Tissue Degeneration in Chum Salmon and Carrying Capacity of the North Pacific Ocean

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Abstract: Seasonal, geographic and interannual occurrence of chum salmon (*Oncorhynchus keta*) with softened (flabby) muscles was related to oceanic abundance of salmon, their lengths, and maturity. The relative frequency of flabby chum was different in various years, and varied during the feeding season in various parts of the ocean; however, their frequency was greatest where concentrations of salmon were dense. The proportion of flabby chum varied with size and degree of maturity. As chum grew and became mature the frequency of flabbiness decreased. I suggest that during growth and maturation flabby individuals either die or recover, depending on the extent to which they were affected. The cause of tissue degeneration is most likely poor quality food where salmon aggregate. However, the condition is probably exacerbated by high densities in some regions. This suggests that the carrying capacity of the North Pacific is nearly reached.

INTRODUCTION

In recent years the abundance of Pacific salmon has reached a high level. Over 900,000 tons were taken by all nations in the North Pacific in 1995. This value is close to the historic maximum. This period of increase in the abundance of natural salmon stocks coincided with a period of large scale enhancement. The result was the creation of a large stock of chum salmon (*Oncorhynchus keta*), particularly by Japan. In terms of biomass this is the largest stock of salmon in the Pacific. Since the early 1980s Japan has been releasing nearly two billion young chum salmon annually. By 1990 the return of chum released from hatcheries in Honshu and Hokkaido (Japanese chum) exceeded 200,000 tons. The appearance of such a quantity of fish in the ocean, which had never before been recorded in conventional ranching areas, could not help but change the ecology of the area. Japanese chum salmon began to predominate in regions which had previously been occupied mostly by chum from Russian rivers (Russian chum), and chum salmon became the main consumer of food resources in the North Pacific. Signs now indicate that the raised abundance has begun to affect the stocks of salmon, primarily chum salmon themselves. Hence, beginning from the 1970s the rise in the abundance of chum from Japanese hatcheries was accompanied by a decline in most of the Asian stocks. From the 1970s the increase in chum salmon reared at Japanese hatcheries was associated with a drop in their mean length and weight, and a rise in the mean age at maturation (Ishida et al. 1993; Kaeriyama 1996).

We noted another phenomenon possibly caused by high density of salmon in feeding areas. In 1994 we found and described mass softening of chum salmon body tissues. The proportion of fish having softened skeletal muscles varied between 35 and 60 percent in various areas and seasons. Such fish also had an unusual herring-shaped elongated body (Gritsenko et al. 1995). We call this condition "flabby chum".

This paper describes the spatial and temporal distribution of flabby chum, and its relationship with salmon densities. Causes and mechanisms of degeneration of tissue are suggested.

MATERIALS AND METHODS

Studies were conducted between April and October, 1994–1998, in the Bering Sea and North-West Pacific in waters adjacent to the East Kamchatka and Kuril Islands beyond territorial waters, but within Russia's 200-mile economic zone. Driftnets of 60 mm mesh size were used. In addition, pink salmon (*O. gorbuscha*) taken from fixed seines off southwest and southeast Sakhalin in 1995 were examined.

Fish to be examined were collected from nets immediately after lifting the catch on deck. Species composition of the catch was determined, and condition of all species of salmon was visually evaluated.

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Chum and other species of salmon were classified by body shape and degree of tissue resiliency into "fair" or "normal" (n), "poor" or "flabby" (f), and intermediate (sf). Normal fish were salmon-shaped with elastic muscles, while flabby ones were elongated, with herring-like bodies, and a noticeable loss of resiliency in muscles, and loss of scales. Sampling for quality of salmon was occasional in 1994 and 1995, and throughout the whole season of investigations in 1996–1998. In 1996 sampling was from four ships simultaneously over the entire summer feeding area of Asian salmon; these data were used to describe the spatial and temporal changes in chum salmon quality.

Sampled salmon were measured for length (mm fork length), and the state of maturity of gonads was assessed. The stages of chum gonand maturity were estimated according to the scale by Murza and Christoforov (1991) as follows: Stage I (juveniles), gonads are like a thin transparent thread, blood vessels are absent, sex is not determined; Stage II, ovaria are a bit larger, semitransparent, color is yellow or sky-blue; there is one major blood vessel in each gonad; the largest oocytes are visible; testes are elastic and pink; Stage III, the gonads fill about 1/3 of the abdominal cavity, not transparent; the ovary color is yellow, the testis pale-pink, testis borders do not flow when cut, the oocytes have different sizes; Stage IV, gonads are of maximal size and occupy the greater part of the cavity, blood vessels are well developed, oocytes are full size, testis borders flow when cut, there is one drop of sperm when the abdomen is pressed; Stage V, eggs (ovulation), or liquid sperm (spermiation) flow from genital pores when abdomen is pressed. During intermediate stages (II-III, III-IV) gonad size is the same as in the preceding stage, and gonad cell content is the same as at the next stage.

We examined published references on fish pathology. The most common pathology appears to be infestation with endoparasitic protozoans such as mixo-and microsporidia, which may cause a pronounced softening of the muscles in some sea fish (Shulman 1966; Voronin 1983). Therefore a parasitological analysis of tissues was carried out in 1997 to investigate the possible causes and mechanisms of degenerative changes. Muscles, kidneys and liver of 125 samples (100 f and 25 n) were examined microscopically to determine the presence of endoparasitic protozoans and helminths. Intestines of chum salmon (from pylora to anus) were also examined for helminths (Golovin and Klovatch 1999).

RESULTS AND DISCUSSION

Seasonal and Geographic, Occurrence of Flabby Chum Salmon

Flabby chum salmon exhibited a herring-shaped body, softened musculature, and, as a rule, a considerable loss of scales. Body height/length ratio in normal chum varied within 0.23–0.27; in flabby chum (f) and (sf) this ratio was between 0.18 and 0.22. Condition factor of flabby chum was usually lower than in normal individuals. Among the other species of salmon few fish had an unusual body shape and flabby muscles.

Flabby chum salmon were abundant among large catches indicating dense concentrations. The condition appears to be associated with high densities at feeding grounds. Some individual pink salmon with a similarly degenerated skeletal musculature had previously been recorded off Southeast Sakhalin during years of extremely high abundance, for instance in 1991. In 1995 we examined pink salmon taken from fixed seines off Southeast and Southwest Sakhalin. There were no flabby fish among the small stock of pink salmon off Southwest Sakhalin, but they did occur there in the mixed concentrations of Russian and Japanese chum salmon, and in the abundant chum stock off Southeast Sakhalin.

In 1996 our surveys covered the entire range of Asian chum salmon between the northern Bering Sea and South Kuril Islands, including the Bering Sea (regions 1 and 2 in Fig. 1), East Kamchatka (region 3), and the Pacific side of the North and South Kuril Islands (regions 4 and 5). The monthly variations in percentage of flabby chum salmon in the Bering Sea on the one hand, and off East Kamchatka and North Kurils on the other hand followed opposite trends (Fig. 1). The proportion of flabby fish off East Kamchatka between May and August increased from 26.6% to 82%, whereas in the Bering Sea it decreased between June and October from 61% to 3.2%. This occurrence of flabby chum coincides with the migration of Japanese chum (Kondo et al. 1965; Neave et al. 1976; Ogura 1994; Myers et al. 1996) which appear in Russian waters in late May and June (Fig. 2). A few fish move to East Kamchatka, but most pass to the Bering Sea through the Aleutian chain straits and scatter in the northern part of that sea. In August the maturing Japanese chum migrate south along Kamchatka intermingling with chum feeding in that area. Later these stocks join and move along the Kuril chain to the islands of Japan. The highest proportion of flabby chum in the Bering Sea occurred in late June (about 60%), at East Kamchatka in August (about 80%), and off South Kurils in October (about 80%). At these times the proportion of Japanese chum in these areas is the largest, hence concentrations of chum are the most dense.

Fig. 1. Geographical and seasonal distribution of "flabby" chum salmon in 1996.

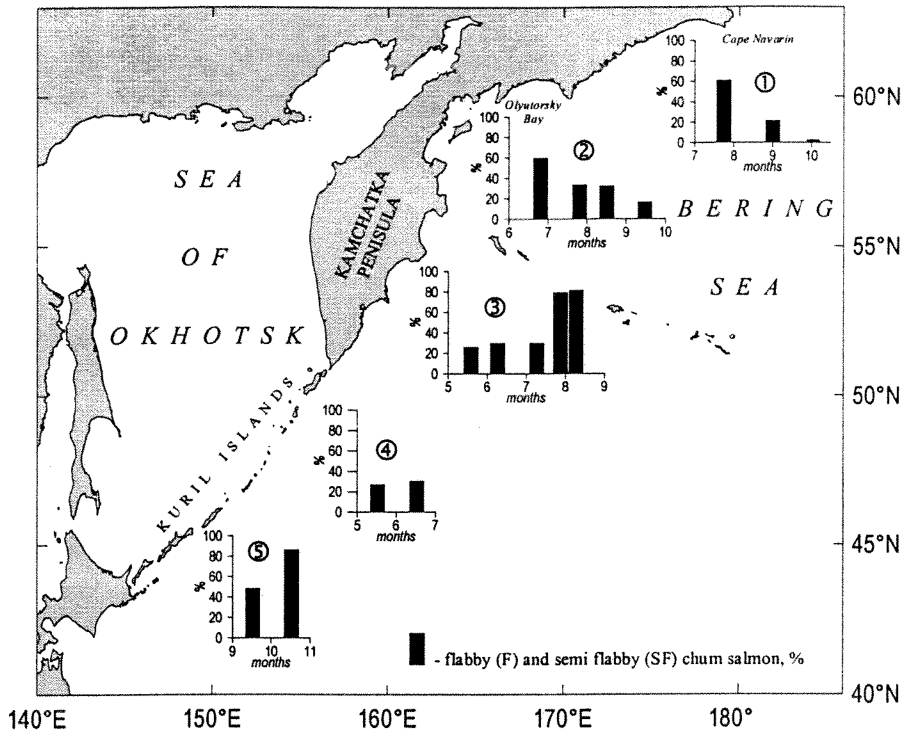
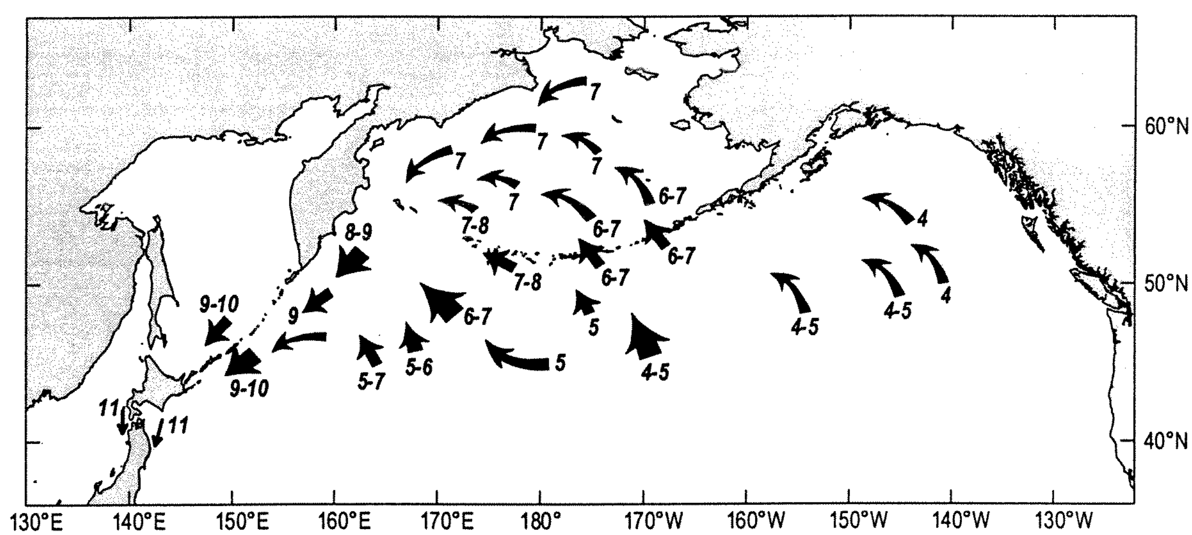
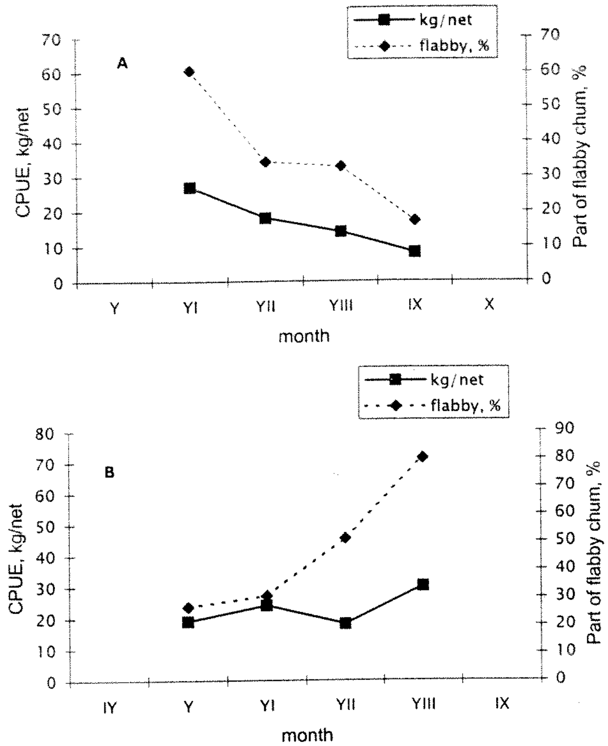


Fig. 2. Hypothesized migration route of maturing chum salmon originating from Japan. Figures beside arrows indicate month (from Ogura 1994).



The proportion of flabby individuals in catches usually varied according to the changes in CPUE (Fig.3). The correlation between the proportion of flabby individuals and catch rates in the Bering Sea was high (r = 0.96), while in the Pacific waters of Kamchatka it was lower (r = 0.68). Studies of vertical migrations in salmon have shown that they shift diurnally from the surface down to 15 m or more at night. Occurrence in the surface layer varies among the species of salmon, and depends on a number of factors, in particular the surface water temperature. Chum, sockeye (*O. nerka*) and pink salmon remain mostly near the surface at 7–8°C in summer months in the Bering Sea, whereas during the same months off East Kamchatka they descend to 10–15 m where the temperature is 1–2°C lower than 10–11°C at the surface (Ishida et al. 1997). At these depths fish become inaccessible to the netting (9 m deep). Catch rate and surface water temperature data for the entire summer showed that catches peaked at 7–8°C. Thus,

Fig. 3. CPUE (kg/net) and proportion of flabby chum salmon (%). A, Bering Sea; B, Pacific ocean off East Kamchatka.



at water temperatures higher than 8°C, CPUE reflects salmon densities to a lesser extent than at lower temperatures.

The occurrence of flabby chum varied among years. Over the five years of observation the maximum was in 1996 (average 40%), the minimum in 1998 (average 12%). This interannual variation coincides with the trend in world catches of Pacific salmon. The largest catches of salmon in the North Pacific were recorded in 1995. In 1996 catches on the American coast decreased notably, and in 1997 they began to decline on the Asian coast as well. In 1998 catches in all areas were lower than in 1997 (Beamish et al. 1998). Our CPUE data also show a downward trend in salmon concentrations at sea, especially in the Bering Sea. For example, in August–September 1995 catches of salmon in the Bering Sea were 20 kg per net. For the same period in 1996 they were 12 kg per net; in 1998, 5 kg per net. The proportion of flabby chum decreased simultaneously, from 27.3% in August 1996 to 18.6% in August 1998.

Relation of Flabby Chum Salmon to Length and Maturity

The proportion of flabby chum varied among fish of various sizes and stages of maturation. The maximum frequency occurred among fish under 50 cm (there were no fish under 40 cm in catches); the lowest frequency was among the largest individuals of over 65 cm (Fig. 4). To determine the relation between quality of chum and the degree of maturation we selected the size group 51–60 cm, which was the most numerous in catches, and included individuals with gonads of different degrees of maturity. The largest proportion of flabby fish was among those having gonads at stages II and II-III of maturity; the lowest proportion was among the maturing fish with gonads at stages III-IV and IV of maturity (Fig.5).

A histological analysis of chum muscles revealed a deterioration in muscle fibres. In addition, some displacement of liver and spleen was observed. However, some muscle fibres showed signs of regeneration, suggesting that degeneration of muscle tissue in chum may be reversible, given improved conditions. Histology experts from the Moscow University suggest that recovery or death of affected individuals may depend on whether or not the reproductive system has been affected.

Though the condition is not entirely understood there seems little doubt that chum salmon with flabby muscles occur when densities are high in areas of feeding at sea.

Fig. 4. Frequency of chum salmon of various lengths with N, normal muscles; SF, semi flabby muscles; F, flabby muscles. A, May–June 1996; B, May–June 1998; C, July–August 1997. Pacific ocean off East Kamchatka.

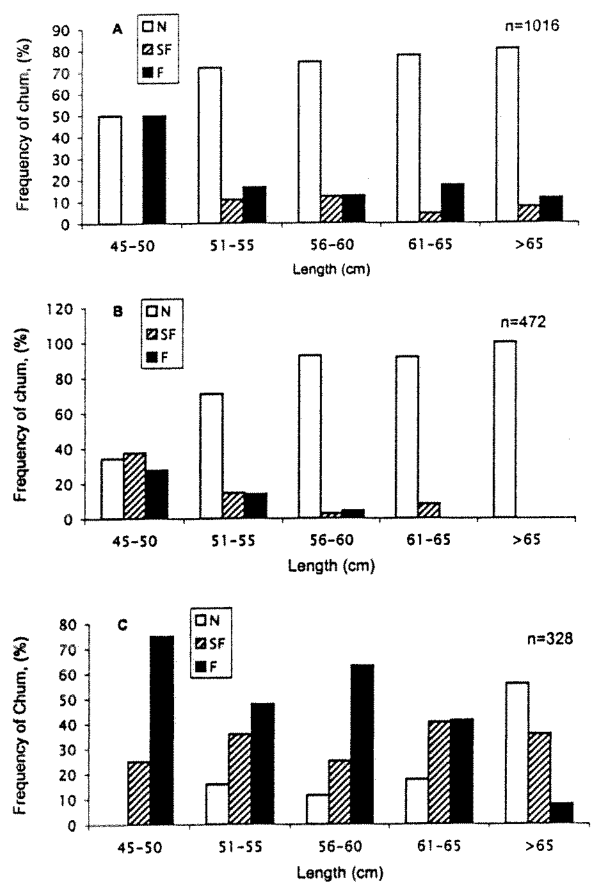
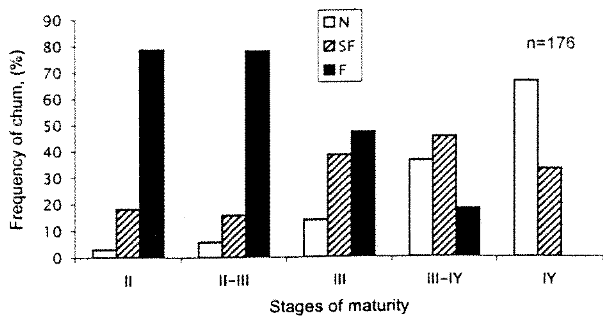


Fig. 5. Frequency of chum salmon of various stages of maturity with N, normal muscles; SF, semi flabby muscles; F, flabby muscles. Pacific ocean off East Kamchatka. July–August 1997.



Possible Causes of Flabby Chum Salmon Muscles.

I considered two hypotheses of possible causes of softening chum muscles: (1) presence of some pathogenic organism; (2) feeding of chum on inferior food where fish are concentrated.

Clinical and pathological examination of the sub-skin and deeper layers of the muscles did not reveal any noticeable changes of the skin in flabby fish, or the presence of visible cysts or capsules of parasitic protozoans or helminths. Dissection of muscle tissue from various parts of the body, kidneys and liver of the fish did not show the presence of any agents. Microscopic examination of the muscle tissue, kidneys and liver of fish immediately after capture excluded the presence of protozoans of myxosporidia, etiological agents that can cause various muscle pathologies in fish, including softening of muscle tissue.

Electron microscopic examination of muscle and liver samples from chum having normal and soft musculature was made to identify smaller parasitic protozoans (mycrosporidia). None of the samples contained protozoans.

Since the condition of the intestine in fish, especially of its rear absorbent part can affect metabolic processes, we analyzed the intestines of flabby and normal chum for parasites. All the fish contained helminths in intestines: cestodes, nematodes, proboscis worms and individual flukes. Invasion intensity was 3–10 to 50–90 ind./fish. However, even under a high infestation rate the helminths found did not cause any significant pathology of intestinal walls, while their number did not correlate with the resiliency of muscles of the fish examined (Golovin and Klovatch 1999).

Thus, the clinical, pathology-anatomy and microscopic examination of the muscles and inner organs of chum, as well as helminthological analysis of the intestines ruled out parasites as a factor causing flabbiness of chum salmon muscles at sea.

Our five years' study of the food habits of chum at sea showed that in large measure food consists of salps, jelly-fish and ctenophores marked by jelly structure and low caloric value, and containing 94% water (near 100% in some regions in certain periods). The caloric value of jelly-fish is 136 cal/g, whereas that in crustaceans is 589–743 cal/g, in fish 1185 cal/g (Davis et al. 1998). The high frequency of coelenterates as food of chum in the Bering Sea and the Pacific in the 1990s was also pointed out by Ishida et al. (1997), Volkov et al. (1997), and Ueno et al., (1998).

In the 1960s the abundance of salmon was much lower than at present, and the importance of jelly-fish and ctenophores as food for chum was lower. Ctenophores and jelly-fish were recorded as food items of chum only during years of high abundance of pink salmon, even more so during its mass pre-spawning migration (Andriyevskaya 1966).

It is known that the chemical composition of fish reflects their diet (Love 1976). Food of low-caloric value may change the chemical composition of the body. The relationship between the lipid composition of gut content and body muscles has been shown for larvae of Atlantic cod (*Gadus morhua*) (Lochmann et al. 1996). During starvation or inadequacy of necessary food components, lipids are first utilized, independently of their location in the body, and proteins of white muscles are utilized secondly. This causes cod muscles to become flabby (Love 1976). Juvenile steelhead salmon (*O. mykiss*) grow best when their food contains 13% lipids and 0.5% unsaturated fatty acids by dry weight (Gershanovich et al. 1988). Experiments have shown that salmon require 9.5% unsaturated fatty acids by dry weight in their food (Bogut and Opacak 1996).

The availability of food in different years may be indicated by the mean condition factor of chum salmon in the area of East Kamchatka in July, 1996–1998: in 1996 the mean condition factor was 1.08; it was 1.14 in 1997, and 1.21 in 1998. Correspondingly the highest frequency of flabby chum salmon in catches was noted in 1996, and the lowest in 1998.

I suggest that when chum feed on jelly-like organisms the loss of polyunsaturated fatty acids is not replaced by those ingested, which causes loss of lipids in musculature and destructive changes; muscles soften and body shape is modified. This is a hypothesis which needs further verification. However, there seems little doubt that flabby chum occur primarily in regions of high density, which may be an indication that the carrying capacity of epipelagic waters of the North Pacific is being exceeded.

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