SPATIAL DISTRIBUTION OF JUVENILE CHUM SALMON
IN THE JAPAN SEA COASTAL WATER

by

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ABSTRACT

We examined spatial distribution of juvenile chum salmon in a coastal water of the Japan Sea off northern Honshu to assess the growing and surviving environments. Juvenile distributions were different with their sizes that were bounded by 70 mm in fork length. While juveniles smaller than 70 mm were distributed in nearshore regions and less affected by water temperature and salinity, larger juveniles inhabited around 28 in salinity and less affected by the distance from shore line. Distribution of larger juveniles was restricted in the low saline water mass, which would be related with physiological tolerance in sea water or prey distribution. Chum salmon juveniles aggregated in a fine scale, which would be attributed to shoaling behavior and small-scale variability of environment. Spatial distributions of juvenile chum salmon would be restricted or determined by oceanographic processes and other biological factors such as prey availability and social interaction. Oceanographic environment affected to distribution of juveniles, and should also affect to growth and survival of juveniles in hatchery reared chum salmon populations.

INTRODUCTION

In anadromous Pacific salmon (_Oncorhynchus_ spp.), mortality is often extensively high soon after they enter the ocean (Pearcy 1992). Most chum salmon (_O. keta_) populations are maintained by artificial propagation in Japan. The development of juvenile rearing techniques provides the recent significant increase of Japanese chum salmon population (Mayama 1985). Hatchery-reared chum salmon juveniles reach coastal waters within several days after release (Mayama et al. 1983; Kaeriyama 1986). Artificial rearing techniques and shortened duration in natural freshwater environments have depressed freshwater mortality of hatchery reared populations. Bax (1983) indicated that early sea mortality in coastal waters is much higher than subsequent stages in the life history of hatchery-reared chum salmon, and would determine adult population level. To assess growing and surviving environments of juvenile chum salmon in coastal waters, we examined spatial distribution of juveniles related to oceanographic environment in the Japan Sea coastal waters off Honshu, Japan.

MATERIALS AND METHODS

We collected chum salmon juveniles by surface trawls and observed water temperature and salinity using a CTD at 2 (A), 5 (B), 10 (C), 15 (D), and 20 (E) km off Fukura, Yamagata Prefecture, from April to May in 1993-1996 (Fig. 1). Surface trawls were towed at a speed of c.a. 4 km h^{-1} by two fishing boats along the shore line in 1 set of 30 minutes or 3 sets of 15 minutes at each station (Suzuki et al. 1994; Suzuki and Fukuwaka In press). Latitudes and longitudes at net sets were measured by a global positioning system. Collected juveniles were fixed in 10% formalin and measured for fork length in millimeter. Catch per unit effort (CPUE) was calculated as number of collected juveniles per 30 minutes trawls.

To detect the fish size changing distribution pattern, Morisita's index of interspecific correlation was estimated for the relationships in spatial distributions between above and below given fork lengths (Morisita 1959). The index ranges from -1 (completely avoid each other) to 1 (completely attract each other), and 0 value indicates that their distributions are not correlated.

Water temperature and salinity were averaged in every 1 m depth at each station for half-monthly structures of the coastal water from April to May, related to juvenile distribution among sampling stations. Cumulative CPUE was calculated to evaluate the relationships to distance from shore line, surface water temperature and surface salinity. The most restricting factor of juvenile distribution was detected by plotting cumulative frequency of CPUE on cumulative frequency of net sets (Yamamuro et al. 1990). In this method, the plotting of the most restricting factor lies in the largest range of cumulative frequency of net sets, and increases most rapidly.

In 1995 and 1996, for distributional pattern of juveniles within stations, we towed a surface trawl in 3 sets of 15 minutes in each sampling station off Fukura in April and May (Fig. 1). Mean density and mean crowding were calculated in each station: $\bar{x} = \sum_{j=1}^{Q} x_j \Big/ Q$, and

$x^* = \sum_{j=1}^{Q} x_j(x_j - 1) \Big/ \sum_{j=1}^{Q} x_j$, where $\bar{x}$ is mean density, x_j is number of collected juveniles by j

set, Q is number of sets at each station, and x^* is mean crowding (Lloyd 1967). Mean crowding-mean density relationship was used to assess the dispersion of juvenile chum distribution (Iwao 1968). The relationship is almost linear, and the slope indicates the distributional pattern: 1, random or regular distribution; < 1, positive binomial distribution; and > 1, aggregate distribution. The intercept indicates the tendency to crowding (positive) or repulsion (negative) of individuals.

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RESULTS

Juvenile chum salmon changed their distribution at around 70 mm in fork length (Fig. 2). Morisita's interspecific correlation was decreased until 70 mm in fork length, and subsequently increased in larger juvenile chum salmon. It shows that the distribution of larger juveniles than 70 mm was not correlated for smaller juveniles.

Low-saline water below 32 was observed in the surface layer of the coastal water until 15 km off in the first half of April off Fukura, reached 20 km off in early April, and then expanded beyond 20 km off in May (Fig. 3). Smaller juveniles than 70 mm were distributed in the nearshore region. Many larger juveniles distributed 10-15 km off in the riverine plume that was low-saline water mass below 32 in surface salinity. Water temperature ranged mostly in 9-14°C during the juvenile collections.

Most juveniles smaller than 70 mm in fork length distributed nearshore regions until 3 km from the shore line (Fig. 4A). Smaller juveniles were observed widely below 14°C in water temperature and in the range of salinity from 20 to 34 (Fig. 4B, C). Larger juveniles were distributed in a narrow range of salinity from 25 to 30 (Fig. 4C). Larger juveniles were few above 14°C in water temperature, which was the same pattern for smaller juveniles (Fig. 4B). Larger juvenile distribution was less affected by distance from shore line (Fig. 4A).

The distance from shore line restricted spatial distribution of juveniles smaller than 70 mm in fork length (Fig. 5A). The plotting of the distance for smaller juveniles draws the most concave line in 3 environmental factors, and lies in the largest range and increases most rapidly. Surface salinity restricted larger juvenile distribution most strongly (Fig. 5B). The plotting of salinity for larger juveniles draws the most concave line in environmental factors.

Distributional pattern of chum salmon juveniles is classified in aggregate distribution within sampling stations, and it appears to be more aggregate for high densities than 20 individuals per set (Fig. 6). The relationship between mean crowding (x^*) and mean density ($\bar{x}$) was linear for spatial distribution of chum salmon juveniles, except for two plottings larger than density of 20 individuals per set. The regression equations were not different between for larger and for smaller juveniles than 70 mm in fork length (ANCOVA, $P > 0.05$), and were commonly expressed by a equation: $x^* = -0.486 + 1.51\bar{x}$, $R^2 = 0.872$, $n = 34$). The slope is significantly larger than unity (t-test, $P < 0.001$), and the intercept ian not different from 0 (t-test, $P > 0.05$). These are consistent with the characteristics of aggregate distribution of individuals.

DISCUSSION

Chum salmon juveniles were changed their distributions at c.a. 70 mm in fork length

(Fig. 2). Chum salmon changes ontogenetically their distributions from streams as spawning and incubating habitat to the sea as growing habitat (see Salo 1991). In the early sea life of chum salmon, fry (30-50 mm in fork length) distribute in estuary and intertidal region, pre-fingerlings (50-80 mm) disperse in inshore region of coastal water, and post-fingerlings migrate to offshore or northward (Mayama et al. 1982; Kaeriyama 1986; Irie 1990; Salo 1991). Our results were approximately consistent with these. While smaller juveniles than 70 mm in fork length were restricted in inshore region, larger juveniles distributed relatively offshore, as also described in our previous report (Suzuki et al. 1994).

The difference of juvenile distributions would be caused by the difference in the ability of habitat selection. While smaller juveniles were restricted in inshore region, and were observed in a wide range of salinity, larger juveniles distributed in a narrow range of salinity around 28. Swimming ability of fishes increase with their size (Beamish 1978). Skeletal structure related to swimming ability was intensified considerably in the pre-fingerling stage (50-80 mm in fork length), and was completed in the post-fingerling stage (80-120 mm) of juvenile chum salmon (Kaeriyama 1986). Chum salmon have osmoreguratory ability in their early life and their juveniles increase salinity preference temporally, which related to ontogenetic habitat shift in their migration (see Clarke and Hirano 1995). While juveniles tolerated high saline waters above 48‰, they preferred to low saline water below 12‰ Cl. (c.a. 22‰ in salinity) (McInerney 1964; Clarke and Hirano 1995). Koshiishi (1986) also showed growth rates of fry (1 g in body weight, c.a. 50 mm in fork length) decreased in high saline waters of 32‰. These indicate that high saline water is not preferred by chum salmon juveniles and inappropriate for their growth. Larger juveniles, therefore, selected actively for water masses around 28 in salinity, while smaller juveniles would have less ability of habitat selection in offshore region of coastal waters.

The upper limits of water temperature would be determined by physiological tolerance in coastal distribution of chum salmon juvenile. Larger and smaller juveniles were distributed below 14°C in surface water temperature off Fukura. Juvenile chum salmon distributed in water masses below 14°C in water temperature commonly in other region (Kaeriyama 1986; Irie 1990). Chum salmon juveniles decreased feed efficiency in rearing experiments in water temperature 15°C (Kaeriyama 1986). Mayama (1985) suggested that coastal water temperature at release timing affects strongly to the abundance of hatchery reared chum salmon population in Japan.

Chum salmon juveniles would form loose aggregations (including < 20 ind.) that show aggregated patterns in the coastal water off Fukura. In our result, the relationship was linear in lower density than 20 ind. set^{-1}, but two plottings in larger density were much higher than the linear. Iwao (1968) found that mean crowding-mean density relationships were linear for various distribution patterns, and developed the analyze method of spatial patterns using the relationship. Although he (1972) did not show apparently in figures, he indicated that

mean crowding-mean density relationship in various quadrat sizes was linear for aggregated patterns of colonies, in which the linear was bending at spatial size of colony and the slope was larger than unity before and after bending. Our result is appeared to be similar to aggregated pattern of loose colonies of individuals (Iwao 1972).

Juvenile chum salmon would form small shoals that aggregated non-socially in coastal waters. School means a synchronized and polarized swimming group that is included by shoal (social aggregation) (Pitcher and Parrish 1993). Salo (1991) reviewed that down-migrating juveniles do not form compact schools in rivers when undisturbed. Schools of juveniles were observed in some estuaries and inlets (Irie 1990). Mayama et al. (1982) suggested that juveniles migrated northward within large schools in the Japan Sea coast of Hokkaido. Shoals of juvenile chum salmon may increase the probability of finding to prey patch or appropriate microhabitat. Zooplankton and fish larvae often forms dense aggregations on surface slicks or front regions of sea water (Mackas et al. 1980; Govoni et al. 1989; Fortier et al. 1992; Brodeur 1997). As fish density rise, randomly located food is found sooner by one fish or another, and non-finders then benefit by moving to the food (Pitcher and Parrish 1993). Brodeur (1997) hypothesized that juvenile salmon utilize neuston aggregations formed by small-scale hydrodynamic processes in their foraging behavior. Small-scale hydrodynamics may form various microhabitats in which the environment is different in salinity, water temperature, prey availability, and so on. In our result, juveniles aggregated in lower density and more aggregated in high density. Shoals of juveniles would select prey patch or microhabitats.

In conclusions, oceanographic environments affect directly to distribution of chum salmon juveniles among sampling stations, and may also affect to growth and survival. The lethal effect of water temperature to juvenile survivals can be partly controlled artificially by release timing (Mayama 1985). Distributional pattern in a fine scale may also affect growth and survival of juvenile chum salmon through predation intensity, prey availability, and competition within a shoal. Further studies on juvenile ecology and survival, and oceanographic processes are needed for assessment and forecasting of chum salmon population dynamics.

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