日水研報告，（48）：17-25，1998.
Bull. Japan Sea Natl. Fish. Res. Inst.,（48）：17-25，1998.

Density-dependent Effects on Body Weight of the Pink Salmon in the Japan Sea

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Abstract

Fork length FL, body weight BW, and condition factor $100 \cdot BW / FL^3$ of the pink salmon *Oncorhynchus gorbuscha* (WALBAUM) distributed in the Japan Sea are examined in relation to stock size. Body weight and condition factor of the specimens caught by research vessels from April to May 1978-1991 are inversely correlated ($P < 0.01$) with stock size (number of individuals) calculated using Virtual Population Analysis by 10 days, while there are no significant correlations in March. Occurrence of specimens with empty stomachs is also correlated with the stock size with the exception of 1989. Spawning success, which is measured as a logarithm of recruitment / spawning biomass ratio, is correlated ($P < 0.01$) with the spawning biomass (negative) and condition factor (positive). From this, we suggest that there are density-dependent effects on the body size and spawning success of pink salmon distributed in the Japan Sea.

Key words：*Oncorhynchus gorbuscha*, stock size, spawning success, stomach contents, condition factor

Introduction

The pink salmon *Oncorhynchus gorbuscha* migrate from the Pacific Ocean and Okhotsk Sea and appear in the Japan Sea from February or earlier (HIYAMA and MARKOVTSEV 1993). They distribute along frontal zones and vigorously feed to grow and mature by June (ISHIDA 1966). Density-dependent effects on growth have been observed in the spawning rivers in Russia. SEMKO (1939) reported that the average length of pink salmon are smaller in years with a large stock size than in years with a small stock size (from ISHIDA 1966). Clarification of the density-dependent effects on growth are important for the understanding of density-dependent fluctuations in the stock size. It is supposed that intraspecific competition for prey exists in the open waters of the Japan Sea. In this study, we examine the fork length and body weight of pink salmon with respect to the stock size calculated using Virtual Population Analysis (POPE 1972).

Materials and Methods

1 Biological measurements

The samples were fished with drift nets by the research vessels, "Oyashio-Maru" of the Hokkaido Chuo Prefectural Fisheries Experimental Station, "Too-Maru" of the Aomori Prefectural

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Accepted: October 31, 1997. Contribution A No. 518 from the Japan Sea National Fisheries Research Institute.

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Fisheries Experimental Station, "Senshu-Maru" of the Akita Prefectural Institute for Fisheries and Fisheries Management, "Mogami-Maru" of the Yamagata Prefectural Fisheries Experimental Station, "Tateyama-Maru" of the Toyama Prefectural Fisheries Experiment Station, "Hakusan-Maru" of the Ishikawa Prefecture Fisheries Research Center, "Ohtori-Maru" of the Oki High School of Fisheries, and "Mizuho-Maru" of the Japan Sea National Fisheries Research Institute. The drift net surveys were conducted at night over a broad area of open waters in the Japan Sea between March and June 1979-1991 (Fig. 1). Each ship used 40 to 200 nets of 55 to 157 mm mesh size.

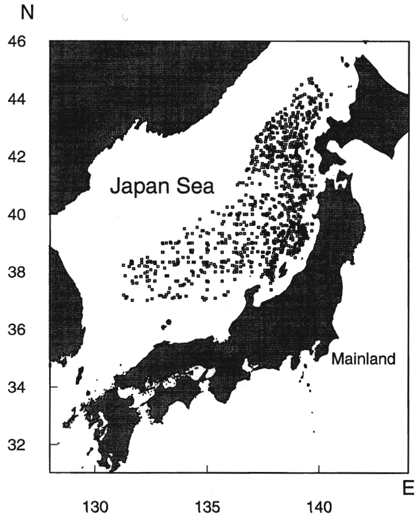

Fig. 1. Location of stations where pink salmon were sampled.

The fork length and body weight were measured by 1 cm and 10 g onboard. The condition factor is expressed as $100 \cdot BW / FL^3$, where FL and BW represents the fork length in cm and body weight in g, respectively. The amount of stomach contents was classified into four degrees, A : Empty, B : Few prey specimens, C : Ten to thirty specimens as *Euphausia pacifica* HANSEN, and D : Stomach one third full and over.

2 Virtual Population Analysis

The number of specimens caught by commercial fisheries, which consist of drift nets and longlines, was calculated for each ten days from March to June 1978-1991 (HASEGAWA and KATO unpublished). The terminal fishing mortality coefficient F_T, which is F in late June, in 1978 was assumed to be $0.1 \cdot (10 \text{ days})^{-1}$, and F_T for each year was calculated according to the ratio of the total number of drift nets in each year to that in 1978 for 1979-1991. The natural mortality coefficient M was assumed to be $0.03 \cdot (10 \text{ days})^{-1}$. The stock size (number of individuals) was calculated for each ten days from March to June.

In this study, we designate the stock size (number of individuals) at middle of each month as the stock size for each month. We consider the stock size (number of individuals) in March as recruitment R (10000 individuals), and the stock size in weight in June as spawning biomass E (1000 metric tons). Here, the body weight in May is used to calculate the spawning biomass, because there are little data for body weight in June.

3 Environmental factors

Environmental factors that might affect the body size of pink salmon include water temperature and zooplankton biomass. Records of average water temperature at a depth of 50 m in the coastal area of mainland of Japan, i.e., the Tsushima Current area, from 1978 to 1991, were provided by the Japan Sea National Fisheries Research Institute (NAGANUMA and ICHIHASHI 1985). Records of zooplankton biomass (mg / m^2) collected using NORPAC or Marutoku nets (mesh size 0.35 mm) in an area of 38-44° N, 130-137° E between March and May, from 1982 to 1990, were provided by the Japan Sea National Fisheries Research Institute (HIROTA and HASEGAWA 1997). In order to examine the food availability per individual pink salmon, plankton abundance is defined as the ratio of the zooplankton biomass to stock size.

Results

Figure 2 shows the monthly average fork length (FL) and body weight (BW) of pink salmon for 1978-1991. Vertical lines show the standard deviation from the mean. In both FL and BW, females are larger than males in March and April, while females and males are almost the same size in May and June.

Figure 3 shows the recruitment *R* of pink salmon in the Japan Sea 1978-1991. The recruitment of pink salmon decreased between 1978 and 1986, then remained at a low level between 1986 and 1991.

Table 1 shows the correlation coefficients of stock size, plankton abundance, and water

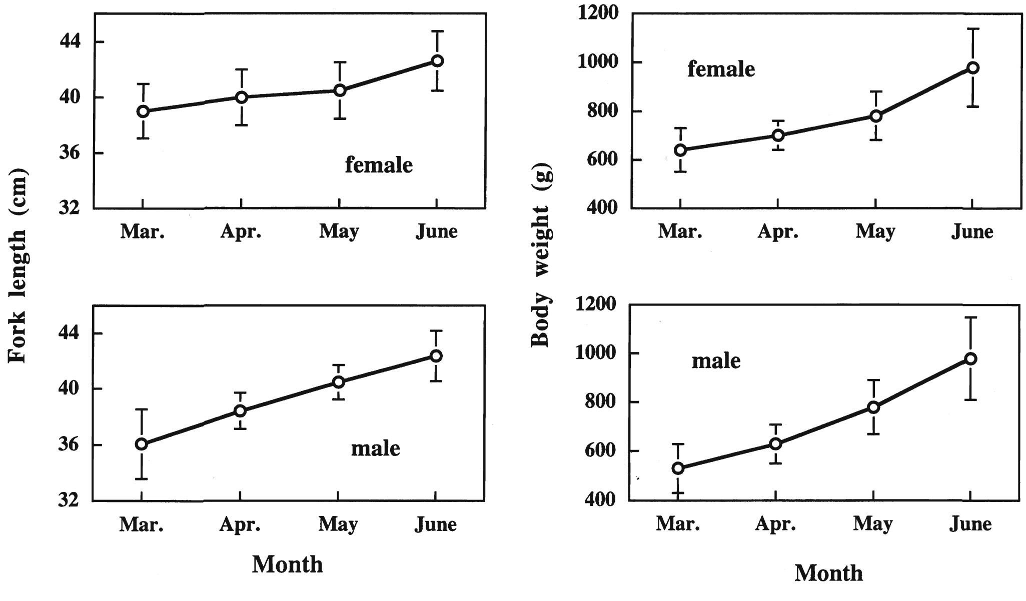

Fig. 2 . Average monthly fork length and body weight for male and female pink salmon 1978-1991. Vertical lines show standard deviation from mean.

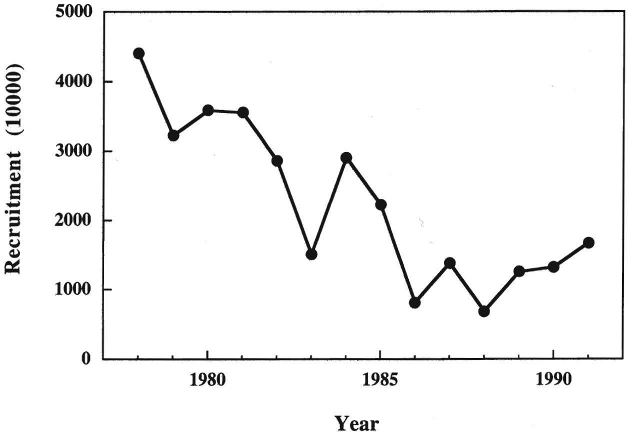

Fig. 3 . Pink salmon recruitment in the Japan Sea

temperature with fork length, body weight, and condition factor. There are high inverse correlations ($P < 0.01$) for body weight and condition factor with stock size in May, while there are no significant correlations between fork length and stock size. The correlation coefficient of body weight and condition factor with stock size increase from March to May for both female and male. Figure 4 shows plots of condition factor $100 \cdot BW / FL^3$ as a function of stock size. Plankton abundance also shows high correlations between body weight and condition factor in April and May. There are no significant correlations however between body size and water temperature with an exception of condition factor in March.

Table 1. Correlation coefficients of stock size, plankton abundance, and water temperature with fork length, body weight, and condition factor. Figures in the upper, middle, and lower part of each cell correspond to March, April, and May.

	Correlation coefficient						Number of replicate years
	Fork length		Body weight		Condition factor		
	Female	Male	Female	Male	Female	Male	
Stock size (number of individuals)	-0.175	0.117	-0.024	0.171	0.325	0.044	14
	-0.479	-0.480	-0.679**	-0.605*	-0.568*	-0.538*	
	-0.279	-0.510	-0.662**	-0.706**	-0.847**	-0.802**	
Plankton abundance plankton biomass (Mar. - May) / stock size	0.418	0.118	0.273	0.050	-0.426	-0.084	9
	0.398	0.433	0.721**	0.718**	0.826**	0.940**	
	0.530	0.478	0.717**	0.672**	0.826**	0.837**	
Water temperature in winter (Jan. - Mar.)	0.440	0.319	0.213	0.353	-0.491	0.216	14
	0.306	0.297	0.151	0.197	-0.089	0.061	
	0.190	0.316	0.216	0.299	0.169	0.218	
Water temperature in spring (Apr. - June)	0.286	0.116	0.078	0.155	-0.538*	0.215	14
	0.299	0.315	0.201	0.277	-0.191	-0.076	
	0.264	0.367	0.269	0.341	0.165	0.200	

*$P<0.05$; **$P<0.01$

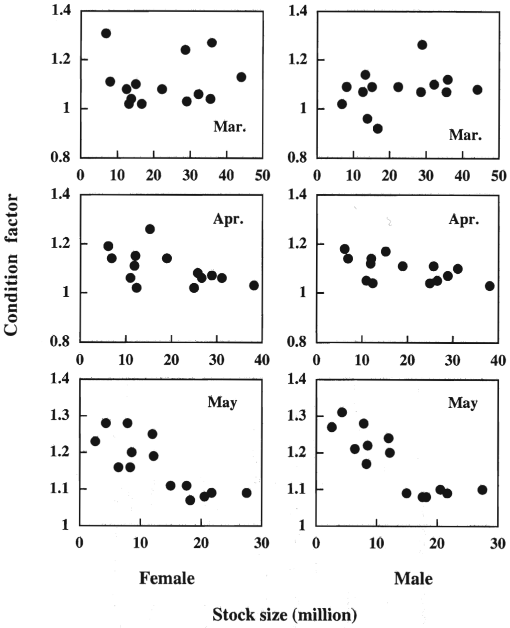

Fig. 4 . Plots of the condition factor 100 · BW (g) / FL $(cm)^3$ as a function of the stock size.

In order to examine the relationship between food availability and body weight, the degree of stomach contents for each year is plotted in Fig. 5. The percentage of specimens with empty stomachs (degree A) is higher in 1979-1982 when the stock size was relatively higher than in 1983-1991, and the percentage of specimens with stomachs one third full and over (degree D) is lower in 1979-1982 than in 1983-1991. In Fig. 6, the percentage of specimens with empty stomachs is plotted as a function of stock size in April. There is a significant correlation ($r = 0.838, P < 0.01$) except for 1989.

We defined the spawning success as ln (R_{t+2} / E_t) , here R is the recruitment, E the spawning

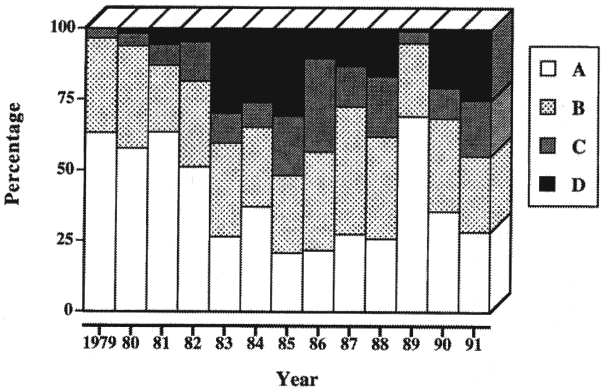

Fig. 5 . Percentage composition of stomach content fullness of pink salmon. A, B, C, and D represent the four degrees of fullness, A: Empty, B: Few prey specimens, C: Ten to thirty specimens as *Euphausia pacifica*, D: Stomach one third full and over.

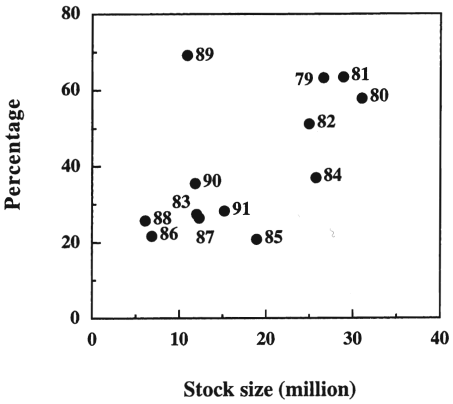

Fig. 6 . Plots of occurrence of specimens with empty stomach (degree A in Fig. 5) as a function of the stock size in April. Figures indicate the year.

biomass, and *t* year. All pink salmon mature at two years old (ISHIDA 1966). First, spawning success should be examined as a function of spawning biomass (Fig. 7A). There is an inverse correlation ($P < 0.01$) between the spawning biomass and spawning success and the correlation implies the existence of a RICKER stock-recruit relationship. Since the condition factor is inversely correlated with the stock size in April and May (Table 1), there is a correlation between the condition factor and spawning success (Fig. 7B).

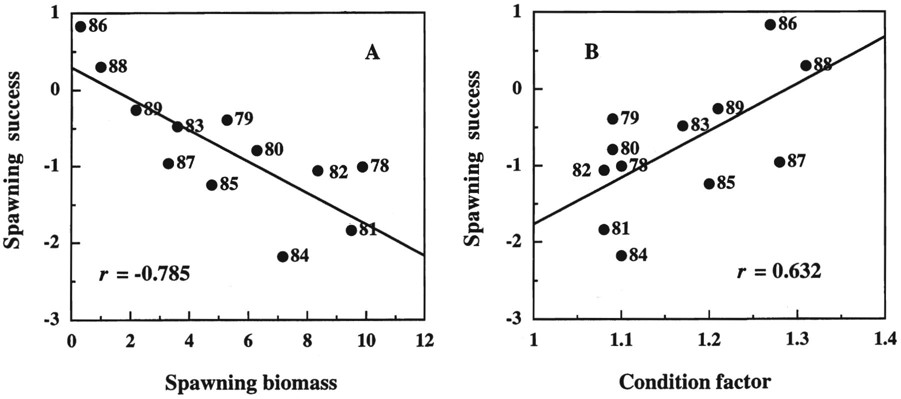

Fig. 7 . Plots of spawning success as a function of spawning biomass (A) and condition factor (B). Spawning success is ln (R / E) , where R is the recruitment and E the spawning biomass. Figures indicate the year when spawning occurred.

Discussion

SEMKO (1939, 1954) reported that the average length of pink salmon is inversely correlated with the number of spawners in West Kamchatka, and that the relationship is probably attributed to the availability of prey (from ISHIDA 1966; HEARD 1991). In this paper, body weight and condition factor have significant inverse correlations with stock size (number of individuals) in the open waters of the Japan Sea, while there are no significant correlations between fork length and stock size. The inverse correlations of plankton abundance with body weight and condition factor (Table 1) and the correlation between the occurrence of specimens with empty stomachs and stock size (Fig. 6) support the assumption that the availability of food affects the body weight of pink salmon. From the tendency that the correlation coefficients increase in the course of time as shown in Table 1, we suggest that the density increasingly affects the size of pink salmon in the open waters of the Japan Sea from April to May.

The most remarkable density-dependent effect at the spawning site is that female can extrude only part of their eggs with high spawner densities (HEARD 1991). KUZNETSOV (1928) pointed out the possibility that areas of spawning grounds where eggs have already been laid are disturbed by other spawners would also become higher with high spawner densities (from ISHIDA 1966). The inverse correlation between spawning biomass and spawning success (Fig. 7A) may mainly reflect these density-dependent conditions associated with spawning. HEALEY (1982) found size-selective mortality in juvenile chum salmon *Oncorhynchus keta* (WALBAUM) during the early sea life. If mortality of pink salmon in the early life stage in the river is size dependent, then larger size of eggs would show higher survival rates. Higher condition factor might produce larger eggs or a higher concentration of energy in each egg. The correlation between condition factor and spawning success (Fig. 7B) might represent this relationship between condition factor and size-selective mortality.

From the results of this paper, we conclude that there are density-dependent effects on the body weight and condition factor of pink salmon in the open waters of the Japan Sea and suggest that the spawning success of pink salmon is affected by the spawning biomass and condition factor.

Acknowledgements

We would like to thank Kosuke NAGANUMA and Yuichi HIROTA for allowing us to use their oceanographical data and for their helpful advice. Yukimasa ISHIDA gave us helpful advice and information regarding the literature. We are grateful to members of the Hokkaido Chuo Prefectural Fisheries Experimental Station, Aomori Prefectural Fisheries Experimental Station, Akita Prefectural Institute for Fisheries and Fisheries Management, Yamagata Prefectural Fisheries Experimental Station, Toyama Prefectural Fisheries Experiment Station, Ishikawa Prefecture Fisheries Research Center, Oki High School of Fisheries, and the Japan Sea National Fisheries Research Institute for providing the biological data.

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日本海に分布するカラフトマスの体重への密度依存的影響について

檜山義明・長谷川誠三・加藤史彦

日本海に分布するカラフトマス*Oncorhynchus gorbuscha*（WALBAUM）の尾叉長，体重と肥満度について，資源量との関係から検討した．1978～1991年に調査船によって採集されたカラフトマスの体重と肥満度は，３月には資源尾数との間に有為な相関関係は見られないが，４月と５月には資源尾数との間に負の相関（$P < 0.01$）があった．空胃個体の出現率は，1989年を除いて，資源尾数と高い相関があった．産卵親魚重量に対する加入尾数の比の対数で表わされる再生産成功率と，産卵親魚量との間には負の相関（$\mathrm{P} < 0.01$）が，肥満度との間には正の相関（$P < 0.01$）があった．これらは，日本海において，カラフトマスの体重・肥満度と再生産成功率に対する密度依存的な影響が存在することを示唆する．