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Changes in Body Size and Age at Maturity of a Chum Salmon, *Oncorhynchus keta*, Population Released from Hokkaido in Japan.

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Changes in Body Size and Age at Maturity of a Chum Salmon, *Oncorhynchus keta*, Population Released from Hokkaido in Japan.

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Abstract

The body size of Hokkaido chum salmon (*Oncorhynchus keta*) at maturity showed a significant decreasing trend from 1979 to 1984 and has leveled off since 1985. A significant negative relationship between the population size and the fork length was observed ($r < -0.8$, $P < 0.001$). In Hokkaido chum salmon population, an average age of a brood-year population at maturity has gradually increased from 3.7 years in 1972 to over 4 years since 1980 brood year. A significant positive relationship between population size and average age of a brood-year population at maturity was observed in the Hokkaido chum salmon population ($r = 0.909$, $P < 0.001$). The result of growth analysis back-calculated from scales showed that the growth reduction occurs after the second year, especially in the third year of oceanic life in Japanese chum salmon population. These synchronous phenomena of both the decrease in body size and the increase in age at maturity would be caused by the negative population-density effect led by the intraspecific competition because of a rise of survival rate and favorable oceanic conditions for Hokkaido chum salmon population. In salmonid enhancement production, therefore, it is extremely important to control a optimum of population system by clarifying the mechanism of population regulation such as density-dependent effect, and by monitoring biological characters of population such as migration pattern, body size, age composition, fecundity, and egg size.

Introduction

Since the 1980s, the biomass of Pacific salmon (genus *Oncorhynchus*) has been increasing throughout the North Pacific Ocean. According to FAO fisheries statistics the annual catch of Pacific salmons in the area averaged 0.72 million tonnes during 1981-1993, and in 1991 exceeded 0.93 million tonnes, which surpassed the historical high. The biomass of chum (*O. keta*) in Japan, sockeye (*O. nerka*) in North America, and pink salmon (*O. gorbuscha*) in North America and Japan is increasing. This increase is thought to have coincided with favorable oceanic conditions and successful artificial enhancement programs (Kaeriyama 1989; Pearcy 1992; Brodeur and Ware 1992; Beamish and Bouillon 1993).

However, with this increase in population size, individual growth reduction has been observed for many Pacific salmon populations, such as Bristol Bay sockeye (Rogers and Ruggerone 1993), Japanese chum (Kaeriyama 1989; Ishida et al. 1993), and Prince William Sound pink salmon (Thomas and Mathisen 1993). These findings suggest that salmon research from a view point of population ecology is very important in order to carry out the stock management and effective artificial enhancement program of Pacific salmon.

It was agreed that an NPAFC science plan must be developed to determine the applicability of planned research activities to the two following critical issues identified by the NPAFC at the First Annual Meeting. (1) The factors affecting current trends in the productivity of the North Pacific Ocean and their impacts on salmonid carrying capacity. (2) The factors affecting changes in biological characteristics of Pacific salmon. These characteristics include growth, size at maturity, age at maturity, oceanic distribution, survival, and abundance (NPAFC 1994).

The aim of this paper is to clarify changes in body size and age at maturity of Hokkaido chum salmon population for the elucidation of population-density-dependent effects on Pacific salmon populations.

Annual change in fork length and average age of adult chum salmon .

A decrease in mean fork length of age 3-5 Hokkaido chum salmon was significant after the late 1970s when the population began to increase exponentially. In the Ishikari River, the mean fork length of age 3-5 female chum salmon showed a significant decreasing trend from 1979 to 1984, and has leveled off since 1985 (Fig. 1A). The average fork length of age 4 female declined by about 9 % from the late 1970s (687 mm) to the early 1980s (638 mm). A significant negative relationship between chum salmon population size in Hokkaido and their fork length was observed ($r<-0.6$, $P<0.001$; Fig. 1B). These negative relationships were also remarked in other many rivers (Table 1).

On the other hand, age composition of a brood year population has changed with recent large returns of Hokkaido chum salmon. The average age for returning adults was about 3.7 years until the 1972 brood year, but it has increased gradually and attained over 4 years since the 1980 brood year (Fig. 2A). A significant positive relationship between population size and average age of a population at maturity was observed ($r=0.9018$, $P<0.001$; Fig. 2B). In this way, the observed decrease in body size has been synchronous with the increase in age at maturity (Kaeriyama 1996).

Growth reduction

Annual growth in fork length of adult Ishikari River chum salmon from 1976 to 1995 was estimated by back-calculation procedures in an allometry formula between scale radius (S, μ m) and fork length (L, mm): $L=0.0358(S-114)^{1.2406}+40$ ($r = 0.9950$, $P < 0.001$), where values "40" and "114" exhibit fork length and focus size at the squamation (Kaeriyama and Bunya 1982; Fukuwaka and Kaeriyama 1994). Growth differences between 1976-1980 (large-size period) and 1985-1995 (small-size period) adults showed the four following results (Table 2):

1) Growth reduction in the third year of ocean life was considerably higher than those in the other years,
2) Growth reduction in the first year of ocean life increased with increasing age,
3) At age 5, growth in the forth year of ocean life extremely decreased,
4) At age 5, growth reduction in the second and the forth years of ocean life were scarcely observed.

These findings suggest that the growth reduction of Hokkaido chum salmon occurs in the ocean life period, especially in the third year when they extend their migration to the eastern North Pacific Ocean and the Bering Sea (Ogura and Ito 1994). Oceanic environment, selection, and heritability by fisheries and hatchery practices may not be the main factor affecting the recent body size changes because of favorable oceanic condition for Pacific salmon and synchronization between the decrease in body size and the increase in average age at maturity. Therefore, population-density-dependent effect appears to have a great potential for the cause of the individual growth reduction of chum salmon returning to Hokkaido.

Conclusion

In the artificial enhancement program and the stock assessment of Pacific salmon, it is extremely important to control an optimum of population system by clarifying the mechanism of population regulation such as population-density-dependent effect, and by monitoring biological characters of population such as migration pattern, body size, age composition, and fecundity.

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Table 1. Relationships between population size and average fork length of Hokkaido chum salmon population. n = number of years of data, a =constant, b = slope, r = the correlation coefficient, and P = the probability that b=0 (*: P<0.05, **: P<0.01, ***: P<0.001).

Area*	River	Age	n	a	b	r	P
OKS	Abashiri	3	32	620	-0.755	-0.4194	*
		4	32	689	-1.406	-0.7133	***
		5	31	715	-0.970	-0.4132	***
	Shari	3	21	632	-1.369	-0.6693	***
		4	21	707	-1.829	-0.8234	***
		5	19	744	-1.798	-0.7730	***
NMS	Shibetsu	3	25	643	-1.524	-0.6911	***
		4	25	703	-1.922	-0.8811	***
		5	23	741	-1.996	-0.8811	***
	Nishibetsu	3	30	644	-1.459	-0.7771	***
		4	36	706	-1.617	-0.8131	***
		5	36	743	-1.626	-0.7376	***
NEP	Tokachi	3	37	636	-0.755	-0.4157	*
		4	37	711	-1.204	-0.5504	***
		5	35	770	-1.740	-0.8359	***
	Kushiro	3	32	635	-1.006	-0.5506	***
		4	34	709	-1.475	-0.7583	***
		5	34	755	-1.649	-0.7456	***
NWP	Shizunai	3	30	629	-0.829	-0.4829	**
		4	34	709	-1.168	-0.6538	***
		5	32	752	-1.380	-0.6344	***
	Yurappu	3	31	653	-0.982	-0.4854	**
		4	31	736	-1.488	-0.7702	***
		5	30	773	-1.287	-0.6051	***
	Shiriuchi	3	31	659	-1.018	-0.6732	***
		4	31	733	-1.723	-0.8011	***
		5	31	772	-1.763	-0.8081	***
NJS	Ishikari	3	40	623	-0.822	-0.570	***
		4	42	693	-1.257	-0.7145	***
		5	40	728	-1.289	-0.6682	***
	Teshio	3	32	636	-1.313	-0.6097	***
		4	34	699	-1.761	-0.8022	***
		5	32	727	-1.471	-0.6242	***

*OKS: Okhotsk Sea area, NMS: Nemuro Strate area, NEP: Northeastern Pacific Ocean area, NWP: Northwestern Pacific Ocean area, NJS: North Japan Sea area.

Table 2. Calculative growth reduction of adult chum salmon returning to the Ishikari River from 1976 to 1995. Annual growth is estimated from the back calculation in allometry formula between the scale radius (S, μ m) and fork length (L, mm): $L = 0.0358\ (S - 114)^{1.2406}+40$.

Age class	Ocean life period	Annual mean growth (mm) 1976-1980	1985-1995	Growth reduction mm	(%)
3	1st year	267	264	3	(1.2)
	2nd year	171	158	14	(8.0)
	3rd year	168	146	22	(13.0)
	Total	606	568	38	(6.3)
4	1st year	268	256	12	(4.3)
	2nd year	165	141	24	(14.7)
	3rd year	147	108	39	(26.4)
	4th year	152	132	20	(13.3)
	Total	732	637	95	(13.0)
5	1st year	276	249	26	(9.6)
	2nd year	140	135	5	(3.7)
	3rd year	131	92	39	(29.9)
	4th year	128	105	23	(18.2)
	5th year	106	116	-10	(-9.5)
	Total	781	697	83	(10.6)

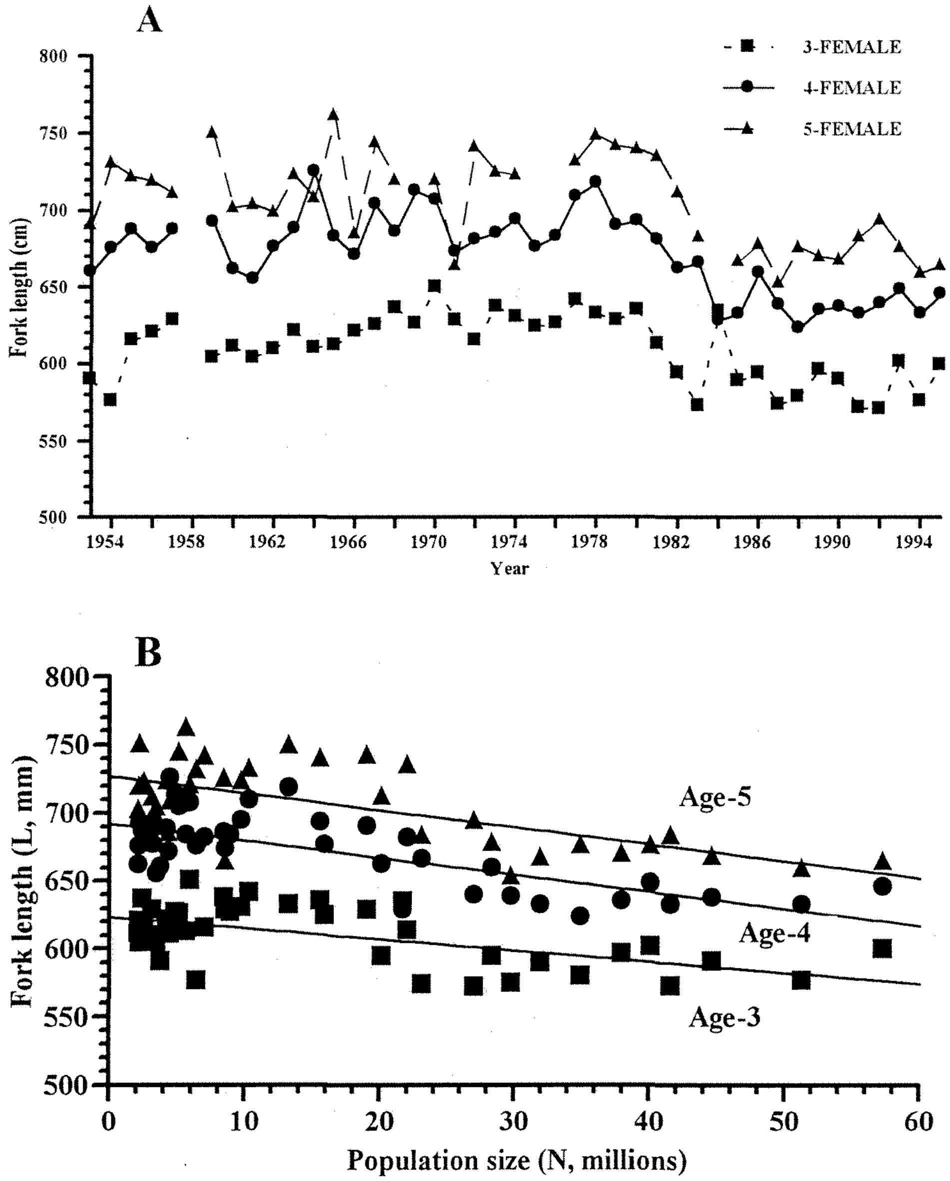

Fig. 1. Annual change in fork length of female adult chum salmon (A), and relationship between Hokkaido population size and fork length of age 3-5 female adult chum salmon returning to the Ishikari River in 1953-1995 (B).

Age 3: $L = -0.822\,N + 623$ (r=-0.5700***)

Age 4: $L = -1.257\,N + 693$ (r=-0.7145***)

Age 5: $L = -1.289\,N + 728$ (r=-0.6682***)

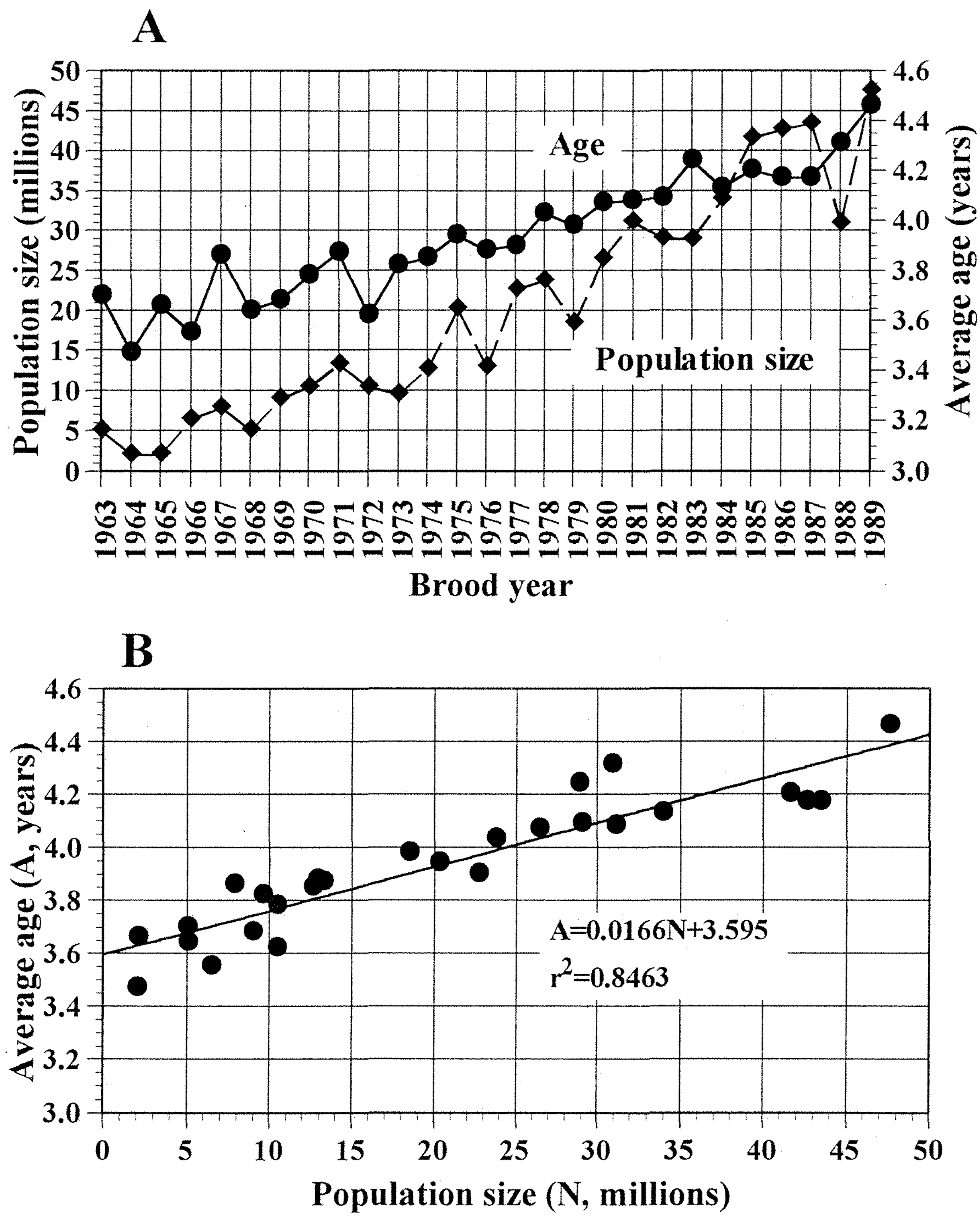

Fig. 2. Annual changes in number and average age of adult chum salmon during the brood years of 1950-1989 (A), and relationship between number (N) and average age (A) at maturity of adult chum salmon during the brood years of 1950-1989 returning to Hokkaido. $A = 0.0166\ N + 3.595$ ($r^2 = 0.8463$ ***).