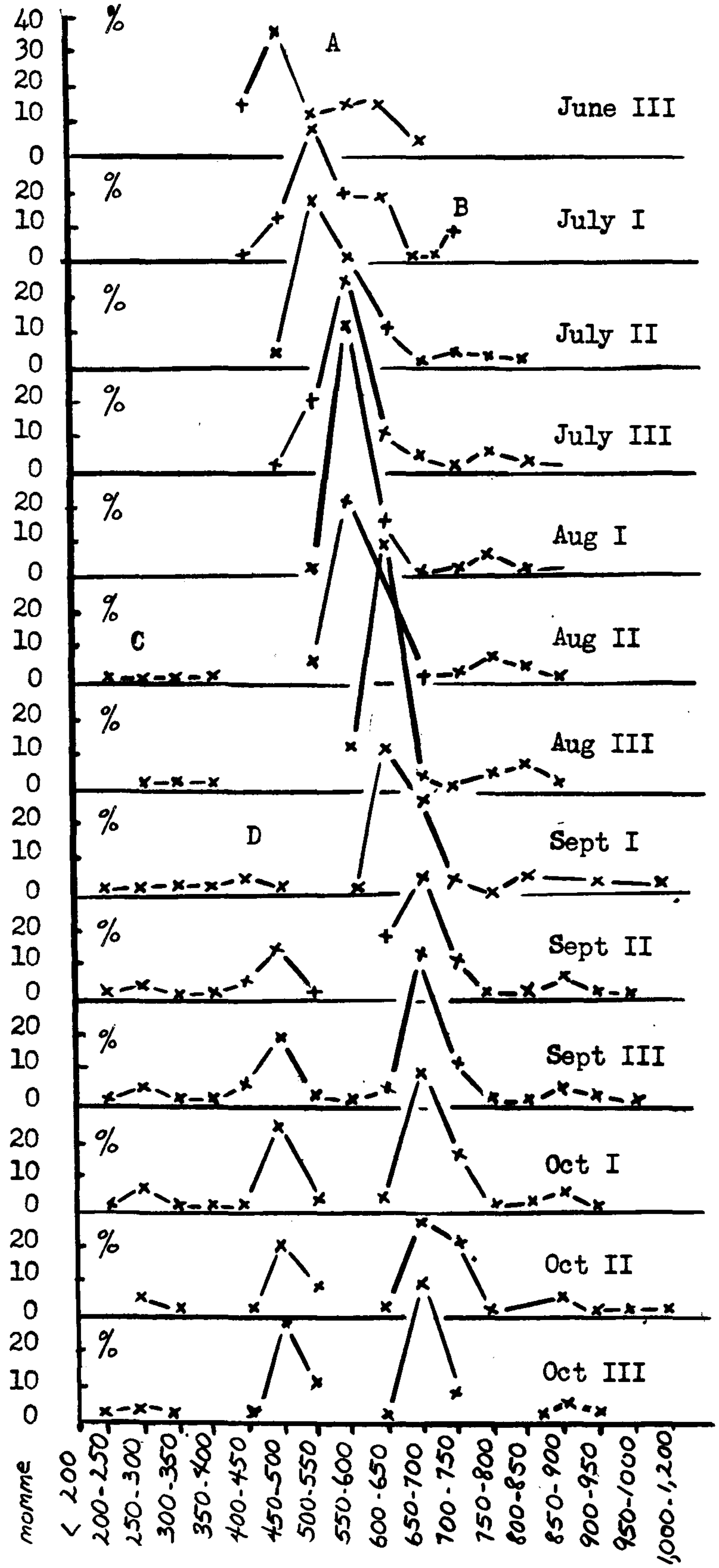

Figure 2 Weight distribution in percentages of all skipjack landed at Kesennuma in Miyagi Prefecture in 1939.