Abundance of salmon carcasses at the upper reach of an adult salmon trap: Ten years of observation at a tributary of the Chitose River, Hokkaido, northern Japan

Tomiko ITO*[1] AND Miyuki NAKAJIMA[2]

[1]*Hokkaido Aquatic Biology, Hakuyo-cho,* 3-3-5, *Eniwa, Hokkaido,* 061-1434
[2]*Hokkaido Fish Hatchery, Kita-kashiwagi* 3-373*, Eniwa, Hokkaido,* 061-1433*, Japan*

Abstract The abundance and biomass of salmon carcasses (*Oncorhynchus keta* and *O. masou masou*) were studied in a spring-fed tributary, the Naibetsu River, Chitose River system, Hokkaido, northern Japan, during 1998-2008. Almost all adult salmon are caught by an adult salmon trap each fall at the lower reach of the Chitose River for a salmon enhancement program. The abundance and biomass fluctuated annually and seasonally, with two peaks in the fall and winter. The range in carcass biomass was 0.05-10 kg 100 m^{-2} in fall and 0.4-61 kg 100 m^{-2} in winter. In some years, the biomass was greater than the lowest effective biomass for stream production, 5 kg 100 m^{-2}, which was evaluated in previous studies. The total number of carcasses in the fall was significantly correlated with the highest water level at the lower reach of the river, indicating that adult salmon swam over the trap at flood stage. Carcass abundance in winter may depend on the population size spawned in the wild at the upper reach.

Key words : abundance, biomass, fish trap, flood, salmon carcass

Introduction

In the last two decades, studies conducted mostly in the Pacific Northwest have revealed that salmon carcasses are important for production in river and riparian ecosystems (reviewed by Kline *et al*., 1997; Cederholm *et al*., 1999; Ito *et al*., 2006). In rivers, salmon carcass nutrients are consumed directly by benthic macroinvertebrate scavengers and indirectly through benthic algae or fungus by grazers and detritus feeders. Because salmon carcasses are carried to riparian zones by birds, mammals, and floods, they are also available for many terrestrial animals and plants.

The consumption of carcass nutrients by aquatic invertebrates results in the rapid growth and high survival rate of salmon juveniles. For example, the growth rate of juvenile coho salmon (*Oncorhynchus kisutch*) is higher in carcass-rich streams than in streams without carcasses (Bibly *et al*., 1998; Wipfli *et al*., 2003), and the return rate of adult coho salmon is higher when their juveniles grow in carcass-rich years than in carcass-poor years in the same stream (Michael, 1995).

In northern Japan, almost all of the adult chum salmon (*O. keta*) that return to spawn have been captured over the past several decades by adult salmon traps in lower reaches of rivers for artificial fertilization and enhancement (Nagata, 2003). However, since the mid 1990s, the adult catch has decreased in many rivers from mid-October to November (Nakajima and Ito, 2003).

We studied the abundance of carcasses in Naibetsu River, a tributary of the Chitose River, which is located upstream from adult salmon traps, in Hokkaido, northern Japan from 1998-2008 and reported the abundance of carcasses, mass-loss process, and the positive effect of carcasses on benthic amphipod reproduction based on the first 5 years of observation (Ito *et al*., 2004, 2005; Kusano and Ito, 2005). The aims of the present study were to estimate the seasonal and annual fluctuation of carcass abundance and to elucidate the factors influencing the abundance based on observations over 10 consecutive years.

* E-mail: tobikera@siren.ocn.ne.jp

Methods

Study site

The Naibetsu River, a second-order spring-fed stream, originates 50 m above sea level, meanders through a deciduous forest for about 3 km, and flows into the Chitose River, where almost all adult salmon are caught at the lower reach for artificial enhancement (Fig.1). In 1964, a 2-m-high dam (without a fish road) used for city water was constructed 300 m upstream from the mouth (the point where the Naibetsu River flows into the Chitose River), which prevents farther upstream migration by salmon. The study site was approximately 2100 m^2 in area (300 m in length and 7 m in average width) between the dam and stream mouth.

At the study site, the stream discharge is about 0.33 $m^3\ s^{-1}$ and the gradient is about 0.5° as measured from a 1/25000 map. Crowfoot (*Ranunculus yezoensis*) and water speedwell (*Veronica americana*) reside in the middle and edge of the stream. Large boulders are absent and a few fallen trees exist, but some pools can hold carcasses. The water temperature ranged from 4.2℃ (January 16, 2000) to 11.7℃ (September 8, 2006), and electric conductivity (HORIBA ES-12; Horiba, Tokyo, Japan) ranged from 5.5 ms m^{-1} (October 10, 2000) to 9.9 ms m^{-1} (September 9, 2001).

Adult salmon traps were set 7 km downstream of the study site from late August to early December every year (Fig. 1). Every fall since 2004, a number of male chum salmon have been released on the upper side of the trap by the Chitose Salmon Museum for observation by the general public. Other features of the study site are shown in Ito *et al*. (2005).

Methods

Carcasses were counted and weighed from September to March 2008, biweekly from 1998 to 2000 and weekly during 2000-2008 to estimate their abundance and biomass. At each visit, the carcasses were counted, identified as to species, and wet weighed to the nearest 0.1 kg using spring scales (Kamoshita or Zanko). Following the data collection, the carcasses were gently placed back in the position where they were found. In subsequent visits, if the same carcass was present at the study site, it was counted and weighed again. Abundance and biomass of carcasses were calculated in 100m^2 units at each visit.

Each carcass was tied at the mouth and opercle with a numbered tape. The total number of carcasses found in the study site was noted by counting the plastic tapes used in each season. The tapes were not used in 1998 and 1999, so we substituted the maximum number counted first for the total number in a season. Therefore, the total number was underestimated in 1998 and 1999.

Because we found many carcasses from mid-January to mid-February 2008, we weighed 20 randomly chosen carcasses and substituted the total weights at each visit.

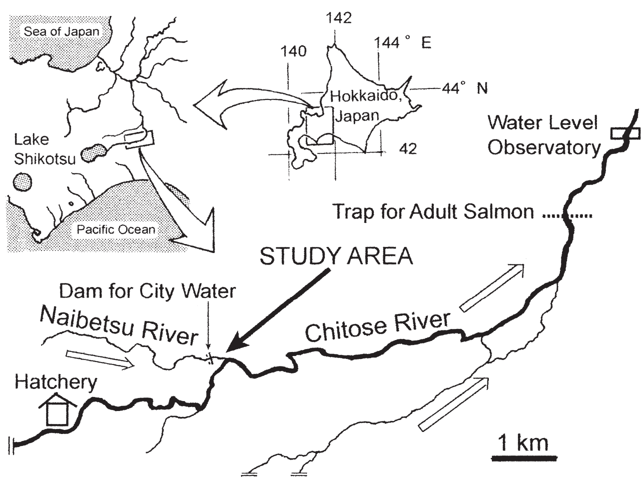

Fig. 1 Map of the study site, adult salmon trap, and water level observatory in the Chitose River system. Open arrows along the river show the direction of flow.

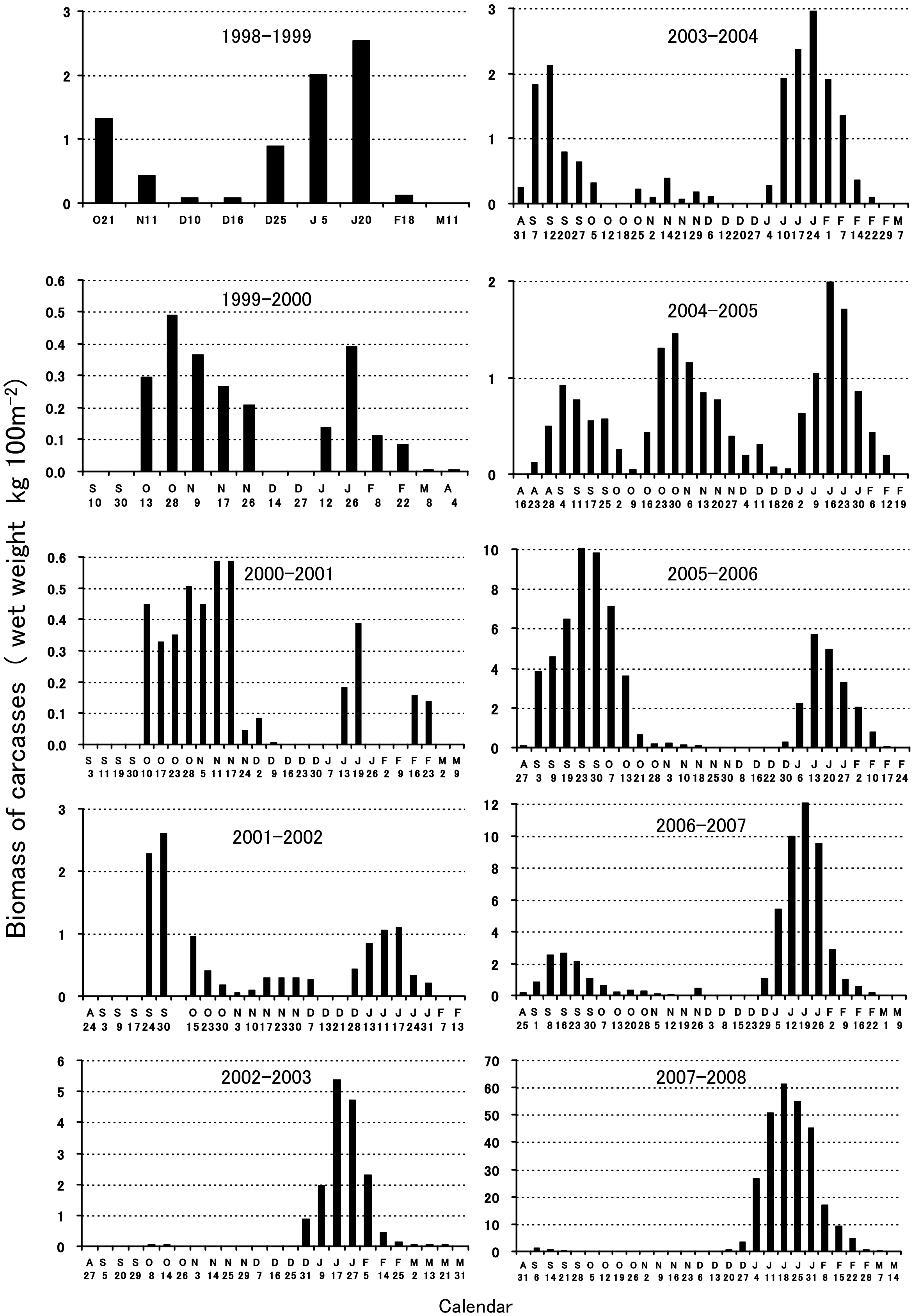

Fig. 2 Biomass of salmon (chum and masu) carcasses at the study site, 1998-2008.

Results

Species of salmon carcasses

Almost all carcasses were chum salmon, but a few masu salmon (*O. masou masou*) were found almost every year: 1/44 (1 masu among a total of 44 carcasses) in 1998 and 1999, 1/7 in 1999 and 2000, 4/8 in 2000 and 2001, 1/48 in 2001 and 2002, 1/63 in 2002 and 2003, 0/66 in 2003 and 2004, 0/67 in 2004 and 2005, 0/199 in 2005 and 2006, 1/183 in 2006 and 2007, and 2/746 in 2007 and 2008. The masu salmon carcasses were found from September to November, but never in other months.

Influence of release by the Chitose Salmon Museum on carcass abundance

In every fall of 2004-2007, a number of male chum salmon have been released on the upper side of the trap by the Chitose Salmon Museum. Numbers of the salmon released and numbers of male chum carcasses found in the study site after the release dates were 300 and 5 in 2004, 400 and 1 in 2005, 200 and 1 in 2006, and 80 and 0 in 2007. Number of the carcasses was not correlated to number of the salmon released (r=0.422, p>0.05), suggesting that the salmon release by the museum did not influence on the carcass abundance in the study site.

Seasonal changes in carcass biomass

Carcass biomass at the study site is shown in Fig. 2. The biomass in the fall fluctuated from one peak (9 years except 2004) to two peaks (2004). The maximum biomass in the fall ranged from 0.05 kg 100 m^{-2} (2002) to 10 kg 100 m^{-2} (2005). The winter biomass peaked in mid or late January and decreased to zero until February or March. Maximum biomass in the winter ranged from 0.4 kg 100 m^{-2} (2000 and 2001) to 61 kg 100 m^{-2} (2008).

Annual fluctuation in carcass abundance

The total number of carcasses in the study site is shown Fig. 3. In the fall, carcasses ranged from 1 (2002) to 28 (2001), while in the winter, they ranged from 3 (2000 and 2001) to 746 (2008). A gradual increase was observed in the number of carcasses found in winter during the last 3 years of the study, and they were extremely abundant in 2008.

Because many adult salmon are caught at the fish trap in the Chitose River, carcass abundance may have been influenced not only by the size of the salmon population migrating up the river but also by the high water level over the trap. We inspected the quantitative relationship between the carcass abundance and total adult catch in fall at the fish trap (National Salmon Resources Center, 1995-2008) and the highest water level at the observatory in the lower reach of the river near the trap (Fig. 1, http://www1.river.go.jp/cgi/SrchWaterData, access date January 31, 2008; Ishikari River Development and Construction, unpublished data) (Fig. 4). Based on the Pearson test, the total number of carcasses was not correlated with the total adult catch (Fig. 4A, p = 0.57), but it was significantly correlated with the highest water level (Fig. 4B, p = 0.01) in the fall. When we analyzed the influential factors of winter carcasses, we omitted the extremely large number found in 2008. The total carcass number in winter was not correlated with either the total salmon catch in fall (Fig. 4C, p = 0.86) or the highest water level in winter (Fig. 4D, p = 0.07).

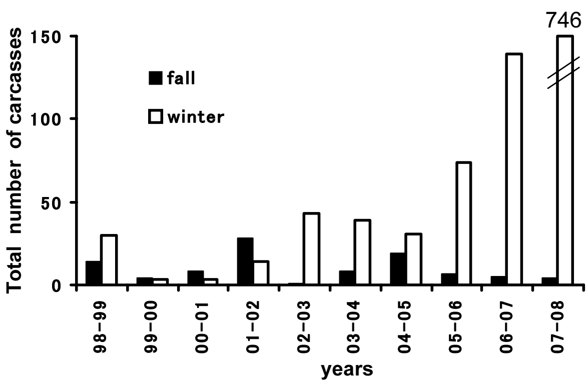

Fig. 3 Total number of salmon carcasses at the study site, 1998-2008.

Discussion

Abundance and biomass of salmon carcasses fluctuated seasonally and annually at the study site (Figs. 2, 3). In the fall, carcass abundance was correlated with the highest water level downstream of the fish trap (Fig. 4B), indicating that the abundance during this season was highly affected by flooding over the trap. This conclusion supports the results from the first 5 years of observation at

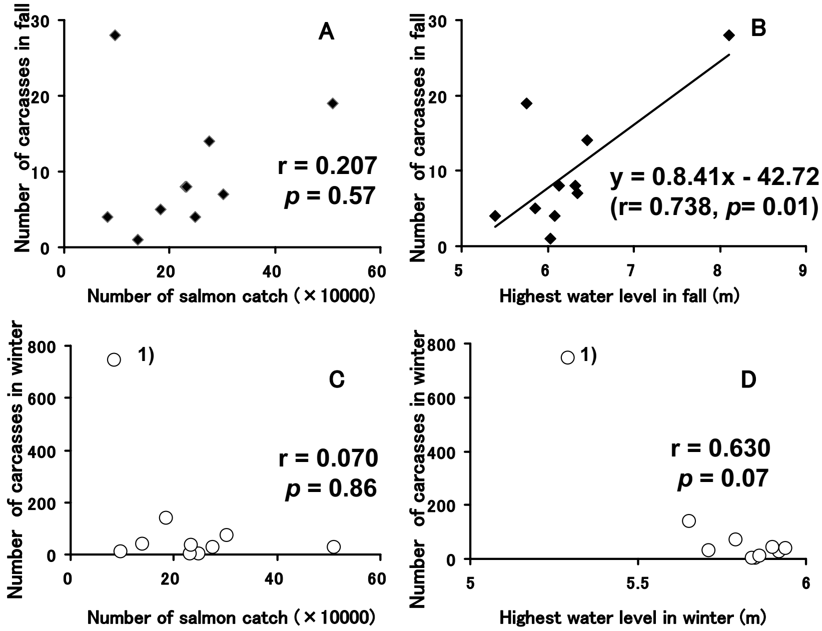

Fig. 4 Relationship between the total number of carcasses in Naibetsu River and the total adult catch or the highest water level at the lower reach of the Chitose River. A. Total number of carcasses in fall versus the total adult salmon catch in fall. B. Total number of carcasses in fall versus the highest water level in fall. C. Total number of carcasses in winter versus the total adult salmon catch in winter. D. Total number of carcasses in winter versus the highest water level in winter. 1) Data omitted for statistical analysis; see text.

this study site (Ito *et al*., 2005). Adult salmon might be stimulated by high flow rate at flood to move upstream (Banks, 1969).

Because the carcass abundance in winter was not correlated with either the total salmon catch in fall or the highest water level in winter (Fig. 4C, D), some adult salmon may have migrated and spawned in the upper reaches of the Chitose River during that season. Moreover, the annual fluctuation in their abundance, including their high abundance during 2007-2008, may have been influenced by the size of the winter population each year. This estimation coincides with our previous study (Ito *et al*., 2005).

The influence of salmon carcasses on stream productivity has been studied in the field and laboratory. Bibly *et al*. (2001) reviewed 26 field surveys in the Pacific Northwest and showed that the increase in carcass-derived nitrogen was first detected in the muscle of juvenile coho salmon at sites with around 5 kg 100 m^{-2} of carcasses. In the laboratory, the adult weight of a detritivorous caddisfly increased about 10 mg by adding a small piece of salmon flesh to a rearing bottle (20 cm^2 bottle bottom area; 0.5 kg 100 m^{-2}) (Ito, 2005). Therefore, 5 kg 100 m^{-2} in field studies and 0.5 kg 100 m^{-2} of biomass in laboratory studies are the lowest estimated effective carcass biomass.

Among 20 seasons, we found four in which the biomass was higher than 5 kg 100 m^{-2} (winter 2003, fall 2005, winter 2007, and winter 2008) and among 15 seasons, they were higher than 0.5 kg 100 m^{-2} (all except fall and winter 1999-2000, winter 2001, fall 2002, and fall 2007) (Fig. 2). Therefore, large quantities of carcasses were present at the study site in some seasons despite the presence of the adult salmon trap at the lower reach in the fall.

Because the river originates from a large lake (Fig. 1), the fluctuation of water discharge from the Chitose River is small compared to other rivers that flow from mountains in Hokkaido (Japan River Association, 1974-2000). Therefore, the possibility exists that adult salmon swimming over traps would be more numerous in mountain streams. In fact, a biomass greater than 5 kg 100 m^{-2}, the lowest effective biomass for wild populations of salmon (Bibly *et al*., 2001), was observed in several other streams in northern Japan (Nakajima and Ito, 2003; Nagasaka and Nagasaka, 2004). The effects of salmon carcasses on stream productivity warrant study in northern Japan.

Acknowledgments

We thank Mr. Kazutaka Shimoda and Mr. Katsumi Takeuchi, Hokkaido Fish Hatchery, and Ms. Yorika Arakane, Chitose Salmon Museum, for their help with our study. Our sincere thanks are due to the anonymous referee for his valuable comments.

References

Banks, J. W.（1969）. A review of the literature on the upstream migration of adult salmonids. *Journal of Fish Biology*, **1**, 85-136.

Bibly, R. E., Fransen, B. R., Bisson, P. A. and Walter, J. K.（1998）. Response of juvenile coho salmon（*Oncorhynchus kisutch*）and steelhead（*Oncorhynchus mykiss*）to the addition of salmon carcasses to two streams in southwestern Washington, U.S.A. *Canadian Journal of Fisheries and Aquatic Sciences*, **55**, 1909-1918.

Bibly, R. E., Fransen, B. R., Walker, J. S., Cederholm, C. J. and Scarlett, W. J.（2001）. Preliminary evaluation of the use of nitrogen stable isotope ratios to establish escapement levels for Pacific salmon. *Fisheries*, **26**, 6-14.

Cederholm, C. J., Kunze, M. D., Murota, T. and Shibatani, A.（1999）. Pacific salmon carcasses: essential contributions of nutrients and energy for aquatic and terrestrial ecosystems. *Fisheries*, **24**, 6-15.

Ito, T.（2005）. Effect of salmon carcasses on larvae and adults of a detritivorous caddisfly, *Lepidostoma satoi*（Kobayashi）: a laboratory experiment. In: Proceedings of the 11th International Symposium on Trichoptera（K. Tanida and A. Rossiter, eds.）pp. 189-197. Tokai Univ. Press, Kanagawa.

Ito, T. Nakajima, M. and Shimoda, K.（2004）. Mass loss of chum salmon carcasses: observation in field and laboratory. *Scientific Reports of the Hokkaido Fish Hatchery*, **58**, 1-7.

Ito, T., Nakajima, M. and Shimoda, K.（2005）. Abundance of salmon carcasses at the upper reach of a fish trap. *Ecological Research*, **20**, 87-93.

Ito, T., Nakajima, M. Nagasaka, A. and Nagasaka, Y.（2006）. Effect of salmon carcasses in river and riparian ecosystem—review until around 2005. In: An introduction to environmental ecology of fishes: interaction between fish and their habitat, from the alpine streams to the abyssal depth（T. Saruwatari, ed.）pp. 244-260. Tokai Univ. Press, Kanagawa.（In Japanese）

Japan River Association（1974-2000）. River discharges year book of Japan. 24-53.（In Japanese）

Kline, J. R. T. C., Goering, J. J. and Piorkowski, R. J.（1997）. The effect of salmon carcasses on Alaskan freshwaters. In: Freshwater of Alaska, ecological syntheses（A. M. Milmer and M. W. Oswood, eds.）pp. 179-204. Springer, New York.

Kusano, H. and Ito, T.（2005）. Effect of salmon carcasses on egg production of a freshwater amphipod, *Jesogammarus jesoensis*: a field observation. *Limnology,* **6**, 79-84.

Michael, J. H. Jr.（1995）. Enhancement effects of spawning pink salmon on stream rearing juvenile coho salmon: managing one resource to benefit another. *Northwest Science*, **69**, 228-233.

Nagasaka, A. and Nagasaka, Y.（2004）. Effects of salmon-derived nutrients on stream water quality and riparian vegetation in Hokkaido, northern Japan. *Annual Reports of the Interdisciplinary Research Institute of Environmental Sciences*, **23**, 109-117.（In Japanese with English abstract）

Nagata, M.（2003）. Chum salmon, *Oncorhynchus keta*（Walbaum）. In: Fisheries and aquatic life in Hokkaido（Y. Ueda et al., eds.）pp. 132-137. Hokkaido News Paper, Sapporo.（In Japanese）

Nakajima, M. and Ito, T.（2003）. Aquatic animal colonization of chum salmon carcasses in Hokkaido, northern Japan. In: Nutrients in salmonid ecosystems: sustaining production and biodiversity（J. G. Stockner, ed.）, pp. 89-97. *American Fisheries Society, Symposium*, **34**. Bethesda, MD.

National Salmon Resources Center（1999-2008）. Database on biological assessment of Pacific salmon populations in Japan, 1998-2007. National Salmon Resources Center, Salmon Database, pp. 8-15.（In Japanese）

Wipfli, M. S., Hudson, J., Caouette, J. and Chaloner, D. T.（2003）. Marine subsidies in freshwater ecosystems: salmon carcasses increase the growth rates of stream-resident salmonids. *Transactions of the American Fisheries Society*, **132**, 471-480.

摘　　要

ウライ（サケ親魚捕獲柵）上流における サケマス産卵後死体の数量： 北海道千歳川支流における10年間の記録

伊藤富子・中島美由紀

最近20年間に主に北アメリカ太平洋岸で行われた研究により，サケマス類の産卵後死体（以下，ホッチャレ）は河川と陸上のさまざまな生物に利用され，水域と陸域の生産性を高めることが明らかになってきた．日本においても河川とその周囲の生態系に及ぼすホッチャレの影響についての研究が進みつつあるが，今後の進展のためには，ホッチャレの数量と現存量を把握しておく必要がある．筆者らは，1998年から10年間，北海道千歳市千歳川水系のウライ（サケ親魚捕獲柵）上流にある支流・内別川において，サケマス類（大多数のシロサケとごく少数のサクラマス）のホッチャレの数量を調べた．そのうち最初の5年分のホッチャレ数量とその分解消失過程，および底生動物の1種オオエゾヨコエビの繁殖に及ぼすホッチャレの効果については，すでに報告した．本論文ではその後の5年分のデータを加えて10年間の調査結果をまとめた．ホッチャレの現存量はほぼ秋と冬にピークのある2峰型の季節変動を示し，年による変動も大きかった．この10年間，毎年のホッチャレ現存量の最高値は，秋 0.05－10 kg 100 m^{-2}，冬 0.4－61 kg 100 m^{-2}であり，既往の研究により河川生物の現存量に影響があるとされている量（野外調査で5 kg 100 m^{-2}，室内実験で0.5 kg 100 m^{-2}）をときどき上回ることが明らかになった．ホッチャレ数の年変動も大きかったが，秋のホッチャレ数は千歳川の日水位最高値と相関していたことから，増水時にウライを乗り越えて上流に上った親魚の一部が内別川で産卵しホッチャレになるものと考えられた．増水時にはウライを越える水位になると同時に，流速の増大により親魚の向流性が刺激され，活発に遡上するものと推察された．冬のホッチャレ数は秋の捕獲親魚数とも千歳川の水位とも相関しないことから，冬に千歳川水系で自然産卵する群の個体数変動を反映しているものと推測された．大きな湖から発する千歳川に比べ，山地から始まる河川では水位変動がはるかに大きいので，ウライを乗り越えて上流で産卵するサケマス類も千歳川水系よりも多いと推測される．従って，人工ふ化放流のため下流のウライでサケ親魚を捕獲している日本においても，河川とその周囲の生態系に及ぼすホッチャレの影響を研究する必要がある．