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Morphometric and Reproductive Characteristics of the Pond Smelt Population in Lake Ogawara

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Summary

The purpose tof the present study was to find a characteristic indicating the past life history of adult pond smelt, which have inhabited different habitats such as lake and sea, by investigating the relative growth, melanophores distribution, size weight and the number of oocyte in an ovary and phase of otolith of the large and small spawners in Lake Ogawara.

In this study it became clear that eye diameter/standard length and upper jaw length/standard length decrease with standard length, but there are no characteristics that distinguished between large and small fish. The number of oocyte in an ovary and opaque core length in otolith increase exponentially with body length. The fecundity and opaque core length depends on the nutritional condition and growth in early life history, respectively. Accordingly, the large fish are considered to inhabit and grow in much different environment from the small fish.

Of the pond smelt (*Hypomesus transpacificus nippoensis* McAllister) population in Lake Ogawara, the spawners can be divided into two groups classified by the body length distribution (1). The fish live in thelake and coastal seas all year and spawn in the fresh water area e.g. the lake and its inflowing rivers (2, 3). But the cause of the occurrence of the two size groups of the spawners in the population and the relationship between their habitat and theit growth has previously unknown.

In order to examine the opportunity of occurrence of these two groups, we endeavored with this study to find a characteristic indicating the past life history of adult pond smelt, which have lived in different habitats such as lake and sea, by investigating the body shape, body bolor, reproductive characteristics and otolith phase of the pond smelt spawners. In this study, we observed the relative growth for the body shape, melanophores distribution for body color, size, weight and the number of oocytes in an ovary for reproductive characteristics and phase of otolith for the past growth record of the pond smelt. We examined the relationships between these characteristics and body length, of the pond smelt in the spawning season in the lake.

Materials and Methods

In order to observe the morphometric and reproductive characteristics of the pond smelt and examine the relationships between these characteristics and body length, we sampled the pond smlet in Lake Ogawara. The fish were caught by a Danish seine fishery about once a month in the lake from July 1993 to January 1994. In the spawning period of the fish, from March to April 1994, we set the set net and caught the fish (Fig. 1). The location of the net was near the spawning ground of the fish, in the southern part of the lake.

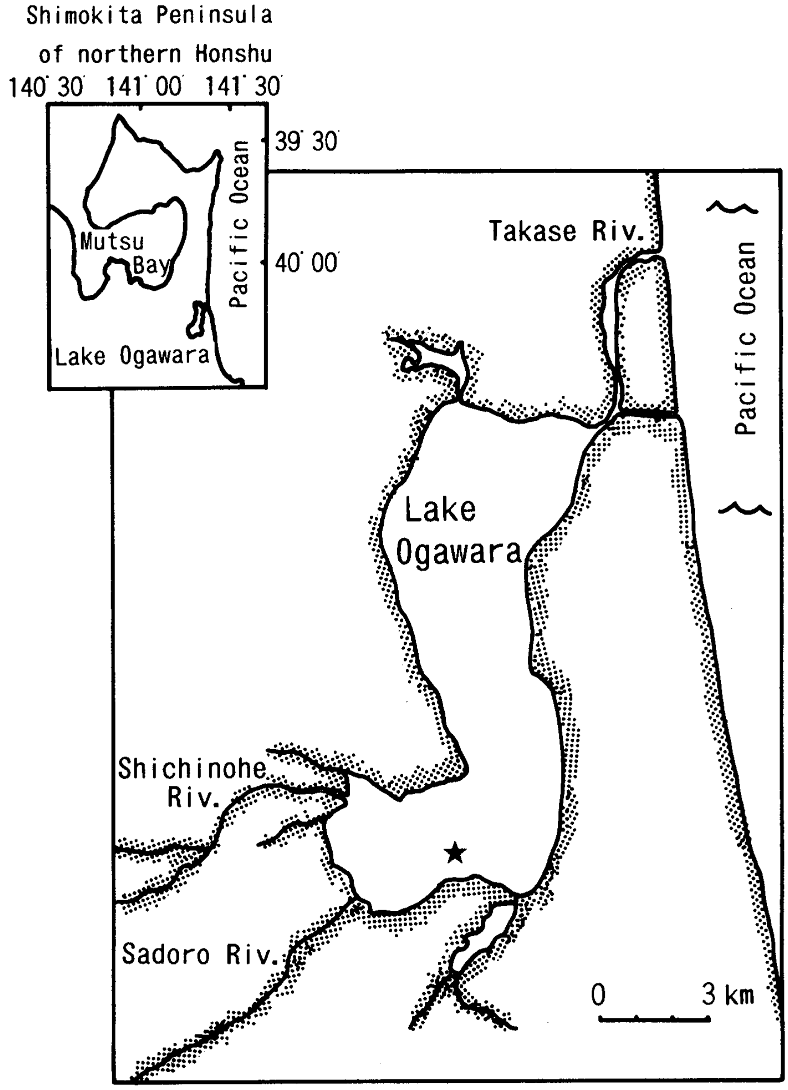

FIG. 1. Map showing sampling location.
Closed asterisks indicate sampling site of pond smelt.

Growth process

For the estimation of the growth of pond smelt in Lake Ogawara, seasonal change in body length distributions of the fish of 1993 year class were examined. About 100 individuals selected randomly from a catch were fixed in with 10% neutral formalin solution. Standard body length (SL) and body weight were measured and weighed. Age was determined by using a otolith, sagittae, because of its preciseness and handiness (3). Immersing the otoliths in water, we observed their phase and distinguished the opaque and translucent parts using a stereoscopic microscope. In this observation, the fish, that had formed a second translucent zone of their otoliths, were estimated to be 1 year old.

Relative growth

We observed 9 morphometric characteristics to examine the relative growth for each individual. Standard length (SL), total length (TL), fork length (FL), head length (HL), predorsal length (DL), preventral length (VL), preanal length (AL), eye diameter (ED) and upper Jaw length (JL) were measured with vernier calipers within a 0.1 mm range (Fig. 2). The relationships between each characteristics and SL were drawn and the existence of an inflection point was observed. If it were not for the point, the allometry formula would have regressed for each relationship.

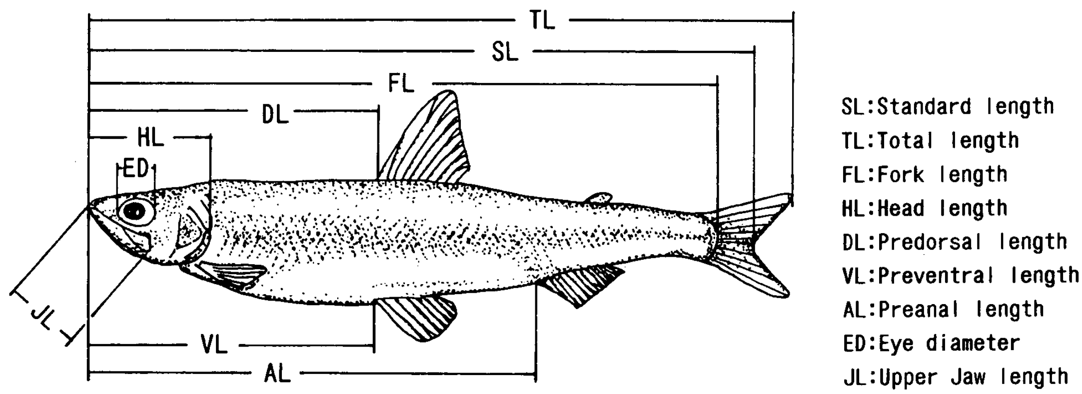

FIG. 2. Morphometric characteristics for measurement.

Body color

Firstly, we observed the melanophores distribution in the whole body of pond smelt fixed with formalin using a stereoscopic microscope. Some fish have many melanophores on the surface of adipose and/or anal fins (Fig. 3), some fish do not have any at all. The rates of the number of fish with melanophores on each fin in all specimens were calculated and compared among body length classes. Furthermore, the rates of fish with melanophores were compared between sexes

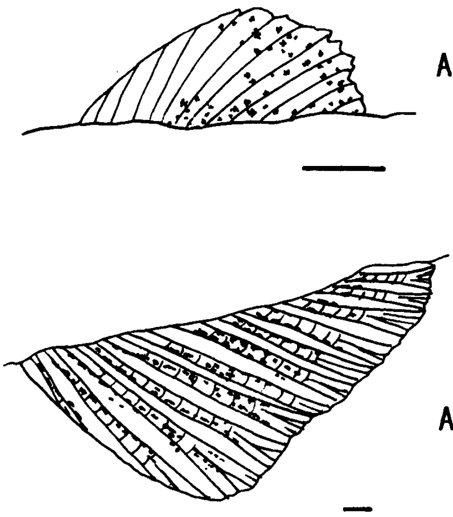

FIG. 3. Melanophores on the adipose fin and anal fin of pond smelt.
Scale bars = 1 mm

and between before and after spawning by the method of t-test analysis.

Egg size and fecundity

The diameter of oocyte at maturation stage in the ovary was used as a index of egg size laid. The maturational stage of oocyte was judged from their appearance. The maturation oocyte looks orange and translucent because of water absorption (4). To determine the part for measurement we observed the distribution of oocyte diameter in an ovary. The right leaf of pond smelt is much larger than the left one as shown in Fig. 4(a). Firstly, the right leaf of an ovary was divided into 5 sections at even intervals from head to tail, and left leaf (Fig. 4(a)). Then, these sections were re-divided to inner and outer parts (Fig. 4(b)). We selected more than 50 oocytes from left leaf and the same parts of right one and measured their diameters using a stereoscopic microscope with micrometer. This measurement was carried out for two ovaries at the vitellogenic and maturation stages. All distributions of oocyte diameters were almost normal and unimodal, therefore, the mean and standard deviation of oocyte diameter of each part sample were compared among these parts. Table 1 shows the means and standard deviations of oocyte diameters of these parts. One-way analysis of variance (ANOVA) was made among left leaf and 5 sections of right leaf and among inner and outer parts, respectively. As a result, the oocyte diameter of inner and outer parts at vitellogenic stage ovary have no significant differences ($P<0.05$), however, that of left leaf and 5 sections of right leaf at both stages and of inner and outer parts at maturation stage have significant differences ($P>0.05$). Accordingly, for measurement, we selected about 100 oocytes from the inner part of the second part from head, which the variance of its diameter is the least. Measuring

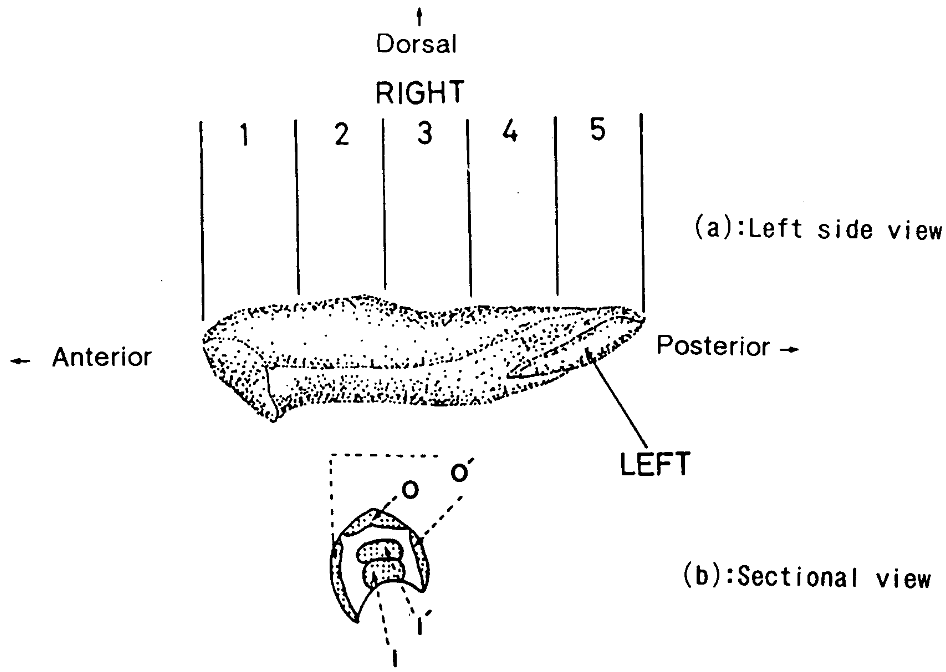

FIG. 4. Left side view (a) and sectional view (b) of pond smelt ovary.
O, O′: Outer part I, I′: Inner part

the diameter of oocyte, we exclude oocytes that were remarkably deformed by fixation.

Egg weight and fecundity

In general, an oocyte absorbs water at final maturational stage, however, dry weight of an oocyte dose not change by absorption (5). Accordingly we weighed not only wet weight but also dry weight of maturation oocyte as indices of egg characterlstic. After weighing ovary weight, wet weight and number of oocytes of the inner part of the second section from the head were weighed and counted, respectively. Then, the ovary except the part removed was dried at 130°C for 24-36 hs and its stable weight was weighed. In this way, wet and dry weight and fecundity were calculated.

Opaque core length of otolith

Concerning the formation process of the otolith of pond smelt, it is known that firstly the opaque core is formed and then translucent zone and opaque zone are formed sequentially. Opaque core (OC) is formed for a few months after hatching until July-August in Lake Ogawara and off Hachinohe (3). Further more, the length of OC, after complete formation, is proportional to the body length from August to October and is considered to correspond to the early stage growth (3). Accordingly, in order to estimate the early growth of large and small

TABLE 1. *Means and standard deviations of oocyte diameter of pond smelt.*
Top table is data from the fish at mature stage (SL. : 75.2 mm) and bottom table is at vitellogenic stage (SL : 70.5 mm).

	Oocyte diameter (μm)							
	Right					Left		
Part of Ovary	1	2	3	4	5		Average	ANOVA (F)
Inner part (I)	701±61.0	701±49.2	724±105	736±73.8	792±60.8	735±73.0	720±80.6	
Inner part (I')		720±65.4	740±79.5	711±67.4			724±72.0	F=20.9
Outer part (O)	767±53.3	709±66.7	694±59.1	608±65.8			670±77.8	>P (0.05)
Outer part (O')		719±55.1	625±51.7	680±85.7			675±76.5	
Average	734±66.3	712±60.1	696±88.4	684±87.9	792±60.8	735±73.0		
ANOVA			F=26.7>P (0.05)					

	Oocyte diameter (μm)							
	Right					Left		
Part of Ovary	1	2	3	4	5		Average	ANOVA (F)
Inner part (I)	580±95.4	625±71.5	608+71.5	608±74.9	653±74.9	576±93.5	608±71.1	
Innter part (I')		625±73.3	600±73.5				612±74.4	F=0.640
Outer part (O)	573±86.9	643±57.7	644±54.4	592±103			613±63.9	<P (0.05)
Outer part (O')		617±79.9	577±88.8				597±86.8	
Average	576±94.0	627±71.6	607±75.6	600±75.59	653±74.9	576±93.5		
ANOVA			F=10.4>P (0.05)					

ANOVA : Analysis of variance

pond smelt spawners in the lake, we measured the OC length of otolith, sagitta, taken out from each specimen. The observation and transcription of the otolith phase which was immersed in water were carried out using a stereoscopic microscope with equipment for transcription. The maximum length of OC, defined as its length, of the transcribed figure was measured with ruler.

Results

Seasonal change in body length of pond smelt

Seasonal changes in standard length (SL) distributions were examined to estimate the growth process of pond smelt inhabiting in Lake Ogawara. The distributions are almost normal and unimodal and skewed to the large a little from July 1993 to January 1994 (Fig. 5). Their modes are 30-35 mm in August and 45-50 mm in December. But in April, the feature of SL distribution is wide and multimodal. Every sample in this period has a mode at 45-60 mm, however, some samples have modes at 80-85 mm (Apr. 19, 21), and 75-80 mm (Apr. 28) shown in Fig. 6.

We will analyze the relative growth, body color, egg size and weight, fecundity and otolith phase, as following, about the sample on Apr. 21 that its SL distribution of 0^+ year old has two modes; 45-50 mm and 80-85 mm (Fig. 7).

Relative growth

In order to find the feature of relative growth of two size group of pond smelt spawners, the allometry analysis was applied to the relationship between morphometric characteristics and SL. The results are shown in Fig. 8. There is no

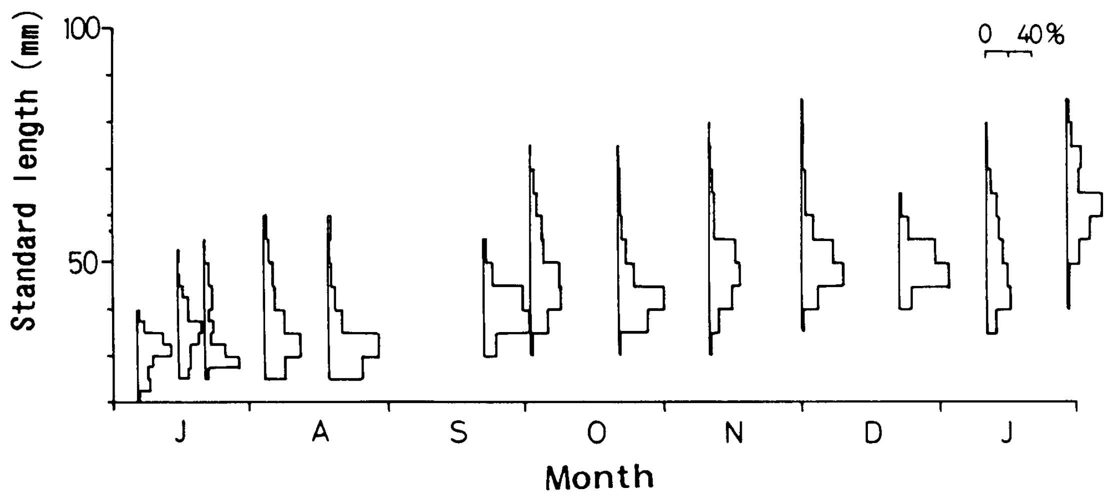

FIG. 5. Frequency distributions of standard length (SL) of pond smelt (0^+) in Lake Ogawara, from July 1993 to January 1994.

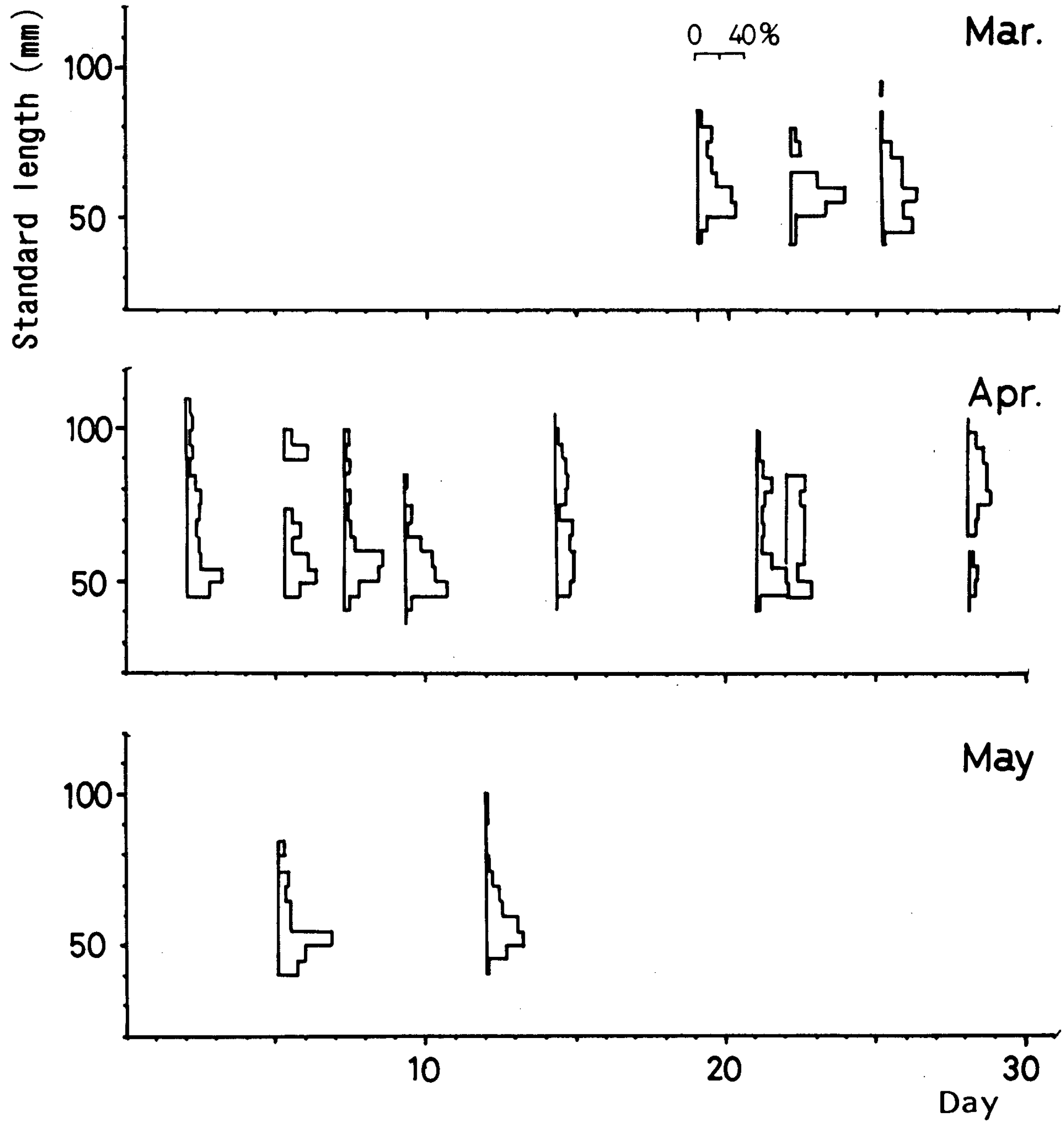

FIG. 6. Frequency distributions of standard length (SL) of pond smelt (0^+) in Lake Ogawara, in the spawning period from March to May 1994.

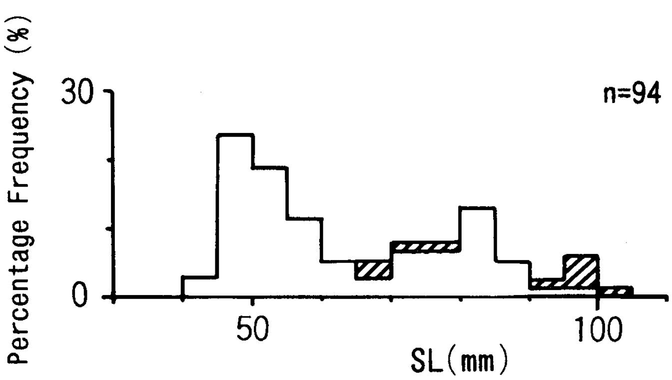

FIG. 7. Frequency distribution of standard length (SL), on April 21, 1994. Open bars indicate 0^+ fish and shaded bars 1^+ one.

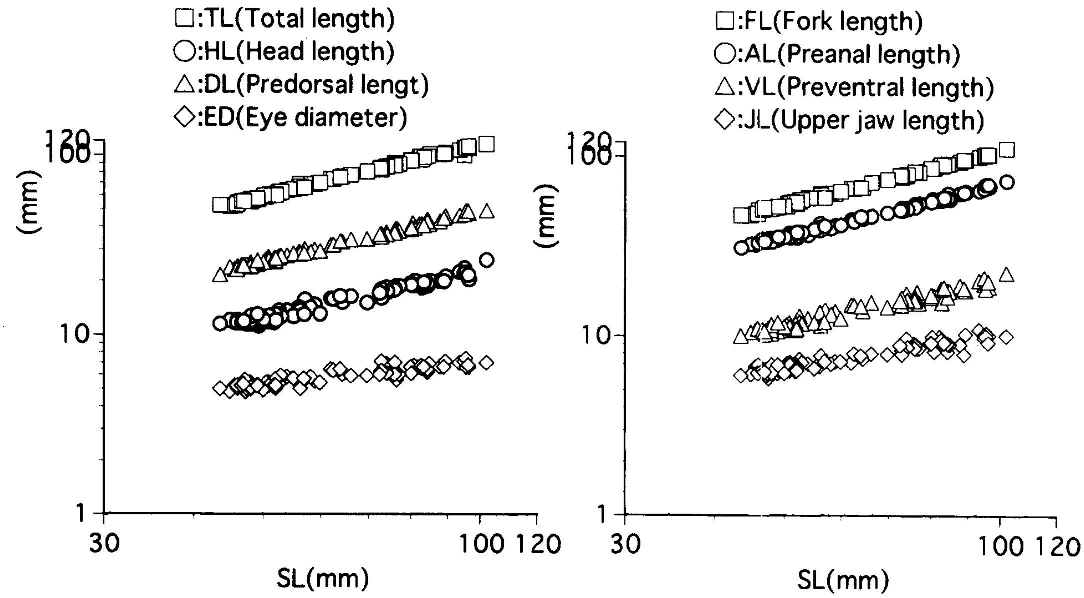

FIG. 8. The relationships with log-transformation between morphometric characteristics and standard length.

TABLE 2. *Relationships between standard length and length of each morphometric characteristics of of pond smelt.*
Regression formula is allometry one ; $Y = a \times X^b$
X : standard length (mm) Y : each character (mm)

Characters		Correlation coefficient r^2	Regression coefficients a	b
Total length	(TL)	0.977	1.23	0.992
Fork length	(FL)	0.998	1.02	1.01
Head length	(HL)	0.963	0.478	0.894
Predorsal length	(DL)	0.992	0.676	0.955
Preventral length	(VL)	0.954	0.535	0.862
Preanal length	(AL)	0.993	0.790	0.955
Eye diameter	(ED)	0.841	3.58	0.433
Upper Jaw length	(JD)	0.895	1.34	0.628

inflection point in each relationship. Table 2 shows coefficients of each regression formulae. Every rate of contribution r^2 is so high, that its least value is 0.841 (ED), therefore each morphometric characteristic is fully regressed by a allometry formula. Therefore the body shape is revealed not to change discontinuously with body length. But some b-values, allometric coefficients, that indicate relative growth rate are 0.894 (HL), 0.862 (VL), 0.433 (ED) and 0.628 (JL) and are obviously under 1. This means that the rate of length of head part, especially eye and mouth, to the body length is lower as the body length lengthens.

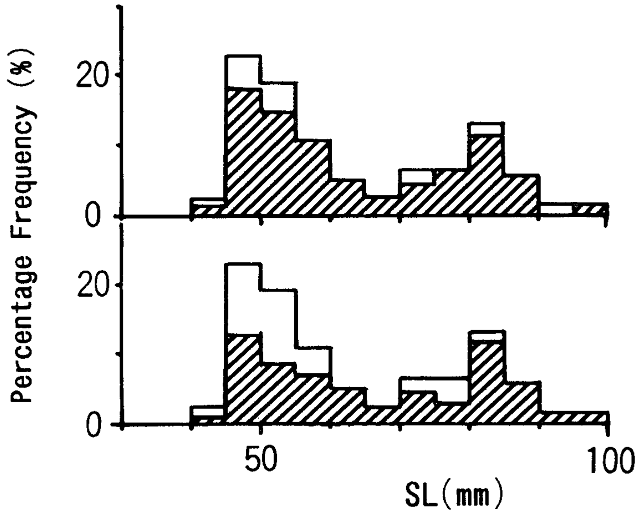

FIG. 9. Frequency distributions of standard length with melanophores (shaded bars) and without them (open bars) on the anal fin (top) and adipose fin (bottom).

TABLE 3. *Comparison of existence rate of melanophores on anal fin (AF) and adipose fin (ADF) between female and male, and between before and between spawning.*

	AF (Observed/total)	t-test	ADF (Observed/total)	t-test
Male	58/62 (93.5%)	2.23<P (0.01)	37/62 (59.7%)	0.0612<P (0.05)
Female	41/53 (77.4%)		31/53 (58.5%)	
Before	23/30 (76.7%)	1.43<P (0.05)	15/30 (50.0%)	1.40<P (0.05)
After	76/85 (89.4%)		53/85 (62.4%)	

Individual difference of melanophores distribution

The frequencies of fish with melanophores and without melanophores on the surface of adipose and anal fins by SL class are shown in Fig. 9, respectively. Fish with melanophores are more than fish without them and covers all SL classes in both fins. There is no difference of existence of melanophores among SL classes.

To examine the factor effecting an existence of melanophores, the percentage of fish with melanophores in all individuals were compared between sexes and between before and after spawning by the method of t-test analysis (Table 3). The rate of female fish with melanophores on anal fin is a little higher than that of male fish with them ($P>0.05$, $P<0.01$). There are, however, no significant difference on adipose fin between sexes and between before and after spawning on both fins ($P<0.05$).

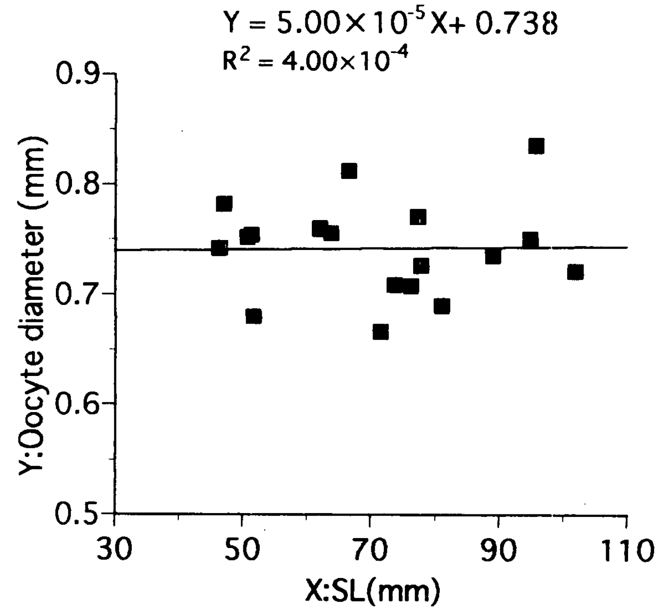

FIG. 10. The relationship between means of oocyte diameter at maturation stage and standard length (SL) with regressive line.

Diameter of maturation oocyte

In order to examine the relationships between the egg size and body length, the relationship between the mean of oocyte diameters at maturation stage of each specimen and SL is shown with regression line in Fig. 10. The means of the diameters cover so wide a range of 0.67 mm-0.84 mm that the contribution rate r^2 of regression is very small ($r^2=4.00\times10^{-4}$). But the slope of the line is 5.00×10^{-5} almost equal to 0. Egg size of pond smelt in Lake Ogawara can be judged not to vary with body length.

Weight of an oocyte and number of oocytes in an ovary

The relationship between wet weight and dry weight of an oocyte at maturation stage and SL are shown with regression lines in Fig. 11, respectively. Wet weight ranges from 291 μg to 452 μg and dry weight from 75 μg to 105 μg. Individual weight does not vary clearly with body length. Fecundities, the number of oocytes in an ovary, varies widely from 525 to 11438 on Apr. 21 (Fig. 12). It increases with SL and really regresses to about the third power of SL. Fecundities on Dec. 21 are plotted on the figure for comparison. They are in a range of 1315-2883 and correspond to the fecundities of standard length 50 mm-80 mm on Apr. 21.

Opaque core length of the otolith

Firstly seasonal change in the distributions of opaque core (OC) length were

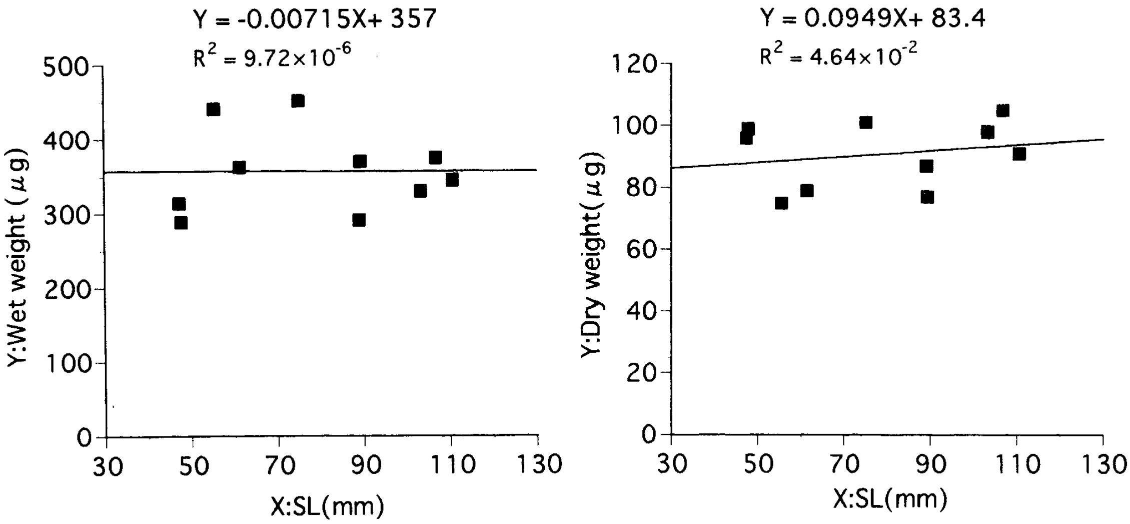

FIG. 11. The relationships between wet weight (left) and dry weight (right) of oocyte diameter at maturation stage and standard length (SL) with each regressive line.

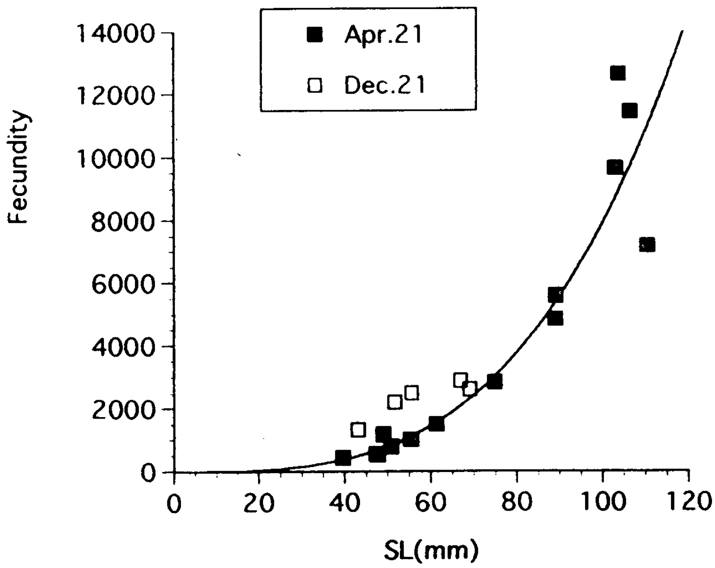

FIG. 12. The relationships between fecundity and standard length (SL) with regressive curve. Closed circles indicate fecundity of the fish on April 21, open circle on December 21. Regressive curve is fitted on only data on April 21.

examined (Fig. 13). They cover a range from 0.5 mm to 2.0 mm and are unimodel from September to November. Their modes are 1.0 mm-1.5 mm. In April the range of OC length is 0.5-3.0 mm resulting from addition of fish with OC over 2.0 mm. It has two modes, 1.0-1.25 mm and 2.0-2.25 mm. For comparison of OC length between large and small fish about this sample on April 21, the regressive relationship with log-transformation between OC length and SL is shown in Fig.

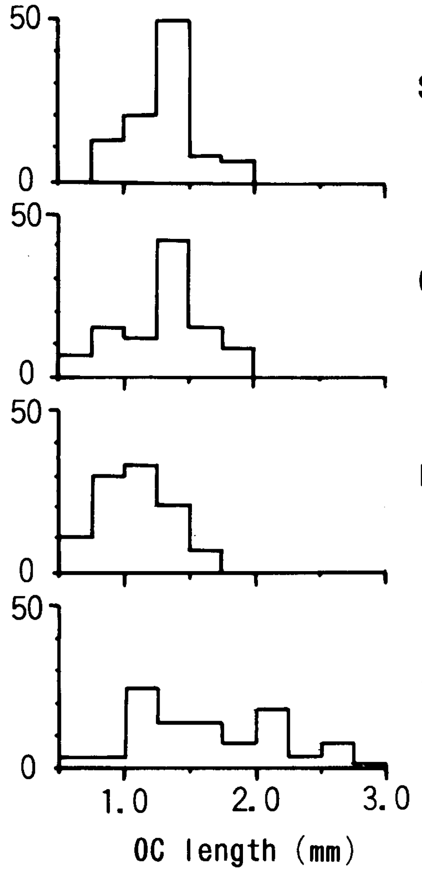

FIG. 13. Frequency distributions of opaque core (OC) length from September 1994 to April 1995.

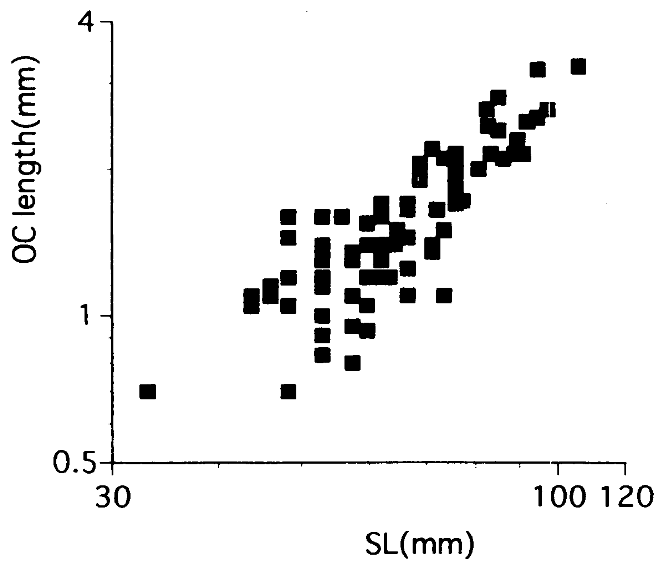

FIG. 14. The relationship with log-transformation between opaque core (OC) length and standard length.

14. There is no clear inflection point. OC length tends to increase as SL increases. Two modes, 1.0-1.25 mm and 2.0-2.25 mm, in the OC length distribution corresponding to SL 40-75 mm and 70-90 mm, respectively, which are well fitted to modes of SL distribution.

Discussion

There are many reports that the biological characteristics are different among fish of differing habitats and growth. The relative growth (6, 7, 8), meristic charasteristics (8, 9) body color (7, 10), egg size and fecundity (11-14) are different between anadromous large fish and resident small fish.

In this study it becomes clear that eye diameter/SL and upper jaw length/SL decrease as SL increases, about large and small pond smelt spawners in Lake Ogawara. But there are not any characteristics that distinguish large and small fish, in body shape, body bolor, egg size and weight.

The fecundity increases exponentially with body length. The fecundity of the fish of SL 100 mm is about 8000 and that of 50 mm is about 1000, which is 8 times greater. Fecundity is greatly influenced by amoant of food taken by fish during the ovarian development period, reported for rainbow trout, *Salmo gairdneri* (15), kokanee salmon, *Oncorhynchus nerka* (16) and masu salmon, *Oncorhynchus masou ishikawae* (17), which spawn once a year as do pond smelt. Therefore, fecundity of pond smelt, which varies with body length of spawners, is considered to depend on nutritional condition of fish during the ovarian development period. The relationship between growth and habitat can be clarified by investigating the physiological mechanism regulating the number of oocytes to be spawned, such as nutritional condition, amount of food, body length, salinity and water temperature.

The length of OC, after complete formation, is considered to correspond to the early stage growth (3). In the spawning season, April, the fish with OC length over 2.0 mm, which have not been in the lake until that time, appear in Lake Ogawara. SL of them are over 70 mm. Namely the large fish with larger OC than that of small fish which is resident in the lake appear in the lake in the spawning period. Therefore the large fish is considered to inhabit and grow in a much different environment in the period from hatching to when OC development is completed, from April-May to July-August. But it is unknown if this environmental difference for pond smelt is a geographical difference between coastal area and lake or a periodical one of the hatching period. In other words, it is unknown whether the large fish grow rapidly in coastal area or the large fish have grown in the lake and then migrate to the sea. We should consider another factor that the difference in growth rate between migratory fish to the sea and non migratory ones could have a different genetic component. From the results of rearing experiment on stickleback, *Gasterosteus aculeatus*, difference in growth rates between nonmigratory small fish and migratory large ones is based on genetic variation (18, 19). Variation of growth, fecundity and anadromous or not of pond smelt would be genetically-based should also be examined.

Acknowledgements

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References

1) Katayama, S., Omori, M. and Okata, A., Estimation on individual life record of pond smelt using otolith increment, *Bull. Tohoku Bra. Jap. Soc. Sci. Fish.*, **43**, 56-57 (1993). (in Japanese)
2) Katayama, S. and Okata, A., Pond smelt spawning in the inflowing river into Lake Ogawara, *Tohoku J. Agr. Res.*, **45**, 87-102 (1995).
3) Katayama, S. and Kawasaki, T., Age determination of pond smelt using otolith phase, *Tohoku J. Agr. Res.*, **44**, 91-106 (1994).
4) Katayama, S., Sugawara, Y., Omori, M. and Okata, A., The maturation and spawning process of pond smelt in Lake Ogawara, Abstr. 1994 *Autumn Meet. Jap. Soc. Fish. Sci.*, p. 68 (1994). (in Japanese)
5) Greeley, M.S.Jr., Holes, H. and Wallace, R.A., Changes in size, hydration and low molecular weight osmotic effectors during meiotic maturation of fundulus oocytes *in vivo*, *Comp. Biochem. Physiol.*, **100**A, 639-647 (1991).
6) Mori, S., Divergence on reproductive ecology of the three-spined sticklebacks, *Gasterosteus aculeatus*, *Japan. J. Ichthyol*, **34**, 165-175 (1990).
7) Yamauchi, K. and Takahashi, H., Migration and hormone, "*Biology of Migratory Fish*", eds. Morisawa, M., Aida, K. and Hirano, T., Gakkai syuppan center, Tokyo, pp. 156-171 (1987). (in Japanese)
8) Copeman, D.G., Population differences in rainbow smelt, *Osmerus mordax* : multivariate analysis of mensural and meristic data, *J. Fish. Res. Board. Can.*, **34**, 1220-1229 (1977).
9) Lavin, P.A. and McPhail, J.D., Adaptive divergence of trophic phenotype among freshwater populations of the threespine stickleback (*Gasterosteus aculeatus*), *J. Fish. Aquat. Sci.*, **43**, 2455-2463 (1986).
10) Uchida, S., Environmental preference of fishes and amphibian animals, "*Environment and Endocrine*", Gakkai syuppan center, Tokyo, pp. 53-82 (1974). (in Japanese)
11) Kanno, Y., On the life history of, *Clupea pallasii* Cuvier et Valenciennes, in the brackish Lake Notoro, Hokkaido III. Reproductive characteristics and feeding habits, *Mem. Fac. Fish. Hokkaido Univ.*, **32**, 316-328 (1981). (in Japanese with English summary)
12) Azuma, M., Studies on the variability of the landlocked ayu-fish, *Plecoglossus altivelis* T. et S., in Lake Biwa IV. Considerations on the

grouping and features of variability, *Jap. J. Ecol.*, **23**, 255-265 (1973). (in Japanese with English summary)

13) Iguchi, K. and Yamaguchi, M., Adaptive significance of inter and intrapopulational egg size variation in ayu *Plecoglossus altivelis* (Osmeridae), *Copeia*, **1994**, 184-190 (1994).

14) Kaeriyama, M., Urawa, S. and Furukawa, M., Variation in body size, fecundity, and egg size of sockeye and kokanee salmon, *Oncorhynchus nerka*, released from hatchery, *Sci. Rep. Hokkaido Salmon Hatchery*, **49**, 1-9 (1995).

15) Kato, T., The relation between the growth and reproductive characters of raibow trout, *Salmo gairdneri*, *Bull. Freshwater Fish. Res. Lab.*, **25**, 83-115 (1975). (in Japanese with English summary)

16) Kato, T., Relation of growth to maturity of age and egg characteristics in kokanee salmon (*Oncorhynchus nerka*), *Bull. Freshwater Fish. Res. Lab.*, **28**, 61-75 (1978). (in Japanese with English summary)

17) Takashima, F., Changes in oocyte number during maturation of female masu salmon, *Bull. Jap. Soc. Sci. Fish.*, **52**, 231-237 (1986). (in Japanese with English summary)

18) Synder, R.J., Migration and life histories of the threespine stickleback: evidence for adaptive variation in growth rate between populations, *Env. Biol. Fish.*, **31**, 381-388 (1991).

19) Synder, R.J., Adaptive, genetically based differences in life history between estuary and freshwater threespine stickleback (*Gasterosteus aculeatus* L.), *Can. J. Zool.*, **37**, 2448-2454 (1989).