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POLYMORPHISM OF LIFE FORM IN MASU SALMON (*ONCORHYNCHUS MASOU*) IN THE RIVERS OF SOUTHERN SANRIKU DISTRICT, HONSHU, JAPAN

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Katsuhiro Kiso (1990) Polymorphism of life form in masu salmon (*Oncorhynchus masou*) in the rivers of southern Sanriku district, Honshu, Japan. *Bull. Inst. Zool., Academia Sinica* 29 (3, Supplement): 27-39. Masu salmon were collected in the rivers of southern Sanriku district (Pacific side of the northern Honshu). They were classified in each phases by morphological characters, and the gonadal growth and body growth were investigated. Fluviatile form and sea-run form of both sexes were appeared in the same river population. Sixty per cent of males came to mature in the first autumn and they became fluviatile form. The first maturation of other male usually occur in the second autumn and become fluviatile form. A few males became smolts and run into the sea in the second spring. Females were divided into two groups after first autumn. One was the group that their ovaries sift sequentially yolk vesicle stage and oil drop stage. Most individuals matured in the second autumn and became fluviatile form. The other was the group that their ovaries stay late perinucleolus stage. Most individuals become smolt and run into the sea in the second spring. A few individuals stay small parr until second spring. In comparison of the growth patterns between fluviatile male and that of female, the initial growth of male was faster than that of female, and the growth of male stop earlier than that of female. Of the two forms of female, the growth rate of fluviatile form was larger in summer and smaller in winter than that of sea-run form. It seems that those differentiation between two forms of both sexes are caused by the differences of amplitude in the growth rates and the speeds of gonadal growth.

Key words: Gonad, Growth, Life from, Masu salmon, Phase

The area of distribution of masu salmon *Oncorhynchus masou* including 4 subspecies, is occupied from southwestern Kamchatka Penisula to Taiwan (Araga, 1984; Behnke *et al.*, 1962; Machidori and Kato, 1984; Oshima, 1957; Tanaka, 1965).

Masu salmon has three life forms. One is lacstrine form which spawns in the river and growth in the lake. Another is fluviatile form which lives in the river whole their life. The other is sea-run form which spawns in the river and grow up in the sea after one or two years of river life. The lacstrine form appears in the natural lakes such as the Lake Biwa or Lake Tohya and artificial lakes such as Lake Shumarinai (Ohno and Ando, 1932;

Osanai, 1982; Oshima 1957). In north-eastern Honshu or more northern area, both the fluviatile and sea-run form are appeared in the same river population. In southern or western Honshu, only fluviatile form is appeared, however sea-run form of the subspecies *O. masou macrostomus*, known as Amago, is appeared in Ise bay or Seto inland sea (Kato, 1975) and very few smolt of *O. masou masou* was caught in the coastal waters of western Kyushu (Dotsu, 1977; Kimura and Tsukahara, 1969).

In the rivers of Hokkaido, Sakhalin, Kamchatka and Primore where are the center of distribution of this species, fluviatile form is known to be consisted of male mostly, and female to be very rare. The ratio of the male in the sea-run form is 30 to 40 percent (Machidori and Kato, 1984; Krykhtin, 1962; Sano, 1968; Semko, 1956; Tsygir and Ivankov, 1987). In the rivers of the Sanriku district (especially southern part) of Honshu, fluviatile form of female could be observed more frequently, and the number of sea-run form in male was few, compared with the northern populations. The ratio of the male in the sea-run form was 6 to 15 percent (Kisco 1986; Miyazawa *et al.*, 1986).

In this study, the differentiation of two forms in both the sexes in southern Sanriku district is shown and discussed with their gonadal growth and the body growth.

MATERIALS AND METHODS

The materials used in this study were totally 342 specimens, consisting of 301 specimens caught in the Oh river system with angling, cast net, fish spear and spoon net during the period from February 1985 to May 1989, and other 41 specimens were caught in the Kitakami river system, the Koizumi river, the Mizushiri river and the Isatomae river with tow nets, angling, gill net and cast net during the period from April 1984 to April 1987. The locations of these rivers were shown in Fig. 1.

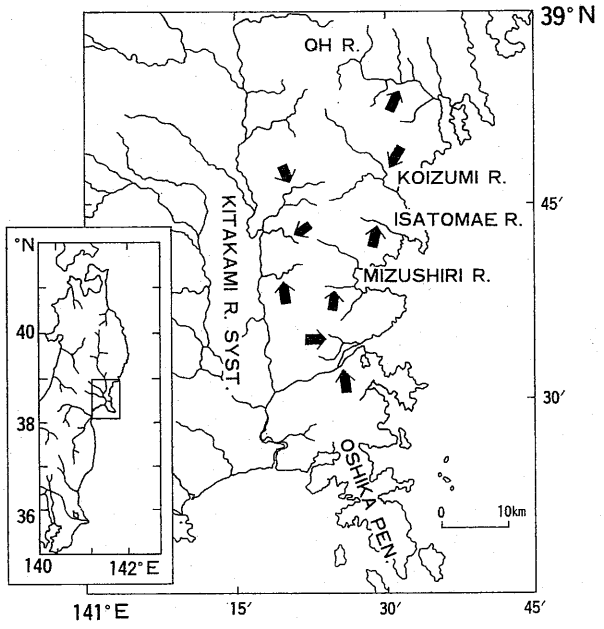

Fig. 1. Map showing the northern Honshu and the location of the rivers where sample collection was made.

All the samples were classified to each phase by their size, coloration and body shape according to the Kubo (1974)'s standards. All the samples except anadromous adults were fixed in 10 percent formalin solution. They were checked sex and measured fork length, body weight and gonad weight in the laboratory.

Ten to fifteen scales were sampled from the fish and were rinsed in 3 percent KOH solution, and stained with alizarin red S, for microscopic examination. The distance from the focus to margical edge,

annulus, and spawning mark were measured. The number of annuli, spawning marks and circuli between each annulus were counted.

Ovaries from the samples collected in the Oh river were fixed in Bouin's solution and used for preparation of cross sections. The histological observations of the samples stained with hematoxylin an and eosin or Bauer-Feulgen's method were carried out. The oocytes were staged after the classification of Yamamoto *et al.* (1959).

The growth patterns were investigated with the following methods; (1) comparison of the sizes between parr and smolt at downstream migration season, (2) comparison of sizes at formations of the first annulus by their scale pattern and the equation between scale radius and fork length, (3) fitting of the growth model. Using data was consisted the individuals caught in four rivers during the period from 1984 to 1987 supplemented with individuals reared artificially in embryo and alvin stage. Age determinations were carried out by scale reading with Kato (1984). The von Bertalanffy's growth model expanded by periodic function (Akamine, 1986) is used for fitting to their growth, because it is known that the growth of fluviatile Amago have cycles as one year (Shiraishi, 1958). Parameters of the growth model were calculated by Marquardt's method of nonlinear optimization from monthly change of mean fork length and their standard deviation of each age group by two sexes. The peak of spawning of masu salmon is usually observed in October in rivers of Honshu (Machidori and Kato, 1984). Then, October 1st was taken as the origin of the growth.

RESULTS AND DISCUSSION

Occurrence of each phase

The phases in all the samples caught in the Oh river system during the period from February 1985 to May 1989 were classified by Kubo (1974)'s standard. Seasonal changes of occurrence of those phases in each sex by age group are shown in Tables 1 and 2.

Male: From 7 to 9 months of age (May to June), all the fishes consist of small parr. In 10 months of age (August), some of them appear nuptial coloration. In 11 and 12 months (September and October), they are divided into two groups, dark parr which has nuptial coloration, and small parr in which nuptial coloration is not fully developed. It is known that fluviatile form of masu salmon don't die after first reproduction, and can mature two or three years (Kosaka 1971; Oshima 1957). A few one year old smolts and pseudo smolts are collected next spring. From 16 to 18 months of age (next February to April), the individuals, that were seemed to mature in first autumn on the basis of the occurrence of spawning mark (Ouchi et al., 1972), lose the nuptial coloration and turn to yellow parr. From 19 to 21 months of age (May to August), most of them consists of yellow parr. And in 22 months, the nuptial coloration are appeared again on their body.

The oldest fluviatile male so far collected was 36 months (just three years old). The fork length of the largest specimen was 23.2cm.

Female: Until 12 months (October), all of them consist of small parr, and it is impossible to distinguished sea-run form from fluviatile form by body shape or

Table 1. Seasonal changes of occurrence of phase in male masu salmon collected in the Oh river by age during the period from 1985 to 1989.

	Age in year after spawned																							
	0								1								2 and 3 (parenthesized)							
	Calendar month																							
	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
Small parr	1	2	2	11	9						-																		
Yellow parr						2	3	1		3	11	18	14	1	1	3						1	1			1			
Dark parr			1		11	8				2		4	1					1(2)	1			1	2						
Silvery parr																													
Pre-smolt											1																		
Mid-smolt																													
Post-smolt											1																		
Pseudo-smolt											2	1																	
Regressive smolt													2																

Table 2. Seasonal changes of occurrence of phase in female masu salmon collected in the Oh river by age during the period from 1985 to 1989.

	Age in year after spawned																							
	0					1											2 and 3 (parenthesized)							
	Calendar month																							
	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
Small parr	1		2	9	9	10		1			1																		
Yellow parr						4	1		2	7	21	13	5		1	1						2	1		1				
Dark parr																		(1)	1			(1)	1						
Silvery parr						2	5	1																					
Pre-smolt						4			4	7																			
Mid-smolt									1	2	19	2										2							
Post-smolt											15	15	1																
Pseudo-smolt						1					3		1	1															
Regressive smolt												2																	

coloration. In 13 months they can be classified into three groups. One is silvery parr that most of them become sea-run form. Another is yellow parr that they become fluviatile form. The other is small parr which is slowly grown. The parr-smolt transformation is occurred during the period from February to April mainly, however a few smolts are collected in the coastal waters in December (Kiso 1988). Most of smolts are one year old and the others are two years old. The body height and the body width of yellow parr in spring are larger than that of smolt. In May, few smolts stay in the river. Pseudo smolts and smolts which do not show the downstream migration become large size. In the second autumn, fluviatile form female appears nuptial coloration. The nuptial coloration remains until next spring aftrer spawning. The oldest fluviatile form female collected was 44 months. The fork length of the largest specimen was 28.4 cm.

The upstream migration adult in sea-run form is occurred during the period from February to July and in early autumn after one year marine life (Kiso and Kasahara in press).

Gonadal growth

Male: Seasonal changes of gonad weight in males caught in the Oh river are shown in Fig. 2. After the first August, it is possible to distinguish the individuals which will mature in the first autumn from individuals which will not reach to mature in the year, by the differences of gonad weight. Almost 60 percent individuals of 0-age male came to mature in the first autumn.

In the spring of one year old, most of gonad weights showed small value as less than 0.15g, however a few of them showed as more than 0.5g. The gonad weights of smolt showed small values as 0.05g. Most of gonad weights of the individuals having spawning mark or remaining nuptial coloration, which had been matured last autumn, showed small value.

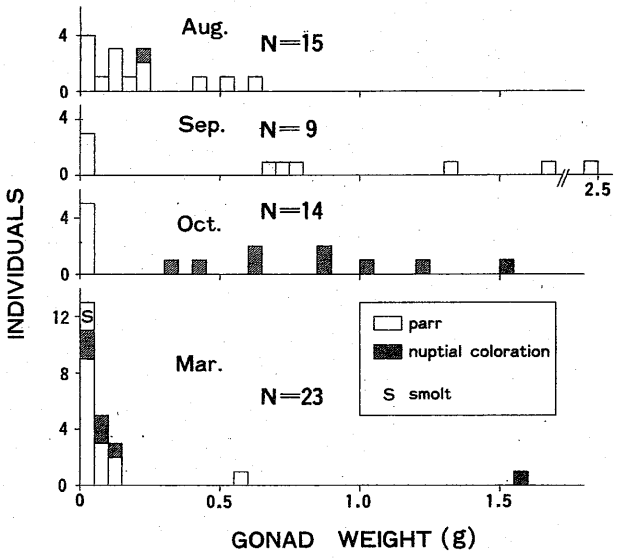

Fig. 2. Seasonal changes of gonad weight in male caught from the Oh river.

Female: Seasonal changes of developmental stages in ovary of masu salmon caught in the Oh river system were shown in Table 3. No females matured in the first autumn. After first autumn, they can be separated to two groups. One is the group that their ovaries sift sequentially yolk vesicle stage and oil drop stage. The other is the group that their ovaries remain late peri-nucleolus stage. All of the former became yellow parr (fluviatile form). Most of the latter became smolt (sea-run form). A few of the latter remained small parr.

Gonad weights of both parr and smolt in the downstream migration season are

Table 3. Number of ovaries of collected masu salmon in the rivers in each stage during the period from 9 to 22 months of age. The stage of ovaries indicates by most abundant stage of oocytes in volume in their ovaries.

Stage	Calendar month													
	J	A	S	O	N	D	J	F	M	A	M	J	J	A
Early peri-nucleolus stage	1	3												
Late peri-nucleolus stage			3	6	6	1	1	1	17	17				
Yolk vesicle stage				7	3	1	2	6	10	3	1			
Oil drop stage									3	9	4	1		
Prime yolk globule stage													1	
Secondary yolk globle stage														1

shown in Fig. 3. The gonad weights of smolt were less than 0.09g and that of yellow parrs were more than 0.1g. The gonad weights of smolts are lighter than that of parrs except small parrs.

In the ovaries of over two years old female of fluviatile form, empty folicles and young oocytes were observed (Kiso and Kosaka unpublished observation), and these had one or two spawning mark(s). This result indicates that fluviatile form female spawn two or three times. On the other hand, sea-run form female can be spawn only once, because all anadromous adults have few young oocytes and they are estimated to stay in the sea only one year by scale readings (Kiso and Kasahara in press).

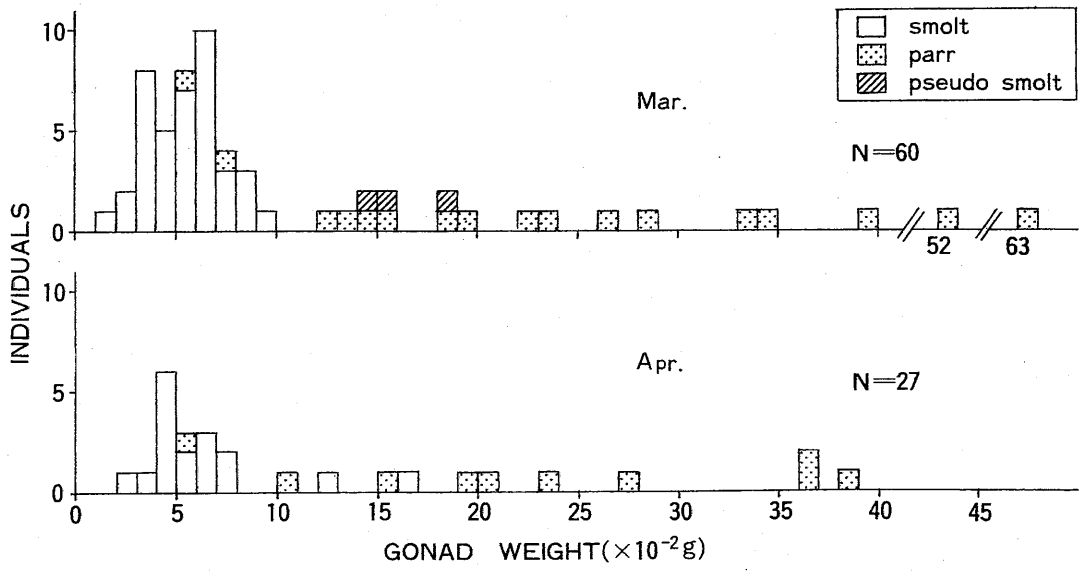

Fig. 3. Gonad weight of sea-run form and fluviatile form of female caught in the Oh river at their downstream migration season.

Body growth

Sizes of two forms during downstream migration and at formation of first annulus: Fork lengths of each phase during downstream migration are shown in Fig. 4. Mean fork length of female fluviatile form is the largest of all. And those of smolt and pseudo smolt are smaller than that of parr.

The sizes at formation of first annulus calculated with the equation between scale length and fork length is shown in Fig. 5. The formation of first annulus on the scale of masu salmon in the rivers of this district occurred in October mainly (Kiso unpublished observation). The sizes in parr of both sexes were larger than that of smolt and pseudo smolt.

Growth curves of fluviatile form: The von Bertalanffy's growth model expanded by periodic function (Akamine, 1986) is expressed as following equation

$$l_t = l\infty\ (1-exp(-K((1+a)(t-t_0)/2+(1-a)(sin2\pi(t-t_1)-sin2\pi(t_0-t_1))/4\pi)))$$

where l_t is the estimated fork length (cm) at age t, $l\infty$ is the asymptotic length, K is the growth coefficient, t_0 is the hypothetical age when length would be zero, both t_1 and a are the parameters

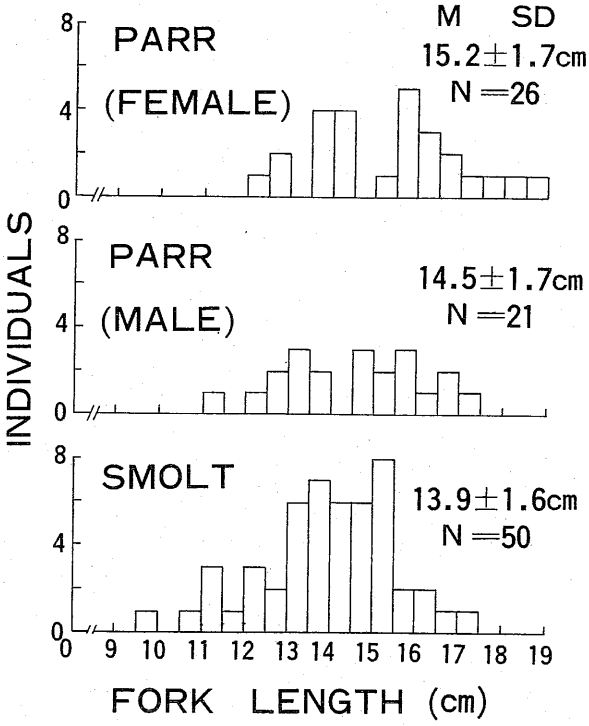

Fig. 4. Frequency distribution of the fork length of masu salmon in downstream migration season.

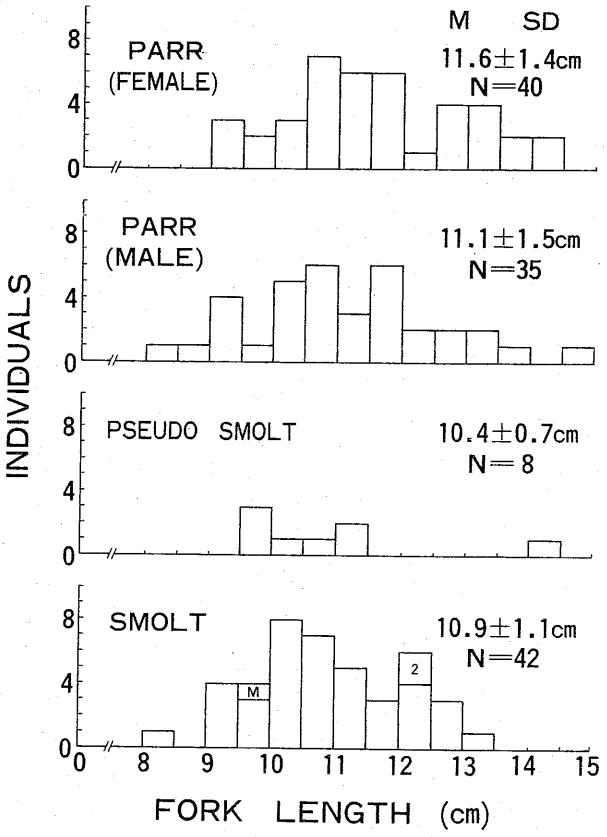

Fig. 5. Frequency distribution of estimated fork length of masu salmon at formation of first annulus on their scales. The fork length is estimated by following equation (Kiso unpublished):

$FL = 3.99+0.0181R$, where FL is fork length (cm), R is scale radius (μm).

Numeral "2 ' means age-2 smolt, and abbreviation "M" means male smolt.

determined phase (topology) and amplitude of growth rate, and t is the age (years).

The fork length growth curves of fluviatile form and the values of parameter and per capita growth rate (Bertalanffy's K: indicated as K_B) are shown in Fig. 6.

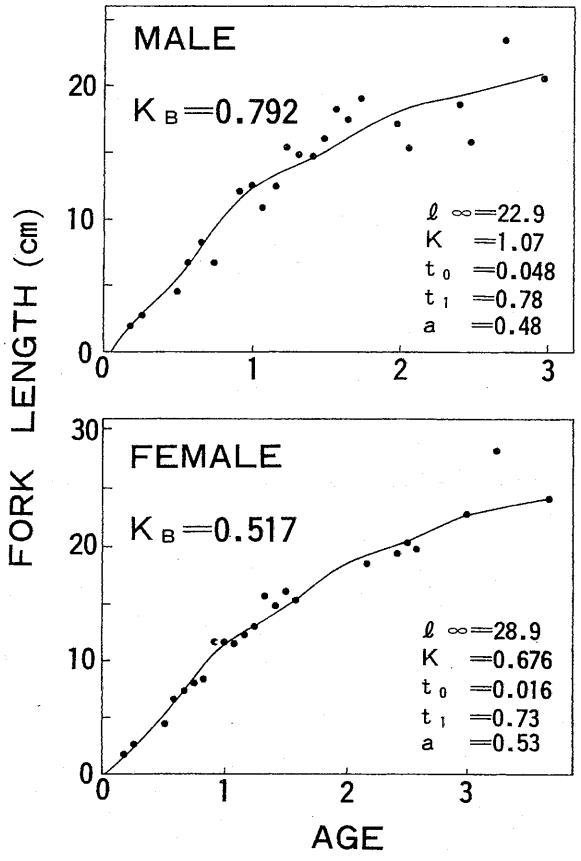

Fig. 6. Growth curves of fluviatile forms of both sexes.

The value of $l\infty$ of males is larger than that of females. The value of K_B of males is larger than that of females. These results indicate that initial growth of male is more rapid than that of female and the growth of male stop earlier than that of female.

Growth of two forms: Growth curves of two forms before downstream migration season were calculated from these equations using the data before eighteen age in month. The value of parameters and K_B of both sea-run form and fluviatile form are shown as following.

Sea-run form: $l\infty = 34.8$, $K = 0.451$, $t_0 = 0.027$, $t_1 = 0.819$, $a = 0.690$, $K_B = 0.381$

Fluviatile form: $l\infty = 30.8$, $K = 0.693$, $t_0 = 0.028$, $t_1 = 0.786$, $a = 0.435$, $K_B = 0.497$

The growth rate of those growth curves are shown in Fig. 7. These two curves showed almost the same phase, but the amplitude of fluviatile form is greater than that of sea-run form. The growth rate curves of the two forms showed large

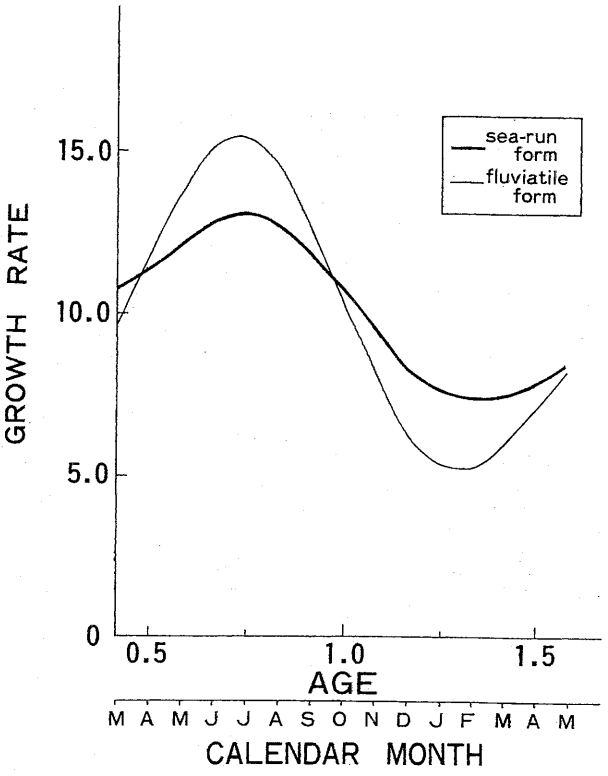

Fig. 7. Growth rate of female two forms before downstream migration season based on Akamine's growth model (1986).

value in summer and showed small value winter.

Differentiation between sea-run form and fluviatile form

The schematic illustration of differentiation between the two forms of masu salmon in the rivers of southern Sanriku district on the basis of present results and previous papers (Kiso, 1988; Kiso and Kumagai, 1989; Kiso and Kasahara in press) is shown in Fig. 8.

In males, the individuals that have grown large size parr will nature in the first autumn. They become fluviatile form and many of them will mature next autumn again. On the other hand, the individuals that have grown small size parr will not mature in the first autumn. Most of them will mature next autumn in the river. A few of them will migrate to the sea. They migrate to mother river in next spring and will mature in the autumn. The sea-run form that stay in the river over two years is disappeared.

In females, no individuals mature in the first autumn. In the individuals that have become large size parrs until the first autumn, the oocytes will develop rapidly after autumn and they will mature in the second autumn. In the individuals have become small size parr until the first autumn, the oocytes will develop slowly after autumn. Many of them will become smolts, and they will run into the sea. They migrate to mother river next spring and will mature in the third autumn. In another individuals, the differentiation

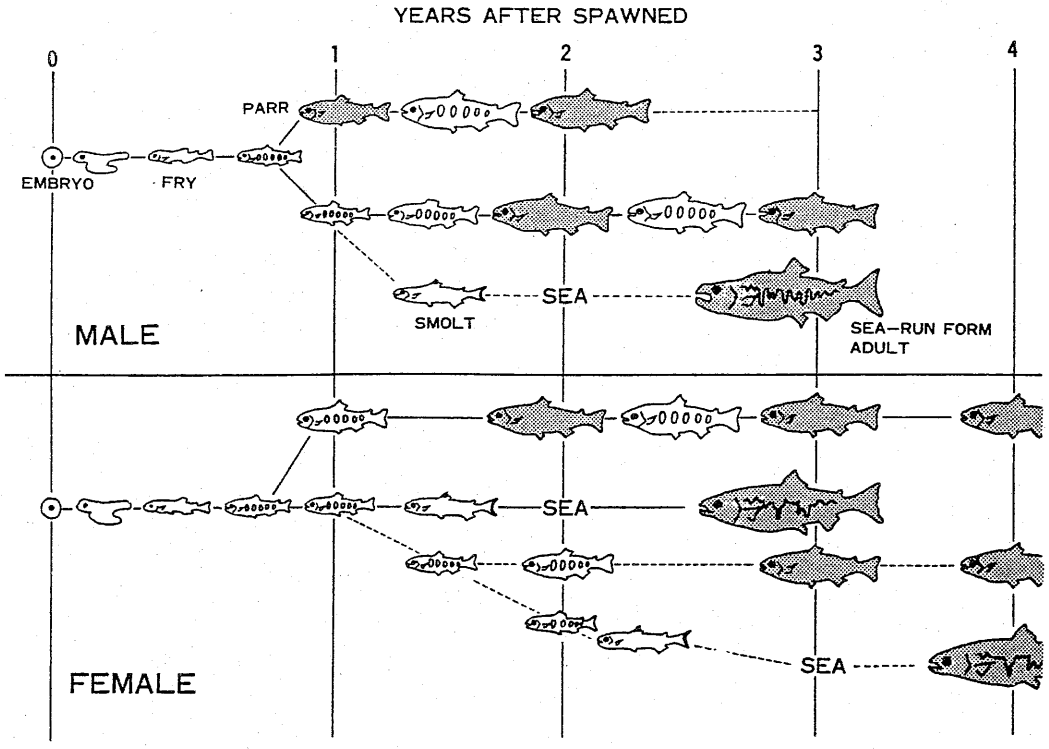

Fig. 8. Schematic illustration of differentiation between sea-run form and fluviatile form of masu salmon in the rivers of southern Sanriku district. Shaded fish means the matured fish with nuptial coloration. Broken line means the rare cases.

between two forms will occur in the second autumn. It seems probable that some of fluviatile forms spawn two or three times, because the oocytes are developed normally in the specimen which have two sawning marks (Kiso and Kosaka unpublished observation).

Pseudo smolt, that is the middle type between smolt and yellow parr, appeared in both sexes. It seems that they do not migrate to the sea, because the process of gonadal development is similar to that of yellow parr. A few females that the developmental stage of their ovaries are oil drop stage are observed in the specimen collected in the coastal waters. They have a chance that their upstream migration will occur after short marine life (Kiso and Kosaka, 1988).

In Hokkaido where the fluviatile form female is very rare, it is known that the differentiation of two forms in male are caused by the difference in process of growth and gonadal development (Kubo, 1980; Uto 1981). In southern Sanriku district where two forms of both sexes are appeared, it seems that those differentiation between two forms of both sexes are caused by the differences of amplitude in the growth rates and the speeds of gonadal growth.

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日本本州三陸地區南方河川櫻鮭生活型之多型現象

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採自日本北本州近太平洋岸三陸地區南方河系之櫻鮭依其形態特徵予以劃分成若干期相並順便調查體質及生殖腺之成長情形。在同一河川族羣中無論雌雄均含河川型及海洋兩大生活型。大約 60%之雄魚在第一年秋季成熟而爲河川型，其餘則延至第二年秋季始成熟爲河川型，其中有極少部份成爲銀色期 (smolt) 並於第二年春季游入大海。雌魚於第一年春季卽分爲二羣：卵巢先後依序進行卵黃胞期與油滴期之發育過程，多數個體俟第二年秋季卽成熟爲河川型。另一類則卵巢停留在周邊核仁期，多數個體成爲銀色期並於第二年春季始出海生活；另有極少數停留在小型黑帶期 (parr) 階段以迄第二年春季。當比較河川型之雄性與雌性間之成長樣式，原先雄魚之成長雖較雌魚爲快，但往後則提早終止成長。若再進一步比較雌魚兩型間之差異性，發現夏季河川型之成長率較海洋型快，冬季則相反。此種生活型中存有性別差異性，乃受到體質成長幅度及生殖腺成長速率之差異性之影響。