STUDIES ON THE OPTIMUM MESH OF SALMON GILL NET

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I. Introduction

1.1. The History of the Salmon Gill Net in the North Pacific

The development of the present drifting gill net fishing for salmon arose from former mother-boat salmon fishery operations in the high seas along the Kamchatka coast beginning in 1927, and also from the salmon drifting gill net fishing based in the Northern Kuril Islands which began in 1930.

The drifting gill net fishing for salmon, based in havens in Hokkaido, were developed during the same period. These fishing operations were conducted in the coastal waters where, in general, dense salmon shoals were found.

In the early stages, the gill nets were made of flax or cotton yarn or ramie thread. Of these the ramie thread net made possible the largest catches, but as it tended to rot, studies in antiseptics were undertaken.

By experience the size of the mesh was set for the size of mature salmon, so the mesh size was larger than it is at present. The flosts were made of paulownia which is very buoyant, so the shackles were heavier than the present ones are.

The fishing boat drifted to the leeward of the set, stretching the warp. So in a storm, the tension on the set increased so much that the net rolled up into a rod. To prevent rolling up, various unsuccessful experiments were tried in the construction of the net. At the conclusion of the peace treaty (1952), Japanese salmon fishing was re-established. During the short term of the trial fishing (1952, 1953), fishing methods of the new fleet followed the prewar pattern. But after experimenting, great improvement was made especially by the adoption of synthetic fiber (1954)[1], friction net houler (1954)[1], and use of radio buoys (1957)[2]. In this period, in order to improve the effectiveness of the gill net, trials were made on multi-walled nets, but these trials did not prove sucessful.

The international nature of North Pacific salmon fishing is obvious. Several international fisheries treaties have been concluded; such as the treaty between Japan, U.S.A. and Canada in 1952, and the treaty between Japan and USSR in 1956, this places on us the responsibilities of catching the maximum yield of salmon, and fulfilling our responsibility to effectively utilize salmon resources.

Among fish that escape from the gill net, some live and swim away, but even those that live are usually more or less seriously injured by the threads of the net, and it is supposed they die before spawning or lose their generative function.

Among adult salmon, fishing mortality is the larger part of the total mortality, therefore whether gill net fishing is wise or not depends on the rate of escape. This is because an increase of the rate of escape, means an increase in mortality beyond human control outside the catch. Therefore, in order to carry out effective fishing, it is necessary to choose the optimum mesh size, with a low escape rate and a high catching power.

In this conection, I would like to examine the present regulations for the mesh size of salmon gill net, clarifying the way the fish are gilled and the way they escape, and giving a clear definition of the optimum mesh, on the basis of characteristics of the body of the fish and the properties of the thread.

1.2. Summary of Past Studies on Mesh Selectivity of the Gill Net

Drifting salmon gill net is a kind of gill net; the size of the fish gilled are closely related to the size of the mesh.

Baranov was probably the first worker to appreciate fully and investigate intensively the problem of gill net selection. As early as 1913 from experimental netting of Caspian herring. Barabov established his first theory on the relation between the length of gilled fish and the mesh size. In 1924 Baranov showed the direct relation between the girth of the fish caught in modal numbers and the perimeter of the mesh, and finally he assumed, as a working hypothesis, that the probability of catching fish of a given size in a given mesh could be describable by the normal "Gaussian" curve of probability[7].

The work of Baranov was extended by a number of students and colleagues. These workers, however, did not appreciably advance the study of selection of fishes of other than modal length. It remained for Holt (1957) to give another demonstration of the deviation of the length-selectivity curve from the catch curves of several meshes used simultaneously.

From experimental netting of herring, Farran (1936) explained the way fish are caught in a gill net, as follows: the lower limit of the catch of a gill net is obviously the smallest fish which cannot push its way through the mesh, and this is determined by the maximum girth of the fish and the perimeter of the mesh; the upper limit of the catch of a gill net is the largest fish that can push its head sufficiently far enough through the meshes to be retained, and this depends on the girth at the operculum and the perimeter of the mesh.

Although, Baranov had not advanced the study of selection of mesh other than of modal length, Farran pointed out the upper and lower limits of the sizes of fish caught by a gill net. This seems to be the first work trying to clarify the way in which fish are caught in a gill net.

Konda (1952) estimated the appropriate mesh for Hokkaido herring by age groups, based on methods similar to those described by Farran.

Konda (1962), on the basis of exploratory fishing of commercial size salmon in the North Pacific Ocean, ascertained that the relationship of the maximum girth of the fish to the fork length of the fish and the relationship of the girth at the breast under the gillcover to the fork length are both represented by a straight line. In this way he defined the selective range of mesh and made it possible to indicate the fish size corresponding to a given mesh size, by the fork length of the fish.

Yamamoto & Mishima, (1962), estimated the appropriate mesh size for each salmon species by season and by area, and pointed out the difference of thread elongation by species.

The study on the gill net selectivity curve was extended after Holt, by Olsen 1959, Garrand 1961, Mc Combie & Fry 1960, Gulland & Harding 1961, and Berst 1961 and on the other side, Ishida has tried to assume the selectivity curve for salmon, sardine and herring, since 1961, by the same method.

All of these studies use the selectivity curve derived from the relative frequency of capture of fish of a given size in a series of gill nets with graded mesh used simultaneously.

Holt, (1957), assumed that the selectivity curve would take the form of a normal frequency distribution, and he added one assumption that the standard deviation of the distributions for two adjacent net sizes would be equal.

Although Holt's assumptions will not always prove true, Mc Combie & Fry (1960), Gulland & Harding (1961) and Ishida (1962) assumed that the standard deviations of the distribution for each size would be proportional to each mesh size and had described the curve of an unnormal frequency distribution.

Either way, the study on the selectivity of gill nets will be useful directly to increase fishery production, and furthermore will be applicable as a method to control the resources. By the selectivity curve, it may be possible to assume from the catch composition the natural constitution of the stock, however this does not explain how fish are caught or escape.

For the more effective utilization of salmon resources, it is the purpose of the paper to clarify way fish are gilled or escape. For this purpose, in former methods, the size and shape of the fish were considered, but as the elongation of the thread and the elasticity of the body were disregarded, therefore the result was not accurate. Furthermore, when deciding on the appropriate mesh size only the catching capability was considered and the studies were not understood to be coping with the natural stock. Studies of the thread elongation and the body elasticity would greatly advance the study on the circumstances of capture and escape in a gill net catch. Formerly, numerous studies have been made on salmon resources by a number of students, of various nationalities, because of the value and singularity of salmon life history. However, little was known of the life of salmon on high seas, up to the begining of the INPFC research.

Since 1952, Canada, Japan and the United States have been carrying out various large scale investigations in the North Pacific Ocean and the Bering Sea to gain an understanding of the oceanic distribution and movements of salmon with reference to continent of origin, under the following four principal topices: (1) distribution in the high seas (2) identification of stock (3) tagging (4) oceanography. This information is needed to resolve a basic problem of the North Pacific Fisheries Convention that of determining a line or lines at sea which best separate salmon of Asian and American Origin.

Furthermore, the Japan and USSR Fisheries Committee, based on the Japan USSR Fishery Treaty (1956), strived to grasp the population dynamics in order to promote conservation of salmon resources. Thus, Canadian, Japanese, United States and USSR students added rapidly to knowledge of salmon resources and their life in the high seas, identification of local stock, ocean structure and the general pattern of high sea distribution of salmon.

Before the main discourse, in order to explain the importance of studies on salmon resources, on the way fish are caught in gill nets and the way they escape from gill nets. I want to give some general information concerning salmon resources and particularly relating to salmon gill nets. In the next chapter I will quote the following authors: Hanamura (1960, '64), Osako (1963), Yonemori (1963, '64-a, b), Ishida (1961), Takagi (1964), Konda (1959, '62, '63, '64), Miyazaki (1963), Doi (1962), Hirano, Dodmead & Favorite (1963), Harrt (1962) and INPFC Anual Reports (1963, '64).

II. Summary of Salmon Resources and Salmon Fishing

2.1. History of Salmon Fishing in Japan

Since about 1550, salmon fishing, together with herring fishing, has been carried out by pioneers of the exploitation of Hokkaido (formerly called Ezo). At first it started as river fishing, and by the invention of primitive trap-nets, it developed an important position in coastal fishing[18].

The foundation in the coastal fishing in Sakhalin (formerly called Oku-Ezo) was established in 1752*1), and in the South Kuril Islands in 1789*2), but since 1875 Japanese fishing in Sakhalin has been interrupted because of a border agree-

*1) In 1752, the feudal lord of Matsumae had opened three fishing bases in Sakhalin (called Oku-Ezo in those days). In 1773, Denbei Murayama, the third baron of Fukuyama has started grand-scale fishing in Sakhalin. He engaged in herring, salmon and cod fishing for 17 years and made a great profit[19][20].

*2) In 1789, Kahei Takadaya, a baron of Hakodate opened 17 fishing bases on Etorof Island. He and his family ruled there for 30 years at the government's request[19].

ment with Russia exchanging Sakhalin for the North Kuril Islands.

After this, some of the Japanese fishermen who had been engaged in Sakhalin fishing continued to engage in salmon fishing in Russian Sakhalin, Primorsk Province and the district around the mouth of the Amur river.

But these pioneers were obliged to retreat to the coast of Kamchatka because of pressure from the Russian authorities*3).

The Japan-Russian Fishing Convention of 1906 established the rights of Japanese salmon fishing along the Siberian coast and it developted rapidly into an enormous industry. In 1917 the Russian Revolution broke out*4), and the confusion in the fishing industry continued untill the right of Japanese Siberian fishing was reaffirmed by the new USSR government in 1925*5).

Japanese salmon fishing in Siberian coastal waters continued until the declaration of war by USSR against Japan in 1945, but from 1929 on it had been decreasing, due to pressures exerted by the new USSR government, which was attempting to expand its own Siberian salmon fishing.

Thus, mother-boat fishing in 1927, land based salmon drift gill nets and salmon trap-net fishing in the North Kuril Islands in 1933, stimulated the rapid expansion of salmon fishing to a large scale industry. This period was the most variegated and prosperous for Japanese salmon fishing, however, Japanese fishing, in accordance with the acceptance of the Potsdam declaration of 1945, never completely recovered from the loss of fishing rights in Siberia and the loss of the North Kuril Islands as fishing base.

In the early period of salmon mother-boat fishing, gill nets were used only supplementally. Salmon fishing was carried out as inshore fishing along the coast of Kamchatka by trap-nets or by purse seines, but since 1935, gill nets took the place of other gear and salmon fishing came to be a dynamic high-seas industry. This was the inevitable result, because of the international nature of salmon fishing.

2.2. Salmon Fishing of the North Pacific, an International Point of View

On June 12, 1953, the governments of Canada, Japan and the United States brought the International Convention for High Seas Fishing of the North Pacific Ocean into force for the purpose of ensuring the maximum sustained productivity of the fishing resources of the convention area. Thus Japanese salmon mother-

*3) The Russian government enacted the following Laws:[20] The Provisional Law of Fishing in Sakhalin, in 1890. The Provisional Law of Marine Products Industry in Primorsk Province, in 1899. The Provisional Law of Fishing in Primorsk Province, in 1901.

*4) In the name of the Peaple's committee the U.S.S.R. government declared the abrogation of all of their treaties related to fishing in the Far East[21].

*5) Treaties conculuded between Japan and U.S.S.R.; The Peking Treaty, in 1925. The Japan U.S.S.R. Fishing Treaty, in 1928[21].

boat fishing made a new start.

The scale of the newly established fleet was very small, but it was rapidly enlarged (Table 2–1), and in 1956, the Japanese government announced 19 salmon fleets would sail out to the North Pacific. On March 21, 1956, the Soviet government declared unilaterally its intention to arrest the growth of the Japanese salmun fleet, by regulation of salmon fishing in the high seas adjacent to the Soviet waters. Following this, on May 14, 1956, the convention for the High Seas Fishing of the North Pacific Ocean, between Japan and USSR was concluded. In this way, Japanese salmon mother-boat fishing was forced to change its course.

The growth of the re-established Japanese salmon fishing industry is clear in Table 2–1. In 1964, 11 salmon mother-ships accompanied by 369 drifters, 293 land-based salmon drifters, 40 small drifters and 369 longliners operated in the North Pacific and Bering sea.

The above Conventions provided for the establishment of Fisheries commissions to promote and coordinate necessary scientific studies and to recommend required conservation measures in order to secure the maximum sustained productivity of fishing in areas of joint interest.

Table 2–1. Fishing effort and catch (in thousand metric tons, round weight) of the Japanese salmon fisheries

Year	Montherships			Drifters		Longliners		Others	Total catch
	Number	Catcher	Catch	Number	Catch	Number	Catch		
1952	3	57	3.8	1,497	23.6				27.4
1953	3	105	13.7	1,932	19.0				32.7
1954	7	205	38.1	1,897	22.0				60.1
1955	14	407	116.2	1,242	47.1				163.3
1956	16	506	92.8	510	41.6		6.5	9.2	150.3
1957	16	461	100.0	490	49.4	373	12.9	19.3	181.5
1958	16	460	91.6	452	59.4	359	9.9	35.8	196.6
1959	16	460	70.9	430	72.2	352	12.1	23.8	179.1
1960	12	410	54.0	415	53.5	367	9.2	30.2	146.9
1961	12	410	53.6	414	68.2	369	14.0	18.3	154.0
1962	11	369	44.6	333	35.6	369	13.0	19.7	112.9
1963	11	369	46.3	333	49.2	369	20.2	20.0	135.7
1964	11	369		293		369			

Basically the United states attempted to expand the Convention Area to the west. United data confirmed the eastward distribution of Asian salmon beyond the Abstention Line, while it also ascertained the westward migration of Alaska sockeye stock beyond the Line.

The convention is now going to meet with the opportunity of reformation. However, it is a knotty problem to decide the line or lines which fairly separate the Alaskan from Asian salmon.

In 1956, the USSR government announced, that the rapid decrease of salmon resources in the Far East along the USSR coast was due to Japanese over catching, and made an endeavor to arrest the development of the Japanese salmon fleet. This is shown in the attached documents of the Japan-USSR Fishery Treaty (1956), and in the various restrictions made by the Japan-USSR fishery committee such as: a limit to the catch, restrictions on fishing equipment (diameter of thread, mesh size) and operations (length and intervals of sets), the shortening of the fishing season, the creation of new closed areas and the enlargement of existing ones, limitations on immature catch and enlargement of the area covered by the treaty.

However, it is clear, that the decrease in the coastal catch is not due to the decrease in stock size alone. Agreement was reached, that the size of the salmon stock should be estimated, approximately, by the total amount of the coastal catch, the pelagic catch and the number of salmon which return to parent streams.

From this information, it is evident, that the decrease in salmon resources is limited to certain species, especially to some specified local stock, such as western Kamchatka pink salmon stock. Thus the Soviet insistence that decrease of the salmon catch on the Soviet coast was reduced by over catching of the Japanese fleet was changed to a substantial increase of the Soviet catch and the preservation of the given local stock.

If a decrease is found in the number of a specified local stock of salmon, and if it is due to human action, it might be our inevitable duty to take appropriate measures for recovery. On the other hand, we might also take appropriate measures in advance to prevent the decrease of other stocks.

In the decisions of the Japan-USSR Fisheries Committee, the quota for the salmon catch has been unstable, and Japanese fishermen have been dissatisfied with it. However, as a natural living resource, the salmon stock fluctuates annually in amount, therefore, even if the Japanese fleet is unstable in their quota and thus in their economics, it might not be possible to expect a perpetual, settled quota.

2.3. Salmon Species in the North Pacific and Adjacent Waters

Pacific salmon (genus Oncorhynchus) is peculiar to the North Pacific Ocean and adjacent waters. They hatch in fresh-water streams of both continents, and grow to maturity in the ocean. Their general oceanic distribution extends from the shores of Asia to the shores of North America. There are six anadromous species in the genus, five of which reproduce on both continents; the sixth (*Oncorhynchus masou*) originates only in Asia. The scientific names and usual common names of the various species of Pacific salmon are:

Oncorhynchus nerka (Walbaum)—sockeye, red, blue-back (in North America)
beni-zake, beni, beni-masu (in Japan)
Красная, Нерка (in Soviet)

Oncorhynchus keta (Walbaum)—chum, keta, dog (in North America)
sake, shiro, toki-shirazu, natsu-sake, aki-aji, osuke (in Japan)
Кета, Хайко (in Soviet)

Oncorhynchus gorbuscha (Walbaum)—pink, humpback (in North America)
Karafuto-masu, honmasu, seppari-masu, ao-masu, ita-masu, masu (in Japan)
Горбуша (in Soviet)

Oncorhynchus kisutch (Walbaum)—coho, silver (in North America)
gin-zake, gin, gin-masu, keiji (in Japan)
Кижуч (in Soviet)

Oncorhynchus tschawytscha (Walbaum)—chinook, spring, king (in North America)
masunosuke, suke (in Japan)
Чавыча (in Soviet)

Oncorhynchus masou (Brevoort)—sakura-masu, masu, mamasu, Kuchiguromasu, hon-masu, ita-masu, taiko-masu (in Japan)
Сима, Морская Форма (in Soviet)

The remarkable catch of Pacific salmon is made by coastal fishing along the Far Eastern coast of the Soviet Union, commercial fishing in Alaska, commercial fishing in British Columbia and Japanese high seas fishing.

The average catch of salmon during the period from 1952 to 1961 was about

Table 2-2. Mean salmon catch in the North Pacific Ocean and adjacent waters by species by region, in thousand of metric tons. An average of the 10 years, 1952-1961

Species \ Region	Soviet coast	Japan	Alaska			British Columbia	Washington Oregon California	Total
			Western	Central	South-Eastern			
Sockeye	4.7	21.5	22.0	7.9	2.5	13.4	6.3	78.3
Chum	45.1	38.9	2.9	11.1	9.9	10.1	2.4	120.4
Pink	64.9	63.0	0.7	19.1	15.7	15.2	4.6	183.2
Coho	4.7	5.4	0.3	1.9	4.8	11.6	5.5	34.2
Chinook	0.9	0.4	1.4	0.6	3.2	8.2	10.2	24.9
Total	120.3	129.2	27.3	40.6	36.2	58.5	29.0	441.1

Table 2-3. Catch ratio of salmon in the North Pacific Ocean and adjacent waters by species among regions (%)

Species \ Region	Soviet coast	Japan	Alaska Western	Alaska Central	Alaska South-Eastern	British Columbia	Washington Oregon California
Sockeye	6.0	27.5	28.1	10.1	3.2	17.1	8.0
Chum	37.5	32.3	2.4	9.2	8.2	8.4	2.0
Pink	35.4	34.4	0.4	10.4	8.6	8.3	2.5
Coho	13.7	15.8	0.9	5.5	14.0	33.9	16.1
Chinook	3.6	1.6	5.6	2.4	12.9	32.9	41.1
Total	27.3	29.3	6.2	9.2	8.2	13.2	6.5

Table 2-4. Catch ratio of salmon in the North Pacific Ocean and adjacent waters by regions among species (%)

Species \ Region	Soviet coast	Japan	Alaska Western	Alaska Central	Alaska South-Eastern	British Columbia	Washington Oregon California	Total
Sockeye	3.9	16.6	80.6	19.5	6.9	22.9	21.7	17.8
Chum	37.5	30.1	10.6	27.3	27.4	17.3	8.3	27.3
Pink	53.9	48.8	2.6	47.1	43.5	26.0	15.9	41.5
Coho	3.9	4.2	1.1	4.7	13.3	19.8	19.0	7.8
Chinook	0.7	0.3	5.1	1.4	8.9	14.0	35.1	5.6

440 thousand metric tons, and the catch by country and by species is summarized in Tables 2-2, 3, (both in thousands of metric tons and in percentages).

As is clearly indicated in the tables, of catchs of the United States, Japan and the Soviet Union are nearly the same, whereas the Canadian catch is considerably lower.

On the whole, the catch of pink salmon is the greatest, however, the principal species caught differ by region and according to the type of fishing; sockeye in western Alaska, pink in Soviet, chum and pink in Japan, coho and chinook in British Columbia, Washington, Oregon and California.

Catch by species and by country are given in Tables 2-2, 4 (in thousands of metric tons and in percentages).

2.4. Local Stocks of Each Salmon Species

Pacific salmon hatch from eggs in fresh-water streams. After hatching and adsorption of the york sac is completed, usually in the spring following spawning, the fry (young salmon) emerge from their gravel beds. After emergence, pink and chum salmon migrate directly to the sea. But other species may live for as many as three years or more in freshwater before descending to the sea. Sockeye and chinook salmon may live in freshwater 1-4 years, coho salmon may live in freshwater 1–2 years. After entering the sea, young salmon remain for some weeks or even months in coastal waters before moving offshore. The length of life in the sea varies both between and within each species. Pink salmon spend only one winter in the sea before returning to the stream where they were spawned or to another steam in the same area. The other species spend longer and more variable lengths of time in the sea; sockeye and chinook salmon spend 2–4 years in the sea, chum salmon spend 3–7 years in the sea, coho salmon spend 1–2 years in the sea. Thus, the total length of life of a single generation varies both between and within each species, from two years for pink salmon to as many as eight years, and possibly longer, for some sockeye and chinook salmon.

Pacific salmon, by nature, return to their spawning grounds, and die after spawning once. There are several local stocks in each salmon specie. In these local stocks, fish are more restricted in their living area. These local stocks are usually distinguishable from each other by variation of the following biological characteristics; homing season, maturing age, growth type, age composition, periodicity in stock size, level of stock size and its changing form. Still more directly, these local stocks may be distinguished by serumological methods, by certain parasites or by tagging.

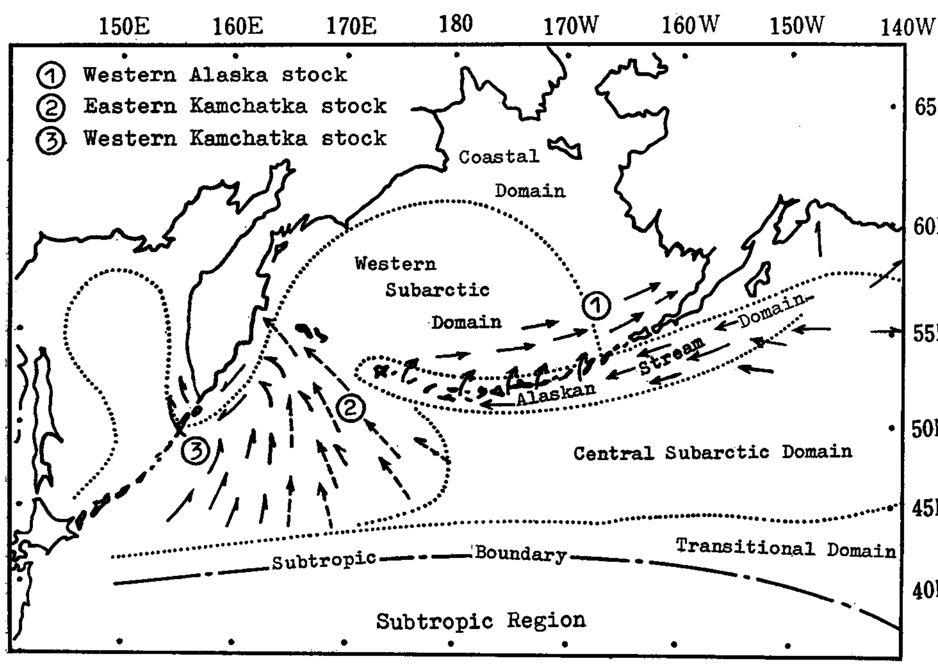

Fig. 2-1. Schematic diagram of distribution and migration of mature sockeye salmon by local stocks

It is obviously valuable to distinguish these stocks from each other, not only for evaluation the stock size or forcasting the future stock for the purpose of salmon controlling, but also as a convenient unit for planning or operating salmon fishing.

(1) Local Stocks of Sockeye Salmon

Japanese salmon fleets operate in the North Pacific Ocean and the Bering Sea to the west of the abstention line–175 degree west longitude. The eastern Kamchatka stock, the western Kamchatka stock and the western Alaska stock of sockeye salmon are distributed in the area where Japanese salmon fleets operate. However, other North American sockeye salmon stocks are not found to the west of the abstention line. The relative size of each sockeye salmon stock as related to Japanese fishing is given in Table 2–5. As is clearly indicated in the table, the west Alaskan sockeye salmon stock is far larger than that of Asian stocks, however, in practice, Japanese fleets do not rely so much on the west Alaskan stock, because only a part of the west Alaskan stock turns up on the west side of the abstention line.

Table 2–5. Relative aboundance of each local stock of sockeye salmon, by the mean coastal catch of the year of 1952–1954, in thousand of metric tons and in percentages

Local stock	Western Kamchatka Stock	Eastern Kamchatka Stock	Western Alaska Stock	Total
Average catch (10^3 ton)	5.8	0.3	21.1	27.2
Average catch (in %)	21.3	1.1	77.6	100

The eastern Kamchatka sockeye salmon stock, generally, pass the winter in the south-eastern region of the Western Subarctic Domain. At the outset of migration, in early May, adults begin to migrate northward or north-eastward and reach the neighboring waters of of the Comandorski Islands in the middle of June, and revolve to the rivers of Kamchatka from June to July (Fig. 2–1).

The western Kamchatka sockeye salmon stock, generally, pass the winter in the Western Subarctic Domain, farther to the west than that of the east Kamchatka sockeye salmon stock. At the outset of migration, about the middle or latter part of May, adults migrate after the eastern Kamchatka stock, and reach the region off the coast of south-east Kamchatka in the middle or latter part of June, then they turn southward along the Kamchatka coast and migrate into the Sea of Okhotsk passing through some northern channels of the Kuril Islands. They return to parent rivers in south-western Kamchatka between late July and the middle of August (Fig. 2–1).

The west Alaskan sockeye salmon stock, generally pass the winter in the Gulf of Alaska. In May, at the outset of migration, adult sockeye migrate westward or north-westward into the Alaskan Stream Domain. After entering the Alaskan Stream, they migrate westward as far as the apex of cluster, reaching the neighboring waters of Attu Islands from late May to early June. From early June to the middle of June, clusters of salmon passing through channels of the Aleutian Islands, migrate into the Bering Sea, and then changing their direction to the east, they revolve to the west Alaskan parent rivers from late July to the middle of August (Fig. 2-1).

In the early stage of migration, immature sockeye generally migrate with mature ones in feeding clusters. However, immature sockeye part, by and by, from mature ones, and make feeding clusters in the neighboring waters of the Aleutian Islands and the Komandorski Islands or in the western region of the North Pacific Ocean and the Bering Sea, while mature have a shoreward migration. It is thought that, in the feeding regions, immature sockeye salmon of various stock will be somewhat mingled together and in addition, that immature sockeye will not migrate into the Sea of Okhotsk.

(2) *Local Stocks of Chum Salmon*

The following eight Asian Chum salmon stocks are found in the area where the Japanese salmon fleet operate; the Primorsk stock, the Amur stock, the Okhotsk stock, the western Kamchatka stock, the eastern Kamchatka stock, the Kuril stock, the Sakhalin stock and the Honshu-Hokkaido stock. However, only a little of the North American chum salmon stock is distributed beyond the abstention line. Each of the above chum salmon stocks can be distinguished as a local stock, by studying their biological characteristics or by tagging. In addition, the Amur chum salmon stock may be subdivided into two stocks-the summer chum stock and the autumn chum stock-based on the difference of the homing season and the variation in growth type between the two stocks.

Table 2-6. Relative aboundance of each local stock of chum salmon, by the mean coastal catch of the year of 1946-1951, in thousand of metric tons and in percentages

Local stock	Primorsk	Amur	Okhotsk	Western Kamchatka	Eastern Kamchatka	Kuril Islands	Sakhalin	Total
Average catch (10^3 ton)	0.2	16.0	21.4	15.6	10.6	1.9	5.1	70.8
Average catch (%)	0.3	22.6	30.2	22.0	15.0	2.7	7.2	100

The relative size of each chum salmon stock as related to Japanese fishing is given in Table 2-6. As is clearly indicated in the table, the Okhotsk chum salmon stock is the largest, with the Amur stock in second place, followed by the western Kamchatka stock. While the Honshu-Hokkaido chum salmon stock is very small in number.

The eastern Kamchatka chum salmon stock, generally passes the winter in the Central Subarctic Domain-180 degress east longitude. In May, at the outset of migration, adult chum migrate northward, and then migrate into the Bering Sea in June. They revolve to parent rivers in eastern Kamchatka during July and August (Fig. 2-2).

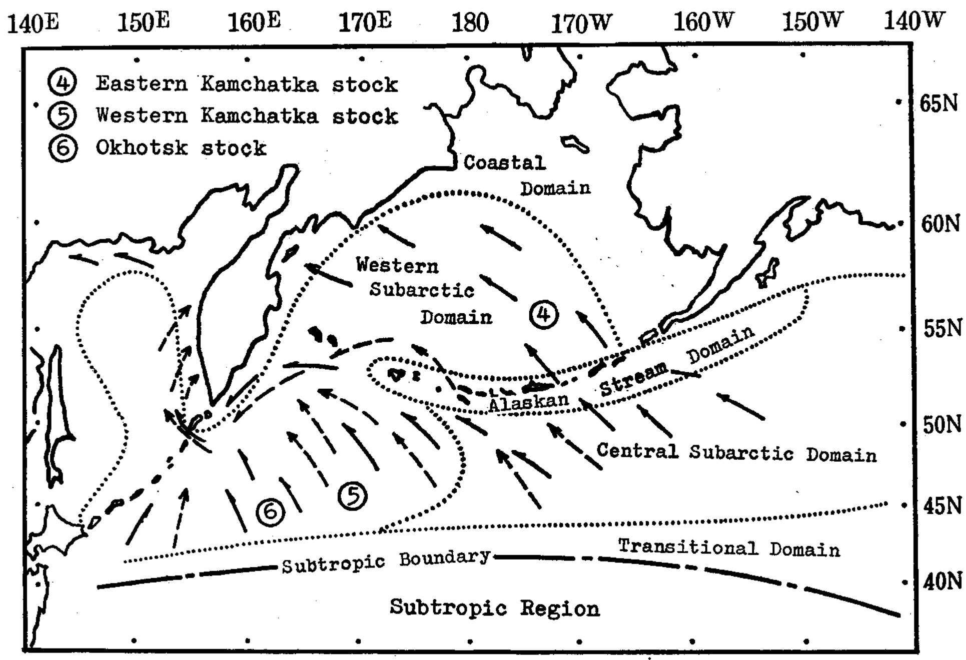

Fig. 2-2. Schematic diagram of distribution and migration of mature chum salmon by local stocks -1

The western Kamchatka chum salmon stock, generally pass the winter in the east region of the Western Subarctic Domain of the North Pacific Ocean. In May, at the outset of migration, adult chum migrate northward and in June when they reach the southern part of the Aleutian Islands, they turn to the west and migrate between the northern Kuril Islands into the Sea of Okhotsk. They return to parent rivers in western Kamchatka in July to August (Fig. 2-2).

The Okhotsk chum salmon stock, generally pass the winter in the western region of the Western Subarctic Domain of north-west Pacific Ocean. In May, at the outest of migration, adult chum migrate to the north or to the north-west,

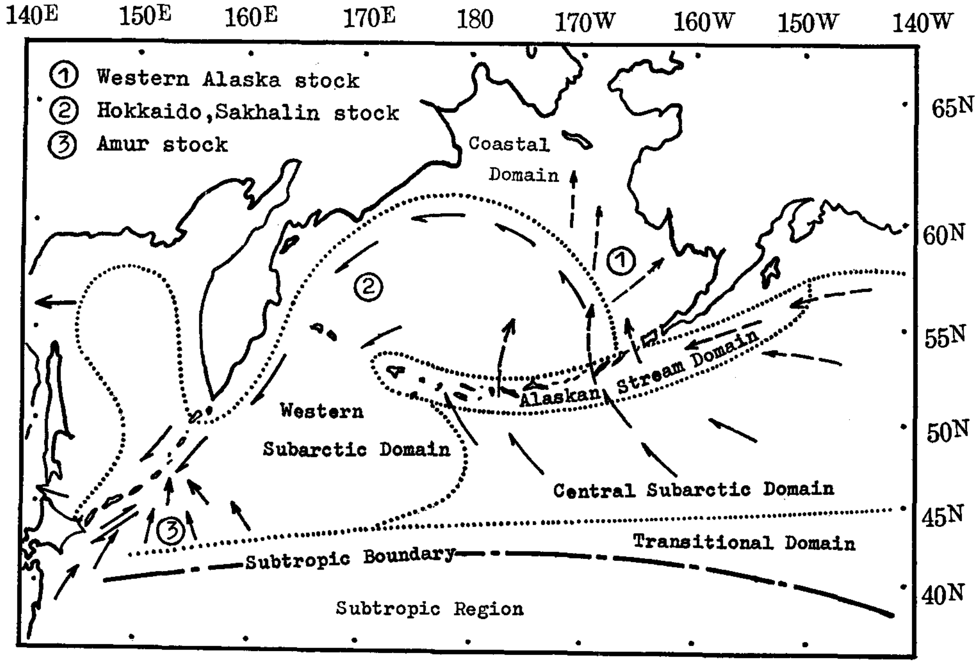

Fig. 2-3. Schematic diagram of distribution and migration of mature chum salmon by local stocks -2

and then, migrate into the Sea of Okhotsk in June. They revolve into parent rivers on the coast of Okhotsk in August (Fig. 2-2).

The Amur summer chum salmon stock, generally pass the winter in the western region of the Western Subarctic Domain of the North Pacific Ocean, farther west than that of the Okhotsk chum salmon stock. In May, at the outset of migration, adult Amur chum migrate to the north, and then in June, they migrate into the sea of Okhotsk by passing between the southern Kuril Islands. They return to the Amur river in August (Fig. 2-3).

In the Amur autumn chum salmon stock, the region where they pass the winter and their course of migration is similar to that of summer chum. However, they migrate into the Sea of Okhotsk after the summer chum, and return to the Amur River in September (Fig. 2-3).

Honshu-Hokkaido chum salmon stock, generally, pass the winter in the Central Subarctic Domain. Adult chum and immature chum migrate northward in spring and then migrate into the Bering Sea in summer. In late summer, adult chum migrate south-westward along the Kuril Islands, and return to parent rivers in Honshu and Hokkaido from October to December (Fig. 2-3).

In the Sakhalin chum salmon stock, the region where they pass the winter and their course of migration is similar to that of the Honshu-Hokkaido chum salmon stock. They return to parent rivers in Sakhalin in April (Fig. 2–3). In the summer, immature chum of each local stock are widely distributed, in feeding clusters, near the Aleutian Islands, Comandorski Islands and the Bering Sea. And in addition, in the summer, Asian immature chum migrate into the eastward part of the Sea of Okhotsk.

(3) Local Stocks of Pink Salmon

The following seven Asian pink salmon stocks are found in the area where the Japanese salmon fleets operate; the Primorsk stock, the Amur stock, the Okhotsk stock, the western Kamchatka stock, the eastern Kamchatka stock, the western Sakhalin stock, the eastern Sakhalin-southern Kuril stock. However, only a little of the North American Pink salmon stock is distributed beyond the abstention line. Each of the above pink salmon stocks can be distinguished as a characteristic local stock, by studying their biological characteristics or by tagging. The relative size of each pink salmon stock as related to Japanese fishing is given in Table 2–7.

As is clearly indicated in the table the western Kamchatka pink salmon stock is by far the largest. The number of pink salmon caught varies according to odd and even years. More are caught in odd numbered years. This variation arises from the difference in size of the stocks which are available in odd and even years. At present, the Amur pink salmon stock abounds in even years and other stocks abound in odd years. As is clearly indicated in the table, the western Kamchatka stock abounds in both years, however, in odd years the Sakhalin-Kuril stock and the Okhotsk stock are conspicuously large, while in even years the Amur stock and the eastern Kamchatka stock are large.

This table is composed from the data from 1946 to 1951, in which years the Japanese fleet was not operating. However, in recent years (from 1955 onward), a rapid decline can be pointed out in the western Kamchatka pink salmon stock.

The eastern Kamchatka pink salmon stock, generally, pass the winter in the Central Subarctic Domain. In May, at the outset of migration, they migrate north-westward, and in June they migrate into the Bering Sea across the Alaskan Stream. They revolve to rivers in eastern Kamchatka in July (Fig. 2–4).

The western Kamchatka pink salmon generally, pass the winter in the southwestern region of the Western Subarctic Domain. In May, they form feeding clusters at the front of subarctic waters. At the outset of migration, they migrate northward or north-westward, and from late June to the middle of July, they migrate into the Sea of Okhotsk through northern channels of the Kurile Islands, and then, they migrate northward along the coast of western Kamchatka.

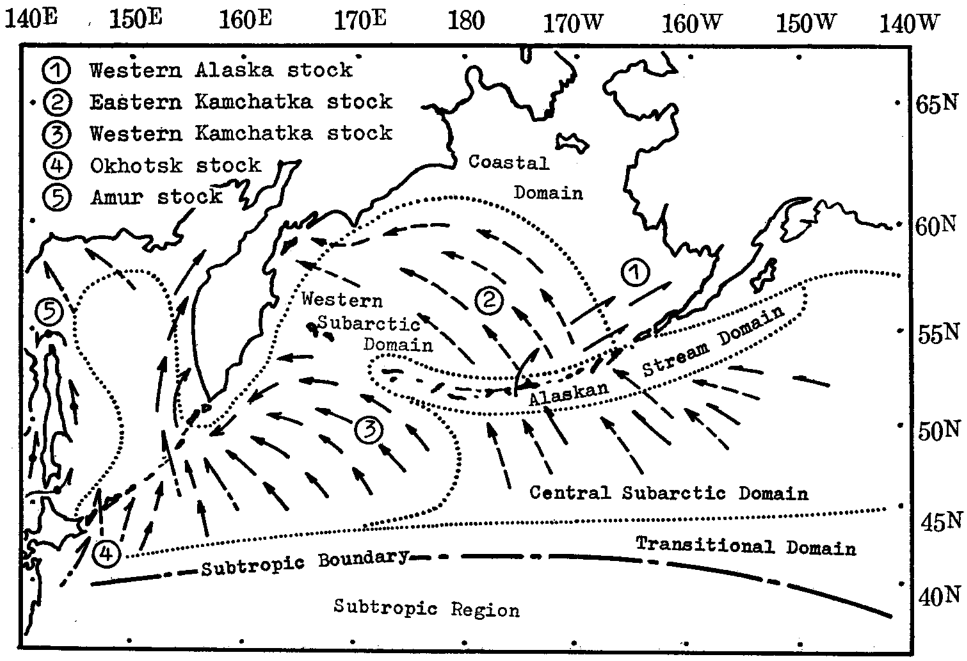

Fig. 2-4. Schematic Diagram of distribution and migration of pink salmon by local stocks

From the middle of June to the early August, they revolve to rivers in western Kamchatka (Fig. 2-4).

The Okhotsk pink salmon, generally pass the winter in the south-west region of the Western Subarctic Domain. From May to early June, they form feeding clusters at the front of the subarctic waters. From the middle of June to the early part of July, they migrate between the Kuril islands into the Sea of Okhotsk. They revolve to rivers in the Okhotsk district from the middle of July to the early part of August (Fig. 2-4).

The Amur pink salmon pass the winter in the Sea of Japan on the northern region of the polar front. From April to June, they migrate north-ward, and in June they revolve to rivers in the Amur district through the Soya Channel or the Tatalski Channel (Fig. 2-4).

The Primorsk pink salmon pass the winter in the Sea of Japan on the northern side of the polar front. From June to July, they revolve to rivers in the Primorsk Province.

The western Sakhalin pink salmon are presumed to pass the winter in the Sea of Japan on the northern side of the polar front, and in June to July, they revolve to rivers in western Sakhalin.

It is supposed that eastern Sakhalin pink salmon pass the winter in the western part of the Western Subarctic Domain along the islands of Japan. They revolve to rivers in western Sakhalin, from July to August.

Note 1) Distribution of each stock in winter is estimated by the distribution at the opening of the fishing season[27,28,29,30,31,32,33] and from the results of tagging by the United States and the Japanese government.[56,57,58,59,60]

Note 2) The distinction between mature and immature salmon is made by the maturity index or the seasonal change of gonad weight.

Table 2-7. Relative aboundance of each local stock of pink salmon, by mean coastal catch of the year of 1952-1954, in thousand of metric tons and in percentages

	Local stock	Primorsk	Amur	Okhotsk	West Kam.	East Kam.	Kuril Is.	Sakhalin	Total
	Average catch (10^3 ton)	2.7	4.2	5.8	56.7	6.3	8.6	12.3	96.3
	Average catch (%)	2.8	4.4	6.0	58.7	6.5	8.9	12.7	100
Odd year	Average catch (10^3 ton)	4.2	1.6	11.3	90.0	6.9	14.2	22.8	151.0
	Average catch (%)	2.7	1.1	7.4	59.6	4.7	9.4	15.1	100
Even year	Average catch (10^3 ton)	1.3	6.8	0.4	23.4	5.6	3.0	1.8	42.3
	Average catch (%)	3.1	16.1	0.9	55.3	13.2	7.1	4.3	100

Table 2-8. Annual variation of species composition in the catch of Japanese motherboat fishing, in Aleutian waters

Year \ Species	Sockeye	Chum	Pink	Coho	Chinook
1952	35.3	30.0	33.5	1.2	+
1953	20.0	35.0	40.0	5.0	+
1954	18.3	46.7	28.3	6.7	+
1955	24.6	36.1	32.8	6.5	+
1956	22.7	40.9	27.3	9.0	0.1
1957	39.5	18.4	42.1	+	+
1958	26.4	37.7	28.3	7.5	0.1
1959	21.7	30.0	45.0	3.3	+
1960	50.0	40.0	7.5	2.5	+
1961	58.4	27.0	13.5	1.1	+
1962	53.2	32.4	5.9	7.6	0.9
1963	38.1	24.9	28.7	8.1	0.2
Mean	34.0	33.3	27.7	4.9	0.1

2.5. Species Composition of Salmon Population in High Seas

Table 2–8, shows the annual variation of the species composition of the catch of Japanese salmon mother boat fishing in Aleutian waters. According to the table, the catch is made up mainly of sockeye, chum and pink salmon which together from a total of 95% of the total catch. Sockeye salmon forms an average of 34% of the total annual catch. It varies from 18.3 to 58.4% of the total annual catch. The chum salmon catch forms an average of 33.3% of the annual catch and varies from 18.4% to 46.7%. The pink salmon catch forms an average of 27.7% of the annual catch and varies from 5.9 to 45.0%. In recent years, a decrease is evident in the even year catch of pink salmon.

According to the intention of each fleet, and the mesh used, the species composition of salmon caught will not always correspond to the actual composition of the salmon resources. However, in general, it may be concluded to approximate the actual composition.

As is clearly indicated in the table, the actual species composition of the high seas salmon resources varies greatly from year to year. This variation arises from various biological characteristics of salmon such as; the annual variation in spawned numbers of each local stock of each species, variation in the length of the fresh water life of the fish, variation in the age of maturity and difference in the distribution area of each local stock of each species.

Most sockeye salmon remain in fresh water after emergence, and spend from one to as many as four years in fresh water before they begin catadromous migration. After entering the sea, they spend from one to four years in the ocean before returning to their parent streams to spawn and die.

There is a difference in the distribution area of sockeye salmon according to local stock. Table 2–9, shows the annual variation in age composition of a recent sockeye salmon catch by Japanese mother boat fishing, in an area where seperate local stocks are distributed. It is possible to point out, from the table, that the available sockeye salmon stock consists of various age groups from four to eight years old. It is also possible to point out that there is a wide annual variation in the age composition.

However, the length composition of sockeye salmon is not consistent with that of their age composition, because their growth is proportional to the length of their ocean life and is less influenced by the length of their fresh water life. Table 2–10, shows the oceanic age composition of available sockeye salmon stock, by area. The table was changed from Table 2–9, for the benefit of future studies in mesh selection. The table indicates clearly that the sockeye salmon stock consists of various ocean age groups, and their ocean age composition varies annually.

Table 2-9. Age composition of available sockeye salmon stock in various areas (%)

(a) Age composition of sockeye salmon where mostly the weastern Kamchatka stock distribute

Year \ Age	4_2	5_2	6_2	5_3	6_3	7_3	6_4	7_4	8_4
1956	17.1	14.7	1.2	36.5	21.7	0.8	4.8	3.2	+
1957	1.7	28.2	0.5	12.9	43.0	0.1	7.2	6.3	
1958	4.1	13.3	2.9	38.1	28.6	1.1	7.6	4.2	+
1959	8.6	15.3	0.3	29.8	28.4	0.4	11.6	5.5	0.1
1960	14.8	13.5	0.6	48.4	13.4	0.2	4.9	4.4	+
1961	4.8	31.5	0.5	23.4	36.6	0.1	1.3	1.9	
1962	5.2	13.4	0.7	32.6	30.6	0.2	16.1	1.2	
1963	17.1	18.4	0.8	22.1	29.6	0.2	2.3	9.4	0.1

(b) Age composition of sockeye salmon where mostly the eastern Kamckatka stock distribute

Year \ Age	4_2	5_2	6_2	5_3	6_3	7_3	6_4	7_4	8_4
1956	16.7	13.8	1.9	39.5	18.2	0.8	6.0	2.8	0.3
1957	2.3	23.9	0.5	15.7	40.2	0.1	11.0	6.3	+
1958	6.6	17.6	3.9	31.2	32.5	1.7	4.2	2.3	
1959	14.3	13.7	0.2	38.4	18.8	—	10.0	4.6	
1960	7.9	23.6	1.4	33.9	23.9	0.5	2.9	5.9	0.1
1961	7.3	23.2	5.1	24.3	34.6	0.3	3.2	2.0	
1962	3.8	20.0	1.4	21.1	44.5	0.4	7.7	1.1	+
1963	15.0	22.3	0.5	24.0	28.0	0.1	2.8	7.2	

(c) Age composition of sockeye salmon where mostly the weastern Alaska stock distribute

Year \ Age	4_2	5_2	6_2	5_3	6_3	7_3	6_4	7_4	8_4
1956	46.8	14.0	0.2	24.9	12.6		0.7	0.7	
1957	2.0	42.4	0.1	25.7	28.2	0.1	0.4		
1958									
1959	29.1	4.2	0.4	52.8	3.9		9.0	0.6	
1960	60.9	11.6		9.6	15.4		1.2	1.3	
1961	1.8	52.4		30.5	14.3	0.1	0.4	0.5	
1962	4.3	16.1	0.3	37.5	36.1	0.5	3.0	2.2	
1963	13.6	22.6	0.3	26.5	33.0	0.1	2.1	1.8	

Note: Original data by Hanamura & Osaka (1964)[34]

Table 2-10. Oceanic age group composition of available sockeye salmon stock in various areas (%)

(a) Age group composition of sockeye salmon where mostly the weastern Kamchatka stock distribute

Year \ Age group	$4_2\,5_3\,6_4$	$5_2\,6_3\,7_4$	$6_2\,7_3\,8_4$
1956	58.4	39.6	2.0
1957	21.8	77.5	0.6
1958	49.8	46.1	4.0
1959	50.0	49.2	0.8
1960	67.9	31.3	0.8
1961	29.5	70.0	0.6
1962	53.9	45.2	0.9
1963	41.5	57.4	1.1
Mean	46.6	52.0	1.4

(b) Age group composition of sockeye salmon where mostly the eastern Kamchatka stock distribute

Year \ Age group	$4_2\,5_3\,6_4$	$5_2\,6_3\,7_4$	$6_2\,7_3\,8_4$
1956	62.2	34.8	3.0
1957	29.0	70.4	0.6
1958	42.0	52.4	5.6
1959	62.7	37.1	0.2
1960	44.7	53.4	2.0
1961	34.8	59.8	5.4
1962	32.6	65.6	1.8
1963	41.8	57.5	0.6
Mean	43.7	53.9	2.4

(c) Age group composition of sockeye salmon where mostly the weastern Alaska stock distribute

Year \ Age group	$4_2\,5_3\,6_4$	$5_2\,6_3\,7_4$	$6_2\,7_3\,8_4$
1956	72.4	27.3	0.2
1957	28.1	71.6	0.2
1958			
1959	90.9	8.7	0.4
1960	71.7	28.3	—
1961	32.7	67.2	0.1
1962	44.8	54.4	0.8
1963	42.2	57.4	0.4
Mean	54.7	45.0	0.3

It is obvious, therefore, that the length composition of available sockeye salmon varies annually also.

Each ocean age group of sockeye salmon stock consists of various age groups which are shown in the following notation:

Oceanic 3 year old group (Oceanic 2)—4_2, 5_3, 6_4—age group

Oceanic 4 year old group (Oceanic 3)—5_2, 6_3, 7_4—age group

Oceanic 5 year old group (Oceanic 4)—7_3, 8_4—age group

Table 2-11. Annual variation of age composition of available chum salmon stock in the catch of motherboat fishing area

Year \ Age	3	4	5	6	7	Total %	Catch per 100 tan
1956	3.6	32.8	62.0	1.6	+	100	159
1957	5.9	66.4	20.0	7.7	+	100	129
1958	17.8	65.6	16.1	0.5	+	100	196
1959	4.1	91.3	4.6	+		100	182
1960	3.3	65.1	31.5	0.1		100	163
1961	3.5	42.7	51.7	2.1		100	123
1962	6.8	59.6	30.3	3.3		100	109
1963	11.5	78.2	9.9	0.4		100	98
Mean	7.1	62.7	28.3	1.9	+	100	

Notes; Original data by Yonemori

Most chum salmon, migrate directly to the sea after emergence, and spend from three years to as many as seven years in the ocean before returning to their parent streams to spawn and die. Therefore, their body length is proportional to their age. Generally, four year old chum salmon abound in the area south of latitude 48 North, where Japanese land based dirifters operate. However, in the mother boat fishing area, mostly four year old and to a lesser extent five year old groups abound. Therefore, as a general tendency, the age composition of available chum salmon in the mother boat fishing area varies annualy and the length composition of chum salmon varies in proportion to the age composition.

Pink salmon, as well as chum salmon, migrate directly to the sea after emargence, and spend only one year in the ocean before returning to their parent streams to spawn and die. Therefore, commercial pink salmon are simple and unitary in age grouping, and their length compositiom varies only according to season.

2.6. Characteristics of Salmon Gill Net

(1) Salmon Fishing Gear

From ancient times, the Ainus, aborigines of Hokkaido, caught salmon with a "Marrepu", sort of fish-spear, and American Indians used a fish wheel in fresh waters to catch fish[24].

At present fish corrals, small set nets, scaft nets, fixed gill nets, drifting gill nets and haul nets are used in stream fishing[24]. Various set nets are used in inshore fishing, and fixed gill nets or haul nets are used around the mouth of rivers. Various kinds of line fishing and trolling are effective along the shore, however, this type of fishing is small in scale. Long line and drifting gill nets are used in pelagic fishing. The latter has been especially adopted for large-scale systematic fishing.

The salmon gill net is a kind of gill net. During the night it drifts according to the ocean current. During the feeding season, salmon disperse over a wide area, forming small schools, and having but slight vertical migration. In the daytime, they move deeper downward and at night they move upward. They are rather stable at the surface, however, ocassionally they form into dense clusters. However, it is difficult to cause them to form clusters artificially. Adult salmon do not crowd together under a lamp light, because of their lack of heliotaxis.

Long line and drifting gill nets are able to double the chance of rare catching, because, in both cases gear cost per unit length is not as expensive as that of other gear. In this sense the above two types of gear are the most convenient for salmon fishing. In long line fishing, each member of the crew must have a high degree of technical skill, while in gill net fishing the skill required is not so great. For this reason, the long line is better adapted for small scale fishing, while the gill net, is more suitable for systematic large-scale fishing.

Salmon gill nets, which are now used extensively in high seas salmon fishing in the North Pacific Ocean, are effective in catching fish by gilling them in the mesh, and are different from other types of gill nets, such as gill nets for king crabs, which entangle them in the net. By experience fishermen know well the size of fish that will be caught by a given mesh size. They use various nets, differing in mesh size, according to species, area of waters and the fishing season. Numerous studies have been made on the relation between mesh size and the size of fish caught, it has been concluded that the size of the fish caught will be in proportion to the size of the mesh[3][4].

Setting a minimum mesh size for trawl nets and set nets allows undersize fish to go through the mesh and thus preserves valuable stock. However this considers only the minimum limit of mesh selectivity. In gill nets, the upper as well as the lower limits of mesh selectivity should be considered, because some large, mature salmon escape from the mesh, more or less injured by the threads of the net, and some of them die or lose their generative function before spawning.

Table 2-12. Chum salmon, injured by gill net, found at Kitami, Hokkaido[47]

Year \ Month		August	September	October	Nobember	Total
1933	Sample		24,401	114,747	60,403	199,591
	Injured		1,513	5,308	3,042	9,863
	%		6.2	4.6	5.0	4.9
1934	Sample	309	41,662			41,971
	Injured	10	1,674			1,684
	%	3.2	4.0			4.0

(2) *Netmarked salmon*

About 1934, in the early stages of salmon drift net fishing in the North Kuril Islands, netmarked salmon were found in the set net catch at Kitami on the Okhotsh coast of Hokkaido (Table 2-12). Coastal fishermen in Hokkaido protested to the government. However, in those days, it was considered that the Hokkaido stock of chum salmon was different from that of the North Kuril Islands[36]. However, at present, it is clear, that those netmarked chum salmon were injured by drift nets, becaus it was proved that in the latter half of the fishing season in the North Kuril Islands, shoales of Hokkaido chum pass through the area[26].

Salmon resources originating in the Far East or in North America pass the winter in a somewhat southern area of the North Pacific Ocean and the Bering Sea. In the spring, they migrate northward, forming feeding clusters, while mature salmon, eventually being shoreward migration toward parent streams for spawning. During this period they are caught by the Japanese fleet (drifters and longliners) on the high seas. And off coast of both continents they are caught by set nets, gill nets and other types of fishing equipment by fishermen of various nationalities.

Netmarked salmon are found among the coastal catch. In recent data, the Hokkaido Salmon Hatchery of the Japanese Fisheries Agency reports that in 1960, 1.35 percent of the salmon captured from homing clusters in the streams of Hokkaido were netmarked (Table 2-13). This is much lower than that of 1934 (Table 2-12). The Soviet government pointed out there is a remarkable increase of

Table 2-13. Net-marked salmon found among their homing clusters in the rivers in Hokkaido (1960)[36]

Species / River	Chum salmon			Pink salmon			Masu salmon		
	Sample	Injured	%	Sample	Injured	%	Sample	Injured	%
Kunbetsu	440	21	4.7						
Shibetsu	1952	24	1.2	1778	22	1.2	78	3	2.6
Yubetsu	4156	6	0.1	114	4	3.5			
Tokoro	1168	0	—						
Iwaobetsu	61	1	1.6	212	1	0.5	17	0	—
Abashiri	1884	10	0.5						
Average			1.35			1.73			1.30

Table 2-14. Ratio of netmarked salmon found at the coast of Kamchatka[37]

Year / Species	1960	1961
Sockeye	7.0%	15.0%
Chum	6.2	15.6
Pink	1.9	10.7

Table 2-15. Netmarked salmon found in the high seas by investigation vessels of the Japanese government

Species / Area of waters	Sockeye salmon				Chum salmon				Pink salmon				Vessel (Year)
	Sample	Ab%	Ac%	T	Sample	Ab%	Ac%	T	Sample	Ab%	Ac%	T	
South of 48 N					1,093	1.5	—	1.5	992	0.5	0.2	0.7	Koyo-M. (1962)
South of 48 N					535	1.7	—	1.7	630	0.8	0.3	1.1	Kagami-M. (1962)
Central Pacific	2,423	0.2	0.4	0.6	1,192	0.3	0.3	0.6	514	—	0.2	0.2	Etsuzan-M. (1961)
North-west Pacific	499	2.8	1.2	4.0	311	1.9	0.6	2.5	582	0.3	0.9	1.2	Hokko-M. (1961)
North-west Pacific	88	2.3	4.6	6.9	63	3.2	—	3.2	76	5.3	—	5.3	Hokko-M. (1962)
The Sea of Okhotsk	388	—	0.2	0.2	1,230	—	0.1	0.1	1,669	0.1	0.1	0.2	Eiko-M. (1961)
The Sea of Okhotsk	99	1.0	2.0	3.0	622	—	0.5	0.5	827	0.1	0.9	1.0	Aliso-M. (1963)

Ab; a scar, Ac; a fresh bruise

netmarked salmon in the catch along the Soviet coast (Table 2–14).

Netmarked salmon are captured on the high seas as well as along the coast, and comparatively high percentage is found in the areas around the channels of the Kuril Islands, where homing clusters of salmon pass through (Table 2–15). There are two types on injured salmon; first, those with fresh bruises and second, those with scars. The former were injured during the season of catch, while the latter were probably injured during a previous season. In the early part of the season, fresh bruised salmon are rare in the high seas catch, but they increase as the season progress (Fig. 2–5). Therefore, net marking is supposed to be caused by the high seas drift nets.

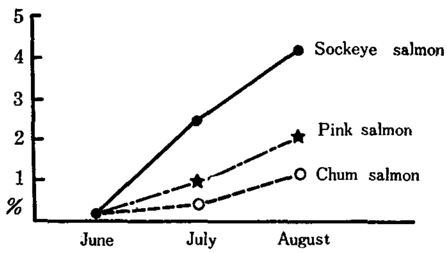

Fig. 2–5. Monthly increase of netmarked fish in the catch

(3) *The Ratio of Escaped Fish from Gill Net*

Netmarked fish are only a part of the total of fish which escape after once being gilled. In gill nets, fish gilled unsecurely escape from the mesh because of the shock of hauling up the net. The ratio of escaped fish varies depending on the relation between the size of the mesh and the size of the fish, wind force, the height of the waves and the number of gilled fish. Based on all data, the ratio of escape is estimated at about 2 percent (Table 2–16).

Of fish that escape from the gill net, some will live and swim away and others will die. The ratio of live ones to dead ones is related closely to the length of time needed to haul up the set. Table 2–17 indicates that the ratio of live ones is high in the early stage of hauling up the set, then it decreases as the hauling in proceeds, and after the 61st shackle all or most of the fish that escape will die[38].

In commercial drifters, most fish which escape during the hauling up of the set will die, because drifters use over 300 shackles of gill net a day.

Not only when hauling in the set, but even while setting the gill net, no small number of fish will leave the net after having once been gilled. However, it is not possible to ascertain. Doi (1962), suggested that the ratio of escape,

Table 2-16. Ratio of fish escaped from gill nets during haul of net

Area	Vessel	Year	Number of Operation	Number of gears (tan) (N)	Number of fish caught (C)	Number of escaped fish (Ev)	$\frac{Ev}{C}\times 100$	$\frac{Ev}{C+Ev}\times 100$	$\frac{Ev}{N}\times 100$	Observed or arranged by
North-west Pacific	Etsuzan	1961	40	3,786	7,596	163	2.15	2.10	4.31	S. Machidori
	Hokko	1961	11	494	1,442	46	3.19	2.82	9.31	M. Konda[39]
Sea of Okhotsk	Eiko	1961	35	2,540	12,154	108	0.89	0.88	4.25	J. Ito
	Ariso	1963	25	494	7,460	147	1.97	1.93	2.97	M. Konda[39]
South of 48 N Pacific	Koyo	1961	30	9,220	48,464	846	1.73	1.48	9.18	S. Nakamura
	Miyako	1961	23	5,303	26,437	221	0.84	0.83	4.17	〃
	Apoi	1961	30	7,179	30,315	312	1.03	1.02	4.35	〃
	Kitakami	1961	33	8,267	55,308	855	1.55	1.52	10.34	〃
	Koyo	1962	40	10,570	31,182	1,099	3.52	3.40	10.40	〃
	Miyako	1962	41	7,654	23,780	910	3.83	3.69	11.89	〃
	Apoi	1962	44	11,349	34,994	1,388	3.82	3.68	11.79	〃
	Kitakami	1962	32	7,215	24,354	466	1.91	1.88	6.41	〃
Average							2.20	2.10		

while setting the net could be estimated by analyzing the change of the catch according to the proceeding of hauling up the set. He ascertained that the escape ratio while setting the net would reach about 50 percent at 4 to 5 hours after the peak of the catch appears (Table 2-18), based on observations at 30 minute intervals[40]. However, the actual ratio is higher than his estimation, because, he supposed that an addtional catch would not be expected after the appearance of the catching peak.

Table 2-17. Variation of live-dead ratio of escaped salmon from gill net while hauling up, by the section of evely ten shackles (ten tans)

Section of shackles	Repeated times observed	Running number of shackles	Number of escaped fish			Escaped fish %	
			Live	Dead	T.	Live	Dead
1—10	23	230	14	28	42	33	67
11—20	23	230	18	49	67	27	73
21—30	23	230	18	61	79	23	77
31—40	23	230	7	48	55	13	87
41—50	23	230	7	44	51	14	86
51—60	22	220	1	37	38	3	97
61—70	19	190	0	27	27	0	100
Total		1,558	65	294	359		
%			18.1	81.9			

Table 2-18. Change of evaluated value in the rate of escape from gill net, special for sockeye salmon and coho salmon, by the section of evely 30 minutes

Species	Times evely 30 minutes	0	1	2	3	4	5	6	7	8	9	10
Sockeye	Catch ratio	1.00	0.94	0.88	0.82	0.77	0.72	0.67	0.63	0.60	0.56	0.53
	Escape ratio	0.00	0.06	0.12	0.18	0.23	0.28	0.33	0.37	0.40	0.44	0.47
Coho	Catch ratio	1.00	0.91	0.83	0.77	0.71	0.65	0.61	0.56	0.52	0.49	0.45
	Escape ratio	0.00	0.09	0.17	0.23	0.29	0.35	0.39	0.44	0.48	0.51	0.55

(By Doi, 1962)

If the pulling up of the set is begun at the peak of the catch, and finished 4 or 5 hours later when the escape ratio reaches as high as 50 percent, according to Doi's data, the average ratio of escape after the appearance of the catch peak could be estimated at about 27.5 percent.

Miyazaki and Taketomi (1963), estimated the ratio of escape from their experiments with pink salmon at Kitami, at 19.2 percent (a range of 14.3–22.0%)[41)42)].

Here the author gives various values connected with dropping or escaping of salmon from gill nets. These values are not too reliable because of the insufficiency of the theory and of the scale of the experiments. However, the results of these experiments show that no small number of salmon having once been gilled leave the mesh during the operation.

(4) *Various Causes of Fish Escaping from the Gill Net*

The fish having once been gilled escape from the net in the following situations: ① when the threads of the net are cut, ② when the mesh is too greatly stretched, and ③ when the fish are gilled unsecurely. It is supposed that the

Table 2-19. Ratio of escape from gill net for pink salmon

Gill net		Number of test	Number of catch (C)	Number of escape (F)	$\frac{F}{C+F}\times 100$	Year tested
Materials	Mesh					
Amilan 15	60.5 mm	5	24	4	14.3%	1963
Amilan 15 Amilan 12	60.5 mm	10	32	9	22.0	1961
Amilan 15	60.5 mm	5	11	3	21.5	1963
Mean					19.2	

By, Miyazaki 1961, Miyazaki and Taketomi 1963

Table 2-20. Strength of thread for salmon gill net

(1) Before the season

Thread	Mesh size	Strength		Elongation	
		Dry kg	Wet kg	Dry %	Wet %
Amilan 210 D2 3/12	60.5 mm	17.6	15.8	27.1	26.9
	65.0 mm	18.3	16.4	26.8	25.8
	68.0 mm	17.9	15.6	26.0	27.4
Amilan 210 D2 3/15	60.5 mm	21.4	19.2	27.8	28.0
	65.0 mm	22.4	19.2	26.8	26.7
	68.0 mm	22.9	19.6	28.9	26.3
Amilan 210 D2 3/18	60.5 mm	26.8	23.2	28.2	26.3
	65.0 mm	25.2	23.2	27.2	26.5
	68.0 mm	26.0	23.4	27.8	26.0

June 9, 1961; Room temperature 22°C; Humidity 59%

(2) After the season

Thread	Mesh size	Strength		Elongation	
		Dry kg	Wet kg	Dry %	Wet %
Amilan 210 D2 3/12	60.5 mm	15.1	14.0	24.7	22.9
	65.0 mm	15.2	14.4	22.4	24.2
	68.0 mm	15.5	14.9	25.7	23.9
Amilan 210 D2 3/15	60.5 mm	20.7	18.8	26.3	25.5
	65.0 mm				
	68.0 mm	20.0	17.5	23.9	24.8
Amilan 210 D2 3/18	60.5 mm	21.5	20.0	25.1	26.4
	65.0 mm	22.6	21.2	25.7	27.2
	68.0 mm	21.6	22.1	27.2	28.8

October 10, 1961; Room temperature 20°C; Humidity 98%

momentum and behaviour of the fish, the movement of the waves and and the shock at hauling up the net also directly influence escape. In addition, concussion with other gilled fishes causes fish to escape from the net.

For a 2–3 kg weight salmon, a velocity of 12.7–15.7 m/sec. is needed to cut the thread of the net.[43] However, in actuality fish are not able to move with such high velocity; therefore, it seems that the strength of the present threads (Table 2–20) is sufficient and that the cutting of the threads at the time of impact is rare.

In the early stage of the Amilan net, the spacing of knots was imperfect, therefore, sometimes fish escaped through the elongation of the mesh. However, at present, knots are fixed almost perfectly by technical improvements such as heating and plasticization. Therefore, it is rare for fish to escape from the mesh from this cause.

If the mesh is perfectly constructed, then fish will be gilled unsecurely under the following conditions; ⓐ when the size of the fish is not in proportion to that of the mesh, ⓑ when the behaviour and momentum of the fish are not suitable for the net. The latter case can not be controlled by human action, therefore the former case is the only one which can be controlled by human action.

Among those fish that escape from the net, some live and swim away, but even those that live are usually more or less injured by the threads of the net. Even though their injury does not seem to be very,[46] some become worse in the ocean and their growth is checked. In fresh water their injury becomes seriously inflamed, and it is supposed that some of them die before spawning or lose their generative function. It is noteworthy that aside from live ones no small number of dead fish will leave the net while it is set in the water. Of course they are not utilized. It is impossible to determine the number of fish thus lost.

As is well known, the gill net is effective for high seas salmon fishing, however, it is always accompanied with a large loss of resources. The rate of escape or loss will decide the effectiveness of gill net fishing. This calls for further study regarding the methods for preventing or reducing from the net to catching salmon more effectively.

In order to further improve the gill net itself, it is necessary to further study on the mechanism of mesh selection and its application to salmon fishing.

III. Materials and Method Employed in the Present Study

In order to advance the study connected with the optimum mesh of salmon gill net, it is necessary to explain the mechanism of capture and escape in gill net fishing. The author carried out the following measurements besides various general biological measurements to advance the study on the length range of mesh selection;

1) girth at the after ridge of the preoperculum (Gp),
2) girth at the front of the base of the dorsal fin (Gm), the maximum girth,
3) girth of the netmark (Gn),
4) portion where fish gilled,
5) degree of injury from the thread of the gill net.

Body girthes (Gp and Gm) and the girth of the net mark (Gn) were measured by a 8 mm wide belt measure. Netmarks were inspected as to the place, the probable reason and the condition of the injury. The various places of the net marks which indicates the place where the fish was finally gilled are indicated by the standard shown in Table 3-1 and Fig. 3-1. The degree of the injury is indicated by the standard shown in Table 3-2. The measurement of the netmark

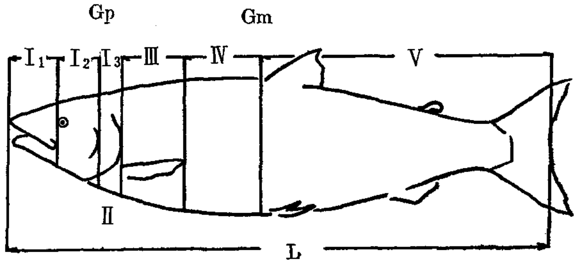

Fig. 3-1. Parts of the body

Table 3-1. Section of the fish body

Section	Sign	Explanations
The head	I_1	From the tip to the end of the maxillary
	I_2	From the end of the maxillary to the preopercle
	I_3	From the end of preopercle to the end of the opercle, on the gill cover
The chest	II	Up to the base of pectoral fin, under the gill cover
The fore part of the trank	III	From the base of the pectoral fin to the end of the pectoral fin
The back part of the trank	IV	From the end of the pectoral fin to the front of the base of the dorsal fin
The others	V	The others

Note: The document No. 76 of the Japan-Soviet Fishery committee[17]

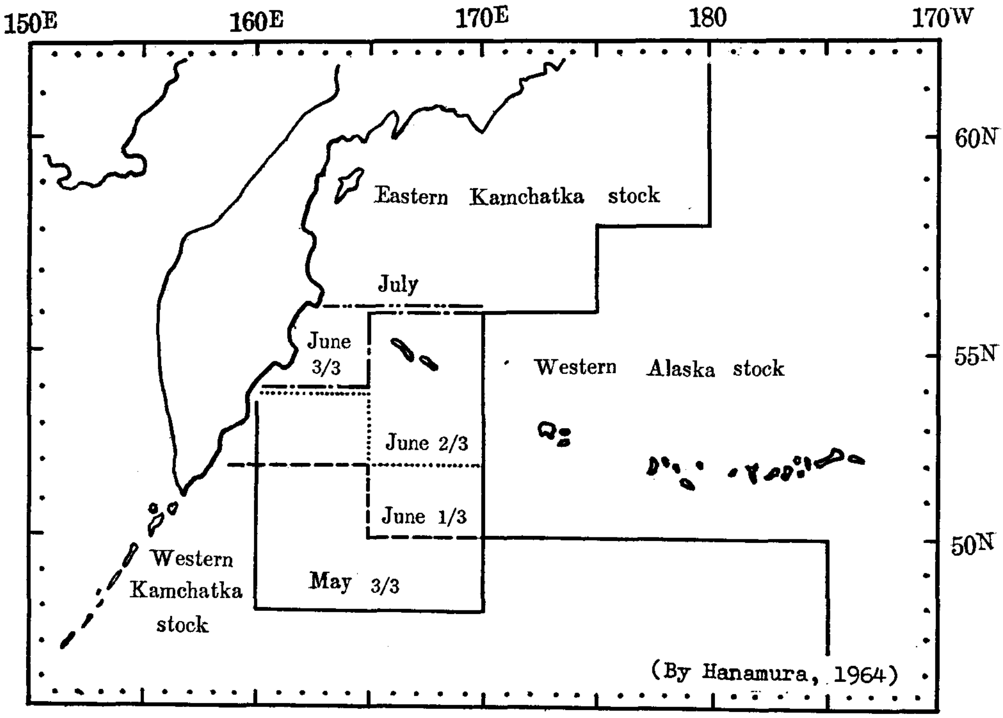

Fig. 3-2. Seasonal variation of sockeye salmon distribution by local stock

Table 3-2. Degree of injury by gill net

Sign	Explanations
A_1	Lose scales, slightly netmarked
A_2	A scratch, netmark is clear
A_3	Skin is peeling off, muscles are not injured
A_4	A gash, muscles are cut
A_5	A lacerated wound, muscles are scooped out

Note: The document No. 76 of the Japan-Soviet Fishry Committee[17)]

was only for the fish which were securely gilled and does not include tangled ones.

In this paper, mesh size (ϕ) expresses the length of mesh side, therefore the mesh perimeter is expressed as 4ϕ, and the mesh size which is customary in U.S.A., Canada and Japan is expressed as 2ϕ. The length of the fish refers to the fork length of the fish.

The relation between length and girth may vary according to sex, however, in this paper, the auther does not deal with them separately, because, secondary sex indications of male salmon are not so evident, so far as the fishing being caried out under present situation.

The body weight is used only as a check upon the length. However, for the future of gill net fishing it will be useful to be able to ascertain the weight

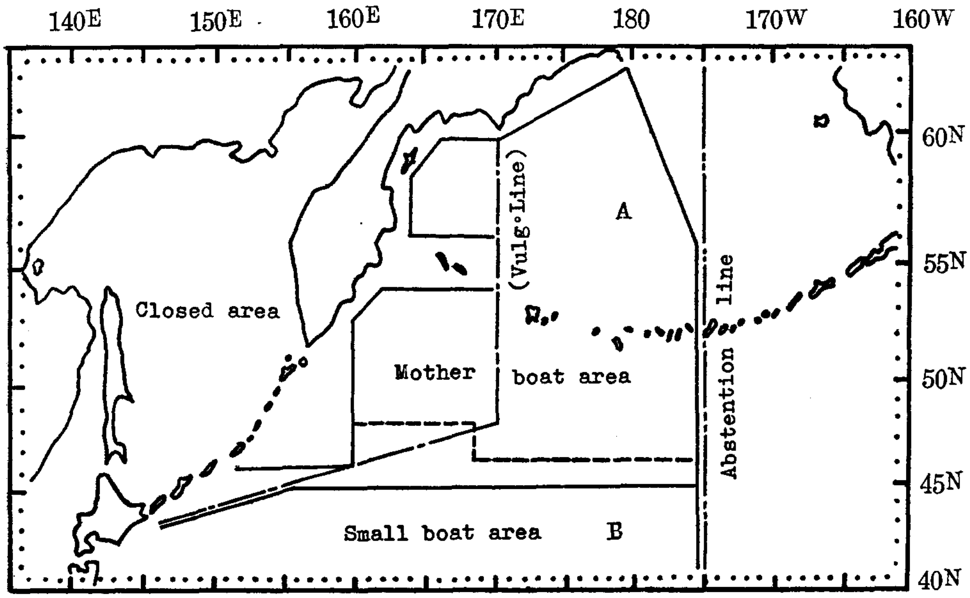

Fig. 3-3. Salmon fishing ground in the north pacific (1964)

range of mesh selection.

The results obtained are applicable only for the Amilan twisted thread net because, the measurement of the netmark was made only for the fish caught by the Amilan twisted thread net.

For the oceanic structure of the upper domains of the North Pacific Ocean I followed the opinion put forth by Dodimead, Favorite and Hirano (1963), and for the areas connected with seasonal variation of sockeye salmon distribution I followed the opinion of Hanamura (1964), (Fig. 3-2). The administrative divisions of the salmon fishing ground in the North Pacific (1964) is shown in Fig. 3—3.

The data which was used to ascertain the relationship between length and girth was obtained from observations carried out by Japanese government research vessels from 1961 to 1963.

Vessel	No. of cruise	Period	Sockeye salmon	Chum salmon	Pink salmon
Etsuzan-maru	1961 No. 2	August 1~20	110		
Etsuzan-maru	1962 No. 2	July 18~August 15		22	
Ariso-maru	1963 No. 1	June 24~July 14		38	
Ariso-maru	1963 No. 2	July 25~August 8			26
Total			110	60	26

Information about the length of the netmark, used to estimate the streching of the mesh and the elasticity of the fish was obtained from observations carried out by the following Japanese government research vessels.

Vessel	No. of cruise	Period	Sockeye salmon	Chum salmon	Pink salmon
Hokko-maru	1961 No. 2	June 25~July 19	459		
Ariso-maru	1963 No. 1	June 24~July 14		81	
Ariso-maru	1963 No. 2	July 25~August 8			111
Total			459	81	111

IV. The Range of Mesh Selection of Salmon Gill Net

4.1. Theory on the Size of Fish Caught with a Given Size Mesh

It is well known to fishermen with experience and it has been pointed out by former students that the size of fish gilled is related closely to the size of the mesh. As the size of mesh gets larger, the size of the fish caught gets larger too; in larger mesh, the range of size of the fish caught and the modal length of the catch move to the large side (Fig. 5–2, 3, 4). The nature of this relationshp between mesh size and fish size is peculiar to the gill net.

Baranov (1913), established his first theory connected with the relation between the length of gilled fish and the size of the mesh; $\phi=K_b\ L_m$, where ϕ is the mesh size, L_m is the modal length of the fish caught, K_b is the constant (in Caspian herring $K_b=0.125$).

Balanov (1924), showed the direct relation between the modal girth of fish caught and the perimeter of the mesh; $4\phi=K_b\ G_m$, where 4ϕ is a perimeter of the mesh, G_m is a modal girth of the fish caught, K_b is the constant.

These theories are useful in estimating the most effective mesh size, however, these theories do not advance the study of the selection of fish of other than those of modal length.[51]

The studies on the selectivity curve by Holt (1957), and others after him make it possible to evaluate the bias produced in a catch per unit effort of various mesh sizes and to estimate the actual size composition of the salmon population, by making adjustments for the effects of mesh selection. However, these studies do not explain how fish are caught in or escape from the net.

Farran (1936), was the first worker to attempt to explain the way fish are caught in a gill net. He showed the range of fish size which a given mesh selects by quality indicator.

Konda (1952), estimated the appropriate mesh for Hokkaido spring herring by age groups, by a method similar to that used by Farran. In 1962, he ascertained that, in commercial sized salmon, the relationships of the maximum girth to the fork length and relationship of the girth at the breast under the gillcover to the fork length are both represented by a straight line. In this way, he defined the rage in size which a given mesh will catch and he made it possible to indicate the fish size corresponding to a given mesh size, by the fork length of the fish. A quality indicator is not used in either of his papers, because, the girth of the body serves as a quality indicator. The methods used by Yamamoto and Mishima (1962), are not essentially different from former methods.

Certainly, the relation between the size of the mesh and the actual size composition of the available stock is the principal factor in connection with capture and escape. However, besides this, the elongation of the thread, the elasticity of the body, shrinkage of the mesh, behaviour and momentum of the fish are also involved.

In former studies, the range in size of fish caught with a given mesh was estimated by studying the relation between length and girth, and then length and mesh size. However, other factors were not regarded.

The value of the constant K_b in formulas by Baranov is the synthetic result of a study of these factors, however, the formulas by Baranov do not help to make clear the way which fish are caught or escape.

In a gill net most of the fish caught are gilled. A few are caught by becoming entangled. Those gilled between the gill cover and the dorsal fin are securely gilled. Some times fish are gilled unsecurely, being gilled at the head before the end of the preopercurum or at the trunk after the dorsal fin. However, such fish being gilled unsecurely escape easily and there are few of them in the catch (Fig. 4-1).

If, we disregard these unstably gilled or entangled fish,

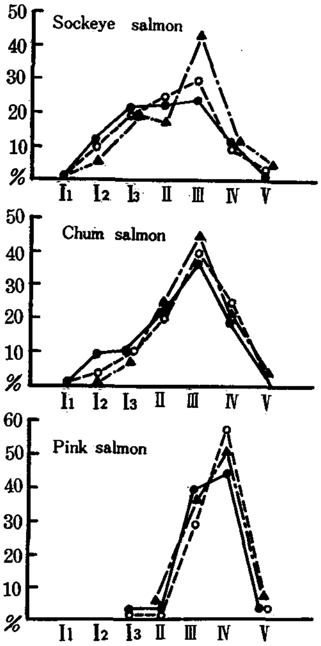

Fig. 4-1. Percentage of catch, by mesh and by division in Fig. 3-1

① the fish gilled at the after ridge of the preoperculum are the largest fish gilled with a certain mesh, and the fish gilled at the front of the base of the dorsal fin (where the girth is the largest) are the smallest fish gilled with a certain mesh.

Therefore, supposing that the thread of the net does not extend when the fish are gilled,

② it is possible to think of the relationship of the girth at the end of the preoperculum (G_p) of the largest fish and the girth at the front of the base of the dorsal fin (G_m) of the smallest fish gilled to the size of a certain mesh (ϕ); $G_p=4\phi$, or $G_m=4\phi$, where 4ϕ is a perimeter of a certain mesh. However these equalities are not real, because the thread of net may extend when the fish are gilled. Therefore,

③ if we suppose the angle of the impact of the fish upon the net to be 90 degrees, and if simply regard the perimeter of the netmark as the size of the mesh when the thread is elongated at impact, then the relation between girth (G) and mesh size (ϕ) may be expressed by the following formulas

$$G_p=4K_p\phi \quad \cdots\cdots (1)$$

$$G_m=4K_m\phi \quad \cdots\cdots (2)$$

Where, K is a constant connected with the rate of elongation of the mesh perimeter, K_p is the constant at the end of the preoperculum, K_m is the constant at the front of the base of the dorsal fin.

The value of K will vary according to the part of the fish, and it may be expressed by following formulas

$$K_p=\frac{G_{np}}{4\phi} \quad\cdots\cdots(3)$$

$$K_m=\frac{G_{nm}}{4\phi} \quad\cdots\cdots(4)$$

where G_{np} is a the perimeter of the netmark at the end of the preoperculum, K_{nm} is the perimeter of the netmark at the front of the base of the dorsal fin.

④ Furthermore, the elasticity of the body when gilled should be considerd as being connected with capture and escape. The rate of elasticity of the body (δ) may be expressed by the following formulas

$$\delta_p=\frac{G_{np}}{G_1} \quad\cdots\cdots(5)$$

$$\delta_m=\frac{G_{nm}}{G_2} \quad\cdots\cdots(6)$$

where δ is a constant of the rate of body elasticity when it is gilled, and the value of δ is always equal to or smaller than 1 ($\delta\leqq 1$), δ_p is a value of δ at the end of the preoperculum, δ_m is a value of δ at the front of the base of the dorsal fin. G_1 is a girth at the end of the preoperculum and G_2 is a girth at the front of the base of the dorsal fin.

⑤ G_2 is equivalent to G_m ($G_2=G_m$), at the portion where girth is the largest, therefore, substituting expression (4) into equation (6) we find

$$\delta_m=\frac{4K_m\phi}{G_m} \quad\cdots\cdots(7)$$

where G_m is a maximum girth which is gilled with a certain mesh, 4ϕ is a perimeter of the mesh used, K_m is a constant connected with the rate of extension of the mesh perimeter when it is gilled at the front of the dorsal fin, δ_m is a constant connected with the elastic rate of the fish gilled at the front of the dorsal fin where the girth is the largest. Therefore, based on formula (7), the largest girth (G_m) of the smallest fish which it is possible to catch with a certain mesh (ϕ) may be expressed by following formula

$$G_m=\frac{4K_m\phi}{\delta_m} \quad\cdots\cdots(8)$$

⑥ G_1 is equivalent to G_p ($G_1=G_p$), at the end of the preoperculum, therefore, substituting expression (3) into equation (5) we find

$$\delta_p=\frac{4K_p\phi}{G_p} \qquad \text{(9)}$$

were G_p is the girth at the end of the preoperculum, 4ϕ is the perimeter of the mesh, K_p is a constant connected with the rate of the mesh perimeter when it is gilled at the end of the preoperculum, δ_p is a constant connected with rate of elasticity at the end of the preoperculum when it is gilled. Therefore, based on the expression (9), the girth at the end of the preoperculum (G_p) may be expressed by the following formula

$$G_p=\frac{4K_p\phi}{\delta p} \qquad \text{(10)}$$

However, expression (10) may be transferred as follows, because the rate of elasticity of the fish (δ_p) at the end of the preoperculum is so small that it is considered to be nearly equal to one ($\delta_p \doteqdot 1$)

$$G_p \doteqdot 4K_p\phi \qquad \text{(11)}$$

⑦ Relationships of the maximum girth of fish (G_m) and the girth at the end of the preoperculum (G_p) to the length of fish (L) are expressed by following formulas

$$L=a\ G_p{}^b \qquad \text{(12)}$$

$$L'=a'\ G_m{}^{b'} \qquad \text{(13)}$$

⑧ Therefore, length L_1 corresponds to the girth G_p which defines the largest fish gilled at the end of the preopeculum and may be expressed by the following formulas bassed expressions (12), (10) and (11).

$$L_1=a\left(\frac{K_p}{\delta_p}\right)^b(4\phi)^b \qquad \text{(14)}$$

or $$L_1 \doteqdot aK_p{}^b(4\phi)^b \qquad \text{(15)}$$

Length (L_2) corresponds to the girth G_m which defines the smallest fish gilled at the front of the dorsal fin and may be expressed by following formula substituting expression (8) into equation (13)

$$L_2=a'\left(\frac{K_m}{\delta_m}\right)^{b'}(4\phi)^{b'} \qquad \text{(16)}$$

Thus, we will be able to estimate the size mesh which will catch a given size fish or the size fish a give size mesh will catch (Figs. 4-4, 6, 8).

The curve A expressed by formulas (11) and (12) is a locus of the average length of large fish captured by various size of mesh, and the curve B expressed by formulas (13) and (8) is a locus of the average length of small fish captured by various size of mesh. Therefore, an interval between the curve A and B is the average range of length which a certain mesh selects. The curve a and b which is computed by adding or subtracting three times the standard variation (3σ) to or from the value of curve A and B, will represent the limit of the range of mesh with 99.7% accuracy.

Fish within the range of the selection of the mesh are gilled securely, while larger ones are not gilled or are gilled unsecurely and escape easily from the mesh, and smaller ones pass through the mesh.

This way of calculating is applicable not only to salmon gill net but also to every other gill net fishing.

4.2. Mesh Size for Sockeye Salmon

Curve (A) presented in Fig. 4-2, represents the relationship between the length (L) and the girth at the end of preoperculum (G_p) on sockeye salmon, based on formula (12). In this case

$$\left.\begin{array}{ll} L=5.325\, G_p^{0.84} & \\ \sigma=\pm 1.08 & 3\sigma=\pm 3.24 \end{array}\right\} \text{ for curve } (A)$$

Curve (a) is computed by adding 3σ to the original curve (A).

Curve (B) presented in Fig. 4-3, represents the relationship between the length

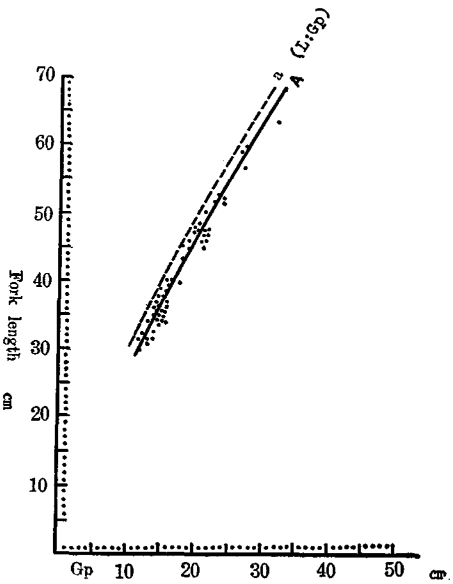

Fig. 4-2. Relationship between "L" and "G_p" of sockeye salmon

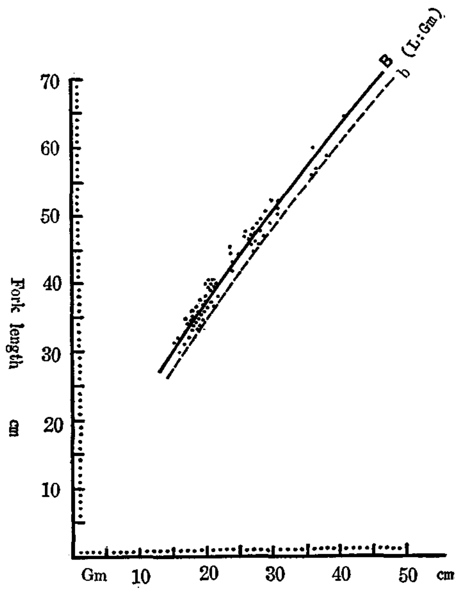

Fig. 4-3. Relationship between "L" and "G_m" of sockeye salmon

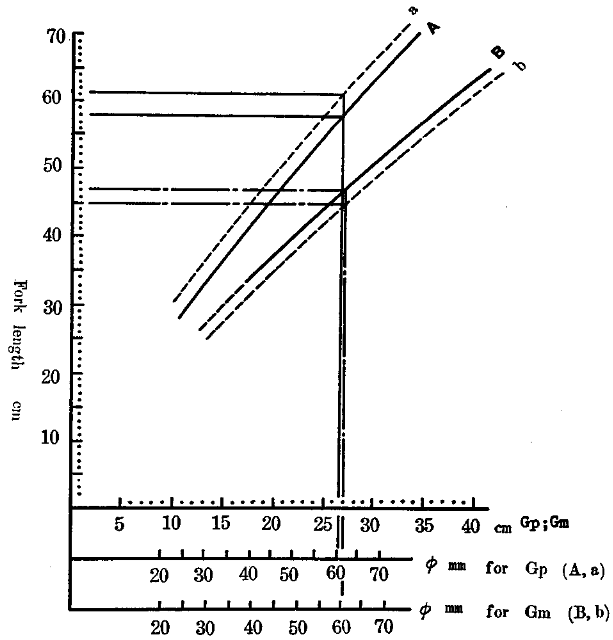

Fig. 4-4. Relationship between "L" and "ϕ" on sockeye salmon

(L) of sockeye salmon and their girth at the front of the dorsal fin (G_m) where the girth is the largest, based on formula (13). In this case

$$\left.\begin{array}{ll} L=6.976\ G_m^{0.75} & \\ \sigma=\pm 1.09 & 3\sigma=\pm 3.27 \end{array}\right\} \text{for curve } (B)$$

Curve (b) is computed by subtracting 3σ from the original curve (B).

Fig. 4-4, shows the relationship between the length (L) and the mesh size (ϕ). In order to replace a girth (G_p) with a mesh size (ϕ) formula (11) is used

$$G_p=4K_p\phi=4.08\phi$$

where the actual survey value of K_p is 1.02 in sockeye salmon (Table 4-1). In order to replace a girth (G_m) with a mesh size (ϕ) formula (8) is used

$$G_m=\frac{4K_m\phi}{\delta_m}=\frac{4\phi\times 1.11}{0.99}=4.48\phi$$

1.11 is the value of K_m for sockeye salmon and 0.99 is the value of δ_m for sockeye salmon according to actual surveys (Table 4-1).

Based on Fig. 4-4, it is possible to predict the range in length of fish which will be caught by a certain mesh, and to choose the size mesh which will corresponds to a certain size of salmon.

The range in length of fish that would be caught with various sizes of mesh is shown in Fig. 4-4.

Table 4-1. Average length, girth and perimeter of netmark by the portion of the body, and other factors connecting with mesh selection, in sockeye salmon

P	L cm	G_p cm	G_m cm	G_n cm	K	K_p	K_m	δ_p	δ_m	N
I										
I_2	62.7	27.4	39.8	26.3	1.09					18
I_3	59.6	24.9	26.8	26.5	1.10	(1.02)		(1.00)		29
II	58.1	24.3	35.6	27.1	1.12					36
III	55.3	22.4	32.5	27.5	1.14					34
IV	49.5	29.6	27.1	26.9	1.11		1.11		0.99	18

Notes: P is a portion of the body shown in Fig. 3-1
$K=G_n/4\phi$, $K_p=G_p/4\phi$, in this table $K_m=G_{nm}/4\phi$
$\delta_p=G_{np}/G_p\doteqdot 1$, $\delta_m=G_{nm}/G_m$ $\phi=60.5$ mm
N is a number of sample

Table 4-2. Range of length which mesh select, in sockeye salmon, by various mesh sizes

Mesh size (ϕ) mm	Average range (S_r) cm		Limit of range cm		$\frac{A+B}{2}$
	Lower limit (B)	Upper limit (A)	Lower limit (b)	Upper limit (a)	
32.0	* 28.0	34.5	* 26.0	38.0	31.3
38.0	* 33.0	40.0	* 30.5	43.5	36.5
41.5	* 35.0	42.5	* 32.5	46.0	38.8
45.5	38.0	46.0	35.0	49.0	41.0
48.5	39.0	48.0	36.0	52.0	43.5
53.0	42.0	52.0	39.0	55.0	47.0
55.0	43.5	53.5	41.0	57.0	48.5
57.2	44.5	54.5	42.0	58.0	49·5
57.5	45.0	55.5	42.5	59.5	50.0
60.5	47.0	58.0	44.5	61.0	52.5
63.2	47.5	59.5	45.0	62.5	53.5
65.0	49.0	61.0	47.0	64.0	55.0
66.5	50.0	62.0	48.0	65.0	56.0
68.0	51.0	63.5	48.5	66.5	57.3

Notes; ϕ is a length of mesh side * were presumed with Fig. 4-4
These values may be applied only for nylon multi-filament thread

4.3. Mesh size for Chum Salmon

The curve (A) presented in Fig. 4-5, represents the relationship between the length (L) and the girth (G_p) of chum salmon, based on formula (12). In this

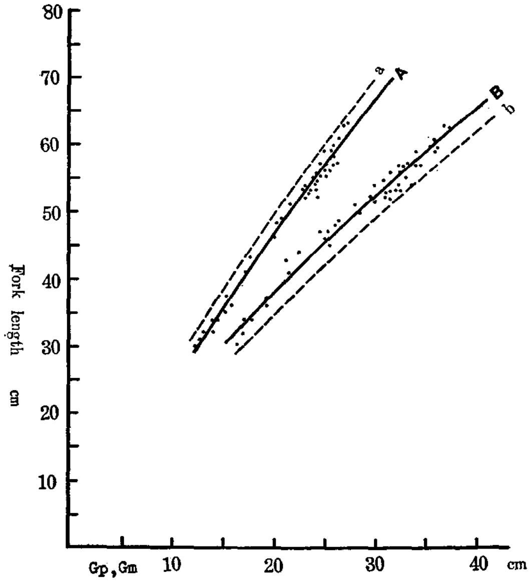

Fig. 4-5. Relationship between "L" and "G_p", "L" and "G_m" of chum salmon

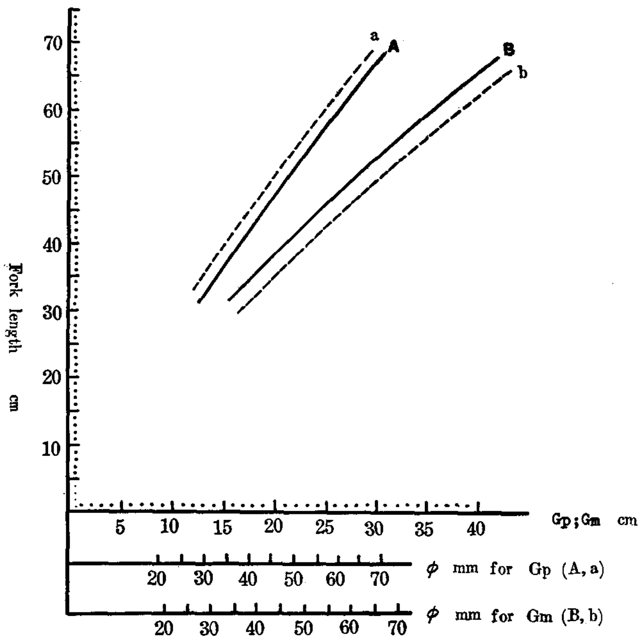

Fig. 4-6. Relationship between "L" and "ϕ" of chum salmon

case

$$\left.\begin{array}{ll} L=4.57\,G_p^{0.87} & \\ \sigma=\pm 1.06 & 3\sigma=\pm 3.18 \end{array}\right\} \text{ for curve } (A)$$

Curve (a) is computed by adding 3σ to the original curve (A).

Curve (B) presented in Fig. 4–5, represents the relation between the length (L) and the girth (G_m), based on formula (13). In this case

Tablc 4–3. Average length, girth and perimeter of netmark by the portion of the body, and other values connecting with mesh selection, in chum salmon

P	L cm	G_p cm	G_m cm	G_n cm	K	K_p	K_m	δ_p	δ_m	N
I										
I_2	60.8	26.1	37.3	25.4	1.05					9
I_3	58.9	24.8	36.2	26.6	1.10	(1.02)		(1.00)		11
II	56.8	22.9	33.5	26.3	1.09					26
III	53.4	22.0	31.2	27.4	1.13					29
IV	51.1	20.2	27.8	27.3	1.13		1.13		0.98	16

Notes; P is a portion of the body shown in Fig. 3–1
$K=G_n/4\phi$, $K_p=G_p/4\phi$, in this table $K_m=G_{nm}/4\phi$
$\delta_p=G_{np}/G_p\doteqdot 1$, $\delta_m=G_{nm}/G_m$　　$\phi=60.5$ mm
N is a number of sample

Table 4–4. Range of length which mesh select, in chum salmon, by various mesh sizes

Mesh size (ϕ) mm	Average range (Sr) cm		Limit of range cm		$\frac{A+B}{2}$
	Lower limit (B)	Upper limit (A)	Lower limit (b)	Upper limit (a)	
32.0	* 29.0	34.0	* 26.5	37.0	31.5
38.0	* 34.0	40.0	31.0	43.0	36.8
41.5	36.5	43.0	33.0	45.5	39.0
45.5	39.5	46.5	36.0	50.5	43.0
48.5	41.5	49.5	37.5	53.5	45.5
53.0	44.5	54.0	41.0	57.5	49.3
55.0	46.0	55.5	42.5	59.0	50.5
57.2	47.0	57.5	43.0	60.5	52.3
57.5	47.5	58.6	44.0	61.0	52.8
60.5	49.5	60.0	46.0	63.5	54.5
63.2	51.0	62.0	47.5	65.0	56.3
65.0	52.5	63.5	48.5	67.0	58.0
66.5	53.0	64.5	49.5	67.5	58.8
68.0	54.0	66.0	50.5	69.5	60.0

Notes; ϕ is a length of mesh side　　* were presumed with Fig. 4–6
These values may be applied only for nylon multi-filament thread

$$\left.\begin{array}{ll} L=6.31\,G_m^{0.77} & \\ \sigma=\pm 1.08 & 3\sigma=\pm 3.24 \end{array}\right\} \text{ for curve } (B)$$

Curve (b) is computed by subtracting 3σ from the original curve (B).

Girth (G_p or G_m) is replaced by mesh size (ϕ) in Fig. 4-6. To replace G_p with

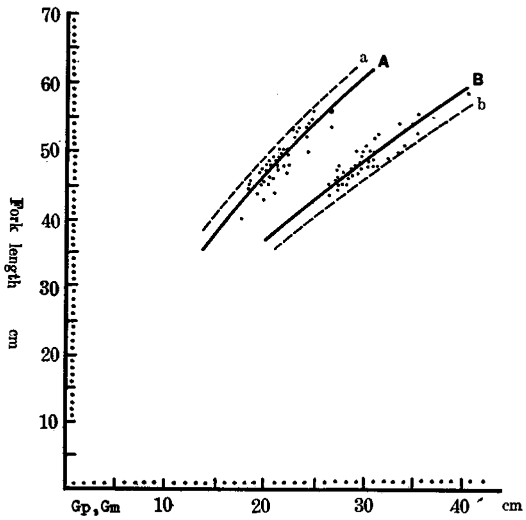

Fig. 4-7. Relationship between "L" and "G_p", "L" and "G_m" of pink salmon

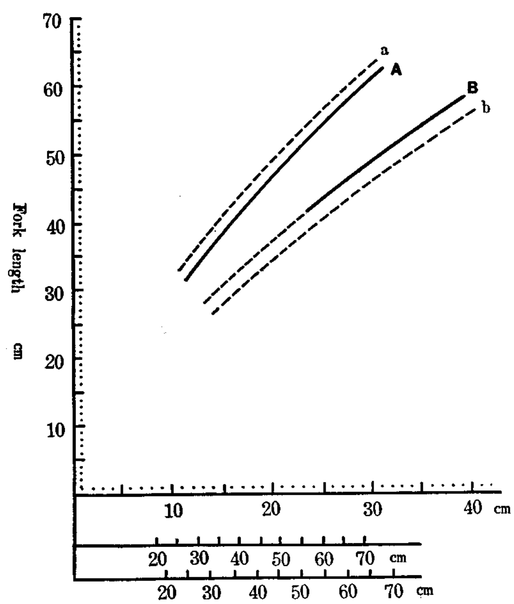

Fig. 4-8. Relationship between "L" and "ϕ" of pink salmon

ϕ, I used formula (11) with K_p at 1.02 as determined by an actual suvery

$$G_p = 4\,K_p\phi = 4.08\phi$$

To relace G_m with ϕ, I used formula (8) with K_m at 1.13 and δ_m at 0.98 as determined by an actual survey (Table 4-3).

$$G_m = \frac{4K_m\phi}{\delta_m} = 4.61\phi$$

The average range and the limit of length which the mesh selects are presented in Table 4-4, by various mesh sizes.

4.4. Mesh Size for Pink Salmon

Curve (A) presented in Fig. 4-7, represents the relationship between the length (L) and the girth (G_p) of pink salmon, based on formula (12). In this case

$$\left.\begin{array}{ll} L = 12.031\,G_p^{0.69} & \\ \sigma = \pm 1.05 & 3\sigma = \pm 3.15 \end{array}\right\} \text{ for curve } (A)$$

Curve (a) is computed by adding 3σ to the original curve (A).

Curve (B) presented in Fig. 4-5, represents the relation between the length (L) and the girth (G_m), based on formula (13). In this case

$$\left.\begin{array}{ll} L = 14.531\,G_m^{0.62} & \\ \sigma = \pm 1.06 & 3\sigma = \pm 3.18 \end{array}\right\} \text{ for curve } (B)$$

Curve (b) is computed by subtracting 3σ from the original curve (B).

Girth (G_p or G_m) is replaced wit mesh size (ϕ) in Fig. 4-6. To replace G_p with ϕ, formula (11) is used with the K_p for pink salmon at 1.04 as determined by an actual survey (Table 4-5).

Table 4-5. Average length, girth and perimeter of netmark by the portion of the body, and other values connecting with mesh selection, in pink salmon

P	L cm	G_p cm	G_m cm	G_n cm	K	δ	N
I_2							
I_3	55.8	25.3	36.3	25.2	1.04		2
II	53.1	21.4	33.7	26.4	1.09		9
III	49.2	19.9	30.7	26.5	1.09		86
IV	47.7	18.6	27.9	27.0	1.11	0.97	97

Notes; P is a portion of the body shown in Fig. 3-1
$K = G_n/4\phi$, $K_p = G_p/4\phi$, in this table $K_m = G_{nm}/4\phi$
$\delta_p = G_{np}/G_p \fallingdotseq 1$, $\delta_m = G_{nm}/G_m$ $\phi = 60.5$ mm
N is a number of sample

Table 4-6. Range of length which mesh select, in pink salmon, by various mesh sizes

Mesh size (ϕ) mm	Average range (Sr) cm		Limit of range cm		$\frac{A+B}{2}$
	Lower limit (B)	Upper limit (A)	Lower limit (b)	Upper limit (a)	
32.0	* 30.0	34.0	* 27.0	38.0	32.0
38.0	* 34.0	39.0	* 31.0	42.0	36.5
41.5	* 36.0	42.0	* 33.0	44.5	39.0
45.5	* 38.0	45.0	* 35.5	48.0	41.5
48.5	* 39.5	47.0	* 37.0	49.5	43.3
53.0	42.0	50.0	39.5	52.0	46.0
55.0	43.0	51.0	40.5	53.0	47.0
57.5	44.5	53.0	42.0	55.5	48.8
60.5	46.0	54.5	43.0	57.0	50.3
65.0	48.0	57.0	45.0	59.5	52.5
66.5	49.0	58.5	46.0	60.5	53.8
68.0	49.5	59.5	46.5	61.5	54.5

Notes; ϕ is a length of mesh side * were presumed with Fig. 4-8
These values may be applied only for nylon multi-filament thread

$$G_p = 4K_p\phi = 4.16\phi$$

To replace G_m with ϕ, formula (8) is used with K_m for pink salmon at 1.11 and δ_m at 0.97 as determined by an actual survey (Table 4-5).

$$G_m = \frac{4K_m\phi}{\delta_m} = 4.58\phi$$

The average range and the limit of length which various sizes of mesh select are presented in Table 4-6.

V. Discussion

5.1. Primary Elements interfering with Capture

Quality, thickness and strength of thread, stretching of the mesh, spacing of the knots and tension upon the mesh are primary elements which decide the effectiveness of a salmon gill net, and still more, the angle of impact of the fish upon the net, the momentum of the fish when it is gilled and the size of the mesh all have a bearing on the effectiveness of the net.

In the early stages of salmon drift gill net fishing, the gill nets were made of flax or cotton yarn or ramie thread. Of these, ramie thread net was the most effective, but it tended to rot. Ramie thread net alone was used during the short term of trial fishing (1952, 1953) while the Japanese salmon fleet was being re-established. However, in 1954, nonrot Amilan net, a synthetic fiber net, was put to practical use. The Amilan net was far more effective than the ramie thread net. Various synthetic fiber net were tried, however, it was ascertained that among them nylon ones are the most effective, if the thickness of the thread is identical.

In 1961, the Amilan monofilament thread net (the Amilan gut net) appeared, it spread so rapidly that it made up more than 50 percent of the set in 1963. The Amilan twisted thread and the Amilan gut are the same in quality, however, the Amilan gut is more transparent, more wiry, more glassy and elastic than the Amilan twisted thread. The reason for the superiority of the Amilan gut net is considered to be its transparency, making it difficulty to see in the water, its elasticity making possible a large extension of the mesh and the delicacy of the thread in comparison with the Amilan twisted thread net (Taguchi, 1963). These facts were proved by primary experiments by Kanda and others (1963), and the result of the experimental netting by the Japanese Fisheries Agency in 1963.[38] However, in this paper, the author is satisfied with exlaining the fact that the effectiveness of gill net varies with a different kinds of thread, because, the author is attempting to discuss only the Amilan twisted thread net.

Miyazaki (1961), concluded that the velocity necessary for a fish to cut the thread when it is gilled, is 12.7–15.7 m/sec, on the basis of Tauchi's theoretical formula $V^2=LT\varepsilon/P_m$, where V is the velocity of the fish per sec., $2L$ is the mesh size, T is the strength of the thread, m is the average weight of the fish, ε is the rate of elongation of the thread when the thread is cut, P is the maximum number of gilled fish which can be supported with the surplus buoyancy of the net. He reported these value; $T=14\sim20$ kg, $m=2\sim4$ kg, $\varepsilon=0.23\sim0.264$, $P=0.0040\sim0.0071$, $L=60.5\sim68.0$ mm, in 210 denier, in 3/13~3/18 Amilan twisted thread.

Therefore, the Amilan twisted thread which is now common in salmon gill net fishing will not be cut, because, in actuality, fish can not swim at the verocity mentiond above. The strength and the elongation rate of the Amilan twisted thread is shown in Table 2–20.

Kanda (1953), suggested that adequate shrinkage for gill net is about 40 percent, because fish pass through mesh exceedingly well at 40 percent shrinkage. Nishiyama and Yamamoto (1954), pointed out, based on their experiments, that in a salmon gill net the size of fish caught is not infulenced by shrinkage as long as it is within 30~50 percent. The shrinkage of present Japanese commercial salmon gill net is almost alway within 42 to 45 percent. Therefore, the size of salmon caught by the commercial gill net does not differ according to the small differrence of shrinkage.

If the spacing of the knots is unstable, the catching capablity varies, and especially the size composition of the catch varies. However, at the present, the knots are fixed and tightened stably by technical improvements. Therefore, it is unusual for a fish to escape because of extension of the mesh perimeter.

Tension for the mesh decides the number of fish gilled, where the stream pressure is constant, surpulus buoyancy will exert an influence upon the tension of the mesh. However, in present commercial salmon gill net, surplus buoyancy is nearly constant as follow; $F-W=7.0$ kg, $F/W=2.00$, F is the buoyancy of the net, and W is the underwater weight of the net. Therefore, in actuality, the effectivenes of the net does not vary much in the present commercial salmon net because of the difference of the surplus buoyancy.

The angle (θ) between the net and the axis of the fish gilled varies. When the angle (θ) is 90 or nearly 90 degrees, fish are gilled securely. However, when the angle (θ) is considerably over or under 90 degrees, the greater part of the fish gilled escape from the net. However, such cases will be seen only in a process of gilling in the mesh.

When the momentum is low, fish are gilled unsecurely and are likely to escape, especially the larger fish even though they are within the size range of fish usually caught with that size mesh. On the contrary, when the momentum is high, even the same size fish are gilled securely.

Small fish within the size range of fish caught with a given size mesh, are gilled unsecurely when their momentum is low and are likely to escape. On the contrary, when their momentum is high, the fish escape through the mesh. The relation between the momentum of the fish and the catching power of the net involves both the characteristics of the fish and of the thread of the net; elasticity of the body of the fish, the momentum of the fish and the elasticity of the thread of the net. These factors vary with each fish.

These various factors connected with the effectiveness of the salmon gill net are difficult to control by human action. However, the effectiveness of the gill net depends on the relation between the size composition of the stock and the size of the mesh. Therefore, it is considered that the study of the size of fish selected by a given size gill net mesh is important for effective fishing, because the important relation between the size of the fish and size of the mesh can be altered by human action.

Studies on the mesh selectivity by Holt (1957) and other studies after him effectively determine the natural composition of the stock by using a non-selective set of gill nets, and on the other hand, studies on the way fish are caught or escape from a gill net help determine the optimum mesh for an available stock.

5.2. General Characters of Mesh Selection

Fig. 5-1, shows the relation between the natural length composition of the high seas sockeye salmon stock and the selective range of various size mesh. It is evident that the adequate mesh size for each length group (S, L_1, L_2) is different. In this figure, the natural length composition of the stock was estimated by the catch of a composed set net which consisted of three kinds of mesh size (Oshoro-maru, 1957).[44]

Fig. 5-2, shows the differences in the length of the sockeye salmon caught

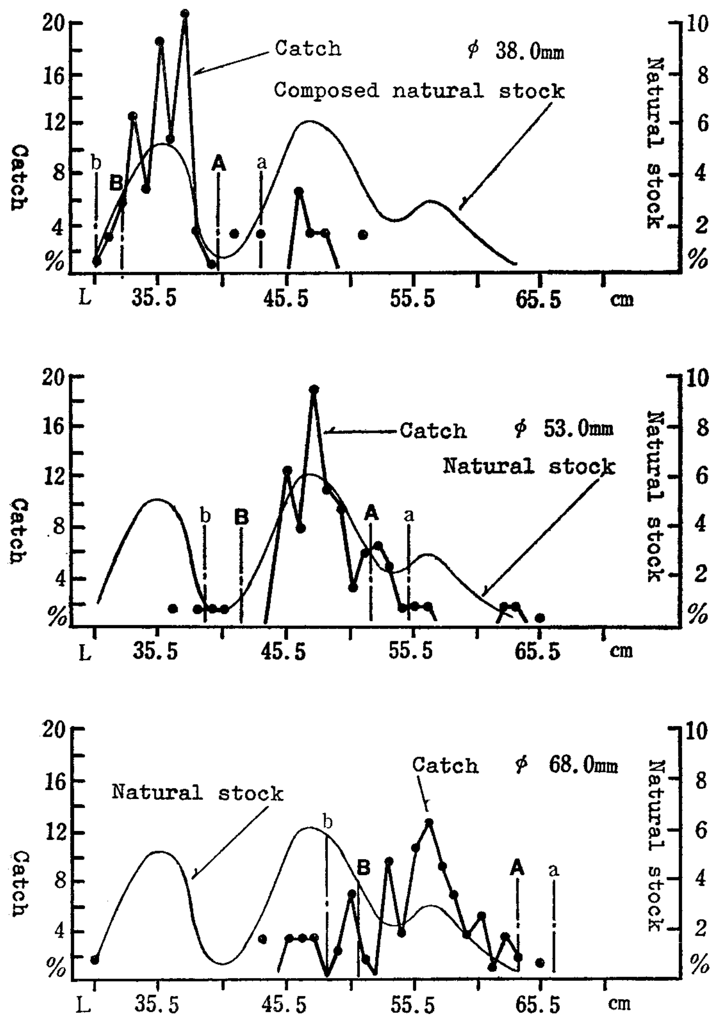

Fig. 5-1. Gill net selection from natural stock by various mesh, of sockeye salmon Original data by the Oshoro-maru (1957)

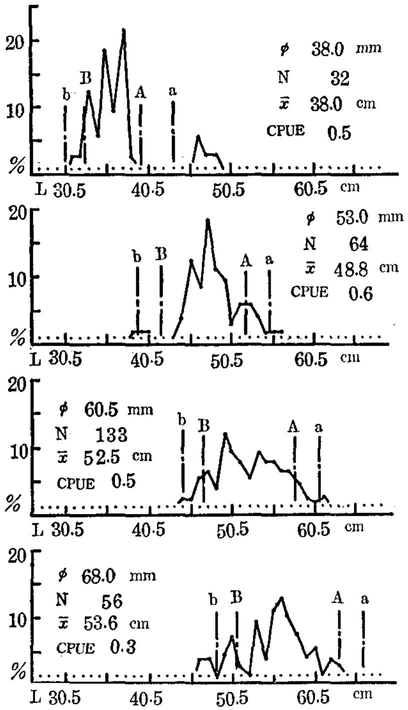

Fig. 5-2. Relation between length composition of the catch and the selective range of the mesh, of sockeye salmon, by mesh "ϕ", size of mesh; N, number of sample; $\bar{x}$, mean length; CPUE, catch per "tan"; A-B, a-b, selective range of mesh and its limits
Catch data by the Oshoro Maru (1957)

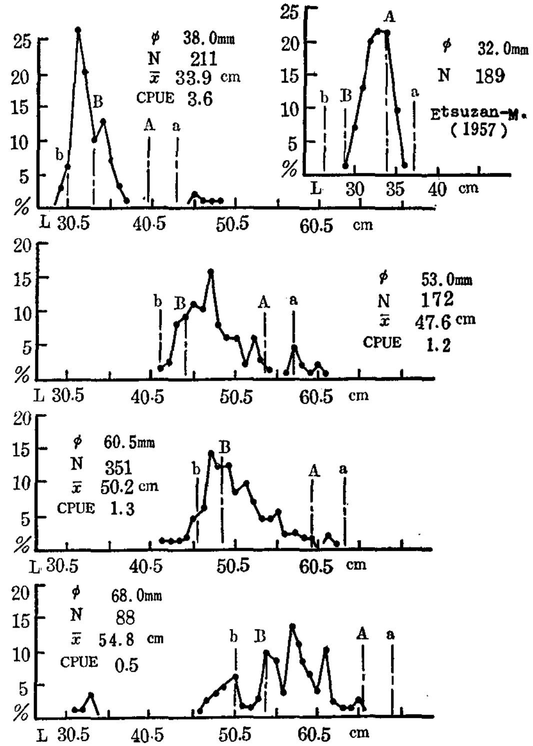

Fig. 5-3. Relation between length composition of the catch and the selective range of the mesh, of chum salmon by mesh "ϕ", size of mesh; N, number of sample; $\bar{x}$, mean length; CPUE, catch per "tan"; A-B, a-b, selective range of mesh and its limits
Catch data by the Oshoro Maru (1957)

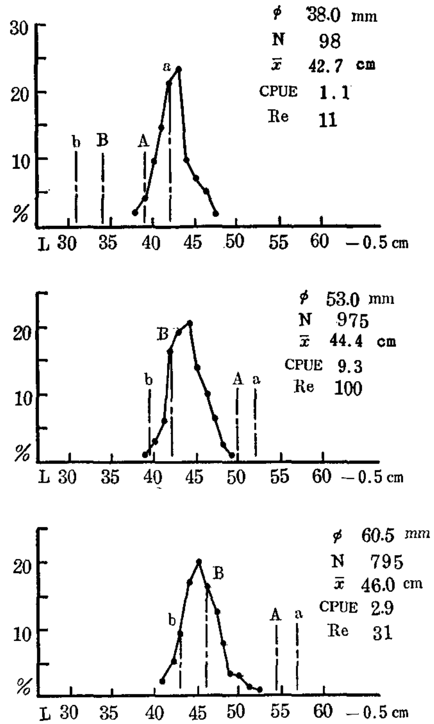

Fig. 5-4. Relation between length composition of the catch and the selective range of the mesh, of pink salmon by mesh "ϕ", size of mesh; N, number of sample; $\bar{x}$, mean length; CPUE, catch per "tan"; A-B, a-b, selective range of mesh and its limits
Catch data by the Oshoro Maru (1957)

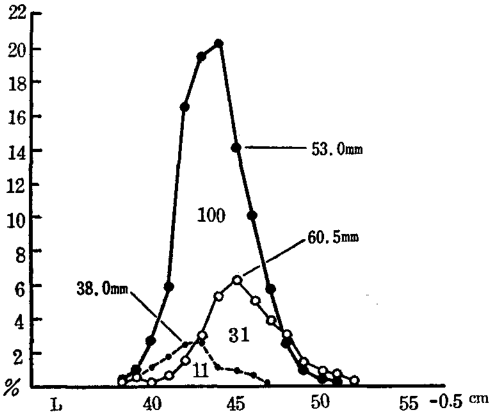

Fig. 5-5. Length composition of the catch by mesh located by the relative efficiency (R_e) of each mesh of pink salmon
ϕ, size of mesh
R_e, Relative efficiency of meshes (53,0 mm....100)
Data by the Oshoro Maru (1957)

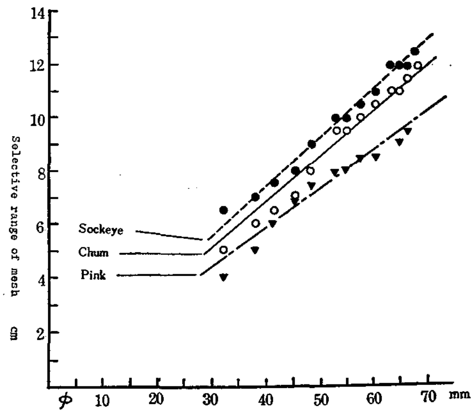

Fig. 5-6. Relationship between size of mesh (ϕ) and selective range of mesh (S_r) by species

with various sizes of mesh. From this figure, it is evident that, the larger the mesh, the more the average length and the modal length of the catch shift to the large side, and the range in length of the catch is well equivalent to the possible range in length for the given size mesh.

Fig. 5-3, shows the differences in length composition of catches of chum salmon according to various sizes of mesh.[44] From this figure, the range in length of the catch is about equivalent to the possible range in length for the given size mesh, however, the composition of the catch made by 38.0 mm mesh is partial to the small side. It shows that the adequate mesh for these small chum is smaller than 38.0 mm. Based on the appended graph, it is considered that 32.0 mm mesh would be more appropriate for the length composition of small chum than 38.0 mm mesh.

Fig. 5-4, shows the differences in the length composition of the pink salmon catch according to various mesh size. In this case, variations in the average length and modal length according to the difference of mesh size are not as clear as the cases of sockeye and chum salmon. This is due to the simplicity in age composition of pink salmon. Based on the catch per unit of effort (CPUE) it is clear that the 38.0 mm mesh is too small and the 60.5 mm mesh is too large for the pink salmon stock.

The above examples, suggest general characteristics of mesh selection as follows;

① The larger the mesh size, the more the average length, modal length, and length range of the fish caught shift to the large side.

② With an increase in the size of the mesh, the range in length of fish which may be caught with that size mesh (S_r) moves to the large side. This relation may be expressed by the formula $k\phi b = S_r$ where ϕ is the size of the mesh, S_r is the range in length of fish which may be caught with a given size mesh, $b \doteqdot 1$, k is the constant (sockeye 0.19, chum 0.17, pink 0.16). This relation suggests that the catching power of the mesh is higher in large mesh than in small mesh (Fig. 5-6).

③ The main range in length of the catch is well equivalent to the possible range in length of the mesh.

④ The catching power of the gill net is the highest when the length composition of the natural stock is equivalent to the length range of the mesh selection.

⑤ If the length composition of the stock is not equivalent to the range in length that the mesh used selects, then the length composition of the catch will not be balanced but be partial to either the large side or the small side according to the length composition of the stock, and of course within the selective range of the mesh.

5.3. How Fish are caught or escape

Most of the fish which are caught with the salmon drift gill net are gilled in the following parts of the body; I_3, II, III, IV and rarely in V (Figs. 3-1, 4-1). Comparatively large fish in comparison with the size of mesh are rarely captured, because these fish are gilled unsecurely in the head (I_1 or I_2) and escape easily. Comparatively small fish in comparison with the mesh size are rarely captured, because, these fish pass through the mesh without being gilled or escape through the mesh having once been gilled in the hind part of the trunk (IV or rarely V).

Fig. 5-7, shows the relation between the length of the fish and the place of the injury. These fish had apparently been injured during the same season of the catch, because, their injury had not yet healed. From this figure, it is obvious that, large sockeye and chum salmon escape from the mesh having once been gilled in the head part. On the other hand, small sockeye, small chum and pink salmon escape through the mesh, having once been gilled in the hind part of the trunk.

Fig. 5-8, shows the relation between the length of the escaped fish and two curves (A·B) which show the upper and the lower limits of the length of fish selected by a given size mesh. Samples were gathered with the fish-spear and netmarks were measured during the operation. Based on this figure, it is obvious that, the small fish (No. 1) which are below the lower limit of the selection of

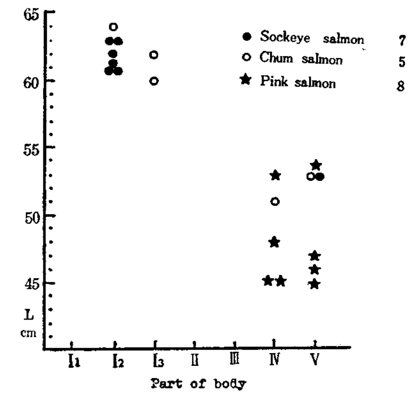

Fig. 5-7. Relation between length of net-marked salmon and the part where it was gilled

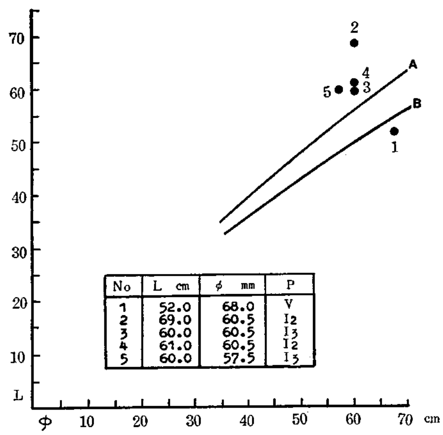

Fig. 5-8. Relationship between length of chum salmon which escaped from mesh "ϕ" and its selective range
L, Forklength, ϕ, size of mesh used
P, Portion where gilled
Nos. 1, 2, 3, (Hokko maru 1961)
Nos. 4, 5, 6, (Ariiso maru 1963)

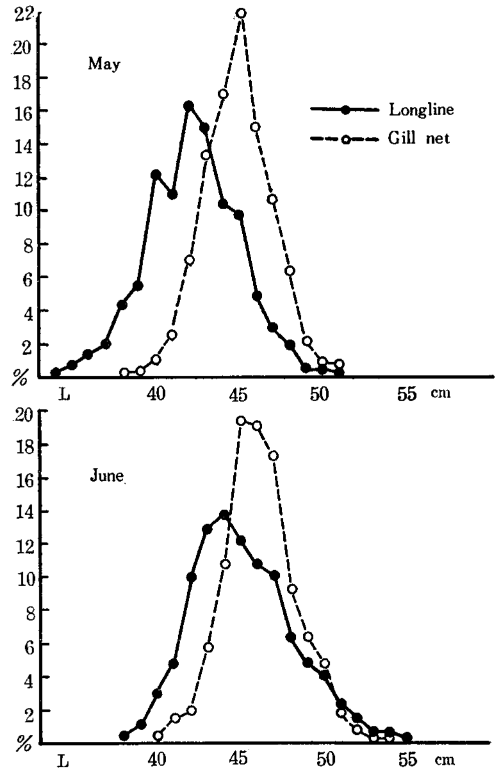

Fig. 5-9. Length composition of pink salmon in "B" area (1962) N, number of sample; $\bar{x}$, Mean length

the mesh escaped through the mesh, and large fish (No. 2 to No. 5) which are above the upper limit of the selection of the mesh escaped having once been gilled at the head part.

Fig. 5-9, shows the length composition of pink salmon caught with a longline and a gill net in the "B" area (north-west Pacific, south of 45N. lat.). The fish caught with a longline are generaly smaller than those caught with a gill net, and this difference is especially evident in May. It is considered that, the length

Table 5-1. Action of escape from mesh assumed by netmark

Action of escape \ Districts	Coast of Kamchatka	Coast of Primorsk Province
Escape, having once been gilled in the head	22.5%	76.8%
Escape through the mesh having once been gilled in the hind of the trank	77.5%	23.2%
Number of sample	40	142
Fishing influence upon the stock	Japanese drifters, in the North-West Pacific	Japanese drifters, in the Sea of Japan

Note: Original data by Soviet document in 1961 committee

composition of the longline catch is approximate to that of the natural stock, because; the sex ratio is far more balanced in a longline catch than in a gill net catch. The selection of fish caught with a fishhook is a balanced selection, because, males as well as females have good appetites. Therefore, it is evident that, the size mesh which is used by drifters operating in the "B" area is too large in comparison with the length composition of the natural pink salmon stock.

Table 5-1, shows that the location of the netmark on the fish differs from area to area. On the Kamchatka coast 77.5 percent of the netmarks are found on the trunk. It shows that the average mesh size in the North Pacifie is comparatively large in comparison with the size of the fish. On the primorsk coast 76.8 percent of the netmarks are found on the head. It shows that the average mesh size in the Japan Sea is comparatively small in comparison with the size of the fish.

Based on the above data, it is obvious that the mutual relation between mesh size and fish size is important in determining how fish are caught or escape.

The regression curve A is a locus of the upper limit of the range in length that the mesh selects and the regression curve B is a locus of lower limit of range in length that the mesh selects. Therefore, the range in length that any given mesh selects is between these two regression curves, A and B (Figs. 4-4, 6, 8).

In my theory, the extension of the thread and the elasticity of the body are considered anew, in addition to the relationship between the girth (G_p or G_m) and the perimeter of the mesh (4ϕ) in order to decide the upper and lower limits of the size of fish that the mesh selects. The perimeter of the netmark (G_n) is regarded to be the size of the mesh when it is stretched at the time of gilling. The rate of the extension of the thread (K) is regarded to be the strain between the perimeter of the mesh (4ϕ) and the girth (G_p or G_m). Based on the formulas (3) and (4) the theoretical value of K is expressed with the following equation; $K=G_n/4\phi$.

The value of K varies with the individual fish and the portion where the fish are gilled. The value of K according to actual survey is shown in the Tables 4–1, 3, 5. The value of K is, generally, comparatively small when the fish is gilled on the head part (I) and large when the fish is gilled on the after trunk (III, IV).

The value of K varies according to the actual perimeter of the mesh and the momentum of the fish when gilled. However, the variance of the actual mesh size of commercial nets is so small ($\pm 1.5\%$) that it can be disregarded. Therefore, the value of K depends on the weight and the velocity of the fish and the stretching of the thread itself.

Based on formula (11), where the value of K is large, fish will be gilled more securely and escape will be reduced for larger fish which are over the upper limit of the range in length which the mesh usually selects. However, where the value of K is small, fish will be gilled unsecurely and rate of escape will increase for larger fish.

Based on formula (8), where the value of K is large, fish will escape through the mesh and the rate of escape, for small fish which are within the range of the mesh selection will increase.

Another factor connected with the escape is the elasticity of the body of the fish. Based on formulas (7) and (9) the rate of elasticity (δ) is expressed by the following equation; $\delta = 4K\phi/G$, where δ is the rate of elasticity, 4ϕ is the perimeter of the mesh, G is the girth of the fish, K is a constant expressis the stretch of the thread. However, the value of δ on the head of the fish (I_3) is so small that it may be disregarded. Therefore, based on formulas (8) and (11), it is enough to consider only fish which are gilled where the girth is the largest, which means the smallest fish which the given mesh selects.

The value of δ is connected mostly with the momentum of the fish when it is gilled. The values of δ presented in Tables 4–1, 3, 5 are the mean values of captured one and do not include the values of escaped ones. If the value of δ is larger than that shown in those tables, the fish will escape through the mesh perhaps after having been temporarily gilled in the trunk.

The stretch and tension of the mesh are primary elements effecting the capture and escape of fish, but in commerciall gill nets the stretch and tension are so well standardized that it is not necessary to take them into consideration.

The angle (θ) between the net and the axis of fish gilled varies according to the behavior of the fish. The angle (θ) is connected with the escape of the large fish or the capture of small fish which are within the range of mesh selection. However, from experience, it has been determined that the angle (θ) of the fish caught is nearly always about 90°.

The momentum of the fish also effects the capture or escape of the fish.

The momentum acts to extend the perimeter of the mesh and to reduce the girth of the body for the smaller fish which are near the lower limit of the mesh selection (formula 8), while it acts only to extend the perimeter of the mesh for the larger fish which are near the upper limit of the mesh selection (formula 11).

The figures showing the sizes of fish caught with a given size mesh (Tables 4-2, 4, 6) may be applied only to the nylon multifilament twisted thread net, because, the elasticity of the thread varies with each material. These figures naturally vary to some degree even with the same thread, because, these values are reached by considering only the average form and momentum of the fish. Therefore, in an actual catch, even of the fish within the size range of the mesh, some will escape and other will be captured. It depends on the constants K* and δ**, which in turn vary according to the momentum of the fish, and with the material of the thread itself or the elasticity of the body itself.

*$K=G_n/4\phi$ ....formulas (3), (4)

**$\delta=4K\phi/G$ ....formulas (7), (9)

Fig. 5-10, shows the relation between the range of the size fish which are likely to be caught with a given size mesh as determined in this paper and the selectivity curve as determined by Ishida[14], when they are both applied to the

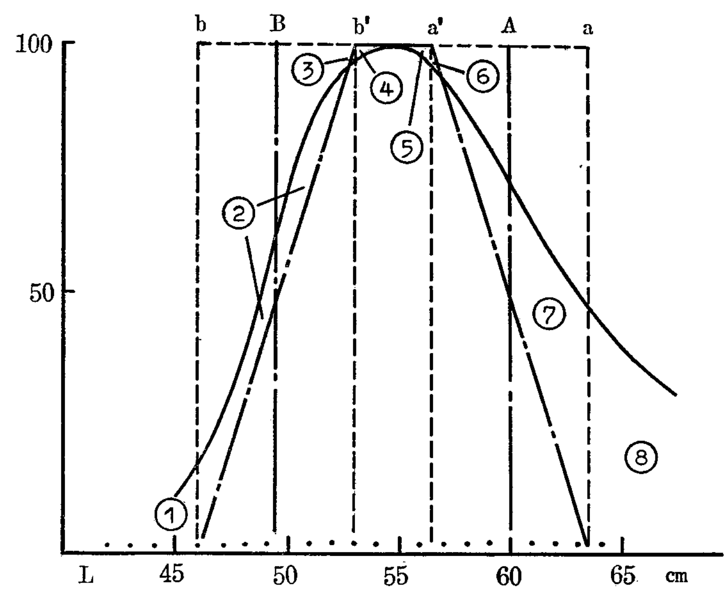

Fig. 5-10. Relation between the selectivity curve (Ishida, 1963) and the selective range of the mesh (in this paper), on chum salmon
A-B, the selective range of the mesh (60.5 mm)
a-b, the range of variation on $L:G_p$
b-b, the range of variation on $L:G_m$

catching of chum salmon with a 60.5 mm mesh. In this figure, the thin line is Ishida's curve. The dot and dash line is the first curve drawn from the length range of the mesh selection and it varies at both the upper and lower limits. The side lines of the retangle will be modified to an *S*-shaped curve in the future.

The characteristics of the eight groups into which the fish are divided is as follows:

① These fish are really too small to be gilled with this size mesh but because of their lack of momentum or because of the particular angle at which they approach the net, a few of them are caught.

② These fish are barely large enough to be gilled and a few of them escape because of their momentum, shape or the angle at which they approach the net.

③④⑤ These fish are large enough to be gilled but a few of them escape for the same reasons which are mentioned above.

⑥ These fish are large enough to be gilled but a few of them escape after having once been gilled because of their angle of approach or their lack of momentum.

⑦ These fish are barely large enough to be gilled and quite a few of them escape, for the reasons mentioned above.

⑧ These fish are too large to be gilled with this size mesh but quite a few of them are caught because they become entangled.

5.4. The Optimum Mesh Size

The salmon gill net, as a fishing tool, is efficient. However, capture is always accompanied by escape when it is used by drifters. The escape rate has not been accurately determined at the present level of study. But based on the present data, the actual escape ratio when hauling up the net and the estimated ratio while setting the net, is from about 21.3 to 29.6 percent. However, as I said, these values are not too reliable. However, results of various experiments show us that no small number of salmon having once been gilled escape from the mesh. Among fish that escape from the net, some die and some live and swim away, but even those that live are usually more or less injured by the thread of the net. Even though their injury seems to be not so severe (Table 5–2), some become worse in the ocean. In fresh water their injury will become seriously inflamed, and it is supposed that some of them die before spawning or lose their generative function.

The rate of escape or loss will decide the rationality of gill net fishing. This is because an increase in the ratio of escape or loss, means an increase in mortality outside the catch. Therefore, this calls for further study regarding the methods for preventing or reducing escape and loss.

Supposing that the material of the threads, and the construction of the net are equal, then the causes for fish escaping from the gill net are:

① individual variation in the form or momentum of the fish or

② a mesh size which does not correspond to the size composition of the available stock. The former can not be controlled by human action, however, the latter can.

The "optimum mesh" which has a low escape rate is reasonable, in order to maintain the resources and utilize them effectively. The definition of "optimum mesh" is not so clear at present. However, according to present information connected with the salmon gill net and the salmon resources, it is considered that "using a mesh which corresponds in size to the size of the available stock will effectively secure the catch and reduce the escape rate" (Soviet document, 1961), and it is understood that "to choose a suitable mesh for the available stock will help to secure the catch, to reduce the escape rate and to maintain the salmon resources" (Soviet document, 1961).

5.5. Grouping Salmon for the Convenience of Gill Net Fishing

The species group, the local group and the age group are the fundamental units of fish from a biological point of view. Each of these groupings is obviously valuable not only in evaluating the stock size or to forcasting the future stock for the purpose of salmon control but also for planning or carrying out salmon fishing.

The length range of the natural stock of sockeye and chum salmon on the high seas is so wide that the selection range of a certain mesh could not cover the whole stock. Therefore, a given mesh is adaptable to merely a part of the whole stock.

As mentioned in the preceding chapter, the actual species composition of high seas salmon resources, and the oceanic age composition of sockeye and chum salmon vary greatly according to the year (Tables 2-8, 10, 11), the season and the area of water.

In sockeye salmon, the oceanic age groups have to be considered as separate units for gill net fishing, because, as is clearly indicated in Table 5-3, their growth is proportional to the length of their ocean life and is less influenced by the length of their fresh water life.

Fig. 5-11, shows the length composition of 5_2, 6_3, 7_4 age groups which are the main elements of the oceanic 4 year old group (Oceanic 3+ group) of sockeye salmon. Based on this figure, 5_2, 6_3, 7_4 age sockeye groups, in spite of their differences of age, have nearly the same length composition as the oceanic 4 year old group. In addition, their length composition is considered to be nearly the same as that of natural high seas sockeye stock, based on the following facts; the average length of each age group (56.3–57.4 cm) is within the average length

Table 5–2. Degrees of injury which injured by gill net, in number of heads

(1) Sockeye salmon

Thread	Amilan 3/12			Amilan 3/15			Amilan 3/18			Total
Diameter	0.728 mm			0.822 mm			0.904 mm			
Degree of injury / Mesh mm	60.5	65.0	68.0	60.5	65.0	68.0	60.5	65.0	68.0	
1	36	32	44	43	36	32	43	26	41	333
2	13	25	24	17	20	19	14	14	17	163
3				1						1
4			1			1				2
5										
Total	49	57	69	61	56	52	57	40	58	499

(2) Chum salmon

Thread	Amilan 3/12			Amilan 3/15			Amilan 3/18			Total
Diameter	0.728 mm			0.822 mm			0.904 mm			
Degree of injury / Mesh mm	60.5	65.0	68.0	60.5	65.0	68.0	60.5	65.0	68.0	
1	23	23	21	25	23	27	23	18	21	204
2	12	10	9	7	21	15	8	14	13	109
3										
4										
5										
Total	35	33	30	32	44	42	31	32	34	313

(3) Pink salmon

Thread	Amilan 3/12			Amilan 3/15			Amilan 3/18			Total
Diameter	0.728 mm			0.822 mm			0.904 mm			
Degree of injury / Mesh mm	60.5	65.0	68.0	60.5	65.0	68.0	60.5	65.0	68.0	
1	60	57	31	65	25	34	64	38	32	406
2	19	14	5	27	27	18	23	13	19	165
3							1			1
4	1	2	1		1	1	1		1	8
5										
Total	80	73	37	92	53	53	89	51	52	580

Note: The original data by Hokko-maru (1961)

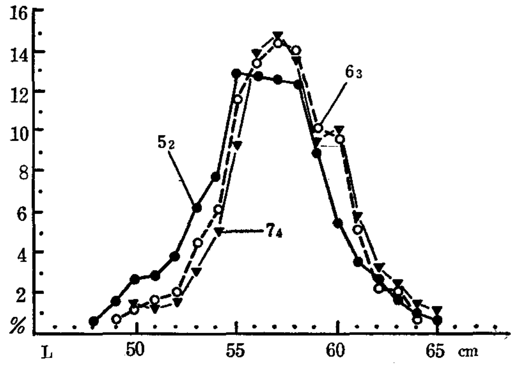

Fig. 5-11. Frequency distribution of fork length of sockeye salmon in catch by age (5_2, 6_3, 7_4, ····Oceanic 3+ group) in the Kamchatka-Kuril area (1959)

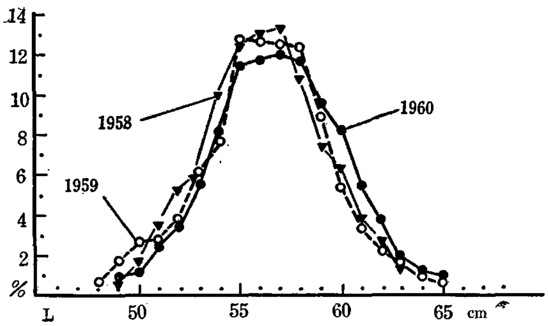

Fig. 5-12. Frequency distribution of fork length of 5_2 sockeye salmon in catch by the year 1958-1960, in the Kamchatka-Kuril area

(55.6-58.3 cm) which was determined measuring the scales (Table 5-3), and the range in length of fish which can be caught is 47-58 cm for 60.5 mm mesh and 49-61 cm for 65.0 mm mesh. These are the sizes of mesh in common use in mother boat fishing.

Yearly variations in length composition are small in the 5_2 and 6_3 sockeye age groups (Figs. 5-12, 13) and the variation by area is not so sharp as to influence the mesh selectivity (Fig. 14). Therefore, in the natural high seas sockeye stock, as far as gill net fishing is concerned, there is no need to divide them into original stocks (Table 5-4).

From Table 5-3, we assume that sockeye salmon grow about 9 cm between their third and fourth years in the ocean. Therefore, the length composition of the sockeye catch will partial to the large side of the length composition of natural high seas sockeye stock, because of the size of the mesh which is used.

Table 5-4, shows the estimated approximate length composition of each oceanic age group of sockeye salmon. In the table, the length composition of the unknown oceanic 3 year old group (n-1 year old) is simply estimated from that of the known oceanic 4 year old group (n year old), supposing annual growth to be 9 cm.

Table 5-5, shows the annual growth of chum salmon during their ocean life. Each value is estimated by scale measurement. The available stock of chum salmon consists of 3, 4 and 5 year old fish. However, as a general tendency, in the mother boat fishing area, mostly the four year old, and to a lesser degree the five year old groups abound, and merely a part of the three year old group appears in the area.

The growth from the 3rd year to the 4th year is great, however, the growth from the 4th year to the 5th year is small and the length distribution of

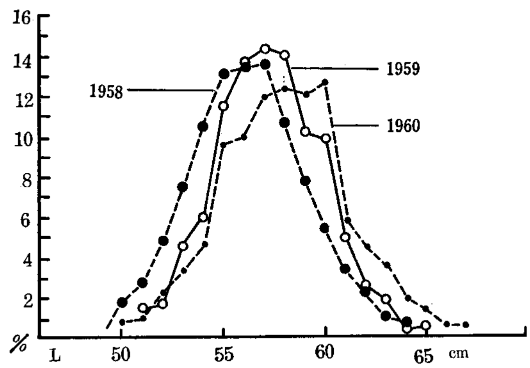

Fig. 5-13. Frequency distribution of fork length of 6_3 sockeye salmon in catch by the year 1958-1960, in the Kamchatka-Kuril area

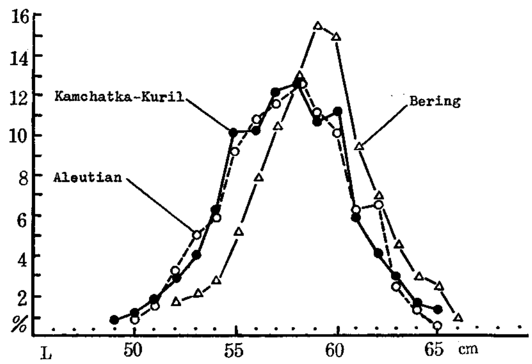

Fig. 5-14. Frequency distribution of oceanic 3+ group sockeye salmon by the area (1960)

Table 5-3. Growth of sockeye salmon during the fresh water and ocean life

Age	Sex	Local stock	Growth in fresh water cm		Growth in ocean cm			Growth 2 to 3 cm	Length in fishing season cm
			Full 1 year	Full 2 year	Full 1 year	Full 2 year	Full 2 year		
6_3	♂	Alaska	9.9	14.4	36.5	49.4	58.6	9.2	62.0
		W. Kam.	8.3	12.4	34.3	47.0	56.0	9.0	57.9
		E. Kam.	8.5	12.4	33.9	47.6	57.1	9.5	59.8
	♀	Alaska	9.4	13.8	35.3	47.5	56.0	8.5	59.0
		W. Kam.	7.8	11.2	34.6	46.2	54.8	8.6	57.1
		E. Kam.	8.3	12.0	33.7	45.3	54.5	9.2	56.7
5_2	♂	Alaska	10.4		33.9	49.0	56.6	9.6	60.8
		W. Kam.	9.7		32.0	45.7	55.8	10.1	58.0
		E. Kam.	9.3		30.9	44.8	55.5	10.7	58.7
	♀	Alaska	10.2		31.9	45.3	54.8	9.5	57.9
		W. Kam.	9.5		31.5	43.9	53.4	9.5	55.7
		E. Kam.	9.5		30.3	43.7	54.2	10.5	55.6
Average length					33.2	46.1	55.6		58.3
Average growth					12.9	9.5		9.5	

Note: The original data by Osako (1960)

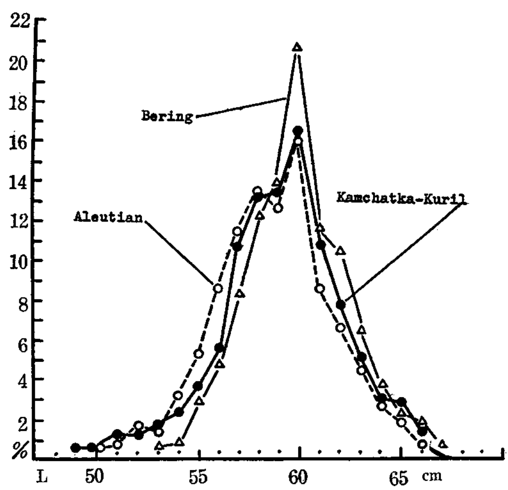

Fig. 5-15. Frequency distribution of fork length of oceanic 3+ group of sockeye salmon by the area (1961)

the 5th year old group is within that of the 4th year old group.

The fresh water life of chum salmon is very short. The growth of chum salmon is proportional to their age, therefore, each age group is regarded as a

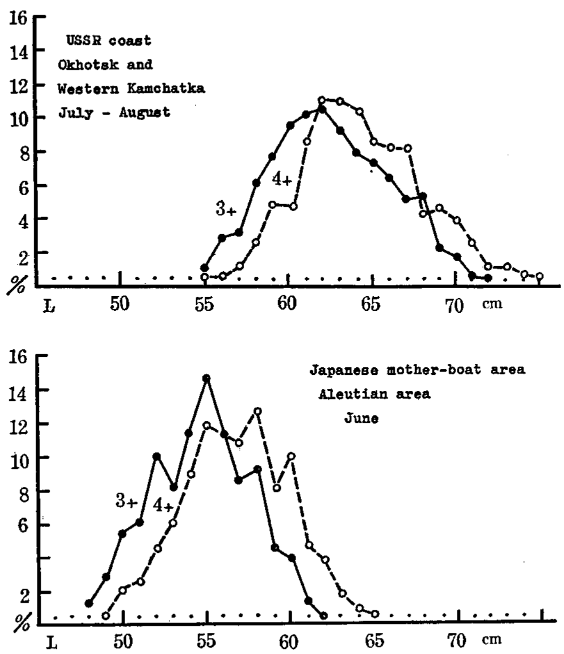

Fig. 5-16. Frequency distribution of fork length of 3+ and 4+ chum salmon in catch, by the area (1961)

unit group for the convenience of gill net fishing.

Fig. 5-16, shows the relation between the length composition of the catch of chum salmon by Japanese drifters in June in the Alutian area and in August along the Soviet coast where the above mentioned high seas group revolves.

The length composition of the four and five year old chum salmon catch by Japanese drifters (Table 5-6) is nearly the same as that of the natural stock of the same age. The high seas chum salmon catch is regarded as being less influenced by the mesh selection. This conclusion is based on the following facts; 1) the length composition of the 4 and 5 year old chum salmon caught by Japanese drifters in June is similar to that of those caught along the Soviet coast by set net in August. 2) the difference between the range in length of the 4 and 5 year old chum caught by Japanese drifters is as small as that of the Soviet coastal catch. 3) the difference of the growth in the period from June to August for four year old and five year old age groups is small. 4) the range in length of chum salmon caught by Japanese drifters (47-65 cm) almost correspond to the range in length (49.5-63.5 cm) which it is possible to gill with commercial mesh sizes (60.5 and 65.0 mm).

The length distribution of the 4 and 5 year old age groups are nearly the same in every local Asian chum stock, except the Amuru summer chum salmon

Table 5-4. Length composition of sockeye salmon by ocean age groups (%)

Fork length cm \ Unit group	Oceanic 3 years old group (4_2, 5_3, 6_4 ······)	Oceanic 4 years old group (5_2, 6_3, 7_4 ······)
38	0.1	
39	0.2	
40	0.6	
41	1.4	
42	2.0	
43	3.0	
44	4.8	
45	7.1	
46	11.4	
47	12.0	0.1
48	13.4	0.2
49	12.3	0.6
50	9.6	1.4
51	9.3	2.0
52	4.9	3.0
53	3.2	4.8
54	2.1	7.1
55	1.1	11.4
56	0.9	12.0
57	0.2	13.4
58	0.2	12.3
59	0.1	9.6
60		9.3
61	0.1	4.9
62		3.2
63		2.2
64		1.1
65		0.9
66		0.2
67		0.2
68		0.1
69		
70		0.1
$\bar{x}$	48.1	57.1

Nole: The length composition of oceanic 3 years old age group was calculated from that of oceanic 4 years old age group

Table 5-5. Average growth of chum salmon during the ocean life

Age	Full oceanic age	Average growth cm	Annual growth cm	Annual growth ratio %
2 years old	1	27.8		
			14.5	0.52
3 years old	2	42.3		
			6.6	0.16
4 years old	3	48.9		
			3.6	0.07
5 years old	4	52.5		

Note: Original data by Yonemori and Ito, S. (1959)

stock which is small in stock size.

Table 5-6, shows the estimated approximate length composition of each age group of chum salmon. In this table, the length composition of the unknown three year old (n-1 year old) group is simply estimated from that of the known four year old (n year old) group, supposing the annual growth to be 7 cm.

Table 5-7, shows the average length of a recent catch of pink almon along the Soviet Far East coast by districts. From the table, you can see that the size of pink salmon varies according to each local stock. Generally the western Kamchatka pink salmon are larger than the eastern Kamchatka pink salmon. In odd years the fish are larger than in even years.

The south-western Kamchatka pink salmon and the eastern Kamchatka pink

Table 5-6. Length composition of chum salmon by age group (%)

Fork length cm \ Unit group	3 years old (2+)	4 years old (3+)	5 years old (4+)
37			
38	0.1		
39	0.3		
40	0.9		
41	2.1		
42	3.9		
43	8.6		
44	9.7		
45	11.7	0.1	
46	12.3	0.3	
47	11.7	0.9	
48	11.1	2.1	0.3
49	8.4	3.9	0.5
50	6.4	8.6	2.2
51	4.9	9.7	2.9
52	3.0	11.7	4.9
53	2.3	12.3	7.5
54	1.2	11.7	9.5
55	0.7	11.1	13.0
56	0.4	8.4	12.1
57	0.2	6.4	11.3
58	0.1	4.9	10.2
59		3.0	8.0
60		2.3	7.4
61		1.2	3.7
62		0.7	2.6
63		0.4	1.6
64		0.2	1.0
65		0.1	0.7
66			0.3
67			0.1
68			0.1
69			0.1
$\bar{x}$	46.8	53.8	56.4

Note: The length composition of 3 years old age group was calculated from that of 4 year old age group salmon are mostly distributed in the mother boat fishing area. The north-western Kamchatka stock, the Okhotsk stock, the eastern Sakhalin stock and the South Kuril stock are distributed in the B area where land based drifters operate. The Amur stock, the western Sakhalin stock and the Primorsk stock are distributed in the Japan Sea (Fig. 2-4).

Fig. 5-17, shows the estimated length composition of pink salmon which

Table 5-7. Average length of pink salmon in Soviet coastal catch (cm)

Year \ Local stock	E. Kamchatka	S. W. Kamchatka	N. W. Kamchatka	Okhotsk coast	S. Kuril	E. Sakhalin	W. Sakhalin	Amur coast	Primorsk province
1958	44.3	51.9	53.0	46.8		43.2		42.0	44.3
1959	47.2	52.9	50.7	48.8		49.7		49.2	52.3
1960	46.4	52.4	53.5	46.4		47.2		46.7	49.8
1961	49.0	55.1	53.0	49.1		49.0		49.1	51.8
1962	46.4	53.0	52.3	50.8	51.5	52.9	50.2	49.8	52.1

Note: Based on the statistical data of the Japan-USSR Fisheries Committee
E: Eastern, S.W.: South-Western, N.W.: North-Western, S.: South, W.: Western

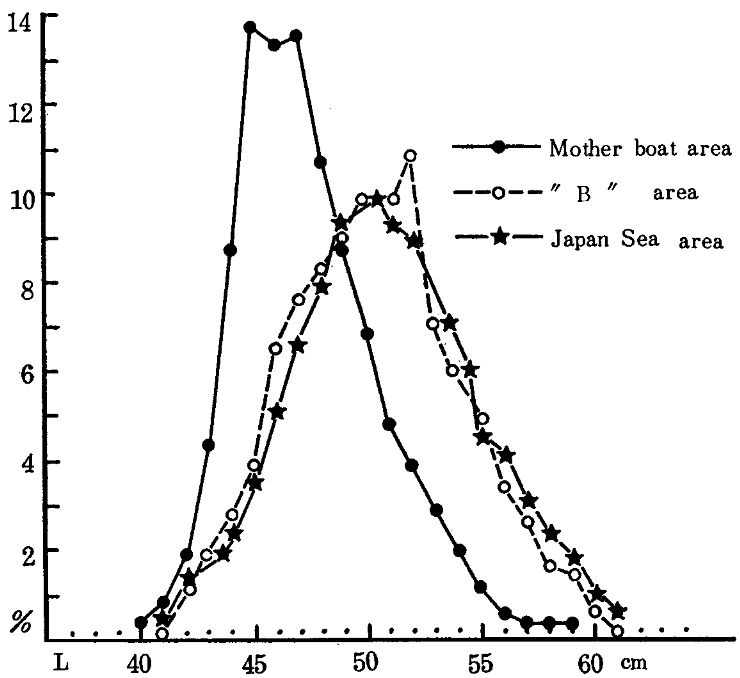

Fig. 5-17. Frequency distribution of fork length of pink salmon caught at USSR coast by the area, correspond to each pelagic distribution

migrate to the Soviet coast from the three areas mentioned above (the mother boat fishing area, the B area and the Japan Sea). The length composition is calculated on the assumption that the fishing activity will effect each component local stock equally in a given area, and also supposing that the ratio of mingling of local stocks in any given area is the same as in the catches along the coast where they migrate. Based on this figure, the estimated length composition of the M group (the coastal catch which came from the mother boat fishing area) is evidently small and may be distinguished from the B group (the coastal catch which came from the B area) and the J group (the coastal catch which came from the

Table 5-8. Assumed length composition of high seas pink salmon stock, by area and by month

Area / Month / Length	Mother boat fishing area			B area			
	June	July	Season	May	June	July	Season
32 cm				0.3			0.1
33				0.9			0.3
34				1.9			0.6
35	0.1			2.7	0.3		1.0
36	0.4		0.2	3.8	0.9		1.6
37	0.8		0.4	6.5	1.9		2.8
38	1.9		0.9	7.6	2.7		3.4
39	4.3	0.1	2.2	8.3	3.8	0.3	4.1
40	8.7	0.4	4.5	9.0	6.5	0.9	5.4
41	13.7	0.8	7.2	9.9	7.6	1.9	6.5
42	13.3	1.9	7.6	9.9	8.3	2.7	6.9
43	13.5	4.3	8.9	10.9	9.0	3.8	7.9
44	10.7	8.7	9.7	7.1	9.9	6.5	7.8
45	8.8	13.7	11.3	6.2	9.9	7.6	7.9
46	6.9	13.3	10.1	4.8	10.9	8.3	8.0
47	4.8	13.5	9.2	3.4	7.1	9.0	6.5
48	3.9	10.7	7.3	2.6	6.2	9.9	6.2
49	2.9	8.8	5.9	1.6	4.8	9.9	5.4
50	2.0	6.9	4.5	1.4	3.4	10.9	5.2
51	1.2	4.8	3.0	0.6	2.6	7.1	3.4
52	0.6	3.9	2.3	0.3	1.6	6.2	2.7
53	0.4	2.9	1.6	0.3	1.4	4.8	2.1
54	0.4	2.0	1.2	0.1	0.6	3.4	1.4
55	0.4	1.2	0.8		0.3	2.6	1.0
56	0.3	0.6	0.3		0.3	1.6	0.9
57	0.2	0.4	0.3		0.1	1.4	0.5
58	0.2	0.4	0.3			0.6	0.2
59		0.3	0.1			0.3	0.1
60		0.2	0.1			0.3	0.1
61		0.2	0.1			0.1	
$\bar{x}$	43.5	47.5	45.5	41.5	44.5	48.5	44.8
Assumed grows		4.0			3.0	4.0	
Note	Mingling rate of local stocks in the area Western Kam. stock 3.2% Eastern Kam. stock 96.8%			Mingling rate of local stocks in the area North-eastern Kam. stock 30.4% Okhotsk stok 35.7% Eastern Sakhalin stock 18.3% South Kuril Islands stock 15.6%			

Japan Sea). The annual variation in the length composition of each local stock is not so marked that the length composition of the catch is influenced by the mesh selection. Therefore, if there is no marked change in the size of each stock (for instance, such as a sudden recovery of the south-western Kamchatka stock), it is possible for the convenience of gill net fishing to divide pink salmon into two unit groups by area, the mother boat fishing area and the rest area.

Table 5-8, shows the estimated length composition of each unit of pink salmon, for each the month during the fishing season. In this table, the length composition in May was determined from the longline catch. The length composition in July was determined from the Soviet coastal catch. The estimated monthly growth and the ratio of mingling of local stocks are shown in the table. The growth was ascertained with Birman's data,[48] and the rate of mingling of local stocks in a certain pelagic area was calculated on the assumption that the rate of mingling is proportional to the rate of the catch of the coastal area which corresponds to the pelagic area.

5.6. The Optimum Mesh for Each Unit Group

As mentioned above, a certain mesh suits merely a part of the natural stock, bacause, the length distribution of the natural stock is so wide that any given size mesh would not be suitable for all of them. However, the length distribution of each of the unit groups into which the salmon has been divided for the convenience of the gill net fishing (oceanic age groups for sockeye, age groups for chum and fishing area groups for pink salmon) are each nearly equivalent to the range in length which a given mesh selects. Therefore, it is possible to determine the optimum mesh for each unit groups.

Fig. 5-18, shows the relationship between the average selection range of the mesh ((A+B)/2) and the mesh size when applied to sockeye salmon (Table 4-4). From the figure, we can determine the standard optimum mesh size for each unit group (oceanic age group) of sockeye salmon. The results are shown in Table 5-9.

Fig. 5-19, shows the relationship between the average selection range of the mesh ((A+B)/2) and the mesh size when applied to chum salmon (Table 5-6). From this figure, we can determine the standard optimum mesh size for each unit group (age group) of chum salmon. The results are shown in Table 5-10.

Fig. 5-20, shows the relationship between the average selection range of the mesh ((A+B)/2) and the mesh size (Table 4-6) when applied to pink salmon. From this, we can determine the standard optimum mesh size of each unit group of pink salmon. The results are shown in Table 5-11.

In pink salmon, the size of the fish which migrate from the B area are

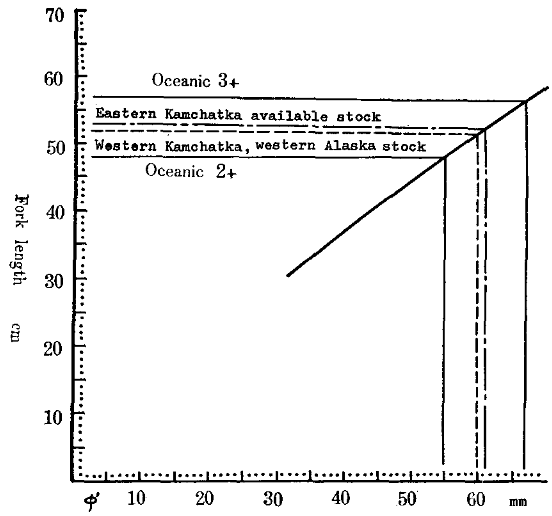

Fig. 5-18. Relationship between fork length and its optimum mesh size (ϕ) in sockeye salmon

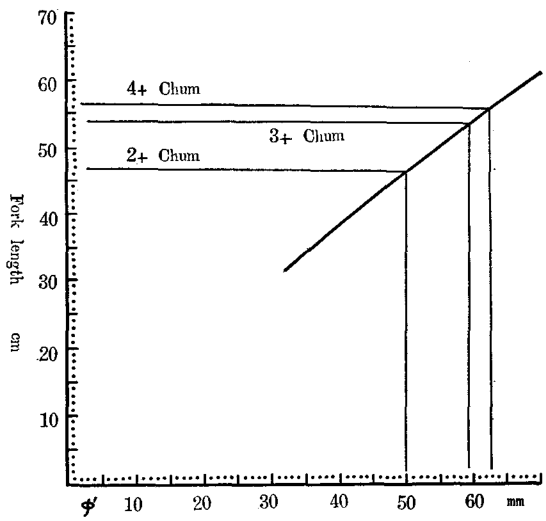

Fig. 5-19. Relationship between fork length and its optimum mesh size (ϕ') in chum salmon

comparatively larger than those from mother boat fishing area (Fig. 5-18). However, on the contrary, the actual fish caught in the mother boat fishing area are larger than those caught in the B area. This is because of the following facts; the eastern Kamchatka pink salmon stock which recently are in a majority in the mother boat fishing area migrate comparatively early in the season (july) and the fishing is done in the latter half of the season (June to July), while all of the various stocks of pink salmon in the B area migrate comparatively late in the season (July to August) and the fishing there is done in the first half of the season (May to June). Therefore, the optimum mesh for mother boat fishing is larger than the optimum mesh for the B area drifters. And in addition, the fish which migrate from the B area and those from the Japan Sea are nearly the same in their length composition (Fig. 5-19). However, the actual fish caught in the Japan Sea are much smaller than those caught in the B area, because in the Japan Sea, the fishing season opens early in the season. Therefore, the optimum mesh for the Japan Sea drifters is far smaller than the optimum mesh for the B area drifters.

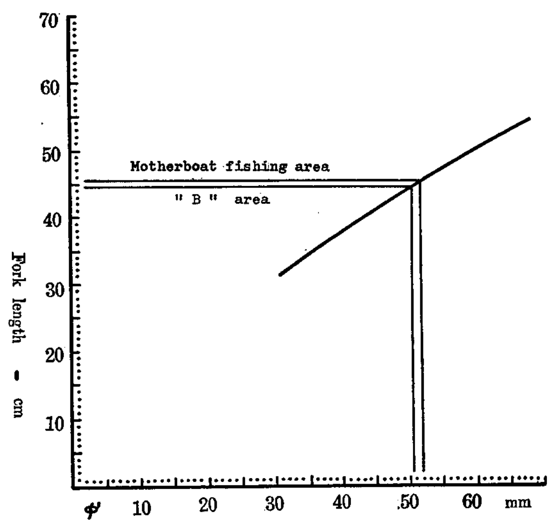

Fig. 5-20. Relationship between fork length and its optimum mesh size (ϕ') in pink salmon

5.7. An Enquiry into Common Commercial Mesh Sizes

In present mother boat salmon fishing, 60.5 mm mesh (40%) and 65.0 mm mesh (60%) are in common use. The relationship between the length composition of each unit group and the range in length of the fish which can be caught with various sizes of mesh is shown in Figs. 5-21, 22, 23.

In these figures, A-B shows the average range in length which the mesh selects, a-b shows the limits of the range in length which the mesh selects, a-a′ or b-b′ shows the variation in the relationship between $L:G_p$ or $L:G_m$ and the area between a-a′ or b-b′ shows the variation in the upper and lower limits of the range in length which the mesh selects. Therefore, it is possible for fish in section b-B-b′ to escape through the mesh and it is possible for fish in section a′-A-a to escape from the mesh having once been gilled in the head part. While all of the fish under "b" escape easily through the mesh because they are too small and the fish beyond "a" escape easily from the mesh having once been gilled in the head part because they are too big.

Based on these figures, the relative suitability of each mesh size for each unit group of salmon is shown in Table 5-12.

Table 5-9. Standard mesh correspond to the unit group of sockeye salmon

Unit group	Average length (cm)	Standerd mesh (mm)
Oceanic 3 years old (Oceanic 2+)	48.1	56.5
Oceanic 4 years old (Oceanic 3+)	57.1	69.5

Note: The average length is based on the Table 5-4
The mesh size signify the length of mesh side

Table 5-10. Standard mesh correspond to the unit group of chum salmon

Unit group	Average length (cm)	Standerd mesh (mm)
3 years old (2+)	46.8	52.0
4 years old (3+)	53.8	62.0
5 years old (4+)	56.4	65.0

Note: The average length is based on the Table 5-6
The mesh size signify the length of mesh side

Table 5-11. Standard mesh correspond to the unit group of pink salmon

Unit group	Average length (cm)	Standerd mesh (mm)	Main fishing season
Mother boat fishing area	45.5	52.0	June～July
B area	44.8	51.0	May～July

Note: The average length is based on the Table 5-8
The mesh size signify the length of mesh side

Fig. 5-12. Fitness of common mesh for unit salmon group

Unit group		Fitness of common mesh	Optimum mesh
Sockeye salmon	Oceanic 3 years old	57.5>60.5>65.0 mm	56.5 mm
	Oceanic 4 years old	57.5<60.5<65.0	69.5
Chum salmon	3 years old	57.5>60.5>65.0	52.0
	4 years old	57.5<60.5>65.0	62.0
	5 years old	57.5<60.5<65.0	65.0
Pink salmon	Mother boat area	57.5>60.5>65.0	52.0
	B area	57.5>60.5>65.0	51.0

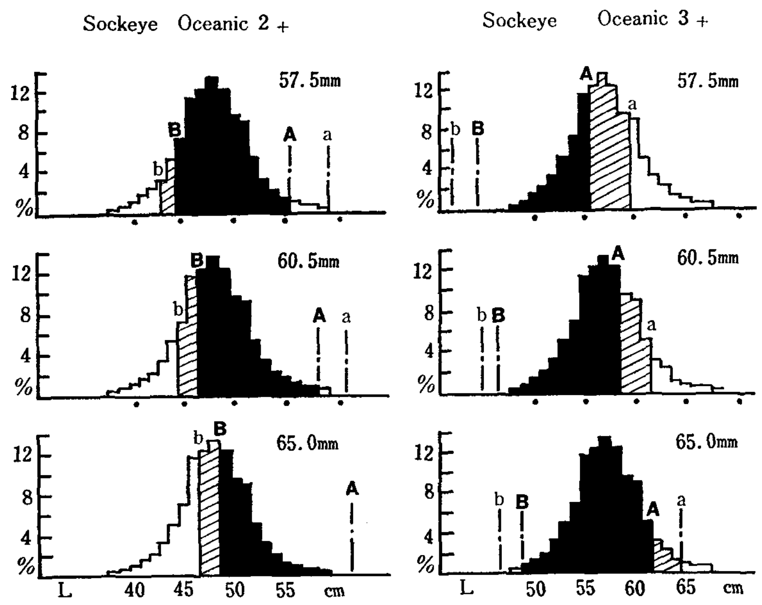

Fig. 5-21. Fishing efficiency by mesh, in each sockeye salmon oceanic age groups

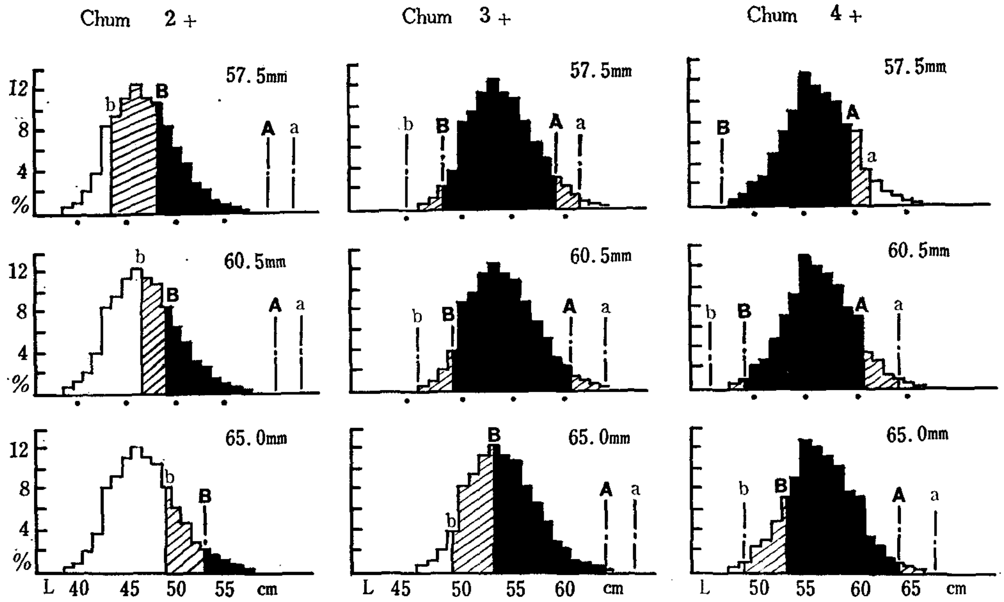

Fig. 5-22. Fishing efficiency by mesh, in each chum salmon age groups

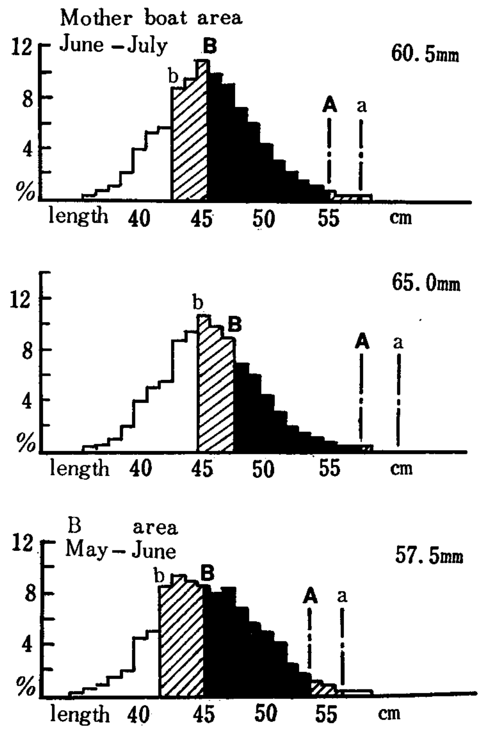

Fig. 5–23. Fishing efficiency by mesh, in each pink salmon groups

VI. Conclusions

Up to now, the author has described various ideas and improvements that were made in fishing gear for salmon, in response to the demand of the times. Even in mother boat salmon fishing, in the early period it was carried out as inshore fishing along the coast by trap-nets or by purse seines, but soon, drift gill nets took the place of other gear and salmon fishing began its growth as a dynamic high-seas fishing industry. Drift gill nets have various advantages in capturing high seas salmon. However, gill net fishing is inevitably accompanied with some escape or loss of salmon. Therefore, this calls for further study regarding the methods for preventing or reducing escape and loss from the net.

The following elements connected with the gill net construction and fish behaviour are considered to be factors deciding the rate of escape; quality of the thread, thickness of the thread, strength of the thread, tightness of the knots, tension upon the mesh, stretch in the mesh, the angle at which the fish hits the net and the momentum of the fish.

Present commercial salmon gill nets, are almost perfect in construction and it is not considered possible that further improvements would effect the future escape ratio noticably. Therefore, these elements connected with escape can not be further controlled by human action. Therefore, of the factors which can be controlled by human action the one in which there is room for improvement is in choosing the mesh size that corresponds to the size of the fish.

Table 6-1. Selection range of present average mesh

Mesh size		Species	Sockeye salmon (cm)	Chum salmon (cm)	Pink salmon (cm)
57.2 mm in B area	Average range	Minimum (B)	44.5	47.0	44.5
		Maximum (A)	52.0	53.5	52.5
	Limit of the range	Minimum (b)	42.0	43.0	41.5
		Maximum (a)	55.0	56.5	54.5
63.2 mm in mother boat fishing area	Average range	Minimum (B)	47.5	51.0	47.0
		Maximum (A)	56.0	58.0	56.5
	Limit of the range	Minimum (b)	45.0	47.5	44.5
		Maximum (a)	59.0	61.0	58.5

It is not possible to decide on a single absolute optimum mesh size for salmon, because, any given size mesh is appropriate for merely a part of the natural stock, and furthermore, the species and age composition of the available salmon stock changes annually, seasonally and regionally. However, it is possible to determine the optimum mesh for each age group, because, the range in length of each unit group is nearly equivalent to the range in length which a given size mesh can catch.

Using the optimum size mesh will not only make for effective fishing but it will also help to maintain salmon resources, because, it will reduce the rate of escape and hence the rate of needlessly injured fish.

It is important to examine the present regulations for the mesh size of salmon gill net. Whether these regulations are effective or not for the demand of fishing itself or sufficient to perform the duty which the fishing owes for effective utilization of salmon resources should be investigated.

Under the present regulations for mother boat salmon fishing, the mesh size is restricted to mesh which is over 60.5 mm long on mesh side, and still further, it is stipulated that 65.0 mm mesh shall be used in more than 60% of the set. Fishermen, generally, use 40% 60.5 mm mesh and 60% 65.0 mm mesh in their sets, and the average mesh size is about 63.2 mm.

In the B area, the mesh size is restricted to over 55.0 mm. 56.8 mm and 57.5 mm mesh are in common use, and the average mesh size is 57.2 mm in the

B area. The selection range of these mesh sizes are shown in Table 6-1.

The available sockeye salmon stock consists mainly of Oceanic 3 and 4 year old age groups, and other oceanic age groups are rare (Table 2-10). On the average, the oceanic 4 year old age group is dominate in Asian stocks, while, oceanic 3 year old age group dominate in the western Alaska stock.

The frequency distribution of available salmon stock in the mother boat fishing area is shown in Fig. 6-1 and Table 6-2. The range of the length of sockeye salmon is so wide that any one mesh size is appropriate for merely a

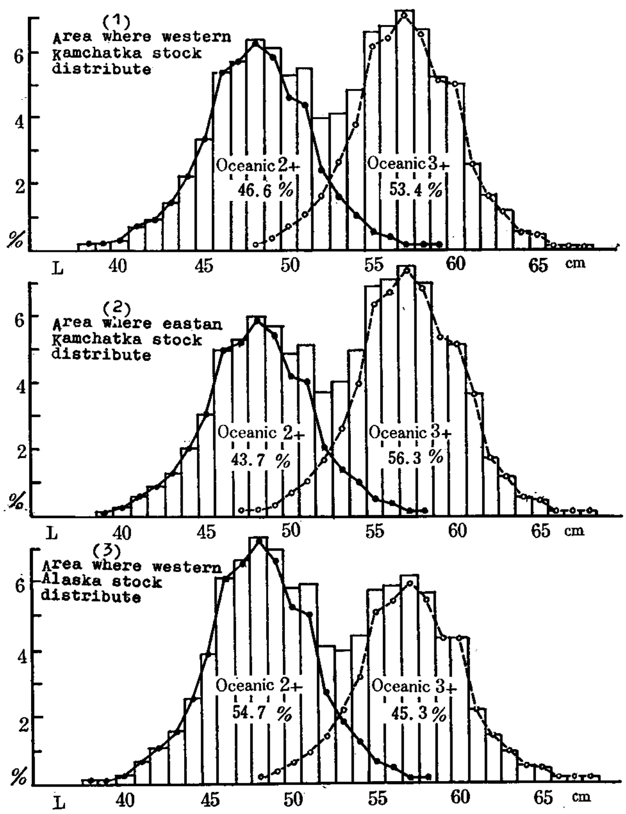

Fig. 6-1. Frequency distribution of available sockeye salmon stock by the area

part of the stock. The average size of commercial mesh used at present in mother boat fishing is 63.2 mm. Standard optimum mesh sizes which correspond to the average length of each of the local sockeye salmon stock are estimated to be as follows (Fig. 5-18); 60.0 mm mesh for the western Alaska and the western Kamchatka stock, 61.5 mm mesh for the eastern Kamchatka stock. Therefore, the present regulations for salmon gill net in mother boat fishing area regarded to be too large both in mesh size and arrangement (because the actual average mesh size is fixed at 63.2 mm), while the optimum mesh which coresponds to the average size of available sockeye salmon stock would be 60.0 mm and 61.5 mm. More flexible regulations for mesh size and net arrangement would make it possible to secure the catch and to reduce escape and loss.

Table 6-3, shows the size of the catch per 100 shackles (per 100 tans) and the relative efficiency of various mesh during the years from 1960 to 1962, in the area where Asian sockeye dominate. Based on this table, in 1960 and 1962, the order of the effectiveness of these three mesh is obviously as follows; 60.5 mm>65.0 mm>68.0 mm, while in 1961, they were almost equally effective.

Table 6-2. Length distribution of available sockeye salmon by local stock (%)

Stock	Western Kamchatka			Eastern Kamchatka			Western Alaska		
Length (cm) \ Age	Ocean 2	Ocean 3	Total	Ocean 2	Ocean 3	Total	Ocean 2	Ocean 3	Total
38	0.1		0.1				0.1		0.1
39	0.1		0.1	0.1		0.1	0.1		0.1
40	0.3		0.3	0.3		0.3	0.3		0.3
41	0.7		0.7	0.6		0.6	0.7		0.7
42	0.9		0.9	0.9		0.9	1.1		1.1
43	1.4		1.4	1.3		1.3	1.6		1.6
44	2.2		2.2	2.1		2.1	2.6		2.6
45	3.3		3.3	3.1		3.1	3.9		3.9
46	5.3		5.3	5.0		5.0	6.2		6.2
47	5.6		5.6	5.2	0.1	5.3	6.6		6.6
48	6.2	0.1	6.3	5.9	0.1	6.0	7.3	0.1	7.4
49	5.7	0.3	6.0	5.4	0.3	5.7	6.7	0.3	7.0
50	4.5	0.7	5.2	4.2	0.7	4.9	5.3	0.6	5.9
51	4.3	1.1	5.4	4.1	1.1	5.2	5.1	0.9	6.0
52	2.3	1.6	3.9	2.1	1.7	3.8	2.7	1.4	4.1
53	1.5	2.6	4.1	1.4	2.7	4.1	1.8	2.2	4.0
54	1.0	3.8	4.8	1.0	4.0	5.0	1.2	3.2	4.4
55	0.5	6.1	6.6	0.5	6.4	6.9	0.6	5.2	5.8
56	0.4	6.4	6.8	0.4	6.8	7.2	0.5	5.4	5.9
57	0.1	7.2	7.3	0.1	7.5	7.6	0.1	6.1	6.2
58	0.1	6.6	6.7	0.1	6.9	7.0	0.1	5.6	5.7
59	0.1	5.1	5.2		5.4	5.4		4.3	4.3
60		5.0	5.0		5.2	5.2	0.1	4.2	4.3
61		2.6	2.6		2.8	2.8		2.2	2.2
62		1.7	1.7		1.8	1.8		1.4	1.4
63		1.2	1.2		1.2	1.2		1.0	1.0
64		0.6	0.6		0.6	0.6		0.5	0.5
65		0.5	0.5		0.5	0.5		0.4	0.4
66		0.1	0.1		0.1	0.1		0.1	0.1
67		0.1	0.1		0.1	0.1		0.1	0.1
68					0.1	0.1		0.1	0.1
69									
70					0.1	0.1			
$\bar{x}$	48.1	57.1	52.3	48.1	57.1	53.2	48.1	57.1	52.2
Rate*	46.6	53.4		43.7	56.3		54.7	45.3	

* Average rate from 1956 to 1963 (Table 2-10)

Oceanic 3 years old group include over oceanic 4 years old group

Table 6-3. Relative efficiency of various mesh in sockeye salmon (%)

Mesh \ Year	1960		1961		1962	
	CPUE	Relative efficiency	CPUE	Relative efficiency	CPUE	Relative efficiency
60.5 mm	2.5	100	2.1	100	1.22	100
65.0 mm	1.5	60	2.0	95	0.98	80
68.0 mm	1.0	40	2.1	100	0.64	52

Note: Original data by North Pacific Mother Boat Fishery Association

Table 6-4. Oceanic age composition of available sockeye salmon in the investigating area (%)

Year \ Age	Oceanic 2	Oceanic 3	Oceanic 4	Total	Oceanic 4, 5
	$4_2\ 5_3\ 6_4$	$5_2\ 6_3\ 7_4$	$6_2\ 7_3\ 8_4$		
1960	67.9	31.3	0.8	100	32.1
1961	29.5	70.0	0.5	100	70.5
1962	53.9	45.2	0.9	100	46.2

Note: Based on the Table 2-10 (a)

Table 6-4, shows the oceanic age composition of available sockeye salmon in the same area and for the same years which are mentioned in the above table. Based on this table, it is obvious that the oceanic 3 year old sockeye group was dominate in 1960 and 1962, while in 1961 the oceanic 4 year old sockeye group dominated in the area.

Fig. 6-2, shows the relation between the percentages of older oceanic age groups in the available sockeye stock and the relative efficiency of the three mesh (60.5, 65.0 and 68.0 mm mesh). Based on this figure, it is obvious that, 60.5 mm mesh is more efficient than 65.0 and 68.0 mm mesh, when the percentage of older oceanic age groups is low (when the average size of the fish caught is comparatively small). However, as the percentage of older fish rises, the difference in the relative efficiency of these mesh sizes becomes smaller, and when it reaches 70% the relative efficiency of these three mesh is nearly the same. However, the percentage which older oceanic age groups form within the available sockeye stock is only 53.4% on a long term average (Table 2-10). Therefore, 60.5 mm mesh is the most effective of the three mesh above, for catching sockeye in this area. This proves the optimum mesh which I estimated at from 60.0 mm to 61.5 mm.

The standard optimum mesn for oceanic 3 year old sockeye group is about

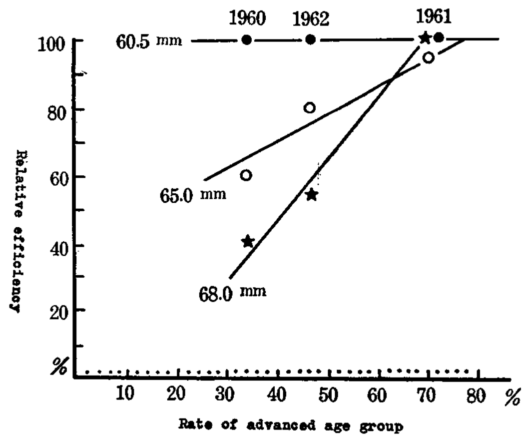

Fig. 6–2. Relation between rate of advanced oceanic age group and relative efficiency of three mesh, in sockeye salmon

55.0 mm (Fig. 5–18). However, it would not be advisable to use such mesh, because, it would increase the number of immature fish caught.

The available chum salmon stock consists of 3, 4 and 5 year old age groups, and generaly, the 4 year old and occasionally the 5 year old age group dominate in the available stock. However, some of the 3 year old age group are also in the available stock (Table 2–11). The frquency distribution of available chum salmon stock in the mother boat fishing area is shown in Fig. 6–3 and Table 6–5. The range in size of chum salmon is so wide that any one mesh is appropriate for merely a part of the total stock. However, based on Fig. 5–19, the standard optimum mesh which corresponds to the average length (54.1 cm) of available chum salmon stock in the mother boat fishing area is estimated at 59.5 mm. Therefore, the present regulations for salmon gill net for mother boat fishing are regarded to be too large in mesh size and arrangement (actual mesh size being fixed at an average of 63.2 mm), as compared with the optimum mesh (59.5 mm) for the long term average size of available chum salmon.

Table 6–6, shows the number of fish caught per 100 shackles (per 100 tans) and the relative efficiency of various mesh during the three years (1960–1962) in the mother boat fishing area. Based on this table, in 1960 and 1962, the order of the effectiveness of these mesh is obviously as follows; 60.5 mm>65.0 mm>68.0 mm. In 1961, the difference in the effectiveness of these mesh sizes is very small.

Table 6–7, shows the age composition of available chum salmon stock in the mother boat fishing area in the same years which are mentiond in the above table. Based on this table, it is obvious that the 4 year old age group

Table 6-5. Length distribution of available chum salmon in mother boat fishing area (%)

Length (cm) \ Age	3 years old	4 years old	5 years old	Total
37				
38				
39				
40	0.1			0.1
41	0.2			0.2
42	0.3			0.3
43	0.6			0.6
44	0.7			0.7
45	0.8			0.8
46	0.9	0.2		1.1
47	0.8	0.6		1.4
48	0.8	1.3	0.1	2.2
49	0.6	2.4	0.2	3.2
50	0.4	5.4	0.7	6.5
51	0.3	6.1	0.9	7.3
52	0.2	7.3	1.5	9.0
53	0.2	7.7	2.3	10.2
54	0.1	7.3	2.9	10.3
55	0.1	7.0	3.9	11.0
56		5.3	3.7	9.0
57		4.0	3.4	7.4
58		3.1	3.1	6.2
59		1.9	2.4	4.3
60		1.4	2.2	3.6
61		0.8	1.0	1.8
62		0.4	0.8	1.2
63		0.3	0.5	0.8
64		0.1	0.3	0.4
65		0.1	0.2	0.3
66			0.1	0.1
67				
68				
69				
$\bar{x}$	46.7	53.8	56.4	54.1
Rate*	7.1	62.7	30.2	

* Average rate from 1956 to 1963 (Table 2-11)
5 years old group include over 6 years old groups

Table 6-6. Relative efficiency of various mesh in chum salmon

Mesh \ Year	1960		1961		1962	
	CPUE	Relative efficiency	CPUE	Relative efficiency	CPUE	Relative efficiency
60.0 mm	1.5	100	1.6	100	1.2	100
65.0 mm	1.1	73	1.5	94	1.0	87
68.0 mm	1.0	67	1.3	81	0.7	58

Note: Original data by North Pacific Mother Boat Fishery Association

Table 6-7. Age composition of available chum salmon in the investigating area (%)

Year \ Age	2_+	3_+	4_+	5_+	Total	Over 5 years old
1960	3.3	65.1	31.5	0.1	100	31.6
1961	3.5	42.7	51.7	2.1	100	53.8
1952	6.8	59.6	30.3	3.3	100	33.6

Note: Based on the Table 2-11

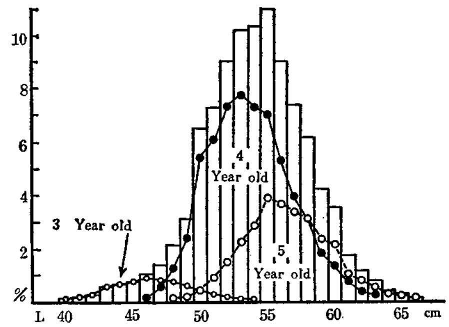

Fig. 6-3. Frequency distribution of available chum salmon stock in the mother boat area

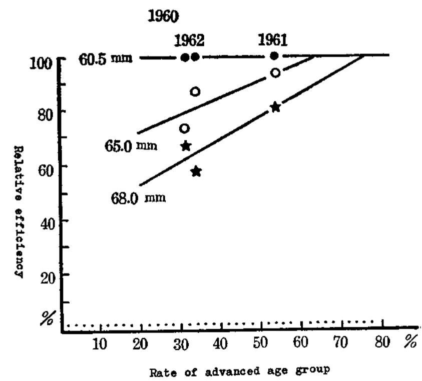

Fig. 6-4. Relation between rate of advanced age group and relative efficiency of three mesh, in chum salmon

dominated in 1960 and 1962, while in 1961, the 5 year old age group dominated.

Fig. 6-4, shows the relation between the percentage of older age groups in the available stock and the relative efficiency of the three mesh (60.5, 65.0 and 68.0 mm mesh). Based on this figure, it is obvious that, the 60.5 mm mesh is more efficient than the 65.0 and 68.0 mm mesh, when the percentage of older age groups is low (when the averge size of fish caught is comparatively small). However, in proportion as the percentage of older fish becomes higher, the difference of the relative efficiency of these three mesh becomes smaller, and when it reaches 50%, the difference is very small. However, older age groups make up only 30.2% of the available chum stock on a long term average (Table 2-11). Therefore, the 60.5 mm mesh size is the most effective of these three mesh sizes for catching chum. This proves the optimum mesh which I estimated at about 59.5 mm (Fig. 5-19).

As I have mentioned before, the 52.0 mm mesh is the optimum size for pink salmon in the mother boat fishing area, and 50.0 mm mesh is the optimum size for pink salmon in the B area (Table 5-13, Fig. 5-20). Therefore, the present actual average mesh (63.2 mm) is quite too large in comparison with the natural length composition of the pink salmon stock.

The first regulation of mesh size of salmon drift gill net is found in the attached document of Japan-USSR Fishery Treaty (1956). The minimum mesh size prescribed to be 55.0 mm in the mother boat fishing area. Since then the trend has been to make the mesh size regulations more and more strict. In 1962, the attached document was revised. The minimum mesh was set at 60.0 mm, and in addition, it was stipulated that 60% or more of the set must be 65.0 mm or over in mother boat fishing after 1963. The progression of mesh regulations is shown in Table 6-8.

Table 6-8. Progress of mesh regulation in salmon mother boat fishing

1956	Mesh size should be 55 mm or over in drift gill net	The attached document of the Japan-USSR Fishery Treaty
1958	Mesh size should be 60 mm or over in mother boat fishing	The revised attached document of the Japan-USSR Fishery Treaty
1959	Over 1,000 shackles of 65 mm mesh net should be used in mother boat fishing	An agreement in the 3rd meeting of the Japan-USSR Fishery Committee
1960	Over 25% of 65 mm mesh net should be used in mother boat fishing	An agreement in the 4th meeting of the Japan-USSR Fishery Committee
1961	In 1961 and 1962, over 50% of set should be 65 mm mesh net in mother boat fishing	An agreement in the 5th meeting of the Japan-USSR Fishery Committee
1962	Mesh size should be 60 mm or over in mother boat fishing. 50% or over of the set should be 65 mm mesh net in 1962, and 60% or over of the set should be 65 mm mesh net after 1963	The revised attached document of the Japan-USSR Fishery Treaty (actually in force)

Based on these regulations, 60.5 mm mesh (40%) and 65.0 mm mesh (60%) are used in mother boat fishing, and the average size mesh of the set is calculated to be about 63.2 mm.

Table 6-9, shows the relation between the common commercial mesh size and each age group of salmon. However, optimum mesh sizes which correspond to the average length of the available stocks of each species are estimated at from 60.0 to 61.5 mm for sockeye (Fig. 5-20). Therefore, it is concluded that the present actual average mesh (63.2 mm) is too large for sockeye and chum salmon, and is much too large for pink salmon.

As is clearly indicated in Table 6-8, the minimum mesh size has been raised since 1958 in mother boat fishing. This helps restrict the catching of the western Kamchatka pink salmon which is now regarded as being to preserve. At the same time it reduces the effectiveness of fishing for the eastern Kamchatka pink salmon stock which it is not necessary to preserve at present. The effectiveness

Table 6-9. Relation between common mesh and age groups of salmon in the mother boat fishing

Mesh size (mm)	Unit group	Sockeye salmon		Chum salmon			Pink salmon
		Oceanic 2	Oceanic 3	2	3	4	
60.5	40%	Too large	Too small	Too large	Appropriate	Too small	Too large
65.0	60%	Too large	Appropriate	Too large	Too large	Adequate	Too large
63.2	Average	Too large	Somewhat small	Too large	Appropriate	Somewhat small	Too large

of the gill net is decreased. It is less effective in capturing oceanic 3 year old sockeye and 4 year old chum which form important components of the available salmon stock.

On the other hand, it is supposed that, enlarging the mesh size will certainly decrease the escape or loss of comparatively large sockeye or large chum, while it will increase the escape or loss of oceanic 3 year old sockeye, 3 and 4 year old chum and pink salmon.

The range in length of the available salmon is so wide that the any one size mesh is merely able to cover a part of the whole stock. Therefore, it is obvious that, the present actual average mesh size which is a result of the present regulations is too large in comparison with the average size of the fish.

The mesh regulations are valuable as a method of controlling the stock, because, gill net mesh sellects the fish according to their size. However, whether the mesh used is the optimum one or not, will effect not only on the number of fish caught but also the rate of escape or loss which means the mortality outside the catch. Therefore, mesh size should correspond as close as possible to the range in size of the available stock.

Immature fish are included in the commercial catch to a certain degree*. However, the migration of immature fish is rather well defined. Therefore, it would be possible to restrict the catch of immature fish by restricting the fishing grounds and fishing seasons, without regulating the size of the mesh.

Certain local stocks which are being reduced or in danger of being reduced in stock size, should also be protected. Distribution area and migration courses are different for each local stock of salmon. Therefore, it would be possible to restrict the catching of a given stock by restricting the fishing area and the

* The rate of immature fish in the sockeye salmon catch;
1957 6.7%, 1958 15.6%, 1958 28.8% (oceanic 2 84.3%, oceanic 3 15.5%, oceanic 4 0.2%), Takagi, 1960.

fishing season.

Present regulations for size and arrangement of the mesh in the set do not correspond to the catchable high seas salmon stock. Reduction of the catching power, increase of escape or loss and annual variation of high seas salmon stock are disregarded in the present mesh regulations, and only adaptation of the mesh size to salmon in the older age groups is considered. Therefore, the actual average size of mesh in mother boat fishing is fixed to a comparatively large mesh in comparison with the average size of catchable salmon, and the regulations make it difficult to change the size of the mesh to correspond to the variations of the catchable salmon stock.

In practice, it is difficult to change the mesh in the set, for each area and for each season. However, over 30% of the net of the set is renewed annually. Therefore, it would not be difficult to choose mesh and to arrange the set to correspond to the length distribution of the forecasted catchable stock.

For these reasons, it is considered that, it would made for more effective fishing and conservation of the salmon stock, if the regulations for size and arrangement of the set were more flexible.

The above mentioned argument is the result of considering the relation between the range in size of fish which can be gilled with a given size mesh and the size of the catchable salmon.

The range in size of fish which a given mesh selects was estimated by using various actual survery values, a theory about how fish are caught and escape. The value of length range of mesh selection was proved by actual catches with various mesh size, and also by comparing it with mesh selectivity curves which were made by another student. The natural length compositions of younger age groups were estimated from those of the older age groups, with full consideration for annual growth. The efficiency of a given mesh was estimated not only by the number of fish caught but also by whether the mesh corresponds exactly to the natural stock or not.

The result described in this paper is reliable, on the whole. However, it leaves much to be desired because the nature of the subject makes absolute accuracy impossible.

Areas requiring further study are as follows;

① The characteristics of the extension of the perimeter of the mesh, in connection with in quality of the thread, the mesh size, the species of fish and the portion in which fish is gilled and the lapse of time after the fish is gilled.

② The effect of the quality of the construction of the net (shrinkage and tension of the mesh) and fish behaviour (action of the fish upon the mesh and the momentum of the fish) on capture and escape. The purpose of such a study would be to clarify the circumstances of capture and escape.

③ An estimation of the escape rate during setting of the net, to determine the rationality of drift gill net fishing.

④ An investigation of the actual length composition of immature salmon and an investigation of nonselective gears and a nonselective arrangement of the set, to determine the make up of high seas salmon stock.

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General Summary

1. At first Japanese salmon fishing started as river fishing, and by the invention of primitive trap-nets, it developed into an important position in the coastal fishing in Hokkaido. Japanese salmon fishing advanced to the east coast of Russia, but after 1929 it was forced to draw back, due to pressures exerted by the new Soviet government, which was attempting to expand its own Siberian salmon fishing. Thus, mother boat salmon fishing was stimulated to rapidly expand into a large scale industry.

2. Japanese salmon fishing newly started after the war developed as high seas drift gill net fishing. Therefore, it is related interests of many other count-

lies and is restricted by international conventions.

3. The rationality of Japanese salmon fishing on the high seas, preceding the shore fishing is discussed in this paper. Gill net is effective for high seas fishing, however, it is always accompanied with some loss of resources. The rate of escape or loss will decide the rationality of gill net fishing. This calls for further study into the methods for preventing or reducing escape and loss from the net. In order to further improvement the gill net itself, it would be necessary to advance the study on the mechanism of mesh selection and its application to salmon fishing.

4. The quality, thickness and strength of the thread, the tendency of the net to stretch the spacing of knots and the tension upon the mesh are primary elements which decide the effectiveness of a salmon gill net. However, in this paper, I am discussing only the Amilan twisted thread net, so these elements are constant. The angle at which the fish approaches the net and the momentum of the fish are other elements which decide the effectiveness of the salmon gill net. However, these elements can not controlled by human action.

5. Salmon gill nets, which are now extensively used in high seas salmon fishing are effective in catching fish by gilling them in the mesh. The size of the fish gilled is related closely to the size of mesh. Therefore, to choose the size of mesh with full consideration of the range in size which that net can gill and the range in size of the available salmon is the only element which can be controlled by human action.

6. The fish gilled at the after ridge of the preopercle are the largest fish gilled with a certain mesh, and the fish gilled at the front of the base of the dorsal fin (where the girth of the trunk is the largest) are the smallest fish gilled with a certain mesh.

7. The relationship of both the maximum girth of fish and the girth at the after ridge of the preopercle to the length of fish are expressed by revolution curves for each species. The girth may be substituted for mesh size with corrections for the stretch of the thread and the elasticity of the fish body. Thus it is possible to estimate the range in size of fish which can be gilled in a given size mesh.

8. Fish within the range in size which the mesh selects are gilled securely, while larger fish are gilled unsecurely and escape easily from the mesh, and smaller fish pass through the mesh.

9. The definition of an optimum mesh is not so clear at the present. However, it is considered that it is most effective to secure the catch and to reduce escape, if the size of mesh corresponds to the size composition of the available stock.

10. The growth of salmon is proportional to the length of their ocean life and is less influenced by the length of their fresh water life. Therefore, for the convenience of gill net fishing, sockeye salmon may be divided into oceanic age groups and chum salmon into age groups. Pink salmon may be divided into three groups by area; the Japan Sea group, the B area group and the mother boat fishing area group.

11. The length distribution of salmon is so wide that any given mesh is appropriate for merely a part of the whole stock. Therefore, it is not reasonable to try to define a single optimum mesh for all salmon. However, for the convenience of gill net fishing it is possible to consider an optimum mesh for each group listed above.

12. The mesh regulation is appropriate for controlling some stocks. However, the catch of under sized fish or immature fish could be restricted by restricting the fishing ground or fishing season, without regulating the mesh size.

13. The average mesh size of present mother boat fishing is fixed at too large a size in comparison with the average size composition of the available salmon stock. At present, methods for forecasting future salmon stock are making rapid progress, and fishermen would be able to adjust the mesh size in their sets to the size composition of the available salmon stock, if the regulations would permit. Therefore, it is necessary to investigate for minimum mesh over again, and furthermore, to investigate the possibilities for more flexible regulations of mesh size and net arrangement, in order effectively utilize salmon resources.

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