**On the Sweeping Trammel Net Fishery along the Coast
in the San'in District—VI*¹
Yearly Variation in the Population Size of Branquillos
in Wakasa Bay**

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The population size of branquillos, which was estimated from the catch statistics with sweeping trammel net, varied from 55 to 165 tons in Wakasa Bay from 1961 to 1970. To examine yearly variation in the population size, analyses were made with length and age compositions of branquillos catch in the sweeping trammel net fishery in the bay, 1961-1970.

The length and age compositions indicated that the population size was greatly dependent on the abundance of 2 and 3 years old fish (19-25 cm in length) and that there were predominant year classes such as 1958 and 1964. The survival (processes) of each year class could approximately be represented by an exponential function in a certain age range. The analyses of age compositions gave a density dependent reproduction curve of branquillos, although plots were found scattered to a certain extent. Further, it was found that a yearly variation in availability affected the estimation of fish number index, and hence survival rate, with the length composition of catch.

There appeared considerable fluctuation in catch of branquillos, *Branchiostegus japonicus japonicus*, with sweeping trammel net in Wakasa Bay. The annual catch ranged from 18 to 100 tons over the period of 1961 to 1970 as shown in Table 1. The fished population size, which was estimated from the catch statistics of the sweeping trammel net fishery, varied from 55 to 165 tons over the ten years period in the bay (Table 1).

Table 1. Annual catch of branquillos, the fished population size and the index of the population number in the sweeping trammel net fishery in Wakasa Bay from 1961 to 1970.

Year	Catch(ton)	Population size(ton)	Index of population number
1961	89.5	152	111
1962	99.5	164	124
1963	88.5	152	
1964	45.5	90	61
1965	18.1	55	34
1966	29.6	81	112
1967	83.6	160	170
1968	51.0	114	82
1969	29.5	75	
1970	41.9	92	110

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A comparison between the annual catch and the population size generally tells that their yearly variations correspond to each other to a great extent. This may suggest that the annual catch is dependent chiefly on the fished population size in the branquillos fishery of sweeping trammel net in Wakasa Bay though it is affected by such various factors as fishing effort and availability etc.

In the present paper, analyses are made on yearly variation in the fished population size of branquillos in Wakasa Bay using the data concerning this fishery. Further, this paper shows the characteristics of the variation in the population size.

Materials and Methods

The present paper employed the data on the commercial fishery of branquillos with sweeping trammel net in Wakasa Bay in summer, 1961–1970. Fukui Prefecture has systematically recorded the commercial catch statistics of this fishery, which contain the daily catch for size categories in market by every boat, since 1961, the year of its license. Analyses were made with the fished population size which was estimated from the decrease in the daily catch per boat-day over the period of 1961 to 1970. The values of the population size are those which were obtained in the previous paper¹⁾ for 1961–1965 and ones for 1966–1970 were estimated by the same method (Table 1).

This paper employed the length compositions of the commercial catch with the gear in the bay in the period of 1961, 1962, 1964–1968 and 1970. The mesh selectivity curve used here is one determined in the preceding paper.²⁾

In order to compare quantitatively the annual length compositions among years, an index N' of the population number was estimated from the length composition and the population size P (in tons) by the following method. Since fish size measurements show body weight to be nearly proportional to the cube of length, N' can be represented by

$$N' = 10^6 P / \sum l_i^3 F_i, \quad (1)$$

where F_i refers to relative number of fish of length l_i in the population in percentage. Consequently, we can obtain as an index N'_i of the fish number at length l_i

$$N'_i = F_i N' / 100. \quad (2)$$

Age compositions were estimated by analysing the length compositions into each components using TANAKA's³⁾ and CASSIE's⁴⁾ methods. To examine the methods used here, a comparison was made between the results obtained by the above methods and age determination, using the data concerning the commercial catch of branquillos with sweeping trammel net off Hamada, Shimane, in July of 1966 and in August of 1967.

An index E of egg number was calculated by the following method. Maximum gonad weight indices of branquillos for each length are almost constant for length below 16 cm and increase sharply over the length range of 16 to 24 cm, and then remain con-

stant for length above 24 cm.⁵⁾ FUNADA⁵⁾ discussed that some of 1 year old fish could also spawn. For these reasons, all fish above 20 cm in length may be supposed to spawn. As the sweeping trammel net fishery is carried out in summer and branquillos spawn chiefly in autumn in Wakasa Bay, the fish which has not been fished contributes to the reproduction if natural mortality is neglected in the period between fishing and spawning seasons. Under these conditions, denoting gonad weight index and body weight at length l_i by G_i and W_i , respectively, E can be given as follows:

$$E = \sum G_i W_i N'_i (1 - f_i) \times 10^{-1}, \quad (3)$$

where f_i refers to exploitation rate for fish of length l_i . The relation of G_i to l_i and the values of f_i used here are ones obtained by FUNADA⁵⁾ and in the preceding paper⁶⁾, respectively. The values of E for 1960 and 1963 were computed using the length compositions for 1961 and 1964 instead of the term $N'_i (1 - f_i)$ in Eq. (3), respectively.

Results

A Relation of Population Size to Length Composition Table 1 shows the fished population size obtained from the decrease in catch per boat-day in Wakasa Bay from 1961 to 1970 and it ranged from 55 to 160 tons. Four good years of 1961, 1962, 1963 and 1967 and two poor years of 1955 and 1969 were observed and the general trend seemed to fluctuate periodically. Fig. 1 gives the annual length compositions of the commercial catch corrected by the mesh selectivity curve in percentage for 1961, 1962, 1964–1968 and 1970. The length compositions in Fig. 1 show a gradual decrease in larger fish with years. As seen from this figure, in 1966, fish below 18 cm in length were relatively abundant in the catch and, on the other hand, the catch in 1968 was dependent chiefly on fish of 20–29 cm in length.

An attempt was made to examine a relation of the population size to the length composition. The annual length compositions given in Fig. 1 can not be compared quantitatively with years each other because the population size changes year to year as mentioned above. In order to compare quantitatively the annual length compositions among years, therefore, the index N' of the population number was estimated from the length composition and the population size by Eq. (1) and the estimated values of N' are given in Table 1. Fig. 2 presents the annual length compositions of the population calculated from the length compositions in Fig. 1 and N' in Table 1 according to Eq. (2). A comparison between the length composition and the population size, generally, tells that, when 19–25 cm length class, or 2 and 3 years old fish classes, are greater, the population size is bigger and *vice versa*, and that proportion of larger fish decreases with years. In 1961, 1962 and 1967 the population sizes were relatively bigger owing to the abundance of 19–25 cm length class and in 1965 and 1966 the population shrank with the decrease

Fig. 1. Annual length compositions of branquillos in the sweeping trammel net fishery in Wakasa Bay over the period of 1961, 1962, 1964–1968 and 1970. The data are corrected by the mesh selectivity curve.

Fig. 2. Annual length compositions of branquillos calculated by Eq. (2) in Wakasa Bay over the period of 1961, 1962, 1964–1968 and 1970.

of 19–25 cm length class. After a few years since the licensing of the fishery, especially, the population was greatly dependent on fish of 19–25 cm in length because of large fish being poor, and hence, the population size varied markedly from year to year. This shows that the population size is pronouncedly influenced by the occurrences of the predominant year classes, especially, in the years when the relatively intensive fishery has been carried out.

A Relation between the Yearly Variation in Population Size and Age Composition

Next, an analysis was made with age compositions of the population to clarify the yearly variation in more detail. The results obtained by CASSIE's method were compared with ones by age determination to test the reliability of the methods used here, using the data on the commercial catch of branquillos with sweeping trammel net off Hamada, Shimane Prefecture, in July of 1966 and in August of 1967. Table 2 gives age composi-

Table 2. Age compositions (%) obtained by CASSIE's method and age determination with scale using the data on the commercial catch of branquillos with sweeping trammel net off Hamada, Shimane Pref., 1966 and 1967.

Age class	1966		1967	
	CASSIE's method	Age determination	CASSIE's method	Age determination
I	10	8.5		
II	85	84.6	73	75.4
III	0	1.1	12	9.4
IV	3.5	3.4	14.5	14.4
≥V	1.5	1.4	0.5	0.5

Table 3. Age compositions F_t (%), modal lengths $\bar{l}$ (cm) and standard deviations σ (cm) of age classes estimated from the length compositions of branquillos catch in the sweeping trammel net fishery in Wakawa Bay.

Age class		I	II	III	IV	V	VI
1961	F_t	3.9	40.0	40.0	15.5	0.6	
	$\bar{l}$		19.2	24.4	30.8		
	σ		1.6	1.7	1.2		
1962	F_t	9.4	50.0	32.0	3.2	4.7	0.7
	$\bar{l}$		21.1	25.0	29.4	33.2	
	σ		1.4	1.6	1.4	1.2	
1964	F_t	1.5	62.0	19.0	14.5	2.7	0.3
	$\bar{l}$		21.7	25.7	29.8	33.4	
	σ		1.6	1.5	1.3	1.2	
1965	F_t		20.0	54.0	18.0	7.0	1.0
	$\bar{l}$		21.1	24.6	30.0	32.3	
	σ		1.3	1.5	1.2	0.8	
1966	F_t	65.0	20.0	9.5	3.5	2.0	
	$\bar{l}$	15.9	19.6	24.4	29.5	31.7	
	σ	1.0	1.3	1.5	1.3	1.1	
1967	F_t		72.8	24.0	1.9	1.0	0.3
	$\bar{l}$		19.9	23.2	27.0		
	σ		1.1	1.2	1.2		
1968	F_t		10.0	55.0	31.0	4.0	
	$\bar{l}$		20.5	22.5	26.9	31.2	
	σ		1.3	1.2	1.3	1.0	
1970	F_t	40.0	33.0	20.0	4.5	2.5	
	$\bar{l}$	15.0	20.4	22.6	26.8	31.2	
	σ	0.9	1.4	1.3	1.5	1.0	

tions estimated by the respective methods in percentage and shows considerable agreement with each other. Accordingly this may support that age compositions can be estimated by analysing the length compositions into each component using CASSIE's method.

Table 3 gives age compositions F_t , modal lengths $\bar{l}$ and standard deviations σ

Fig. 3. The estimated modal lengths of each age class plotted against age, the curve showing the growth of branquillos determined with scales.

estimated for 1961, 1962, 1964–1968 and 1970.

The estimated standard deviation ranges from 0.8 to 1.7. The modal lengths are plotted against age in Fig. 3, which shows the growth curve of the species determined with scales* as well. As seen in Fig. 3, the modal lengths show a good agreement with the curve.

The above mentions seem to support the analysis of the length compositions into age classes to some extent.

An index N'_t of fish number of age t is defined as the product of relative fish number of age t in Table 3 and N' in Table 1 for a given year to compare the annual age compositions with years. For 1961, 1962, 1964–1968 and 1970, the indices of the abundance of age classes are given in Fig. 4. The indices in Fig. 4 increase with age and reach a peak at 2 or 3 years old, and then decrease as age increases. There is yearly variation in age when the indices of year classes reach a peak. This may be considered to be ascribable to the availability, which seems to vary with the abundance of age classes, in relation to fish size as discussed later.

A relation between yearly variations in age compositions and the population sizes shows a trend similar to the results in the last section, that is, the population sizes were big in 1961, 1962 and 1967 when 2 and 3 years old fish were abundant and it was small in 1965 and 1966 when they were poor. It is seen from this fact that the population size is dependent greatly on the abundances of 2 and 3 years old fish.

Fig. 4. Annual age compositions of branquillos in Wakasa Bay over the period of 1961, 1962, 1964–1968 and 1970.

* Unpublished.

As seen from Fig. 4, there appeared a pronounced variation in year class sizes, for example, the indices of fish number at 3 years old ranged from 11 to 45. A trend of the age classes in Fig. 4 showed that there occurred predominant year classes such as ones of 1958 and 1964. Accordingly, the occurrence of predominant year classes can be regarded as one of main factors affecting the yearly variation in the population size and it is necessary to predict the abundance of year class for managing the population.

Survival Process in the Exploited Phase In order to verify the survival process in the exploited phase, the plot of $\log N'_t$ against the year corresponding to age is made for every year class from 1957 to 1966 in Fig. 5. Generally, the plots for each year class

Fig. 5. $\log N'_t$ plotted against year corresponding to age, marks showing year classes.

increase sharply with age and reach a peak at 2 or 3 years old, and then decrease linearly as age increases with the exception of 1963, 1965 and 1966 year classes although they scatter more or less. It is seen from Fig. 5 that the slopes of the straight line are nearly equal to each other in the year classes of 1957 and 1958 and are also nearly equal to one another in ones of 1959 to 1964. This fact shows that the survival processes can be approximately represented by an exponential function in a certain range of age. The difference of the slopes may be supposed to be due chiefly to fishing effort.

The survival rates for more than 3 years old fish were calculated from the abundance indices in Fig. 4 by LEA's method. Table 4 shows the estimated survival rates and fishing effort (in boat-day) every year. Unfortunately, as we had no data on the length compositions of the commercial catch for 1963 and 1969, we could not obtain the survival rates for 1962, 1963, 1968 and 1969 by the above method directly. For these years, the rates were given as the square root of the one during two successive years under the

Table 4. Survival rates of more than 3 years old fish and fishing effort every year.

Year	Survival rate	Fishing effort (boat-day)
1961	0.17	3020
1962-1963*	0.19	2878
1964	0.40	2370
1965	0.22	1151
1966	0.32	1456
1967	0.60	2062
1968-1969*	0.20	1777

* The values of 1962-1963 and 1968-1969 are given as the mean over two successive years.

Fig. 6. Logarithm of survival rates plotted against fishing effort.

assumption that natural mortality was constant. The survival rates in Table 4 ranged from 0.17 to 0.60. Logarithms of the rates are plotted against fishing effort in Fig. 6 to examine a relation of the rate to effort. The plot in Fig. 6 is likely not to show any relation between the rate and effort.

A Relation of Parent to Progeny

An analysis was made on a relation between parent and progeny to clarify the characteristics of the variation in year class size which affected the population size pronouncedly as mentioned previously. On the basis of the results obtained in the last section, an index N'_2 of progeny was estimated by extrapolating the line of each year class into the year corresponding to 2 years old in Fig. 5. Table 5 gives the values of N'_2 determined thus for the year classes of 1960 to 1962 and 1964 and the indices E of egg number estimated by Eq. (3) from 1960 to 1966. For the year classes of 1963, 1965 and 1966, however, the indices N'_2 of progeny were calculated from N'_3 or N'_4 of the respective year classes using the survival rates estimated for they could not be estimated by the above method. In Table 5, are given the values of N'_2 estimated thus for the year classes of 1963, 1965 and 1966.

Under the assumption that branquillos recruits into the exploited phase in the same area as spawning population, N'_2 is plotted for E in Fig. 7, in which a dotted curve is drawn with eyes. It seems that the plot in Fig. 7 increases with increasing of E and reaches a peak for E of about 30, and then decreases gradually as E increases although it scatters more or less. This indicates that the rate of increase in adult is reduced as the number of egg increases and hence suggests that there exist some factors dependent

Table 5. The index N_2' of 2 years old fish number of year classes and the index E of egg number every year from 1960 to 1966.

Year	N_2'	E
1960	72	46
1961	56	44
1962	36	46
1963	128	28
1964	135	31
1965	125	28
1966	110	19

on density over the developing stages of egg to adult. Unfortunately, however, we have no information on the factors dependent on density.

$\log(N_2'/E)$ is plotted against E after RICKER's⁷⁾ reproduction curve in Fig. 8, which shows a good regression line with the slope of -0.030 through 1.45 for $E=0$ and gives the correlation coefficient -0.939 ($|t|=6.11$, degree of freedom: 5). If the plot in Fig. 8 is represented by RICKER's reproduction curve,

$$N_2' = 28.3E \exp(-0.0690E). \quad (4)$$

The theoretical curve calculated by Eq. (4) is shown by solid line in Fig. 7 and is different to some extent from one shown by the dotted line. As seen from Fig. 7, it is not evident whether the plot follows RICKER's curve, but it is likely that N_2' has a maximum value for E of 15–40. Some deviation may suggest the other factors, such as abio- and bioenvironmental conditions, except the population density.

Fig. 7. N_2' plotted against E . The dotted curve is an eye estimation and the solid curve is computed by RICKER's model.

Fig. 8. N_2'/E plotted against E .

Discussion

To examine yearly variation in the fished population size, analyses were made with length and age compositions of branquillos catch in the sweeping trammel net fishery. The length and age compositions indicated that the population size was dependent greatly on the abundances of 2 and 3 years old fish (19–25 cm in length) and that there occurred predominant year classes such as 1958 and 1964 year classes. Further, the analyses of age compositions gave a density dependent reproduction curve of branquillos although the plot scattered more or less. Many investigators^{8–10)} reported that the fluctuations in fish populations consisting of several age classes were ascribable to the occurrences of predominant year classes, and that they gave usually good catches. Especially, HJORT⁸⁾ put emphasis on the need of the investigations on vital statistics for analysing fluctuations in herring and cod catches of Norway.

Theoretical studies have been made on a relation between numbers of parent and progeny by several fisheries biologists,^{7,11–13)}. RICKER⁷⁾ discussed a theoretical reproduction curve and showed the examples of the obtained data about fishes such as pink salmon, *Oncorhynchus gorbuscha*, coho salmon, *Oncorhynchus kisutch*, and sockeye salmon, *Oncorhynchus nerka*, etc. BEVERTON and HOLT¹¹⁾, and TANAKA¹²⁾ dealt with a relation of progeny to parent, proposing another reproduction curve, respectively. Some fisheries biologists reported that RICKER's model held for the data on some henthic fishes, yellow croaker, *Pseudociaena polyactis*¹⁴⁾, lizard-fish, *Saurida tumbil*¹⁵⁾, in the East China Sea and red sea bream snapper, *Pagrus major*¹⁶⁾, in the Yellow Sea. There were the reports in which RICKER's model was approximated for the fish populations which inhabited lakes or rivers during all or early stages of their life span, for example, isaza, *Chaenogokius isaza*^{17)*}, in Lake Biwa and pink salmon of the Karlak River, Alaska.

FUNADA⁵⁾ reported that branquillos spawned chiefly in September and October and that egg number estimated from gonad ranged from 12×10^4 to 22×10^4 for fish of 20–23 cm in length. According to OKIYAMA¹⁸⁾, the species of 1.78–13.2 mm and 28.4–34.8 mm in total length were collected from the middle layer of 10–50 m in depth and from the bottom of 54 m in depth, respectively. He discussed also that the species might make little migration after the change of the habitat from pelagic to benthic.

These facts may suggest the possibility that there is the density dependent reproduction curve of branquillos in Wakasa Bay. If the relation between parent and progeny sizes is the effect of density dependence, it may naturally considered that there appears apparently a periodic trend of the variation in the population size as shown above for it is greatly affected by the abundance of 1 and 2 years old fish. For the fishery regula-

* The relation between numbers of 0₊ and 1₊ age groups was approximated by RICKER's reproduction curve.

tion, therefore, it is important that the parent population size is optimum for sustaining the great recruitment. However, there is no information on the mechanism of the density dependent reproduction and on the recruitment into the exploited phase from spawned egg. To clarify these problems, it is necessary to carry out the ecological research about the development stages from egg to adult over a long period.

There appeared some vagueness in the above results, for example, the yearly variation in the ages when the index of fish abundance reaches a peak, and the relation of survival rate to fishing effort etc. The preceding paper⁶⁾ treated daily changes in size category composition of the catch taken by fishermen belonging to Hiruga Fishermen's Union in August, 1962, and showed that the fishing became intensive on fish of small size (200–400 g) as the informations on the fished population were cumulated through the daily operations. This result may support the presence of a yearly variation in availability to the fished population with relation to the abundance of year classes, and may suggest that there is some difference in habitat areas among fish sizes. For the reasons mentioned above, the yearly variation in availability is regarded as one of the main factors affecting the estimation of the fish number index, and hence the survival rate, with length compositions of the catch. In order to obtain the informations without bias through the commercial catch as much as possible, it is necessary to collect the data on statistics and length compositions of the commercial catch for sub-areas into which fishing area is divided.

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