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# The Migratory Biology and Feeding Habits of Downstream-Migrating Juvenile Chum Salmon *Oncorhynchus keta* in the Amur River of Northeast China

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**Abstract:** The size of chum salmon juveniles is crucial to their survival. In order to understand the population status and migration patterns of juvenile chum salmon in the waters of the Amur River in China, this study investigated the status of juvenile chum salmon resources and their basic biological characteristics in the Amur River and the Ussuri River in China. The results showed that the average catch per unit effort (CPUE) of chum salmon in river margins was 0.140 ind·$10^{-3}$ $m^3$ for the Amur River and 0.255 ind·$10^{-3}$ $m^3$ for the Ussuri River. Chum salmon migrate downstream, mainly in mid-May in the Amur River and in early May in the Ussuri River, and no fish was caught in the rivers after June. Most chum salmon migrated when the water was between 10 and 14 °C. The average FL (fork length) and BW (body weight) of the Amur River samples were 37.1 ± 2.9 mm and 0.42 ± 0.09 g, respectively, while the Ussuri River samples' FL and BW were 34.9 ± 3.7 mm and 0.36 ± 0.08 g, respectively. The empty stomach rate of the samples was zero, and the prey category of the samples was composed of fish, aquatic insects, *copepods*, and *cladocerans*, of which *Ephemeroptera* had the largest percentage index of relative importance (*IRI*%), with a value of 58.45%. The size of the downstream-migrating juvenile chum salmon in this study is similar to the size of those in some other rivers, and the CPUE varies depending on the river conditions.

**Keywords:** resource density; CPUE; stomach content; downstream migration pattern

**Key Contribution:** The paper is the first to study the resource and feeding habits of juvenile chum salmon in China. It will provide basic data for the protection of chum salmon.

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## 1. Introduction

Chum salmon, *Oncorhynchus keta* (Walbaum, 1792), are the second most abundant Pacific salmon species [1] and the most abundant in China [2]. As a typical anadromous species, chum salmon are highly dependent on the freshwater rivers where they breed and live during the early stages of their life [1]. Chum salmon in China can be divided into four geographical populations, of which the Ussuri River and the Amur River have the largest and second-largest populations, respectively [3]. Due to the serious decline in chum salmon stocks in recent decades, it is urgent and necessary to protect their resources. Understanding the resource status of chum salmon is a prerequisite for their protection. Due to the limitations of geographical location, we can only investigate the adult populations and juvenile populations in rivers in China. Some research focuses on returning populations, considering aspects such as their life history [4], resource status [5–8], and biological characteristics [9,10], but the status of juvenile chum salmon in China is poorly understood.

As the recruitment of chum salmon the juvenile resource status largely determined the quantity of return populations in the next few years [11]. Studies of juvenile salmon stocks are helpful to infer the locations and sizes of spawning grounds. Juvenile chum salmon are characterized by downstream migration, which is the result of their long-term adaptation to the ecological environment [12]. The timing of their migration into the sea affects their adaptability to the marine environment, which is highly important throughout their whole lifecycle. Previous research has found that the mortality rates of Pacific salmon during the marine phase of the lifecycle exceed 90%, and it is widely believed that most mortality occurs due to predation in the first few weeks to months after ocean entry [13]. According to the "size-dependent mortality" theory, the size of the juveniles during their migration to the sea is the key factor determining their survival rate: the larger the size, the higher the survival rate [14,15]. Larger members of a cohort are thought to gain a survival advantage over smaller conspecifics due to their decreased vulnerability to predators [15]. In addition, the prey status, which reflects the survival status of chum salmon in the area, is another important factor affecting survival rates [16–18].

To a certain extent, the ecological characteristics of juvenile chum salmon in the Amur River and Ussuri River during the downstream migration period can also reflect the survival rate of the salmon during the period when it enters the sea. Therefore, the long-term monitoring of the characteristics of juvenile chum salmon can be used to predict their survival rate. Juvenile chum salmon are a key component of the resource background, and the understanding of their resource status and biological characteristics is highly important for resource protection.

In view of this, this study monitored the downstream migration of chum salmon in the Amur River and the Ussuri River in China, investigating the timings of downstream-migrating juvenile chum salmon, as well as the resource density and feeding habits of juveniles, so as to understand their resource status and important biological and ecological characteristics. This study provides basic data that can be used for the protection of chum salmon resources.

## 2. Materials and Methods

### *2.1. Study Area*

The Amur River is 4440 km long, 3000 km of which is the boundary river between China and Russia. The river flows into the Okhotsk Strait in Russia, and the drainage area is $1.856 \times 10^6$ km$^2$. About 1400 km upstream of the Amur River estuary, the Ussuri River flows into the Amur River. Sampling of the Amur River occurred near Fuyuan City, approximately 70 km upstream from the confluence of the Amur River and the Ussuri River. A major tributary of the Amur River and the boundary river between China and Russia, the Ussuri River is 890 km long and flows into the Amur River at Khabarovsk. Sampling of the Ussuri River occurred at three stations (Hutou, Raohe, and Haiqing) along the river, in order from upstream to downstream (Figure 1).

### *2.2. Fish Sampling*

Fish sampling was conducted in the Amur River at the Jiaxinzi island station and in the Ussuri River at the Haiqing, Raohe, Hutou stations (Figure 1) from April to May in 2016. The sampling sites were set in the rivers' margins, which were within 30 m of the shoreline and were characterized by a water velocity less than 0.8 m/s and a water depth less than 3 m.

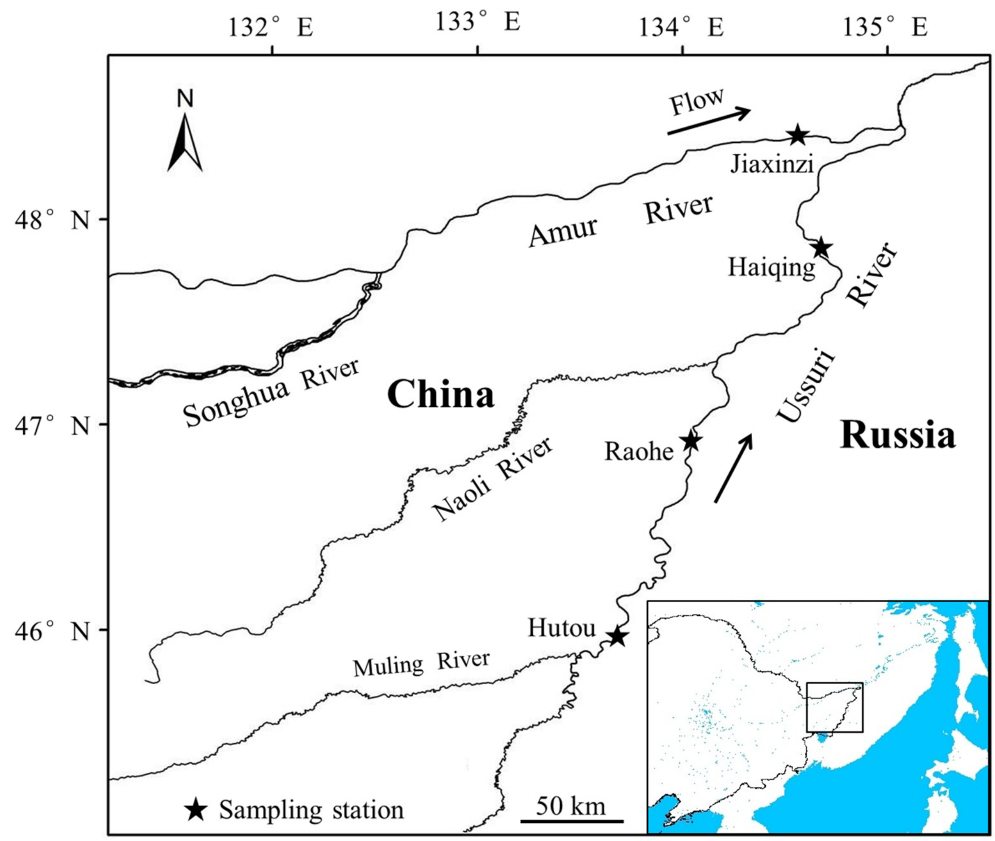


**Figure 1.** Sampling stations. There were four sampling stations in total, of which Jiaxinzi station is in the Amur River and about 70 km upstream of the confluence of the Amur River and the Ussuri River; Hutou, Raohe, and Haiqing stations are in the upstream, midstream, and downstream areas of the Ussuri River, respectively.

A surface wingless fyke net system was used to capture the fish. The fyke net system consisted of a 1.0 m × 1.5 m metal frame, to which we attached a buoy to control the depth of fishing (0–1.0 m) so as to ensure that the upper frame of the net was on the water surface. A flowmeter was installed in the center of the frame to record the amount of water flowing into the net. A tapered net (2.0 mm mesh) 6 m in length was attached to and towed behind the frame, and a "live box", with eight corners suspended from a wooden frame to keep the open upper part above the water surface, was connected to the back of the net. The "live box" was made from mesh with a size of 0.5 mm. The frame was connected to a fixed anchor by a four-line bridle that affixed the corners of the frame to a main line, which was connected to the anchor. During a 24 h continuous sampling, samples were taken directly from the "live box" every 12 h (06:00 and 18:00 every day), and the net was cleaned after collection. The temperature recorder was used to record the water temperature at the sampling station, and the data were recorded every 2 h (HOBO U22-001). The collected fish were transferred to a container with water and were identified at the species level. The chum salmon were measured (fork length mm, body weight g) and a portion of them were randomly selected and fixed in 10% formalin solution as samples for the next analysis, while the rest were released immediately. All animal sampling and experiments were conducted in accordance with the guidelines and approval of the Animal Research and Ethics Committees of the Heilongjiang River Fisheries Research Institute (20160318-001).

### *2.3. Sample Processing and Data Analysis*

The catch per unit effort (CPUE) for juvenile chum salmon was calculated as 1000 × [(catch in each set)/(volume of water sampled in each set)], similarly to past research [19]. These CPUE (number of fish $\cdot 10^{-3}$ m$^3$) values were used to compare relative abundances among stations. The stomach contents of the juvenile chum salmon samples were analyzed using traditional analytical methods. The stomach filling degree of the samples can be divided into six levels, where level 0: empty stomach; level 1: a small amount of food in the stomach; level 2: food accounts for 1/2 of the stomach; level 3: food accounts for 3/4 of the stomach; level 4: food fills the stomach; and level 5: gastric distention. The importance of bait groups was described according to the percentage by number (*N*%), percentage by weight (*W*%), and percentage frequency of occurrence (*F*%).

The specific calculation formulae are as follows:

$$N\% = \frac{\text{Biological weight of particular food item}}{\text{Total weight of all food items}} \times 100\%;$$

$$W\% = \frac{\text{Number of particular food item}}{\text{Total number of all food items}} \times 100\%;$$

$$F\% = \frac{\text{Frequency of occurrence of particular food item}}{\text{Number of stomach with food}} \times 100\%$$

The index of relative importance (*IRI*) [20] and the index of preponderance ($I_P$) [21] were used to evaluate the importance of food items. The higher the parameter value, the higher the importance of the food items. The *IRI* is expressed in the form of a percentage, the percentage index of relative importance (*IRI*%).

$$IRI = F\% \times (N\% + W\%);$$

$$IRI\% = \frac{IRI}{\sum IRI} \times 100;$$

$$I_P = \frac{W_i F_i}{\sum W_i F_i} \times 100$$

where $W_i$ is the percentage by weight for the prey category $i$; $F_i$ is the percentage frequency of occurrence of the prey category $i$. The Shannon–Weaver diversity index ($H'$), evenness ($J'$), and the dominance index ($D$) were used to judge the diversity of the food items' biological composition.

$$H' = -\left(\sum P_i \times \ln P_i\right);$$

$$J' = \frac{H'}{\ln S};$$

$$D = \sum P_i^2$$

where $S$ is the total number of food categories considered at a given taxonomic level and $P_i$ is the percentage by number for the prey category $i$.

The data were analyzed using Excel and the map was processed with Arcgis.

## 3. Results

### 3.1. Capture of Juvenile Chum Salmon

The chum salmon captured in both rivers comprised only fish aged 0. In the Amur River, chum salmon were investigated for 29 days from April 25 to May 25, except for April 29–30, because of the weather. During the investigation period, the density of the samples fluctuated significantly with time, and no sample was collected for six days (Figure 2). The CPUE for chum salmon was high from May 11 to May 17; the maximum value was 0.952 ind$\cdot 10^{-3}$ m$^3$ on May 14. The mean CPUE for the samples during the survey period was 0.140 ind$\cdot 10^{-3}$ m$^3$ (Table 1). The water temperature range of the samples collected during the investigation was 7.81–16.21 °C, and the corresponding water temperature range at the high value of the CPUE for the samples was 10.98–12.16 °C.

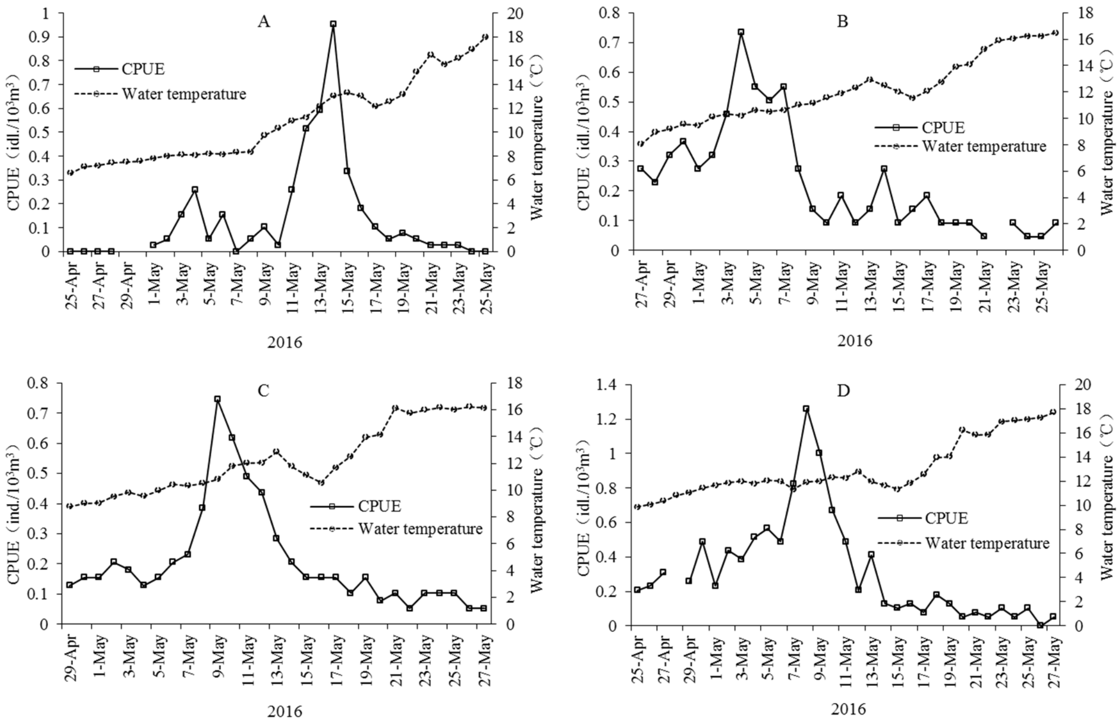


**Figure 2.** The everyday CPUE (number of fish·$10^{-3}$ m$^3$) for the chum salmon sampled at the Jiaxinzi station of the Amur River (**A**) and the Hutou (**B**), Raohe (**C**), and Haiqing (**D**) stations of the Ussuri River from late April to late May (solid line) in 2016. The dotted line represents the water temperature (°C).

**Table 1.** Mean (±SE) CPUE (number of fish·$10^{-3}$ m$^3$) and FL (mean and range) for juvenile chum salmon caught from the Amur River and the Ussuri River in 2016.

| River | Sampling Station | Mean CPUE | Mean FL (mm) | Range of CPUE | Rang of FL (mm) |
|---|---|---|---|---|---|
| Amur River | Jiaxinzi | 0.140 ± 0.213 | 37.1 ± 2.9 | 0–0.952 | 33.5–47.5 |
| Ussuri River | Hutou | 0.234 ± 0.178 | 30.3 ± 1.9 | 0.046–0.734 | 26.9–36.1 |
| | Raohe | 0.209 ± 0.167 | 35.4 ± 2.9 | 0.051–0.746 | 29.7–46.2 |
| | Haiqing | 0.315 ± 0.290 | 36.6 ± 3.4 | 0–1.260 | 31.0–46.6 |
| | Pooled | 0.255 ± 0.227 | 34.9 ± 3.7 | 0–1.260 | 26.9–46.6 |

The chum salmon samples were collected for 91 days at the three stations of the Ussuri River in April and May, including 29, 29, and 33 days at the Hutou, Raohe, and Haiqing stations, respectively (Figure 2). No samples could be collected on May 22 for Hutou station and April 29 for Haiqing station due to the weather conditions. The CPUE values in the time series were almost unimodal with the high values in early May in the three stations. The largest CPUE values of the Hutou, Raohe, and Haiqing stations were 0.734, 0.746 and 1.260 ind·$10^{-3}$ m$^3$, respectively, while the mean values were 0.234, 0.209, and 0.315 ind·$10^{-3}$ m$^3$, respectively (Table 1). The water temperatures of the three sites were similar throughout the survey, and the range was 8.03–17.15 °C.

According to the results, this study showed that the density of juvenile chum salmon has significant time distribution characteristics. The population of the Jiaxinzi station of the Amur River was mainly concentrated in the middle of May, while that of the stations of the Ussuri River were mainly concentrated in early May. It can be seen that the main downstream migration period and water temperature range of the Amur River and Ussuri River populations are basically the same.

*3.2. Size of Samples*

The size of the chum salmon samples collected from the Amur River were slightly larger than those from the Ussuri River (Table 1). The average FL and BW of the Amur River samples were 37.1 ± 2.9 mm and 0.42 ± 0.093 g, respectively, while the values for the Ussuri River samples were 34.9 ± 3.7 mm and 0.36 ± 0.081 g, respectively. Fork length in the range of 35–38 mm was the dominant group, constituting 70.7% of the Amur River samples, and ranging from 34 to 37 mm and occupying 48.4% of the Ussuri River samples (Figure 3).

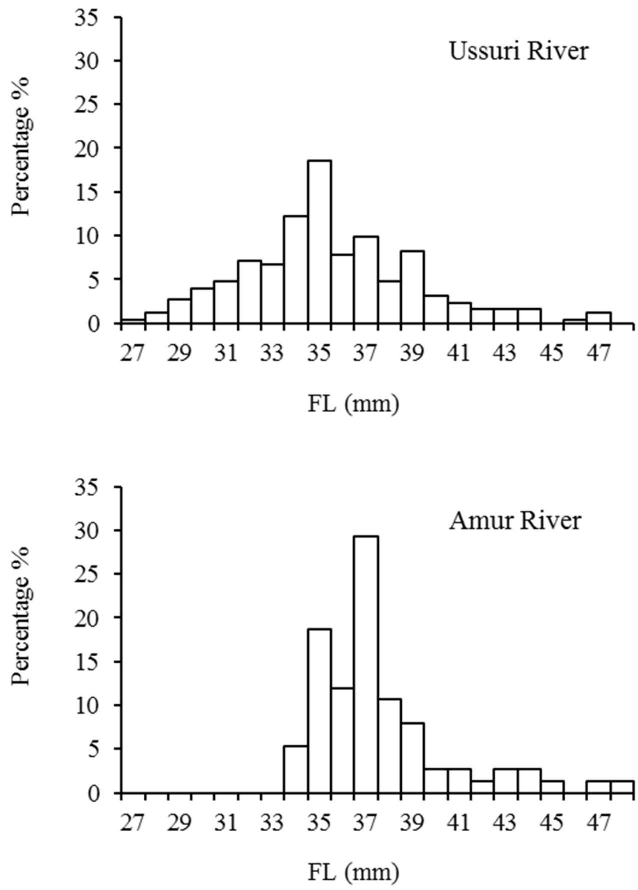


**Figure 3.** Frequency distribution of fork length for the Amur River and Ussuri River samples. The fork length groups were determined using 1 mm sections. The samples from the Amur River mainly occupied the 35–38 mm groups, with a value of 70.7%; meanwhile, for the Ussuri River, the samples fell into the 34–37 mm groups, representing 48.4%.

*3.3. Feeding Habits*

The stomach contents of 63 juvenile chum salmon samples were analyzed and the results showed that the empty stomach rate was zero. The prey categories of the samples were fish, aquatic insects, *copepods*, and *cladocerans* (Table 2). According to the percentage by number, *copepods* accounted for 63.96%, followed by aquatic insects, *cladocerans*, and fish, with *N*% values of 33.49%, 2.36%, and 0.19%, respectively. In terms of the percentage by weight, aquatic insects represented 91.83%, followed by *copepods*, fish, and *cladocerans*, with *W*% values of 6.85%, 1.15%, and 0.18%, respectively. For the percentage frequency of occurrence, aquatic insects accounted for 93.65%, followed by *copepods* (58.73%), *cladocerans* (25.40%), and fish (3.17%). Among the *IRI*% of the prey category, aquatic insects were the highest, accounting for 92.36%, followed by *copepods* (32.73%), *cladocerans* (0.51%), and fish

(0.033%). The results revealed that the $I_P$ values of aquatic insects, *copepods*, *cladocerans*, and fish were 94.41%, 5.47%, 0.065%, and 0.052%, respectively, which was consistent with the *IRI*% values.

**Table 2.** Index of the percentage of relative importance and comprehensive dominance of the food organisms of juvenile chum salmon. The prey categories of samples were fish, aquatic insects, *copepods*, and *cladocerans*. The results showed that *Ephemeroptera* was the most prominent food of juvenile chum salmon.

| Prey Category | Frequency Percentage *F*/% | Percentage by Number *N*/% | Percentage by Weight *W*/% | Index of Relative Importance *IRI* | Percentage Index of Relative Importance *IRI*/% | Index of Preponderance *Ip* |
|---|---|---|---|---|---|---|
| Fish | 3.17 | 0.19 | 1.15 | 4.25 | 0.03 | 0.05 |
| Aquatic insect | 93.65 | 33.49 | 91.82 | 11735.74 | 92.36 | 94.41 |
| *Ephemeroptera* | 80.95 | 22.83 | 68.91 | 7426.89 | 58.45 | 79.84 |
| *Tendipes* | 19.05 | 2.08 | 3.76 | 111.13 | 0.87 | 1.02 |
| *Psychodidae* | 4.76 | 0.38 | 0.57 | 4.51 | 0.04 | 0.04 |
| Unidentified insect | 50.79 | 8.21 | 18.58 | 1360.69 | 10.71 | 13.51 |
| *Copepoda* | 58.73 | 63.96 | 6.85 | 4158.72 | 32.73 | 5.47 |
| *Cyclopoidea* | 57.14 | 56.13 | 6.62 | 3586.12 | 28.22 | 5.42 |
| *Harpacticoida* | 22.22 | 4.15 | 0.05 | 93.36 | 0.73 | 0.02 |
| *Calanoida* | 14.29 | 3.68 | 0.17 | 55.04 | 0.43 | 0.04 |
| *Cladocera* | 25.40 | 2.36 | 0.18 | 64.42 | 0.51 | 0.07 |

Among the food organisms, the *N*% of *Cyclopoidea* was the highest, with a value of 56.13%; the *F*% and *W*% of *Ephemeroptera* larvae were 80.95% and 68.91%, respectively, which were all the highest values. *Ephemeroptera* had the largest *IRI*% with a value of 58.45%, followed by *cyclopoidea* (28.22%) and indistinguishable aquatic insects (10.71%), while the others had values of less than 1%. The $I_P$ of *Ephemeroptera* larvae was the highest, with a value of 79.84%, followed by indistinguishable aquatic insects (13.51%) and *cyclopoidea* (5.42%), and the others had values of less than 2%.

The results of the analysis of the feed biodiversity of juvenile chum salmon showed that the diversity index $H'$ value was 1.32, the evenness index $J'$ value was 0.60, and the dominance index $D$ of the feed organism was 0.52.

## 4. Discussion

### *4.1. Timing of Juvenile Chum Salmon Migration in the Amur River System*

As an anadromous fish, chum salmon hatch and develop in freshwater rivers, making them highly dependent on the river habitat during the early stages of life. The status of juvenile chum salmon stocks can reflect the homing population's resources and the environment of the habitat. In China, chum salmon are mainly distributed in the Ussuri River and the Amur River, and this study was the first to systematically monitor the resource status of juvenile chum salmon. Although the study was only conducted over the course of one year, the temperature and the flow were fairly average in 2016, so our findings can still reflect the basic situation. Previous studies have shown that the vertical spatial distribution of juvenile chum salmon in rivers seems to show no pattern, and there is no significant difference in the distribution at different depths in the river [22]. In horizontal space, juvenile chum salmon are distributed in both the margins and the mid-channels of the river, and are more concentrated at the margins [19]. Because both the Ussuri River and the Amur River are boundary rivers between China and Russia and operations cannot take place on the other side of the river, and because of the limitations of the network the research cannot be conducted in the center of the river, this study only sampled the nearshore waters on the Chinese side. This study showed that the average

CPUE of chum salmon in the river margins was 0.140 ind·$10^{-3}$ $m^3$ for the Amur River and 0.255 ind·$10^{-3}$ $m^3$ for the Ussuri River, values lower than those in the Tanana River (Nenana) and higher than in the Yukon River (Eagle) in northern America [19]. In terms of spatial distribution, the status of the juvenile fish stocks at each sampling site reflects the size of the spawning ground upstream. Thus, this study indicates that the chum salmon resources in the Ussuri River are better than in the Amur River. For the three sampling stations along the Ussuri River, the resource status of chum salmon was characterized by there being more fish downstream and fewer upstream, which may be due to the effect of juvenile fish supplementation via those hatched in spawning grounds between the sites.

Significant fluctuations in the number of downstream-migrating juvenile chum salmon can be found in the time series. Juvenile chum salmon were first caught in the Amur River on May 1; they peaked in mid-May and could not be caught after late May. Because of the limits of the sampling net, low-density juvenile chum salmon stocks were difficult to collect. At the beginning of the investigation, a certain number of juvenile chum salmon could be caught in the Ussuri River (Figure 2), but the status of chum salmon migration before late April cannot be known. Based on the relationship between the density of juvenile chum salmon and environmental factors, there was little difference in the water temperature corresponding to the downstream migration period between the Amur River and the Ussuri River, with the temperature ranging from 10 to 14 °C at the peak of juvenile downstream migration. According to this study, the timing of the migration of the chum salmon in the Amur River and the Ussuri River is different from that in the Tanana River, where the migration period can last until September [19]. This is because the rivers are different in terms of their environment conditions and chum salmon resource status.

The migratory characteristics of juvenile chum salmon are the result of their long-term adaptation to the natural environment and can provide important guiding significance for chum salmon stocking practices. The downstream migration is a key part of the chum salmon's lifecycle, and the downstream migration period determines the time and environmental conditions of their entry to the estuary. The chum salmon survival rate is closely related to their early entry into the ocean phase of life [14,23]. Once the optimal time for downstream migration is missed, the survival rate decreases. Therefore, the enhanced release time of chum salmon should refer to the downstream migration period of natural populations. According to the results of this study, the best time for the enhanced release of chum salmon in the Amur River and the Ussuri River is in early and mid-May, and the corresponding river water temperature range is 10–14 °C. According to the principle that the place of release should be close to the spawning ground, the release sites should be situated in the area upstream of the sampling stations. At present, there are no unified standards or norms for the enhanced release of chum salmon in China. A study of the migration characteristics of chum salmon would be of great significance to the improvement of their enhanced release.

### *4.2. Size and Feeding Habits of Juvenile Chum Salmon*

In this study, the average FL of downstream-migrating juvenile chum salmon was about 4 cm, which is similar to the results from the Yukon River and the Tanana River [19,22], and lower than that from the Chitose River [24]. This may be because, compared to the Chitose River, the climate conditions such as the temperature and ice cover duration of the Yukon River and the Tanana River are more similar to those of the Amur River [25]. The mortality of chum salmon is high in the early stages, especially in the early stages of entering the ocean, and its survival rate is thought to be inversely related to size and growth [26]. On the one hand, chum salmon are very small and easily preyed upon by other animals; on the other hand, their predation ability is weak [13]. If the body size of juvenile chum salmon is larger, they are better able to evade predators and feed and have a higher survival rate, suggesting that "bigger is better" [27]. Therefore, in the artificial enhancement and release of chum salmon, increasing the size of juveniles during the same period can improve their survival rate to a certain extent.

In this study, the empty stomach rate of the juvenile chum salmon was 0, indicating that the feeding of juvenile chum salmon is vigorous and the bait organisms in the water area are abundant. The highest values for the frequency of occurrence and the quantity of food composition of chum salmon were mainly from copepods, and the food weight was mainly provided by aquatic insects because of their large size. This finding is consistent with previous studies, which showed that juvenile chum salmon mainly feed on surface benthos [28–30] and macrozooplankton in coastal waters [30–32]. The food of juvenile chum salmon includes not only cladocerans and small zooplankton, but also large-scale organisms such as aquatic insects. The composition of the chum salmon's food has a large span. Similar results have been found in previous studies [12,33]. Chum salmon tend to choose larger zooplankton [29,34], which are larger and more easily caught. It is difficult for chum salmon less than 5 cm in length to catch food greater than 1 mm [33]. Copepod zooplankton are suitable to meet the food requirements of chum salmon. In this study, copepods were represented in the largest numbers, and similar findings were also found in [35,36]. Therefore, in this investigation of chum salmon habitats, food abundance can be comprehensively determined according to the number of aquatic insect larvae and copepods, so as to provide guidance for the calculation of chum salmon's enhanced release capacity.

## 5. Conclusions

This study systematically investigated the downstream migration patterns and resource density of juvenile chum salmon for the first time by selecting one and three sampling stations in the Amur River and the Ussuri River, respectively. According to our results, the density of the juvenile chum salmon population in the Ussuri River is higher than that in the Amur River, and the migration period is concentrated in early and mid-May. The water temperature range corresponding to the downstream migration peak of chum salmon was 10–14 °C. The migration time and density distribution characteristics of juvenile chum salmon in natural waters have reference significance for the selection of enhancement and release times and locations. The average FL values of chum salmon samples were 37.1 $\pm$ 2.9 mm and 34.9 $\pm$ 3.7 mm for the Amur River and the Ussuri River, respectively. Juvenile chum salmon feed vigorously, and the prey categories of the samples were fish, aquatic insects, *copepods,* and *cladocerans*, of which *Ephemeroptera* was the dominant species. The CPUE of the juvenile chum salmon differed from those from the Yukon River and the Tanana River, while their sizes were similar. Because of the limitations of the research area (the boundary between China and Russia), this investigation could only be conducted on the Chinese side and therefore cannot accurately reflect the resource status of the entire river.

**Author Contributions:** Software, W.L. (Wanqiao Lu); investigation, P.L., W.L. (Wanqiao Lu), and F.T.; resources, W.L. (Wei Liu); writing—original draft, J.W.; writing—review and editing, J.W.; supervision, J.W.; project administration, W.L. (Wei Liu). All authors have read and agreed to the published version of the manuscript.

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**Institutional Review Board Statement:** All animal experiments were conducted in accordance with the guidelines and approval of the Animal Research and Ethics Committees of the Heilongjiang River Fisheries Research Institute (approval code: 20160318-001; approval date: 2016.03.18).

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The datasets used and/or analyzed during the current study are available from the corresponding authors on reasonable request.

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