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Caviars and Fish Roe Products

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ABSTRACT: Fish roe products are extremely valuable and currently enjoy expanding international and domestic markets. Caviars represent the best-known form of fish roe products; however, several other product forms are also consumed, including whole skeins and formulations with oils and cheese bases. Caviars are made from fish roe after the eggs have been graded, sorted, singled-out, salted or brined, and cured. Most caviar is marketed as a refrigerated or frozen food. Several types of caviar from different fish species are marketed as shelf-stable products. Market preferences for lower salt content have raised food safety concerns. Descriptions of and processing technologies for many delightful fish roe and caviar food products are presented here.

KEY WORDS: caviar, ikura, tobiko, mentiko, sujiko, fish eggs, roe, sturgeon, salmon, lumpfish, herring, pasteurization, microbiology, curing

I. WHAT IS CAVIAR?

Caviars are the salt-cured and preserved eggs of aquatic animal eggs that have been singled out and screened or otherwise separated from the supporting connective tissue. Fish eggs are commonly referred to as roe, particularly when they are in skeins. The most widely recognized and valued caviar is made from sturgeon harvested from the Caspian Sea. Only sturgeon caviar can be labeled in the U.S. as "caviar". Caviar from other fish or aquatic animal species must be identified with a qualifying term that includes the common name of the fish used. For example, salmon caviar or ikura must be labeled "salmon caviar."

A. European and Asian Sturgeon Harvests, Production, and Value

Sturgeon caviar has been a popular commercial product for numerous centuries and was a traditional item of trade for the Persian and Russian Empires. More than 20 species of sturgeon are harvested for caviar. The most famous are the caviars produced from the Russian and Iranian Beluga (*Huso huso*), Osetra (or Osietr or Ossietre) (*Acipenser sturi*); [*A. guldenstadti* also listed as source of Osetra as per Keyvanfar *et al.* (1988)), and Sevruga (*A. stellatus* or *sevru*) sturgeons. Also widely consumed are caviars from the Chinese or Kaluga sturgeons (*Huso dauricus, A. dauricus, or A. mantschuricus*) and the

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Amur River sturgeon (*A. schrenki*), which inhabits the Amur River watershed that transcends both China and Russia. All are important sources of high quality and expensive sturgeon caviar. Other important sources of caviar are the Russian sturgeon (*A. gueldenstaedti*), ship sturgeon (*A. nudiventris*), and Siberian sturgeon (*A. baerii*) (DeSalle and Birstein, 1996). Depending on the species and environmental conditions, it can take 15 to 20 years for a female fish to become sexually mature and suitable for caviar production in the wild.

Despite a strong demand for sturgeon caviar, supplies have been decreasing. Over the last few decades, sturgeon harvest from the Caspian Sea has dwindled, and currently production cannot keep up with consumer demand for black caviar. The production of Caspian Sea sturgeon caviars (*Huso* spp.) and *Acipenser* sp. in Europe and Central and Eastern Asia have decreased in recent years. Because of this, other fish species have received increased attention as sources of black caviar.

The supply of sturgeon roe has also decreased due to political changes, environmental impacts, and overfishing in Iran and the former Soviet Republics surrounding the Caspian Sea. Some sturgeon species are now close to extinction (Logan et al., 1995). There are indications that poachers have taken 12,000 to 14,000 tons of sturgeon illegally in recent years. This would have yielded roughly 1200 tons of black caviar. A single one-ton white (Beluga) sturgeon can produce 350 pounds of caviar worth hundreds of thousands of dollars on the wholesale market (Iversen, 1990). In 1995, the international trade in caviar was 450 tons, but the legal production from the two largest producing nations, Russia and Iran, was only 228 tons (DeSalle and Birstein, 1996).

Current prices for imported black caviar can exceed $125.00 per ounce (Passy, 2001). These prices have resulted in numerous incidents of caviar being smuggled into the U.S. in recent years. In 2000, the U.S. Fish and Wildlife Service seized one ton of illegal imported product through its enforcement powers under the Endangered Species Act, destroyed it, and fined the importers over 10 million dollars. The situation with poached sturgeon has become so desperate that Russia is considering establishing a governmental monopoly on sturgeon harvest as a means to control poaching to some extent and maintain a viable fishery. Predictions are that illegal fishing generates $2 to 4 billion dollars a year in Russia and the former Soviet republics (Anon, 2001). The Dagestani Coast Guard confiscated 64 tons of fish and 184 kg of caviar from poachers in 2000 and 10 tons of sturgeon through April 2001. In April 2001, a crowd of at least 300 poachers stormed a coast guard station in Izberbash, Dagestan, to forcibly retrieve their confiscated boats and fishing nets in a well-organized attack that local officials described as part of the ongoing war with the local "caviar mafia" (Anon, 2001a). Poachers used their wives and children as human shields in this attack. The seizure was a result of a new Russian restriction on sturgeon fishing and the caviar trade.

Misbranded and adulterated products are also common (DeSalle and Birstein, 1996), and problems of poaching and trade in endangered and threatened species of caviar producing fish in China and Siberia are similarly problematic. Decomposed, adulterated, and misbranded Osetra, Kaluga and Beluga caviars have made their way to U.S. markets, and, when detected, have been seized.

B. Sturgeon Aquaculture in Europe and Central Asia

This lack of wild sturgeon provides an opportunity for the marketing of black caviars from other sources, including aquaculture. Sturgeon aquaculture programs in Iran, Russia, and North America can be commercially viable. Also, commercial aquaculture of the sterlet (*Acipenser ruthenus*) in Hungary, Poland, other European countries, and Florida is emerging to meet international demand for gold caviar.

Although captive breeding programs for sturgeon in Russia began in the 1930s, development was much later in other countries. There are currently commercial aquaculture operations for sturgeon in Germany, Hungary, Romania, Italy, France, Spain, Portugal, Israel, Chile, Argentina, Iran, the Czech Republic, and Uruguay. France and the Czech Republic each produce roughly 10 tons of caviar annually, with French production expected to double in the next 2 years (Anon, 2001b).

C. Caviar from Cultured Sturgeon in the United States

The most common source of black caviar in North America is the white sturgeon (*Acipenser transmontanus*). This is also the most common sturgeon found on the North American continent. However, the production of caviar from the native wild stock is not normally permitted due to the near extinction of certain sturgeon species and subspecies in some North American watersheds. Therefore, almost all commercial production of sturgeon for either caviar or meat is from aquaculture. Captive breeding programs for white sturgeon along with federal, state, and tribal management projects for wild stocks in the Snake, Columbia, and Missouri River systems should reverse a decline in wild fisheries stocks. The Nez Perce, Kalisbell, and Yakama Nations have wild white sturgeon broodstock in captivity and are developing fisheries enhancement programs for the sturgeon. Some of the tribal organizations are expanding their restoration efforts to include production and growout facilities for fish suitable for caviar production. By coupling restoration efforts with production, there is a greater likelihood that programs will remain viable because they would become financially self-sustaining.

U.S. aquaculture of sturgeon began in the late 1970s. In 1979, the U.S. began an intensive aquaculture program for white sturgeon at the Aquaculture and Fisheries Program of the University of California, Davis (Logan et al., 1995). For this program, wild female brood stocks were harvested and their eggs surgically removed. The eggs were fertilized and the first hatchlings produced in 1980. After this first success, commercial aquaculture firms began raising sturgeon for caviar from *A. transmontanus* possible between 6 to 10 years of age (Logan et al., 1995); other sources indicate 8 to 9 years (Wade and Fadel, 1997). Dozens of sturgeon farms were started in California in the 1980s (Iversen, 1990) and Idaho. Southern states, including South Carolina and Louisiana, began evaluating programs for culturing Atlantic and Gulf sturgeons during this period.

Cultured sturgeon are harvested at 1.5 to 6 years for meat production and 8 to 10 years for caviar. Determining the sex of even mature sturgeon can be relatively difficult. Currently, the most practical method of sex determination requires a small incision in the upper part of the fish's abdomen and a visual examination of the gonadal tissue. Male fish are generally diverted to harvest for meat and the female fish are returned to grow out facilities where they remain until they have reached sexual maturity at 8 to 10 years of growth. At maturity, female fish may weigh from 40 to 80 kg.

As of 2002, there were several companies with sturgeon aquaculture operations in the U.S. with commercial production primarily located in California and Idaho. Premium caviar from farm-raised sturgeon is valued starting at $36.00 per ounce (Passy, 2001), with production in California farms projected at 30,000 pounds annually (Anon., 2001b).

Preferably, black caviar processing begins with the removal of the roe immediately after the fish has been killed. Wild sturgeon are generally harvested by seining and are transported alive to the processing facility. In some instances, the roe is removed from the sturgeon on board the harvest vessel. Cultured sturgeon are removed from the grow-out tank and transported immediately to the processing room where they are stunned and the roe is immediately removed. The fish flesh is commonly processed into fillets, steaks, roasts, etc. In some cases, the roe is removed by Cesarean section, and after a short recovery period the fish returned to the aquaculture production facility. Fish have been returned to the wild or to fish ranching operations after surgery. Roe can be harvested again from these fish during later spawning cycles. Sternin reported that eggs were taken from a single bester seven times over a period of 15 years (Sternin and Dore, 1993).

The Gulf of Mexico sturgeon (*Acipenser oxyrinchus* desotoi) is a subspecies of the Atlantic sturgeon distributed from the Mississippi River to Tampa Bay, which was commercially harvested in inland Florida in small quantities until the mid-1980s for caviar products (Chen et al., 1995). As with other North American sturgeons, culture programs have been established for the Gulf sturgeon.

D. Paddlefish Caviar Culture and Production

Besides sturgeon and fish closely related to it, other fish are sources of black caviar. In North America, fresh water sturgeons (*Acipenser* sp.), the shovel-nose catfish (*Hemisorubim platyrhynchos*), and paddlefish (*Polyodon spathula*) are harvested from wild stocks for black caviar production. The quality of these products can be very high and reasonably priced from $10.00 to 20.00 per ounce (Passy, 2001). However, this is not always the case. In 2001/2002, the wholesale price of U.S. domestic paddlefish caviar (before processing) exceeded $120.00 per pound reaching a peak of $190.00 in late 2001.

Domestic production of black caviar from North America paddlefish is predicted to be 60,000 pounds or roughly 1/3 of the U.S. consumption by the end of 2001 (Passy, 2001). Paddlefish are found mainly in the Mississippi–Missouri River systems, reaching as far north as Minneapolis and St. Paul, Minnesota; as far east as Pittsburgh, Pennsylvania; and as far south as New Orleans, Louisiana.

The commercial culture of paddlefish has also become a reality because the fish are now raised both for their meat and for their roe. The meat is primarily smoked, and the roe is converted to caviar. Paddlefish feed on plankton, and this has led to a unique method of polyculture for these animals in the U.S. Paddlefish are placed at a relatively low density in catfish ponds where they feed on the natural algal blooms and on blooms resulting from the breakdown of uneaten feed and fecal material. A major concern in this polyculture operation is that the paddlefish need to be of a large enough size before they are introduced to discourage predation by the catfish.

The roe from paddlefish harvested in recreational fisheries in Montana are sold by non-profit civic organizations and the government with funds used so support fisheries and wildlife programs.

II. OTHER FISH ROES

The reduction in the availability of Caspian Sea sturgeon caviar (*Huso* sp.) and *Acipenser* sp. has resulted in increased attention being paid to caviar products from other species of fish. In addition, the increased popularity of sushi and sashimi, and a heightened interest in haute, international, and fusion cuisines, has spurred the development of expanded markets and new products from roe from other species of fish. There are expanding markets for roes that are of small size, have a good "pop", can withstand distribution and handling, and can be colored or flavored to match existing products such as black caviar or tobiko, which are in short supply.

A. Catfish Roe Products

Channel catfish (*Ictalurus punctatus*) has been evaluated as a source of raw material for black caviar production (Eun et al., 1994). More properly, it would be referred to as a black caviar "substitute". The caviar produced from some catfish, including *Ictalurus* sp. and *Clarius* sp., species resembles that from paddlefish or sterlet; however, the color can range from dark charcoal to even a golden hue.

B. Salmon or Red Caviar (Ikura)

There are a wide variety of other fish roes consumed in their own right, as well as products sold as substitutes for sturgeon roe. Among the most popular are "red" or salmon caviars, or "ikura" in Japan. The major countries having wild harvest fisheries for Pacific salmon are Japan, Russia, U.S., and Canada (Bledsoe, 1996).

The largest volume and value for salmon caviar production from Pacific salmon is from chum salmon, followed by pink salmon. Chum salmon caviar production ranges between 2000 to 3000 MT per year for chum ikura style caviar (individual eggs style) caviar. Salmon eggs are a major source of income for Alaskan harvesters and processors. The value for chum and pink salmon meat is low. It is against the law to simply harvest the roe and not the rest of the carcass, a process known as "roe stripping". Developing profitable markets for chum and pink salmon is an important issue in seafood technology, particularly in years where the level of returning fish is extremely high, as was the case for several seasons in the late 1990s. Returns of salmon are cyclic and the chum fishery in the Pacific Rim collapsed during 2000, meaning that the valuable roe was in incredibly short supply. Chum salmon returns for the 2001 harvest season were similarily grim.

Most of the salmon roe harvested in Alaska is exported. Some is processed into ikura in Alaskan facilities, but much of the "green" roe is simply packed in bulk, frozen, and exported with a relatively small, but rapidly increasing, amount consumed domestically. About 30% of the salmon roe harvested in Alaska is transported to Washington State by refrigerated airfreight where it is processed into ikura and then exported. The U.S. exports over 90% of the salmon roe it produces to Japan, France, Spain, Germany, Taiwan, Holland, China, Korea, and Scandinavia. Salmon caviar is primarily exported to Japan as sujiko (salted and cured whole ovaries or skeins), cured single egg product (ikura) (Himelbloom and Crapo, 1998), or frozen green or unprocessed roe.

Farmed salmon is most commonly harvested before reaching sexual maturity, but due to the current glut of salmon on the world market, some culturists of Atlantic salmon and also steelhead trout (*O. mykiss*), are holding fish to sexual maturity, and beginning to harvest roe commercially on a small scale. There may be major oversupplies of these salmonids by 2010, permitting even greater portions of the harvest to be directed toward the production of roe products.

Further development of markets for caviar products has required new technological developments in the seafood industry, and new strategies for marketing and ensuring a consistent supply of raw materials. However, the potential for meeting new market demands for salmon roe products is good. Farmed Atlantic salmon (*Salmo salar*), coho salmon (*O. kisutch*), rainbow trout (*O. mykiss*), and its ocean run variant steelhead trout (also referred to as salmon trout) are available in large quantities, exceeding 1 billion pounds per year. Although there are limited wild stocks of Atlantic salmon, signs indicate that the fishery is recovering in certain areas of New England and south through the Gulf of Mexico.

Eggs from salmonid fish are much larger than sturgeon roe, for chum, the eggs range from 4 to 5 mm diameter to as large as 7 mm for Chinook salmon and are generally processed with less added salt and have a less "fishy" flavor than sturgeon caviars (Table 1). The majority of salmon caviar is produced from Pacific salmon, with chum salmon (*Oncorhynchus keta*) and pink salmon (*O. gorbuscha*) being the most popular. Salmon caviar is also produced from the other Pacific salmon: coho (*O. kisutch*), sockeye or red (*O. nerka*), and king or Chinook (*O. tshawytscha*).

Aquaculture-reared rainbow trout (*O. mykiss* formerly *Salmo gairdneri*), specifically the ocean run variant "steelhead" trout, often referred to as salmon trout in Europe, is also a popular source of red caviar. Atlantic salmon (*Salmon salar*) and Arctic char (*Salvelinus alpinus*) are also used for caviar production. The Pacific masu or cherry salmon (*O. masou* masou) is a minor source for ikura, restricted to small regions of Japan and Korea (Sternin and Dore, 1993).

III. PROCESSING SALMON ROE PRODUCTS — SUJIKO

Salmon roe are most commonly processed into cured, individual eggs (ikura) or as a whole egg product, sujiko. Sujiko is prepared from whole roe skeins that are first brined for approximately 20 min in a solution of salt, nitrites, polyphosphates, and other additives and seasonings. After brining, the skeins are sorted by quality and size. The skeins are then alternately layered with fine salt in plastic or wooden containers (most commonly containing 5 kg of the finished product) and then curing process under compression for 3 to 5 days at refrigerated temperatures below 50°F (11°C). The freshly brined product contains approximately 20 ppm nitrite and the finished product no more than 5 ppm, which is the maximum concentration allowed for import into Japan.

The principal species used for the production of sujiko is sockeye or red salmon, although chum and pink salmon are also used. The early summer run of sockeye salmon in Bristol Bay constitutes the largest single supply of sujiko, and every effort is made to speedily process and ship it to Japan each summer in order for it to be available for the Japanese summer festival of Obon in which sujiko is traditionally consumed. A byproduct of sujiko production is "barako", which are the singled-out eggs from broken or rejected skeins of sujiko. The broken skeins are removed following the sujiko brining process, and the eggs are simply singled by mechanically separating them from the skein membrane using a screen.

IV. PROCESSING SALMON ROE PRODUCTS — IKURA AND MARINATED ROES

Once the predominant salmon roe product in Japan, the popularity of sujiko is decreasing; however, the popularity of lightly salted ikura and flavored/marinated "green" or untreated salmon roe is increasing. Marinated roe now constitutes up to 80% of some Japanese ikura markets (Atkinson, 2002). It is prepared by taking green roe, which is commonly singled out and marinated in a solution of garlic, mirin (Japanese sweet rice wine vinegar), soyu (soy sauce), sugar, or other seasonings to roe a short time before serving. Roes treated in this fashion are used in a number of dishes, including sushi and in sushi-rice combinations (domboro). The popularity of this and other forms of salmon

TABLE 1
Roe Yield and Egg Size for Selected Caviar-Producing Fish

Fish Species	Yield (% weight) Min	Max	Average	Egg Size (mm diam)
Salmon				
Chum	3-8	10-20	8-13	4-5
Pink	3-10	11-23	7-11	3.5-4
Coho	4-8	12-20	7-12	3.5-4
Sockeye	3-5	11-15	6-8	4-4.5
Chinook	1-2	19	10	6-7
Sturgeon[1]	14	34	20	Large (>2.5) Medium (2.2-2.5) Small (<2.2)
Cultured Beluga		25		
Herring	9	25	18	0.9-1.2
Alaska Pollock	4	25	14	
Mackerel	5	7	6	0.8-1.0
Carp	6	20	26	0.8-1.6
Whitefish	6	17	14	0.9-1.4
Pike	-	-	-	2.5-2.8
Flounder	-	-	-	0.8-1.2
Lumpfish	20	29	23	

Data From: Sternin (1992), Sternin and Dore (1993), Bledsoe (1996) and Crapo *et al.* (1988); Ishii *et al.* (1987).
1. Captured wild sturgeon (*A. transmontanus*) produce 5,600 eggs/Kg compared to 3,200 eggs/Kg for cultured sturgeon (Logan et al. 1995).
*Based upon % weight.

caviar is also increasing in Europe, North America, China, and other Asian countries with a growing market demand.

In Europe and North America, ikura or "red caviar" is commonly consumed as a hors de' oeuvre. It is also added to cream or white sauces in pasta dishes, as a garnish on seafood salads, fish or poultry entrees, and served as a condiment with egg dishes. The traditional wild salmon caviar markets in

Europe have been in Germany, Spain, and France, while the newest growth has been in the Scandinavian countries (Bledsoe, 1996). Several Atlantic salmon and salmon trout farmers in Norway and Finland are now rearing significant quantities of fish to the spawning stage to take advantage of these markets with salmon ikura from cultured fish appearing in Japanese markets. Complaints are that the product has an "aquaculture" smell, but that the color and sheen are excellent (Anon., 2001c).

Traditional Native American/Alaskan salmon roe products include compacted and dried whole skeins (salmon egg cheese) or "stink eggs" that are produced by covering the skeins in animal skins and burying them in the ground, allowing them to ferment under anaerobic conditions and reasonably cool temperatures.

A. Lumpfish Caviar

Lumpfish (*Cyclopterus lumpus*) roe is an extremely popular, moderately priced caviar. Lumpfish roe is generally colored red or black. In its natural state, lumpfish roe is a small 2- to 5-mm egg and ranges in color from gray-white for the immature roe, to purple to red (mature roe), to reddish-orange for overly mature roe (Power and Voight, 1992). Female lumpfish release approximately 100,000 eggs as a sticky mass on the ocean bottom. The male then guards the nest (Iversen, 1990). Lumpfish roe can survive pasteurization better than other caviar products and can be produced at a high enough salt content and low enough water activity to make it shelf stable. Gum tragacanth may be added to reduce the water activity of lumpfish caviar. Sodium benzoate may also be added (McClane, 1977). Lumpfish caviar is used in the much the same fashion as more expensive black or red caviars.

B. Tobiko or Flying Fish Roe

A popular caviar used in sushi preparations is flying fish roe or tobiko [*Cheilopogon furcatus* (spot fin flying fish)]. This is a small, crisp, golden orange roe with an egg size of 2 mm or less. It is sometimes flavored with chili, wasabi (Japanese horseradish), and dyed a light spring green. As with salmon caviar or ikura, it may also be flavored with Japanese rice wine vinegar (mirin), a fermented soybean paste (miso), soyu, or other seasonings. In these forms, it is generally served with rice. Caribbean Islanders add roe to flying fish pie.

C. Imitation Tobiko

Because tobiko is in short supply, faux tobiko is often prepared from the mature or immature roe of herring (*Clupea* sp.) from the eggs of small capelin (*Mallotus villosus*) and other fish. For making faux tobiko from immature herring roe, brined whole herring roe skeins are used (see process description below). Then the skeins are removed from the brine and graded. The salt content is reduced by rinsing or soaking in weak saline solutions or water. Various colorants or flavors can be added at this point. The individual eggs are recovered by rubbing the skeins on a plastic or metal screen.

D. Whitefish Roe and Similar Products

Other fish with roe of small size* that are sold commercially are mullet (*Mugil cephalus*) and the roe from various white-

* Egg sizes (diameter) are as follows for some of these products: cod (*Gadus morhua*) 13 to 1.4 mm, herring (*Clupea harengus*) 1.3 to 1.5 mm, haddock (*Melanogrammus aeglefinus*) 1.2 to 1.4 mm, whiting (*Merlangus merlangus*) 1.0 to 1.1 mm, saithe (*Pollachius virens*) 0.9 to 1.1 mm, capelin (*Mallotus vilosus*) 1.0 to 1.2 mm, sand eel (*Ammodytes lancea*) approx. 0.3 mm) (Tocher and Sargent (1984).

fish: [*Coregonus huntsmani* (Atlantic whitefish), *Coregonus clupeaformis* (lake whitefish), (Mountain or Rocky Mountain (golden) whitefish (*Prosopium williamsoni*), whitefish or vendace (*Coregonus albula*)]; lavaret (*Coregonus lavaretus*); roach (*Rutilus rutilus*); perch (*Perca fluviatilis*); herring [*Clupea pallasii* (Pacific herring), *Clupea harengus* (Atlantic or Baltic herring)] and burbot (*Lota lota*). These are common products in Europe. There is also a limited roe fishery for the Pacific sardine (*Sardinops caerulea*) (Kataranta, 1980). These roes are brined, cured, and sometimes smoked (Eide et al., 1997; Kaitaranta and Ackman, 1981). Vendace roe are tiny and pink, and green vendace roe is sometimes consumed without heavy salting as a paste or spread (McClane, 1977). Similar roe products are consumed in Central and South America hake (*Merluccius hubssi* and *M. antarcticus*), mullet (*Mugil cephalus*), orange roughy (*Hoplostethus atlanticus*), and white fish (*Coregonus albula*) (Mendez et al., 1992).

E. Cod Roe

Salted cod roe [*Gadus macrocephalus* (Pacific cod), *G. morhua* (Atlantic cod)] and the roe from other whitefish are sometimes flavored with sugar, treated with nitrite, and sometimes smoked. Oil, potato flour, and other ingredients may also be added to these products. These roe may be aged for several months before they are sold (Eide et al., 1999). Cod roes are consumed alone or blended with butter, soft cheeses, or other spreads and herbs for use with breads or crackers. A common Scandinavian spread is produced from cod or other roe that is blended with cream cheese and consumed by younger individuals much as peanut butter is in the U.S. (Bledsoe, 1996). Additional uses include condiments in poultry egg-based dishes or other entrees.

F. Shad Roe

An unusual product, shad roe (*Alosa sapidissima*) is harvested from this anadromous member of the herring family in North American watersheds and along the Atlantic Coast. Originally from the rivers originating in the Great Lake region, colonists transplanted the fish to the Sacramento River in 1871 and the Columbia River in 1876. Shad now range from Cook Inlet, Alaska, to the U.S./Mexican border. Shad roe can be eaten fresh; it is also frozen, and thermally processed in metal cans that resemble large sardine cans. Shad roe is used as a spread, breaded and fried, or incorporated into egg- or meat-based entrees.

G. Unique Mullet Roe Products

Mullet (*Mugil cephalus*) roe (karasumi) is consumed either as a salted product similar to ikura or salted and dried (similar to sujiko) (Ang et al., 1999; Chiou et al., 1998). Dried mullet roe has a unique chewy mouth feel due to the large quantity of wax esters, which can be as high as 60 to 70% of the extracted oil (Lu et al., 1979). It has a yellowish red color and a rubbery texture. The process to make mullet roe involves coating the roe with salt for 4 to 5 h, removing the salt, compressing the roe during the curing process, and air drying the product until 30% of the original product weight is removed (Ang et al., 1999). Mullet roe is also served as a pickled food ("Botargo") in Italy and other Mediterranean countries (Lu et al., 1979; Body, 1989).

H. Orange Roughy Roe and Uses

Another roe with a high concentration of wax esters is the orange roughy (*Hoplostethus atlanticus*) (Body, 1985). Orange roughy lipids have become a suitable replacement for sperm whale (*Physter macrocephalus* and *P. catadon*) oil or jojoba oil for industrial applications.

I. Herring Roe or Kazunoko

Herring [*Clupea pallasii* (Pacific herring), *Clupea harengus* (Atlantic or Baltic herring)] are also a product in high demand in Asia, particularly in Japan. Kazunoko or "yellow diamond" roe is cured whole herring egg skeins, and kazunoko kombu is herring roe on kelp.

Herring produce small, creamy white to yellow eggs (1.3 to 1.5 mm diameter) (Tocher and Sargent (1984)) in skeins about 8 cm long and 3 cm in width. The highest value kazunoko is for perfectly matched pairs of skeins. A perfect pair of skeins would have no surface blemishes or discolorations, large veins, nicks, or other visual defects, and both skeins would be of nearly identical size with the eggs of a consistent degree of maturity and a uniform, natural color.

How the herring are harvested is critical for product quality. Blood appears on the skeins as the fish are ready to spawn; however, the more the fish struggles during harvest, the greater the likelihood that skeins become bruised and discolored (Gagne and Adambounou, 1994).

The herring roe seine fishery in Sitka Sound, Alaska, has the distinction of being one of the shortest in the world. Generally, the fishery is open for only 1 or for a very small number of days. Both purse seine and gill nets are used for harvesting roe herring. Among the shortest openings was 1986 season, with the first opening of only 3 h and 10 min, and the second opening, held about a week later, of 2.5 h long (Iversen, 1990).

Several seiners may join forces to hire aircraft to spot schools of herring. Meanwhile, fisheries biologists sample the herring and permit the opening only when the fish reach the exact, desired degree of maturity and an average roe content of 10% by weight. Biologists signal the start of the opening by radio. State-commissioned aircraft then fly over the harvest area determining the number of successful catches. When the target allowable catch has been reached, the fishery is closed, again signaled by radio. The crowded skies above the harvest areas have to necessitate the assignment of altitudes for the various and sundry array of aircraft surrounding the fishery. The aircraft commonly consist of both fixed-wing and helicopters operated by the aforementioned fishermen, biologists, law enforcement agencies, the U.S. Coast Guard, and the newer nongovernmental and environmental organizations.

The value of the harvested is based on an average roe content of 10%. Actual prices are then adjusted up or down based on the actual roe content of the delivered fish. This is normally determined using a statistical sampling scheme.

The herring roe is not immediately removed from the fish. Instead, the fish are frozen, preferably by using brine freezing, or a combination of brine freezing and blast or plate freezing, the objective being to preserve the natural shape and form of the roe sacs within the fish. The frozen herring is then shipped to processing plants where the kazunoko is produced. The freezing and frozen storage of the herring is part of the process of "conditioning" the herring making roe removal easier.

J. Production of Kazunoko

At the processing plant, the herring are thawed, tempered, or "slacked out" by placing the fish in fresh water that is exchanged several times during the 24-h thawing process. This helps to remove blood and other undesirable constituents from the fish. The skeins are then removed (or "popped") from the herring. While skein removal is commonly done by hand, automated systems are now used at many facilities both to sort the fish by gender and then to remove the egg skeins from the female fish.

The skeins are sorted, brined, cured, and then packed in an approximately 5-gal plastic pails in 100% brine solution, which is topped off with a scoop (500 to 750 g) of loose salt. The product is then shipped and held under refrigerated temperatures of −4°C or lower. The brining process traditionally involves many steps in which the skeins are held in totes of brine of increasing strengths, finishing with a saturated brine solution. All in all, the brining process normally takes 5 to 7 days with daily changes of brine. A primary purpose of this process, in addition to curing, is to remove any discoloration in the skeins due to blood, enzymatic activity, or other contaminants. In some instances, hydrogen peroxide is used by secondary processors as a bleach to remove discolorations. Following brining, the skeins are sorted by quality and size. Specialized, automated weighing machines are used in some instances.

Most kazunoko is shipped to Japan where it is drained, inspected once again, and then packaged for sale. Often individual matched pairs of skeins are packaged in gift packs that sell at retail for $10.00 per pair (approx. 5 oz) or more. The product is commonly prepared as sushi or for dombori.

Individual herring eggs (capelin, cod, or tobiko can also be used) are added to sea vegetable salads and to seafood salads containing, among other things, marine plants (sea vegetables), clams, limpets, or marinated octopus. Another product from herring roe is tarama, a mayonnaise-like product manufactured from emulsified fish eggs that is used as a condiment or salad dressing (Gagne and Adambounou, 1994). Acceptable tarama can be produced from damaged skeins and from overly mature roe.

K. Kazunoko Kombu or Herring Roe on Kelp

A most interesting herring roe product is kazunoko kombu or herring roe on kelp. The product is used in a variety of dish, most commonly soups, and can be very expensive, often times over $100 per pound. For the highest quality kazunoko kombu, a uniform, dense layer of herring eggs of similar size and color covers both sides of a piece of kelp.

Traditionally, Kazunoko kombu has been harvested when herring spawn. Schools of herring release their eggs simultaneously, and the eggs adhere to kelp until the fish larvae hatch. Kazunoko kombu is still harvested in the wild; however, most is now produced by harvesting live herring just prior to spawning and placing them into pens (called "pounds") in which cut kelp has been suspended. When the fish spawn, the eggs adhere to this kelp to a thickness of up to one-half inch per side (or an inch in total thickness). The fish are then released back to the wild and the egg-coated kelp is washed, trimmed, cut to market size, and packed in brine. The finished product is commonly used in soups, salads, or as a side dish.

Due to a shortage of natural kazunoko kombu, there have been several attempts at developing acceptable substitutes. One of the more successful attempts at such uses a surimi-based paste as an adhesive in the highly labor-intensive operation of attaching a layer of herring eggs to pre-cut pieces of kelp. The coated kelp is then placed in a form under slight pressure and heat to set the product, which is then packed in light brine.

L. Pollock Roe or Mentaiko

Another roe product popular in the Japanese/Korean markets is mentaiko (also spelled mentiko). Mentaiko is the Japanese name for Alaska or walleye pollock roe (*Theragra chalcogramma*). The most valuable form of mentiko is whole, matched pairs of skeins, defect free and preferably with the oviduct intact. Mentaiko is brined and cured. It may be dyed (mostly red) and/or flavored.

There are literally dozens of grades of mentiko, depending on the type and degree of the defect. Mako is the grade of pollock roe with no defects. Important defects include defective (generally, kireko), broken skeins, skeins with cuts or tears, discolorations (aoko for a blue green discoloration from contact with bile; kuroko for dark colored roe; iroko for orange stains from contact with digestive fluids), hemorrhages or bruising, crushed roe skeins, large veins or unattractive veining, immature (gamako), overly mature (mizuko) (Nakagawa, 1974), soft (yawoko), fracture of the oviduct connection between the two skeins, paired skeins of non-uniform size, and skeins that are not uniform in color or no longer connected together. Contact with sea water can reduce the quality of the roe, resulting in a two-tone discoloration on a roe sack. It can also toughen or impart a rubbery texture to the skin surrounding the roe sac.

Tarako is the term used for smaller salted roe sacs. Although the literal translation of the Japanese word "tarako" is cod roe, most tarako is actually produced from pollock roe. Tarako (for cod roe) is the term used for salted roe sacs. This is a popular food item and served as a topping for rice or rice balls (musubi) or as a component of a sauce for noodles or spaghetti.

Lower-grade pollock roe is commonly used for the production of mentaiko, seasoned with salt, sugar, monosodium glutamate, garlic and other spices, sesame or other flavored oils, soyu (soy sauce), or sake. Sodium nitrate may be added for products destined for export from the U.S. The product is called "spicy roe" or "metai" and is marketed as a condiment in Korean markets. Karashi mentaiko incorporates ground cayenne or flaked chili pepper. Mentaiko may also be treated with sodium nitrite and ascorbic acid and/or nicotinic acid to produce a product with a pink coloration. In some cases, fresh roe may be treated with a solution containing salt and 25% ethanol at pH 4.0 to 4.2, and brined in solution containing salt, nitrite, and antioxidants (Koizumi and Nonaka, 1974).

Pollock roe may also be used as an ingredient in salad dressings, in pastes or spreads, and in preparations where single eggs (barako) are desirable. Dehydrated tarako or mentaiko are used in seasonings in soups and sauces, some directed at children's markets.

Pacific cod roe (*Gadus macrocephalus*), "tarako" is prepared in a similar fashion as pollock roe, including spicy roe preparations. Pollock roe has been substituted for cod roe in many product lines. Atlantic cod (*Gadus morhua*) roe has long been used for a variety of products by fishers throughout its population range. The skeins may be simply breaded and fried or used in soups. A very popular product in Scandinavian homes (often called "Norwegian Peanut Butter" due to its popularity among children who spread it on toast) consists of a blend of cod eggs and cream cheese or similar ingredients to form a pate'. This is commonly sold in tubes.

M. Hake Roe

Roe skeins from the Southern Atlantic hakes (*Merluccius hubbsi* and other species) are boiled in water and seasoned and is a traditional food in Uruguay served during the autumn (Mendez et al., 1992).

N. Rock Sole Roe

Rock sole (*Lepidopsetta bilineata*) from the North Pacific is also harvested for roe. Fish may be frozen whole and shipped in this form, headed, and sliced diagonally in strips containing both flesh and roe, or the roe may be removed and processed separately on-board. The roe or kirimi is extremely valuable. In 2001, the catcher-processor vessel F/V *Arctic Rose* was lost at sea with all hands while participating in this fishery.

O. Sea Urchin Roe (Uni)

The gonadal tissue of invertebrates, specifically the sea urchin (uni), is also a common roe-based food. Several species of sea urchin are commercially harvested primarily by divers, including the highly valuable green urchin (*Strongylocentrotus pulcheriius*), the red sea urchin (*S. franciscanus*), and purple urchin (*S. intermedius*). *Pseudocentratus depressus* and *Heliocidaris crassispina* are used for fermented uni (Ang et al., 1999) as are lower grades of the *Strongylocentrotus* spp. Both roe and milt from sea urchins are consumed. Sea urchins are cultured in the Mediterranean, Ireland, China, and Japan.

Uni may be sold fresh, but is also steamed, baked, sautéed, or frozen. Uni used for sushi is brined and treated with alum. It may also be colored. Color and condition are important for determining grades of uni, and a bright orange product is the most desirable. The salted gonadal tissue from the sea urchin may also be fermented, producing a paste (neri uni). Also, a more watery preparation, mizu uni, is prepared using a dry cure process. Doro uni is made by washing the gonadal tissue with dilute alcohol, then draining it, and mixing with salt. Sea urchin are cultured in China, and some wild harvested animals are held in raceways where they are fed a high-nutrition diet. Proper husbandry and nutrition can yield over a 40% increase in gonadal production.

P. Sea Cucumber Roe

Roe from the sea cucumber (*Stichopus* spp.) is also consumed (Iversen, 1990) as are dried sea cucumber gonads. The gonads can sell for 50 times the price paid for sea cucumber muscle tissue in China.

Q, Roe from Crustaceans

Roe or "coral" can be also consumed when gravid female shrimp, lobster, and crab are harvested. These crustacea are used in traditional preparations of boiled or steamed lobster or crab. Stir-fried or deep fried dishes, or soups are also common. She-crab soup, available as a canned product in many countries, is an example of a product where gravid female animals are harvested and used in specific products.

R. World Market for Roe Products

The 1999 Annual Report on the U.S. Seafood Industry reported that 1977 MT of caviar and roe were imported for $33,215,000 in 1998. Black caviar and caviar substitutes (492 MT) were imported for $19,156,000. The U.S. imported 67 MT of herring roe for $304,000, 52 MT of mullet roe for $500,000, 206 MT of pollock roe for $1,223,000, 46 MT of salmon roe for $571,000, 1 MT of sturgeon roe for $26,000, 451 MT of sea urchin roe for $7,175,000, and 662 MT of unclassified roe for $4,260,000 (NMFS, 2000).

The U.S. is the fourth largest importer of black caviar and caviar substitutes, with Russia as the main source of U.S. supplies in the years of 1999 and 2000 (National Marine Fisheries Service, 2000). In 1999, 81,399 kilos of black caviar were imported from Russia at a cost of $17,274,927. Russian imports for 2000 are projected at over 45,000 kilos at a cost of $60,000,000 based on cost figures for the first quarter (8806 kilos for $1,278,387).

The major tonnage in the U.S. for roe production is for salmon eggs. This production includes eggs produced for commercial and government hatcheries to sustain and enhance existing fish runs. The 1998 Aquaculture census reported that 23 hatchery farms in the U.S. produced 316,000 pounds of salmon eggs, with a total sale of $1,324,000 (U.S.DA, 1998). Alaska had 20 of the 23 farms for salmon egg production the U.S., followed by Maine and Washington State each with two farms. These roe are produced primarily for fishery enhancement and mitigation purposes. These roe are primarily for fishery enhancement purposes. Alaska sold 282,000 lbs. of salmon eggs at a price of $3.05/lb totaling $860,000. The 1998 Aquaculture census also a total of 24 farms in the U.S. produced 345,044 pounds of trout eggs. Idaho and Montana were the major contributors of farmed trout eggs. Only a small amount of this production is used for salmon caviar production.

The U.S. exports a significant amount of caviar and caviar substitutes. In 1999 Annual 32,723 MT of caviar and roe were exported from the U.S. in 1998: 1173 MT of caviar and roe substitutes were exported for $3,810,000, 6847 MT of herring roe for $17,788,000, 600 MT of mullet roe for $8,410,000, 12,108 MT of pollock roe for $84,621,000, 7136 MT of salmon roe for $50,682,000, 14 MT of sturgeon roe for $151,000, 2104 MT of sea urchin roe for $73,329,000, and 2741 MT of other roe products for $17,748,000 (NMFS, 2000).

Caviar and caviar substitutes were exported from the U.S. mainly to Russia, France, and Spain (NMFS, 2000). Shipments to France involved 2,544,725 kilos of caviar and caviar substitutes for $6,311,797. Spain imported 417,217 kilos from the U.S. for $818,950. Russia imported 15,945 kilos for $139,584 from the U.S., while France imported 13,989 kilos of caviar and caviar substitutes at a cost of $231,960.

V. CHEMICAL COMPOSITION OF CAVIAR

The chemical composition of caviar varies from species to species, with the condition and maturity of the eggs, within and between runs or harvest areas, and from year to year. Caviar composition also differs slightly due to the variation of between eggs within a single skein. This is because the degree of the maturity of the eggs suitable for caviar is greatest in the anterior end of the skein, with the eggs becoming more immature as you progress from the head to the tail of the fish. The proximate composition of the roe from several aquatic vertebrates and invertebrates is provided in Table 2.

A. Proximate Composition of Fish Roe

Like poultry eggs, fish roe have high concentrations of lipid and protein. In general fish roe products are high in protein (16 to 30%). Crude lipid content can vary from less than 5 to 20% with an average value for salmon of around 10%. Like poultry eggs, the distribution of macronutrients within individual eggs is not uniform. For example, the interior fluid of coho salmon (*O. kisutch*) eggs constitutes 98% of the volume of the egg and is primarily a clear to translucent protein solution (Craig and Powrie, 1988). There is a waxy low-density lipid fraction and oil droplets, which constitutes the remaining volume. For chum (*O. keta*) the volume of the oil droplet (Huang et al., 2000) comprises up to 10% of the volume of the individual egg. Ishii et al. (1987) reports that the lipids in mature roe make up about 13.5% of the wet weight of the egg.

As the egg matures, the mass increases and the ratio of moisture to lipid increases. The lipid content of fish roe can double for example, from 10 to 6% on a dry weight basis as the roe matures.

After the roe is brined, the percentage of moisture decreases, the protein content increases because water is removed during the brining process. The ash content increases

TABLE 2
Proximate Composition of Fish Roe

Fish Species	Moisture %	Protein[1] %N x 5.7	Crude Lipid[1]	Total Ash[1]	Cholesterol[2]
Chum Salmon(*O. keta*)	50-56	27-35	12-20	1.5-1.7	-
	57.6+1.1	27.0+0.3	14.1+0.5-		450+8.6
corresponding muscle	75.7+1.3	18.9+0.6	4.1+0.5	-	40+1.3
Pink Salmon (*O. gorbuscha*)	50-60	23-38	10-15	1.9-2.0	-
salted and cured (ikura)	49.3+0.5	31.8+2.6	11.0+0.	7.1+0.9	-
Sockeye Salmon (*O. nerka*)	56-58	20-29	10-13	0.7-1.7	-
Chinook Salmon (*O. tshawytscha*)	51-70	21-34	8-18	1.2-1.9	-
Rainbow Trout (*O. mykiss*)	-	-	7-9	-	200
Caspian Sturgeons (*Huso* sp.)	57-77	17-32	11-18	1.0-2.0	-
Roach(*Rutilus rutilus*)	66-67	24-26	1.7-3.0	-	-
Pike (*Esox* sp.)	64-67	14-27	1.5-2.4	-	-
Alaska pollock (*Theragra chalcogramma*)	67.4+0.8	25.8+0.9	5.2+0.4	-	315+4.1
	71.8	56.5	4.8	5.9	
corresponding muscle	80.0+0.6	17.8+0.3	1.0+0.1	-	37+0.9
salted "tarako"	64.7	45.5	3.9	12.7	
Pacific cod (*Gadus morhua macrocephalus*)	67.9+0.4	26.5+0.5	4.3+0.3	-	304+5.9
corresponding muscle	80.3+0.3	17.3+0.3	1.2+0.1	-	30+0.8
Cod (*Gadus morhua*)	78-80	16-20	0.3-0.7	1.7-2.3	-
Hake (*Merluccius hubbsi*)	67	-	6.6+1.4	-	376
Mullet (*Mugil cephalus*)	52				
	61.5	22.6	13.7	1.8	440
	50.4+0.9	28.7+1.0	19.8+0.8	-	486+6.8
corresponding muscle	69.9+1.2	18.8+0.4	9.4+1.1	-	47+1.8
salted and dried	30.5	35.5	25.7	5.4	
Pacific herring (*Clupea pallasi*)	77.0+0.7	18.7+0.4	3.0+0.6	-	305+5.8
corresponding muscle	77.4+0.8	18.4+0.6	2.8+0.5	-	32+0.4
Herring (*Clupea* sp.)	73-77				
Smelt(*Spirinchus lancerolatus*)	61.4+0.3	24.1+0.6	13.2+0.7	-	556+16.3
corresponding muscle	79.6+0.4	13.4+0.5	5.8+0.6	-	68+4.0
Pacific mackerel(*Scomber japonicus*)	66.6+1.0	25.3+0.7	6.8+0.7	-	416+7.1

because of the added salt, and the lipid content increases proportionately as moisture is removed during brining and curing.

B. Lipid Composition of Fish Roe and Fish Roe Products

With few exceptions, the predominant lipid components in fish roe are triglycerides or phospholipids. Lipid composition and fatty acid profiles have been used to evaluate caviar quality and to determine the species of origin. Also, lipid classes and the ratio of different lipid classes have been evaluated as a means for developing objective quality assessment traits and to determine nutritive values for fish roe products (Table 3). In fish with a total lipid content of 10 to 15%, the majority of the lipid (ca. 70%) is polar lipid (Tocher and Sargent, 1984). For example, Baltic herring (*Clupea harengus*) and roach (*Rutilus rutilus*) have polar lipid content of 75 to 90% (Kaitaranta and Ackman, 1981).

For fish with a high level of polar lipids, the phospholipids may serve as an energy source rather than triglycerides, being more easily mobilized in the eggs. The requirement for alternative sources of energy for the egg is influenced by different incubation periods for individual fish species that are characteristic of the species. However, fish

TABLE 2 (continued)
Proximate Composition of Fish Roe

corresponding muscle	71.5±0.7	21.5±0.3	5.1±0.6	-	53±2.4
Blue mackerel(*Scomber autralasicus)*	-	-	7.3	-	336
Sardine (*Sardinops melandosticta)*	68.7±0.3	24.4±0.6	6.0±0.5	-	395±6.1
corresponding muscle	78.0±0.2	16.9±0.6	3.8±0.5	-	39±1.4
Anglerfish (*Lopius litulon*)	82.1±0.8	11.5±0.2	5.3±0.4	-	312±11.8
corresponding muscle	83.2±1.2	13.1±0.8	2.5±0.6	-	32±2.2
Flatfish (*Limanda herzensteini*)	68.4±0.3	27.2±0.1	3.3±0.2	-	414±7.8
corresponding muscle	80.4±0.5	16.1±0.3	2.4±0.2	-	48±0.4
Nameta flatfish(*Microstomus achne)*	68.3±0.6	27.1±0.1	3.5±0.4	-	424±9.8
corresponding muscle	79.0±0.6	17.9±0.7	2.1±0.3	-	41±0.8
Pacific flounder(*Paralichthys olivaceus)*	70.2±0.7	21.2±0.8	7.3±0.5	-	543±9.4
corresponding muscle	77.2±0.6	19.9±0.7	1.6±0.2	-	43±0.2
Japanese bluefish(*Scombros boops)*	70.1±0.9	19.2±0.3	9.3±0.8	-	348±12.5
corresponding muscle	76.9±1.0	18.9±0.5	2.9±0.5	-	34±2.9
Sea bream (*Pagrus major*)	73.4±0.7	20.3±0.4	4.9±0.5	-	366±14.6
Corresponding muscle	75.9±1.4	19.2±0.9	3.6±0.6	-	35±3.0
Kahawai (*Arripis trutta*)	-	-	12	-	576
Hoki(*Macruronis novaezelandiae*)	-	-	12	-	360
Red cod (*Pseudophycis bacchus*)	-	-	9.6	-	490
Carp (*Cyprinus* sp.)	70	24	2	-	-
Zander(*Sander* sp.)	60-71	18-26	1-11	1.5-3.1	-
Perch(*Perca flutatilis*)	85				
Channel catfish (*Ictalurus punctatus*)	64.5	24.6	8.0	2.4	639
Squid(*Dorytheuthis bleekeri*)	70.0±0.4	23.4±0.7	5.1±0.6	-	374±4.7
Corresponding muscle	81.0±0.2	16.6±0.5	1.1±0.1	-	252±5.8
Poulp (*Octopus ocellatus*)	77.1±0.3	17.3±0.1	4.4±0.3	-	186±8.6
Corresponding muscle	82.2±0.7	14.8±0.3	2.4±0.4	-	87±2.4
Crab (*Protunus triuberculatus*)	55.4±0.6	30.2±0.5	13.0±0.8	-	494±13.0
Corresponding muscle	76.7±1.1	18.2±0.7	3.9±1.2	-	88±1.8
Sea urchin(*Hemicentrotus pulcherrimus)*	74.1±1.1	16.3±0.5	8.4±0.7	-	310±6.7

1. Percentages are on an as is basis by weight. Salt in pink salmon ikura, 2.8±0.5%; mullet roe =5.2%.
Data from: Sternin (1992), Sternin and Dore (1993), Gagne and Adambounou, 1994, Himelbloom and Crapo (1998), Kaitaranta and Ackman (1981); Iwasaki and Harada, 1985); Mendez *et al.* (1992); Body (1989); Kaitaranta (1982); Chiou et al. (1989); Mendez et al. (1992); Lu *et al.* (1979); Body (1989); Eun *et al.* (1994).
2. Cholesterol, mg/100 g

from the same order or family can have widely differing ratios of triglycerides to phospholipids in the roe, for example, chum salmon (*O. keta*) vs. steelhead (or sea) trout (*O. mykiss*) and cod (*Gadus* sp.) vs. hake (*Merluccius* sp.) (Table 3).

A high relative proportion of neutral lipids are often used to define roe ripeness (Body, 1989; Ishii et al., 1988; Kaitaranta and Ackman, 1981). For chum salmon roe (*O. keta*), the lipid fraction consists primarily of triacylglycerols (63%), phospholipids (30%), sterols (4.2%), and sterol esters (0.7%) with measurable levels of furan fatty acids in the phospholipids fraction (0.6% of total Phl) and steryl ester fraction (3.8% of total) (Ishii et al., 1987). Triacylglycerols and phospholipids are the major class of lipids in cured trout (*O. mykiss*) roe (Kaitaranta, 1982; Stolodnik et al., 1992a,b). However, Stolodnik and co-workers report lower amounts of lipid in cured rainbow trout roe (30.9 to 33.7% triglycerides, 32.6 to 38.5% phospholipids) than did Kaitaranta (1982) [46% triglycerides and 51% phospholipids].

The higher lipid content, in general, of the Salmonidae roe compared with Clupeidae roe may be a result of differences in energy needs for the fertilized eggs (Kaitaranta and Ackman, 1981), even though the muscle

TABLE 3
Lipid Composition of Fish Roe Products

Product	% Lipid Wet wt	PL %[1]	CHOL %	CE %	TG %	SAT %	UN %	N-3 %	N-6 %	FFA %	WE+SE %
Trout	6.5-8.8	49-54	1.9-2.4	-	42-49	23	77	37	6.3	0-1.6	0-0.3
Chum salmon	13.5	30	4.2	0.7	63	-	-	-	-	-	-
Sea trout	9.2	21 -39	6.1-8.6	3-7	30-55			0-8			
Whitefish	6.6-9.8	31 -35	1.2-1.6	-	59-66	24	-	44	13	0-2.8	1.4-2.7
Burbot	6-7	11-14	0.6-0.8*		3-5	7	-	37	16	0.3-0.4	80-83
Vendace	6	-	-	-	-	7	93	44	13		
Baltic herring	2-11	68-89	3.6-9.1	1	6-16	31	69	31	2-3	5.7	1.3-2.7
Roach	3.3-4.2	73-85	5.6-6.8		10-15	-	-	-	-	0.8-2.0	0.1-0.2
Perch	4.1	11-17	0.5-0.7	-	1- 2	-	-	-	-	0.1-0.3	80-87
Cod	9.8	71- 76.	5.9-6.8	3-4	12-13	7-21	72-93	31	3	5-6	4.0
Mullet	13.7	-	-	-	-	30	70		13.2	6	-
Hake	5-8	14.0	5.7	-	36-42	23	77	2.6	-	8.5	27.6
Catfish	8	-	-	-	-	27	73	12	11	-	-
Orange roughy	5-6	20.7	13.5	5.1	51	8-38	75	11-32	1-3	0.7	2.9
Blue mackerel	7-8	27	4.6	2.0	36	4.6	95	32	3.4	3.9	26
Kahawai	12	29	4.8	1.3	33	4.9	95	22	4.9	5.0	32
Hoki	12	22	3.0	2.2	39	3.2	97	21	2.9	6.8	26
Red cod	9-10	31	5.1	3.2	36	1.7	98	17	3.0	5.9	15
Haddock	9-10	69-79	9.5	3-4	8-9	20	75	44	5	5-6	5.3
Saithe	11	65-68	11-12	1-2	14-15	20	80	31	3-4	4-5	
Whiting	9	60-62	11-12	4-5	6-8	22	78	40	3-4	13	
Sand eel	12-13	19-28	4-5	22-23	45	27	73	38	3-4	1-2	
Capelin	18-19	49-52	3	7	4-5	25	75	33	2-3	7	
Gulf sturgeon											
Cultured	-	-	-	-	-	-	-	14-30	6-10		
Wild								9-15	4- 6		

1. % of total lipid.
2. PL = phospholipid, CHOL=cholesterol, TG=triglyceride, FFA= free fatty acid, SE = sterol ester, WE=wax ester,

TABLE 3 (continued)
Lipid Composition of Fish Roe Products

LEGEND FOR TABLE 3.

1.% of Total Lipid

Key:
PL = phospholipid, CHOL=cholesterol, *=CHOL+CE, TG=triglyceride, FFA= free fatty acid, SE = sterol ester, WE=wax ester, HC = hydrocarbon,PC=lecithin, LPC=lysolecithin, PE=cephalin, LPE=lysocephalin, SPH=spingomyelin; PA=phosphatidic acid,n3= omega-3 fatty acids, n-6= omega 6 fatty acids, UNK = unknown.
Fish species:
Trout (*Oncorhynchus mykiss*), sea trout (*O. mykiss*), chum salmon (*O. keta*), vendace or whitefish (*Coregonus albula*), Burbot(*Lota lota*), Baltic herring(*Clupea harengus*), roach(*Rutilus rutilus*), perch (*Perca fluviatilis*), cod (*Gadus morhua*), mullet (*Mugil cephalus* or *Mugil cephalus* Linnacus), hake (*Merluccius hubbsi*), channel catfish (*Ictalurus punctatus*), orange roughy (*Hoplostethus atlanticus*), blue mackerel (*Scomber australasicus*), kahawai (*Arripis truttta*), hoki (*Macruronis novaezelandiae*), red cod (*Pseudophycis bacchus*), haddock (*Melanogramus aeglefinus*), saithe (*Pollachius virens*), whiting (*Merlangus merlangus*), sand eel (*Ammodytes lancea*), Capelin (*Mallotus vilosus*), Gulf of Mexico sturgeon (*Acipenser oxyrinchus* desotoi)

Data from: Mendez, *et al.* (1992); Kaitaranta (1982); Hyvonon and Koivistoinen (1994); Stodolnik *et al.* (1992); Kaitaranta and Ackman(1981); Chen et al. (1995); Tocher and Sargent (1984); Body (1989); Ishii *et al.* (1988); Body (1985);Lu *et al.* (1979); Eun *et al.* (1994).

tissue of the Clupeidae is among the food fish with the highest muscle fat content. The lipid content of the roe from either Salmonidae or Clupeidae do not vary greatly with the degree of maturation or from year to year (Kaitaranta and Ackman, 1981). For whitefish (*Corengonus albula*) (total lipid: 6.6 to 9.8%, 14% salt), there are proportionately greater triacylglycerols (66%) compared with phospholipids (31%). Lecithin is the major phospholipid (90%). These products contain some cholesterol, 1.3 to 1.6% of total lipid (Kaitaranta, 1982).

C. Cholesterol Content of Fish Roes

The cholesterol content of roe is about one-fourth of that of chicken eggs. The cholesterol content of vertebrate fish roe ranges from 300 to 500 mg/100 g. Some fish such as smelt, kahawai, and channel catfish are higher with cholesterol values 550 to 640 mg/100 g (Table 2). The cholesterol content of the roe is substantially higher than for the corresponding muscle tissue, generally by a factor of 10 for finfish but less for invertebrates (Tables 2 and 3).

Salmonid roes contain significant amounts of cholesterol although the amount appears to be highly variable (Tables 2 and 3). Kaitaranta (1982) reported 1.9 to 2.4% cholesterol in cured rainbow trout roe. Others have reported higher values (6.1 to 8.6% of total lipid) and cholesterol esters (3.1 to 7.0% of total lipid) (Stolodnik et al., 1992b).

For roes with a similar use as whitefish, the lipid content ranges between 2 to 10%. As an example, hake roe (*Merluccius hubbsi*) contains 6.6% crude lipid (wet weight basis). Of the lipid component, 42% are triacylglycerols, 2.1% diacylglycerols, 8.5% free fatty acids, 14.0% phospholipids, 5.7% cholesterol (376 mg/100 g roe), and 27.6% waxes (Mendez et al., 1992). PUFA content is 2.6 g/100 roe, with EPA at 0.5 g/100g roe, and DHA at 1.3 g/100 g.

Fish with small, light colored eggs with the highest lipid content are the Baltic herring (*Clupea harengus*) (2.4 to 11%), saithe (*Pollachius virens*) (10.9 to 11.3%), cod (*Gadus morhua*) (9.5 to 11.1%) and capelin (*Mallotus vilosus*) (16 to 21%). Those products with the highest cholesterol content are saithe (10.4 to 11.6%), whiting (*Merlangus merlangus*) (11.2 to 12.2%), haddock (*Melanogramus aeglefinus*) (9.4 to 9.6%), and cod (5.8 to 6.8%).

D. Fatty Acid Composition of Fish Roes

The fatty acid composition of the neutral lipid fraction in fish roe contain ca. 24% saturated fatty acids (mainly 16:0) and a lower ω-3 fatty acid content (37%) with a corresponding increase in monoenes (mainly 16:1 and 18:1) to 35% The (n-3)/(n-6) ratio averaged 10:6. The fatty acid composition of the polar lipid fraction for fish roe averaged 29% saturated fatty acids, primarily 16:0, 19% monoenes (primarily 18:1 isomers), and roughly 50% polyunsaturated fatty acids, of which 94% are ω-3 isomers (mainly 20:5 and 22:6). The (n-3)/(n-6) ratio in the polar lipid fraction averages 14:6 (Tocher and Sargent, 1984).

E. Wax and Steryl Esters in Fish Roes

Certain roes have an unusual lipid profile. Sand eel (*Ammodytes lancea*) and capelin (*Mallotus vilosus*) roe have high total lipid contents and a higher percentage of neutral lipid, over 75%. Capelin and sand eel also have high concentrations of steryl esters at a level that exceeds free sterol content (Tocher and Sargent, 1984). These two fish have longer incubation times, roughly twice as long as many other Northern marine fish, and the high neutral lipid content serves as an energy reserve for embryonic and early larval development.

Other fish roe have extremely high levels of wax esters or steryl esters (Kaitaranta and Ackman, 1981), for example burbot (*Lola lola*) (80 to 83%), perch (*Perca fluviatilis*) (80 to 83%), kahawai (*Armpits trutta*) (26%), hoki (*Macruronis novaezelandiae*) (32%), red cod (*Pseudophycis bacchus*) (26%), blue mackerel (*Scomber australasicus*) (26%), hake (*Merluccius hubbsi*) (28%) (Mendez et al., 1992), and haddock (*Melanogramus aeglefinus*) (15%). Levels are reported to be high in other species of mackerel (*Scomber japonicus*) and in mullet (*Mugil cephalus*) (Body 1989). The role of wax esters and steryl esters is unclear, but these chemical attributes can be used for some types of roe to determine the degree of maturity (Body, 1989). Wax and steryl esters may play a role in buoyancy, permeability control, or serve as an insulation or as an energy reserve (Kaitaranta and Ackman, 1981). These esters may serve as a fatty acid reserve for modifying structural lipids after the fertilization of the eggs occur.

F. Effect of Diet of Lipid Profile

Diet can affect the lipid profile of caviar products. For example, cultured Gulf sturgeon (*Acipenser oxyrinchus* desotoi) has a different fatty acid composition than the wild Gulf sturgeon (Chen et al., 1995). The cultured sturgeon had a higher ω-3 fatty acid content (13.8 to 30.2) than wild caught sturgeon (8.86 to 15.5) (Chen et al., 1995). Also, the cultured sturgeon contained 24.5 to 30.1% saturated, 31.6 to 47.2% monoenes, 2.6 to 9.3% dienes, 0.8 to 1.9% trienes, 2.6 to 4.5% tetraenes, 6.6 to 14.3% pentaenes, and 5.6 to 15.9% hexaenes. Wild sturgeon had 30.3 to 33.5% saturated, 46.8 to 54.2% monoenes, 1.80 to 3.67% diene, 3.28 to 6.49% triene, 6.00 to 12.0% tetraene, 7.27 to 15.91% pentaene, and 0 to 4.55 hexaene (Chen et al., 1995).

G. Vitamin Content of Fish Roe

Fish roe are also a rich source of vitamins. Salmon eggs contain 50 to 3000 IU/g vitamin A, 5 to 25 ID/g vitamin D, 10 to 80 IU/100 g vitamins B1, B2, and B12 and 10 to 30 IU/100 g vitamin C. The vitamin content of catfish roe includes: vitamin A –2 mg/100g, vitamin C-0.26 mg/100 g, vitamin D –0.2 mg/100g, vitamin E –0.1 mg/100 g (Eun et al., 1994). Mineral nutrients include calcium, iron, magnesium, manganese, phosphorus, potassium, copper, and zinc (Iwasaki and Harada, 1985; Eun et al., 1994).

H. Protein Quality of Fish Roes

The protein quality of fish roe is high as reflected in the amino acid profiles in Table 4. Methionine/cystine or typtophan/tyrosine are the limiting amino acid.

I. Nutrient Density of Fish Roes

The caloric content of caviar is between 370 and 320 calories/100 g and can vary with the quality and fat content (http://www.gourmetclub.com/htmrast/ caviarlog4.htm). Salmon caviar products are highly digestible and have been used traditionally in Russia to aid patients recovering from surgery as well as to treat rickets in children. Black caviar (Osetra) has 251 to 282 kcal/100 g, with other varieties having a somewhat lower caloric content (220 to 255 kcal/100 g) (Mrochkov and Aranova, 1973).

VI. PROCESSING ROE INTO CAVIAR

Roe products are to be made from wholesome, undamaged eggs, have a proper color and glossiness, texture, a desirable mouth feel, and their characteristic flavor with lim-

Table 4
Amino Acid Composition of Roe from Aquatic Animal Species

AMINO ACID (g AA/16 gN) — SPECIES

Amino	Blue fish	Channel catfish	Sea Bream	Mackerel	Mullet	Sardine	Herring Pacific	Herring Baltic*	RBT	Salmon	Smelt	Cod	Pollock	Angler fish	Flounder	Flatfish	Nemeta	Squid	Octopus	Crab	SeaUrchin
Asp	8.75	8.50	9.55	8.5	7.4-7.6	7.91	8.44	6.4	6.9	9.26	9.69	8.50	9.57	10.18	9.51	10.14	8.39	10.38	9.44	8.89	9.98
Thr	4.87	4.77	4.67	4.29	4.3-4.4	5.05	5.55	4.7	4.2	4.31	5.24	4.62	4.86	3.61	4.57	5.03	4.05	6.04	5.65	4.89	3.95
Ser	4.59	4.80	3.21	5.47	4.2-5.4	4.93	4.37	4.1	4.7	3.54	6.02	4.46	4.87	2.16	4.22	4.43	5.08	4.33	4.40	3.11	1.50
Glu	13.25	11.1	13.8	12.38	12.7-13.5	13.23	12.97	8.9	10.2	12.46	12.22	14.23	14.04	13.62	13.75	14.31	14.65	13.53	16.29	14.59	11.63
Gyl	3.31	3.05	4.61	4.12	3.5-5.2	3.31	3.46	2.6	2.3	2.34	3.03	3.11	3.04	4.85	3.89	3.23	3.08	2.31	2.21	4.10	9.29
Ala	7.03	8.31	6.13	7.31	6.9-7.3	7.66	8.11	5.7	6.3	7.74	7.24	7.48	7.44	5.90	6.55	6.98	7.14	4.03	3.23	4.75	4.56
Val	6.26	5.73	6.04	5.82	4.4-6.3	6.87	7.17	5.2	5.8	7.37	6.37	6.47	6.37	6.05	6.15	6.50	6.11	7.35	7.03	6.81	5.52
Met	3.20	2.72	2.82	2.77	2.3-2.5	2.96	2.90	1.5	2.4	3.28	3.08	2.80	2.70	3.40	2.72	2.33	2.36	2.93	2.82	3.33	2.94
Ileu	5.28	4.43	4.87	5.00	5.0-5.3	6.03	6.19	4.2	4.8	6.15	5.59	6.07	5.94	5.09	5.07	6.02	5.82	8.27	7.10	5.78	4.42
Leu	8.38	7.93	8.68	8.32	8.0-8.8	10.18	10.73	7.7	7.9	10.05	8.72	10.09	10.05	9.01	9.17	10.16	9.86	11.57	11.93	9.70	7.06
Tyr	4.79	2.15	5.16	5.37	4.1-5.4	4.27	5.00	5.1	4.9	4.78	3.95	5.2	5.04	4.76	4.66	4.68	4.84	4.41	5.71	5.59	4.72
Phe	4.80	3.01	4.96	4.74	4.8-4.9	4.23	4.53	4.7	5.1	5.61	4.08	4.45	4.43	5.19	4.54	4.64	4.63	3.65	3.85	4.65	4.63
Lys	8.27	6.22	7.49	8.13	7.2-9.9	8.65	8.10	6.3	6.4	8.59	7.81	8.66	8.33	8.58	8.56	7.92	8.53	9.24	9.79	7.46	7.87
His	2.87	2.15	2.57	3.53	2.68	3.01	2.57	2.3	2.8	3.19	3.11	2.63	2.47	2.73	2.64	2.52	2.78	2.35	2.86	3.24	2.60
Arg	6.46	5.04	7.33	6.26	5.4-6.7	5.67	5.03	4.3	5.6	5.45	6.37	5.66	5.63	7.15	6.61	6.05	5.37	6.28	6.23	6.86	7.91
Pro	5.78	4.87	5.64	4.31	8.3-10.4	4.36	5.42	4.7	4.5	6.10	4.90	5.42	5.91	4.38	4.99	5.55	7.08	4.42	3.76	4.80	4.08
Cys		1.05			1.6			1.3	3.8												
Trp		0.53			1.5			1.6	0.9												
E/NE	0.73		0.68	0.68	0.67	0.80	0.81			0.82	0.72	0.76	0.74	0.73	0.72	0.74	0.71	0.93	0.89	0.76	0.65

Data from: Iwasaki and Harada, (1985); Eun *et al* .1994; Lu *et al.* 1979;Kaitaranta *et al.*1980.

Japanese Bluefish(*Scombrops boops*); Channel catfish (*Ictalurupunctatus*); Sea bream(*Pagrus major*); mackerel(*Scomber japonicus*); Mullet (*Mugil cephalus*); Sardine (*Sardinops melandosticta*); Pacific herring (*Clupea harengus pallasi*); Baltic herring (*Clupea harengus*); Rainbow Trout (*Oncorhynchus mykiss*); Chum Salmon(*Oncorhynchus keta*); Smelt(*Spirinchus lancerolatus*); Pacific cod (*Gadus morhua macrocephalus*); Alaska pollock (*Theragra chalcogramma*); Anglerfish (*Lopius litulon*); Pacific flatfish (*Limanda herzensteini*); Nameta flatfish(*Microstomus achne*); Pacific flounder(*Paralichthys olivaceus*); Squid(*Dorytheuthis bleekeri*); Poulp (*Octopus ocellatus*); Crab (*Protunus triuberculatus*); Sea urchin(*Hemicentrotus pulcherrimus*) ited fishy, bitter, or oxidized flavor notes. The preferred mouth feel varies with species. In the case of ikura or salmon roe, a distinct fracture or "pop" when the egg is broken with the teeth or palate, a smooth, honey-like mouth feel is desired, while with sturgeon caviar a buttery texture that tends to melt in the mouth is desirable.

Often hundreds or thousands of individual eggs are enveloped within ovarian membranes. These skeins of eggs can be processed into roe products, or the individual eggs can be recovered separately and then processed. Fish roes are generally processed into three products: whole ovaries (such as sujiko from Pacific salmon), individual eggs (caviar), and pate or pastes or other products such as dried mullet roe. Technically, caviar should only be used to describe fish eggs that are separated from the connective tissue of the ovaries and then salted and cured.

Roe, regardless of the type, must be an optimal level of maturity to produce caviar. Immature roe tend to produce caviars that are bitter (e.g., herring, salmon) or which do not take up salt uniformly. Overly mature roe maybe soft, lose its elasticity, and not form a plump, full egg after brining. Overly mature salmonid and some other roes develop tough, rubbery outer shells, while still other species may actually become overly soft when overly mature. Also, the flavor and consistency of the lipid and protein change with maturity so that the mouth feel for caviar prepared from overly mature roe is not desirable.

A. Recovery and Yield of Roe

Recovery of roe from whole fish can vary. For pink salmon, the yield of eggs is approximately 15%, although recoveries as low as 3% (range 3 to 10%, average 6%) have been reported (Crapo et al., 1988; Bledsoe, 1996). These differences are due to harvest area, condition of the fish, genetics, feed availability and fish size, in addition to fish maturity. As a comparison, the egg yield for different caviar fish are provided in Table 1.

B. Specific Processes — Ikura

1. Separation of Eggs from Skein Material

The process for separating the eggs from each other and from skein material is called screening. Screening is normally a manual, laborious, and a time-consuming process. There are also enzyme-based processes for removing the connective tissue that surrounds the eggs, which decrease hand labor and may increase the recovery of intact eggs. Enzyme processes have been widely touted for ikura production. There has also been considerable research into, and some commercial production of, mechanical screening or separating devices in recent years.

C. Enzyme Processes for Egg Recovery

These enzyme preparations include high concentrations of collagens and are extracted from crab hepatopancreas, and from other sources (Bledsoe, 1996). The enzymatic process mimics the reproductive activity of the female fish when it releases a specific collagenase to dissolve the connective tissue around the mature roe when the eggs are released into the water column for fertilization. The effectiveness of these enzymes to recover eggs of high quality and with a good yield varies greatly. There are several claimants to the crab hepatopancreas technology, including Dr. V. Sova the developer of "Digestase" and TINRO the Primorskii Krai Fisheries Research Center, Vladivostok, Russia.

To produce ikura (salmon caviar) using the conventional method, the roe is rinsed with a 3% salt brine. Then the individual eggs are removed from the skein mechanically by forcing them gently through a three-part ikura screen.

Proteolytic enzyme mixtures are also used to remove the membraneous egg skein material from the individual eggs. An enzymatic production method for pink salmon (*O. gorbuscha*) caviar has been developed (Bledsoe, 1996). Digestase™ (Alaska Russia Salmon Caviar Co., Anchorage, AK) is added at level of 0.5 g/Kg roe in 25% salt brine. The ratio of roe to brine is 0.5 Kg roe skeins/L. The brine mixture is agitated for 4 to 10 min at 37°C and the debris decanted from the eggs. The separated eggs recovered and rinsed four times with cold 25% salt brine (4°C). This process yields a large number of broken shells and a recovery of only 80%, although the enzyme manufacturer claims a yield of 90% or higher is possible. The finished ikura product has a high moisture content, substantial amounts of free fluid, and high drip loss compared with ikura prepared using conventional methods, with product being grade 2 at best. However, the reduced manual labor for the enzyme method may justify its use. The egg sheath is partially hydrolyzed by incubation with collagenase. The weight required to collapse a mass of approximately 5 g caviar prepared using a traditional mechanical screened process was 601 g (range: 360 to 823 g). The caviar made by the Digestase™ enzyme process was significantly softer, requiring only 535 g (range: 453 to 624 g) to fracture the same quantity of eggs.

In another enzyme treatment process, enzymes from fish viscera have been used for skein removal. The proteolytic enzymes, such as pepsin, recovered from poikilothermic organisms have a higher pH optimum and are more active at lower temperatures than the same enzyme from mammalian origin (Raa, 1996). Some also have a low optimal activity (Rasco and Hultin, 1988).

In one enzyme process, 4% (w/v) roe skeins plus 0.75 g Rozym/Kg roe (Biotec-Mackzymal AS, Tromso, Norway) are added to the following solution: 0.4 g/L citric acid, 10 g/L salt, 25 g/L sorbitol, and 7.5 g/L dextran. The roe are agitated for 5 min at 38 to 40°C at a rate of rotation such that a surface vortex is created. The rate of agitation is doubled for 7 additional minutes. At this point, agitation is slowed and the volume of the solution in the treatment tank increased by 50% with the addition of solution with this composition: 40 g/L salt, 40 g/L sorbitol, and 2.5 g/L potassium carbonate (used to adjust pH). The addition of this solution rinses the enzyme from the eggs. Increasing the volume in the treatment tank expedites the removal of lower density broken shells and skein debris from the eggs. The skein debris floats to the surface of the tank and can be skimmed off. Individual eggs are removed from the treatment tank through a discharge valve at the bottom of the tank, through a screen, and down an inclined tight mesh cleaning screen. Eggs are collected on stainless steel screen baskets and then transferred to a saturated salt solution that may also contain 50 g/L sorbitol and 5 g/L dextran for brining at approximately 40°C until the desired salt content is reached. After brining, the eggs are cured for 12 h at 12°C. The recovery for pink salmon from this process is from 84 to 93% for fresh roe and 76 to 87% for previously frozen green roe (Bledsoe, 1996). The force to break shells of approximately 5 g caviar prepared using this second enzyme process is 648 g (range: 581 to 872 g). The overall quality of the Rozym™-treated product is significantly better than for the Digestase™ method.

D. Brining and Curing Processes for Ikura

Salting fish eggs is still an art and requires a great deal of skill. Fish eggs can be mechanically or enzymatically separated from the egg skein and then salted, or whole skeins off fish eggs can be salted (Eide et al., 1999). During the curing process for salmon caviar, the roe is placed on a stainless steel screen, formerly a cotton sieve, allowing the salt brine to drain from it. Curing salmon roe is conducted at refrigerated temperatures, for at least 30 min and up to 12 h.

Salmon caviar usually contains 3.0 to 4% sodium chloride, although some claim that higher salt contents in the range of 4 to 6% are required for high-grade ikura (Craig and Powrie, 1988). A lighter salt containing caviar (2.8 to 3.5% salt) is becoming more popular as consumer preferences change. "Malasol" is a term used for lower salt caviar and means lightly salted in Russian.

For ikura, the separated eggs are agitated in brine (for saturated brine the egg/brine ratio is usually 1:3 or less). The eggs are brined, generally 2 to 6 min between temperatures of 8 to 12°C or less, until the desired salt content of the final ikura is reached. The shell of the egg becomes fairly firm and an appropriate salt content (3.5 to 3.8% salinity) is reached. The best process control for ikura manufacture is achieved using saturated brine.

Salt uptake of the egg varies between species of salmon. Salt uptake is also dependent on the condition and degree of maturity of the eggs and often is affected by whether the fish are "early" or "late" run. Salt uptake varies with eggs in a given lot, with the salt content varying by 0.5% or more (Huang, et al., 2001).

Roe quality also affects salt uptake rate. Data presented here in Figure 1 show how fresh chum salmon roe of an average and higher quality take up salt at different rates. Salt uptake for average quality roe was significantly faster during the first minute of brining (saturated brine, approximately 20°C). After this point, both the average and high-quality roe exhibited similar salt uptake rates. For the higher-quality roe, the salt

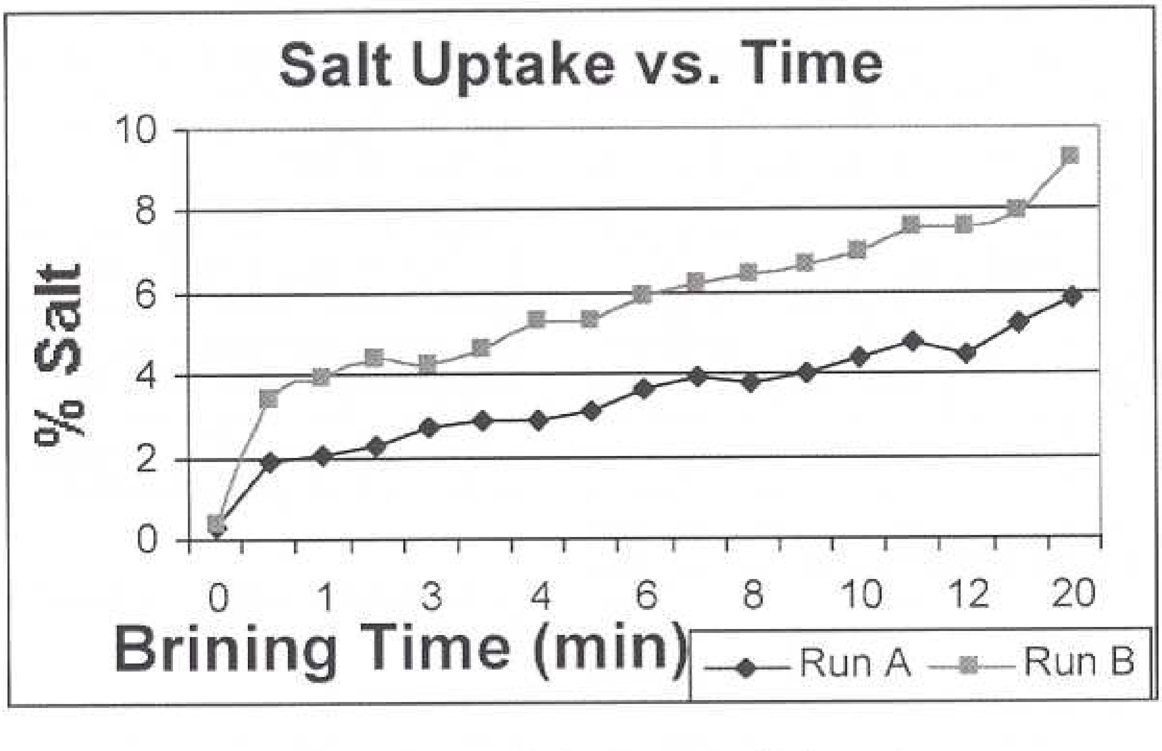

FIGURE 1. Salt uptake rate of high and average quality chum salmon roe.

concentration in the roe after 20 min brining was approximately 6.0%, and much higher for the average quality roe, over 9.0% (Huang et al., 2001). Salt uptake is also faster in frozen roe than in fresh roe, assuming that roe are of the same quality.

Batches of caviar on the market can be found that are both undersalted or oversalted (Huang et al., 2001; Hauschild and Hilsheimer, 1979; Bledsoe, 1996; Southcott et al., 1976). Highly variable salt contents can be found between different production runs and within shipments or containers of the same product (Table 5a, 5b).

After the eggs are brined, they are permitted to cure for 12 h or more at approximately 10°C on inclined perforated plastic baskets or trays. This allows excess surface and cellular fluid to be released from the eggs and drained off. Also, the curing permits the salt concentration within the egg to equilibrate and the eggs sheath to harden slightly.

E. Production of Sturgeon Caviar

Sturgeon caviar is usually dry salted by mixing 4.0 to 5% dry salt by weight with the eggs. A salinity (total salt) of 3 to 3.5% is achieved in the final product after the excess natural brine is drained off the product (Sternin and Dore, 1993). Sturgeon caviar is drained for 5 to 15 min on a fine screen. The final salt concentration will vary depending on egg maturity, freshness, the temperature

Table 5
Variation in Salt Content Between Production Lots

Species	N	Date	% Salt
Sockeye	6	7/10	6.2
	4	7/10	6.5
Coho	9	9/12	8.2
	7	9/12	9.4
Spring Chinook	6	7/26	8.9
	5	7/26	10.5
Chum	7	8/26	6.1
	8	9/6	8.1
	3	10/15	21.1
	7	10/25	13.9
	8	10/28	16.9
	5	11/13	16.7
Pink	3	7/25	13.9
	4	7/26	15.1

Data from: Southcott et al. 1976.

Table 6
Variation in Salt Content Within Same Lot of Product

Position in container	top		middle		bottom	
Location within skein	end	center	end	center	end	center
Sockeye	8.5	8.8.	10	10	10.	11.1
Coho	7.2	8.5	6.8	7.2	7.5	8.0
Spring Chinook	7.8	9.8	8.3	8.8	6.8	8.0
Chum	3.8	3.4	3.6	3.8	5.0	4.4
Pink	8.1	7.5	7.8	7.1	7.5	5 6

Data from: Southcott et al. 1976.

of the roe/salt mixture, and the length of salting time. Salting affects the physical characteristics of the egg and increases the hardness of the egg sheath. Egg sheath assays exemplified the hardness increases from 46.5 g to 85.0 g (0.456 N to 0.833 N) (Stodolnik et al., 1992).

Sturgeon caviar can also be processed into pressed caviar or pausnaya. Small or damaged eggs are lightly salted and compacted into a product that resembles a thick marmalade (McClane, 1977).

F. Production of Lumpfish Caviar

Lumpfish roe is mechanically separated out and the resultant caviar salted to 3 to 5% salinity and packed immediately, or salted to 10 to 14% and then delivered for reprocessing, desalting, and repacking in retail packages (Sternin and Dore, 1993). Salt (13 to 15% by weight) is applied and mixed with the eggs through a sieve. Initially, the eggs stick together when the salt is added, but soon after the salt extracts liquid from the eggs forming a brine. Mixing must continue until the eggs do not stick together and roll off smooth wooden paddles. If the salting operation is too short, the eggs will continue to release liquid later in processing. If salting lasts too long, the eggs form a mass of lumps.

Rinsing roe that has been recovered by a mechanical screening process in 5% salt to remove blood spots, ovarian membrane, and other foreign material can produce lumpfish caviar. It can be stored at 0 to 3°C in vacuum-sealed packages at this point for curing at a later date. Lumpfish caviar is dyed as part of or after the curing process. Most lumpfish is dyed black, but 10 to 15% of the world's lumpfish production is dyed red. Coal tar-based dyes (black) have been used in the past to color lumpfish (Dragoni and Cantoni, 1976). Commonly for brining, 200 g of roe are added to 0.9 g of a black dye, 10 g salt and 44 ml water and held at 4 to 7°C for 1 h, then rinsing the caviar with 5% acidified brine (20 g salt, 5.2 g 8% acetic acid, 0.12 g citric acid), drained for 30 min, and then vacuum packaged and refrigerated (Powers and Voight, 1992). The salt content of commercial lumpfish caviar ranges from 5.85 to 11.32 (Powers and Voight, 1992).

Salting inhibits bacterial growth and possibly endogenous enzyme activity. The bacterial growth as well as the enzyme activity causes the quality of the roe to deteriorate. Therefore, proper salting is important for maintaining shelf life for all types of caviar products. For lumpfish caviar stored under abusive conditions (30°C), a minimal salt concentration of 5.56% salt or a pH of $\leq$5.6 and $\geq$4.67% salt or a pH $\leq$5.2 and $\geq$3.95% salt is necessary for preventing botulism toxin formation (Powers and Voight, 1992).

After salting, lumpfish caviar is cured. This step is important to achieve the desired viscosity of the inner fluids of the egg.

VII. GRADING AND QUALITY ATTRIBUTES OF ROE PRODUCTS

Once completing the curing process, the caviar is graded and packaged. Grading can be a very labor-intensive process required to produce the highest-quality caviar. During grading, any crushed or broken eggs are removed, along with "bullets", which are bitter, dark, undeveloped eggs.

Roe may also be graded according to flavor. Salmon eggs from sockeye, coho, or Chinook have a slightly bitter taste, a main reason the popularity of these roes is lower than for pink and chum salmon eggs, which tend to be sweeter. Sturgeon eggs may have a grassy or muddy aftertaste (Sternin and Dore, 1993). The taste of the roe is dependent on proper processing, the fish's feed, water conditions, maturity, harvest area, or culture practices and characteristics of the individual species. The flavor/taste of the eggs may change, be masked, or disappear after salting. Taste is a prime consideration when roe are graded.

The color of the roe is also critical to grade. There are color standards for each species of fish. However, the color of roe from a single species can vary widely within a single lot. Consistent color for ikura in the Japanese market is important, so roe must be matched for color when it is graded. The color of salmon eggs range from light orange to reddish orange to red.

The color of sturgeon eggs is particularly variable, ranging in shades of gray (light to dark), black, yellowish gray, brownish gray, greenish gray, and even a dark golden color (Sternin and Dore, 1993).

Eggs from other fish species are pale shades of gray, yellow, pink, green, or brown. Depending on the product, some roe are colored and sold as imitation roe of another species (e.g., dyed herring roe for flying fish roe (tobiko); lumpfish roe for "black" sturgeon or paddlefish caviar).

Some caviar products are also graded by size. Sturgeon eggs, due to their great value, are typically size graded. Sturgeon eggs have three sizes: small (diameter < 2.2 mm), medium (diameter = 2.2 to 2.5 mm), and large (diameter > 2.5 mm) (Sternin and Dore, 1993). High-quality ikura (salmon caviar) may also be graded by egg size. Generally, larger fish produce larger eggs. The size of salmonid eggs varies: 3 to 5 mm diameter and larger for chum salmon, 3 mm or larger for pink, sockeye, and coho roe, and 6 to 8 mm for chinook roe. Maturity, feed quality, and nutritional status affect egg size. Fish that tend to migrate further distances may produce roe with higher lipid content.

Shell or sheath toughness is another factor, which is considered when grading. Manual or mechanical tests, which squeeze the egg until it breaks, test toughness. This process works best with larger eggs that come from salmon and sturgeon because their outer membranes are not as strong as smaller eggs from herring or carp. Toughness provides an indication of maturity (soft eggs are immature), staleness or decomposition, if the egg was frozen, or a combination of these factors.

Controlled proteolysis is an important feature for flavor development in roe products such as tarako and karasumi (Chiou et al., 1988). Optimal proteolyis occurs at pH = 5.2, 50 m*M* NaCl) and temperatures above 40°C for casein-like proteins. Salt concentrations above 150 m*M* pH (7.4 to 8.0), 45°C inhibit the activity of endogeneous aminopeptidases, although the relative activity of aminopeptidases remains at 80% even at salt concentrations of 800 m*M*.

VIII. PACKAGING ROE PRODUCTS

Salmon caviar is commonly packaged in 1 to 10 or 35 lb. plastic containers with double bottoms, the layer closest to the product perforated, to allow for draining, curing and drying. Still in use are the traditional Japanese wooden boxes (500 g to 3 kilo). These wooden boxes are lined with multiple layers of cotton cloth, which have been soaked in saturated brine and coated with vegetable oil.

After the product is cured, additional liquid is removed from the product to reduce water activity and to improve product safety and stability. Traditional dehydration methods for sturgeon caviar exposed the product to airborne bacteria; other methods sometimes used are centrifugation or drying with controlled currents of clean air (Sternin and Dore, 1993). To reduce spoilage from oxidation and microbial growth, air is removed from between the eggs after they have been packed by applying pressure to tightly pack the eggs. The use of modern packaging systems includes modified atmosphere packaging and/or vacuum packaging. Some products are pasteurized.

Vegetable oil (olive or cottonseed for sturgeon caviar) or glycerol is sometimes added to the packaged eggs to give a bright, shiny appearance and to prevent the eggs from sticking together. About 50% of sturgeon caviar is packaged into 2-part metal tins of 1.8 kilos (4 lb) encased with broad rubber bands. This product is later repackaged into smaller containers. Sturgeon caviar is also packaged in glass jars (1, 2, and 4 oz) with screw cap, crimp seal, or press-on vacuum closures, and in retail tins up to 90 g or into wholesale tins of up to 1 kg. Traditionally, to check that the product has been properly compressed into a tin, a wooden stick was inserted into the middle of the container. If the stick did not move when the container was turned, the product had been properly cured, drained and packaged (http://www.gourmetclub.com/htmrast/caviarlog4.htm). At this point, lids are placed on the drained tins and pressed down. The tins are laid on their sides for further egg draining. After 2 h, the tins are placed under weight to remove excess liquid and air between the eggs. Finally, a rubber band is placed around the circumference of the tin to ensure that the lid is secured.

Lumpfish roe is generally packed in 10.5-kg plastic barrels. Iceland and Canada are the major producers of lumpfish caviar (Sternin and Dore, 1993). Icelandic companies are processing a larger percentage of the green roe into ready-to-eat lumpfish caviar products than in the past. The most common products are dyed cured roe packaged in 50- and 100-g glass jars with screw- or lug-type closures.

Alaska pollock roe (mentaiko) is sold in several different product forms. The highest quality is defect-free matched skeins in which both ovaries are of uniform size with the oviduct intact, with no bruises, no prominent dark veins, no discolorations, and no cuts. Intact skeins of pollock roe, which include defects, are of lower value. Retail packages can be as small as a single vacuum-packaged pack containing a set of matched skeins. Other product forms include 4, 8, and 16 oz plastic trays (traditionally black in color with a clear lid), 500 g or larger boxes of skeins, nicely arranged, or marinated products sold in glass jars. Sometimes mentiko is packaged in flat 100-g (3.5 oz) cans for retail sale.

Broken skeins of mentaiko are of the lowest value. This product is shipped frozen in bulk primarily to Japan or Korea. It may be marinated in salt or highly spiced with hot chili ("spicy roe"). Spicy roe can be made from either pollock, cod, capelin, herring, mullet, whiting, Southern blue whiting (*Micromesistius australis*), hoki (*Macruronus novaezelandiae*), flying fish, or sometimes lumpfish roe.

After the caviar is packaged, it is stored at –2 to –3°C. This storage temperature can extend the shelf life of caviar up to 1 year, and decreases the need for preservatives and thermal processing. Also, caviar products can be kept in frozen storage for up to 1 year.

IX. FOOD SAFETY ISSUES ASSOCIATED WITH ROE PRODUCTS

Caviar can pose food safety risks if not properly processed and handled. Fish roe can only be heated to a temperature of 70°C without the eggs becoming dull or loosing color (Sternin and Dore, 1993). Irreversible protein denaturation occurs between 70 to 80°C (Starkweather, 2000).

Caviar can be pasteurized, but this is not yet a widely used practice. Refrigerated caviar products are often packaged in the same way as pasteurized products (e.g., in glass jars), and the possibility of inadvertent or unintentional thermal abuse is a major risk and can easily occur because products are often not adequately labeled.

The salt concentration and storage temperature are the factors relied on to preserve and make caviar safe, yet salt concentration varies widely among caviar products of the same type (Table 7). Although pH can sometimes be adjusted downward as a preventive measure for *Clostridium botulinum* or *Listeria monocytogenes* growth, this is not recommended because of detrimental changes to product flavor. The possible exception is for lumpfish caviar; however, with this product, it is not possible to produce an acceptable product with a pH of 4.6 or less.

Ikura (salmon caviar) from pink salmon (*Onchorynchus gorbuscha*) averaged a_w = 0.98, pH 6.1, and 3% salt (Himelbloom and Crapo, 1998). Acceptable salt concentrations for pink salmon caviar are between 2.0 to 3.5% (Bledsoe, 1996). Other ikura (chum salmon, *O. keta*) have an a_w = 0.97 (at 19.7°C) with 2.5% salt (Starkweather, 2000). Romanoff brand red salmon caviar has an a_w = 0.91 (at 21.3°C) (Starkweather, 2000) and salmon caviar of Norwegian origin, 0.964 (pH = 5.6; 5.36% salt) (Hauschild and Hilsheimer, 1978). Lumpfish caviar ranges from 0.906 to 0.979, and sturgeon 0.944 (pH = 5.45, salt brine concentration = 7.74%), and cod–roe paste 0.769 (pH = 5.46, salt brine concentration = 18.60%) (Hauschild and Hilsheimer, 1978). The pH of salmon caviar ranges from 6.1 to 7.0 (Starkweather, 2000; Himelbloom and Crapo, 1998; Hauschild and Hilsheimer, 1978), although values reported by Kizevetter (1958) and Sternin (1993) indicate that the product should be in the range of 4.3 to 5.9.

The pH of herring eggs at all maturity stages fall between 5.7 to 6.5 (Gagne and Adambounou, 1994). pH for herring roe can decrease 0.5 following 1 week refrigerated storage (Stodolonik, 1990). The pH of lumpfish caviar ranges from 5.0 to 5.9 (Powers and Voight, 1992; Hauschild and Hilsheimer, 1978). However, the pH of lumpfish caviar is generally around 5.6, but it can be adjusted to as low as 4.8 without severely affecting product texture as a control measure for pathogen growth (Powers and Voight, 1992). At least for lumpfish caviar, products with a higher pH had greater acceptability, appearance, and flavor.

A compilation of salt, pH, and water activity values for different caviar products are provided in Table 7.

Preservatives can be added to caviar. Borax, urotropin(e), and formaldehyde have been added to Russian black caviars. Misbranded products are routinely imported into the U.S. that contain unapproved preservatives and color additive. Borax is a permissible food additive in Russia and is used in product destined for the domestic market. A compilation of permissible additives to caviar products is given in Table 8. The lack of suitable preservatives for caviars for most markets is a safety concern because caviar is a ready-to-eat product.

The salt content and storage temperature of caviar are key preventive measures for

TABLE 7
Salt, pH and A_w for Various Caviar Products

Caviar product	Storage[1]	N[2]	Salt Cnc	Aw	pH
Lumpfish	refrigerate	4	6.33[3]	0.958	5.60
Lumpfish	refrigerate	2	7.74[3]	0.950	5.71
Lumpfish	refrigerate	4	6.81[3]	0.962	5.60
Lumpfish	refrigerate	4	4.24[3]	0.969	5.41
Lumpfish	refrigerate	4	8.62[3]	0.937	5.32
Lumpfish	refrigerate	3	5.23[3]	0.964	6.21
Lumpfish	shelf stable	6	12.92[3]	0.906	5.41
Lumpfish	shelf stable	4	12.78[3]	0.914	5.81
Lumpfish	-	31	9.5	-	5.5
			6.0-20.7		4.6-6.8
Salmon	refrigerate	3	5.36[3]	0.964	5.60
Salmon	-	13	20	-	5.8
			6.5-25.0		5.5-6.3
Pink Salmon	refrigerate	2	4.7-6.7	0.984	6.05
Chum Salmon	-	-	13.8		
			3.5-25.5		
Steelhead Trout		-	2.3-7.0	-	6.6-6.7
Sturgeon	shelf stable	2	7.74[3]	0.944	5.45
Sturgeon	-	5	14	-	5.5
			11.2-17.3		4.8-5.8
			11.2-17.4		
Whitefish	-	4	-	-	5.5
					4.8-5.9
Herring	refrigerate		-	-	5.68-6.45
Smoked cod roe	-		17.2		5.5
			13.2-38.8		4.8-5.9
Cod roe paste	refrigerate	4	18.60[3]	0.769	5.46

1. Storage recommendations as per label instructions.
2. Number of samples tested. Reported values are averages.
3. Salt concentration in brine. Other reported salt concentration values are by % weight in the edible portion.

Data from: Hauschild and Hilsheimer (1978), Starkweather (2000), Gange and Adambounou (1994), Himelbloom and Crapo (1998), Southcott et al. 1976), Stodolnik et al. 1992b).

producing a safe caviar product. The FDA requires a high enough salt content to inhibit the germination of *Clostridium botulinum* spores (FDA, 1998). However, low-salt caviar products are increasingly popular on the world market (Huang et al., 2001). In

TABLE 8
Preservatives Permissible in Caviar Products

Product	Additive and Use Level	Country
Sturgeon Caviar	Borax (0.3%) & boracic acid (0.1%)	Russia
	Borax (0.3%) & urotropine[1] (0.1%)	Russia
	Potassium nitrate (<0.16%)	Russia
	Sorbic acid (<0.1%)&urotropine (0.1%)	Russia
	Urotropine (<0.2%) & tripolyphosphate (0.15%)	Russia
	Urotropine (<0.1%) & sodium benzoate[2] (<0.1%)	Russia
	Sodium benzoate (<0.1%)	Russia and other countries
	Nisin[3] (<0.1%)	Russia
	Urotropine (≤0.05%) & sodium benzoate (≤0.05%)	France
	Formic acid (<0.05%)	Switzerland
Salmon Caviar (Sujiko)	Sodium or potassium nitrate (<0.012%) & erythrobic acid (<0.025%) & nicotinamide (<0.018%) & polyphosphates (<0.045%) for a total <0.1%	Japan
Carp, Whitefish, Pollack Herring	Potassium nitrate (<0.16%) added for salt in dry cure products	Russia and other countries
Cod	Potassium nitrate, 200 ppm	USA

1. Urotropin or urotropine is hexamethylenetetramine.
2. Benzoic acid and it salts are GRAS and are permissible at a max. level of 0.1% in food. 21 CFR Sec. 184.1021.
3. Nicin is a bacteriocin from *Streptococcus lactis* Lancefield Group N. Nisin is (CAS Reg. NO 1414-45-5) which is a group of related peptides with antibiotic activity. It is currently approved in the United States only for use in cheese spread and processed cheese products. 21 CFR Sec. 184.1538.
Data from: Sternin and Dore (1993), and the Code of Federal Regulations.

general, the salt content alone may not be high enough to inhibit the germination of *C. botulinum* spores. *Clostridium botulinum*-type E can grow at 4.5 to 6% salt and at temperatures of 3.3°C (FDA, 1998). Also, water phase salt concentrations of 10% will inhibit *C. botulinum* germination for low-acid foods held at room temperature. In one inoculated pack study with lumpfish caviar packed in sealed glass jars, different strains of *Clostridium botulinum* were added to caviar at a level of 10^6 spores/50 g of: type A (strain A-6), B (13983-IIB), E (Gordon strain), or a combination of different strains (A-6, A-62, CK-2A, 13983-IIB, 368-B, 426B). The caviars had different salt concentrations (2.27 to 7.09% brine) and pH (5.0 to 5.8). After 4 weeks incubation at 30°C, growth was observed under conditions of high pH and low salt for type A and B (Table 9). It is unlikely that type E would germinate and grow in caviar products with an a_w<0.97, which would correspond to a product salt concentration of 4% (Hauschild and Hilsheimer, 1979). However, the growth of *Listeria monocytogenes* is a potential risk.

Fish roe or caviar is generally distributed at refrigeration or frozen temperatures. However, the refrigeration temperatures may not be low enough to inhibit the growth of microbial pathogens such as *Listeria* spp.; therefore, there is a strong incentive to de-

TABLE 9
Germination of *Clostridium botulinum* in Caviar Products of Different pH and Salt Concentrations

				Strain			
Product	Brine %	a_w	pH	A	B	A+B	E
Lumpfish, 30°C[1]	2.27	0.986	5.0	0	0	0	0
			5.2	0	0	0	0
			5.4	ND[2]	2	1	0
			5.6	3	2	3	0
			5.8	3	2	3	0
	3.95	0.978	5.0	0	0	0	ND
			5.2	0	0	2	ND
			5.4	ND	1	2	0
			5.6	3	0	1	0
			5.8	3	0	3	0
	4.67	0.974	5.4	ND	0	0	ND
			5.6	2	0	1	0
			5.8	2	2	0	0
	5.56	0.968	5.6	ND	0	0	0
	7.09	0.959	5.8	0	0	0	0
Pink salmon[3]							
Green	0.33			+			
Brined	7.1			+			
Cured	8.1			+			
Cured & Frzn	9.1			+			
Sockeye salmon4							
Green	0.33			+	-	-	+
Brined	7.1			+	-	-	0
Cured	8.1			0	-	-	0
Sockeye salmon5							
Green	0.33			+	-	-	+
Brined	7.1			+	-	-	0
Cured	8.1			0	-	-	0
Sockeye salmon6							
Green	0.33			0	-	-	+
Brined	7.1			NT	-	-	NT
Cured	8.1			0	-	-	0

1. Lumpfish caviar following a 4 week incubation at 30C. Number of jars (out of 3) that were toxic.
2. ND = not determined.
3. + indicates presence of viable toxigenic spores following freezing at -24C for 6 months.
4. Inoculated with 106 spores/g roe. Held at 30C under aerobic conditions. + indicates toxin produced.
5. Held at 30C under anaerobic conditions
6. Held at 10C under aerobic conditions

Data adapted from: Hauschild and Hilsheimer (1979); Southcott et al. (1976).

velop pasteurization processes that could improve product safety. Thus far, few systematic studies for producing a pasteurized product have been conducted, and there is little related information in the published literature. Because protein denaturation occurs in caviars between 70 to 80°C, long pasteurization times at 50 to 70°C are feasible, but cause loss of product quality. Sternin (1992) indicates that conventional thermal pasteurization of sturgeon and whitefish caviar should be conducted at temperatures less than 60°C. For salmon and lumpfish, process temperatures up to 70°C can be used.

There are questions regarding the temperature and time necessary to pasteurize caviar, the salt content required to inhibit *C. botulinum* spores in different products, and the shelf life for pasteurized products under different temperature storage conditions remain to be answered. In inoculated pack experiments with *Clostridium sporogenes* (PA 3679) spores, a water phase salt concentration of >13% with 200 ppm potassium nitrate added in chum salmon caviar was insufficient to inhibit the germination and growth of the organism.

Most roe product can be frozen, particularly after brining, and later can be thawed without an appreciable loss of quality.

A. Microbial Quality of Roe Products Bacterial Contamination

Eggs that are aseptically removed from fish are microbiologically sterile. However, when the eggs are used in commercial products or for home use, they do not remain sterile. Screening of eggs contributes to bacterial contamination. Salmon caviar is a raw product that is a good medium for microbial growth (Himelbloom and Crapo, 1998). Vacuum-packed or air-tight-packaged nonpasteurized caviar has a shelf life of 1 to 2 years at −20°C (Sternin and Dore, 1993). When non-pasteurized green roe is stored at refrigeration temperature, it has a shelf life of 3 to 5 days. Whereas, pasteurized salmon ikura with a pH > 5.0 and a_w>0.95 has a shelf life of 30 days at refrigerated temperature (Harlfinger, 1992).

Black caviar can be contaminated with various species of opportunistic bacteria. In one study 57% of Osetra caviar samples (N = 51) were contaminated, and 38% of Sevruga samples (N = 35) were contaminated with *Aeromonas* sp., *Proteus* sp. and *Vibrio* sp. including *Vibrio parahemolyticus* (Boyko, et al., 1993) (Table 10).

Pink salmon (*Oncorhynchus gorbuscha*) ikura (APC ranging from 3×10^3 to 3×10^6 CFU/g) can also be contaminated with a variety of psychrotrohic and mesophilic microorganisms, including *Aeromonas* sp., *Enterococcus* sp., *Flavobacterium* sp., *Lactobacillus* sp., *Micrococcus* sp., *Moraxella* sp. and *Pseudomonas* sp. (Himelbloom and Crapo, 1998).

In channel catfish (*Ictalurus punctatus*) roe, the dominant flora were: *P. shigelloides* and *E. vulgaris*. Also present were E. *agglomerans*, *Corynebacterium* sp., *V. alginolyticus* and various *Pseudomas* sp. Total plate counts ranged from 7×10^3 to 2×10^5 CFU/g (Eun et al., 1994).

Studies of lightly salted (3.5 to 4.0% water phase salt, pH 5.4) lumpfish (*Cyclopterus lumpus*) caviar following 3 months storage at 5°C contained lactic acid bacteria (6.7 to 8.1 log CFU/g [70 isolates]); Enteroacteriaceae (<5 to 6.9 log CFU/g [30 isolates]); and *Vibrio* sp. (<5 to 6.1 CFU/g [8 isolates]) (Basby et al., 1998). Isolates from lumpfish included: *Lactococcus* spp., *Carnobacterium* spp., *Serratia liquefaciens*, *Serratia plymuthica*, and *Morganella morganii* (Basby et al., 1998).

Listeria monocytogenes is a mesophilic, Gram-positive nonsporeforming facultative anaerobe. *Listeria monocytogenes* is ubiquitous in estuarine environments and in seafood processing plants (Jorgensen and Huss,

TABLE 10
Bacterial Contamination of Caviar Products

Microbe	Number of Positive Samples
Aeromonas hydrophila	5
A. salmonicida	9
A. sobria	5
A. caviae	4
Vibrio parahemolyticus	2
V. costicola	7
V. flavialis	1
Proteus inconstans	6
P. mirabilis	6
P. vulgaris	1
P. freundii	6
Klebsiella pneumophila	1
Pseudomonas aeroginosa	3
Flavobacterium sp.	6
Hafnia sp	1

Osetra ***(N=51)*** and Sevruga ***(N=35)***Caviars. Data from Boyko *et al.* (1993).

1998). *Listeria monocytogenes* is capable of growing at the refrigerated temperature and can grow in a temperature range of –0.4 to 45°C and the pH range of 4.4 to 9.4, at $A_w >$ 0.92 and at salt levels up to 10% (FDA, 1998).

Listeria monocytogenes has been isolated in raw oysters (Fletcher et al., 1994), clams (Estela, et al., 1992) and other seafood products (Wetherington, 1998). Ready-to-eat seafood products are often contaminated with *L. monocytogenes* (Ben Embarek, 1994). Weagent et al. (1988) found *L. monocytogenes* in several samples of frozen seafood such as raw shrimp, cooked and peeled shrimp, cooked crabmeat, raw lobster tails, scallops, squid, and surimi-based imitation seafood. *Listeria* sp. is a potential contaminant in caviar and fish roe products, although there are no reports to date of recalls being initiated for caviar or roe products contaminated with this microbe.

There is currently a zero tolerance for *L. monocytogenes* in food products as per U.S. food safety regulations, although other nations permit the presence of this organism at low levels in food. A nonpathogenic but related species to *L. monocytogenes* is *L. innocua* (Duh and Schaffner, 1993). *L. innocua* is commonly used as an indicator organism in model systems for food pasteurization processes because the biophysical traits of this organism is very similar to *L. monocytogenes*.

B. Contamination with *Clostridium* spp.

Clostridium spp. are Gram-positive, mesophilic, anaerobic, spore-forming rods, which are widely distributed in milk, meat, fish, shellfish, and the aquatic environment (Lake et al., 1992). *Clostridium botulinum* type A and proteolytic B and F grow at 10 to 48°C, $A_w >$ 0935, min pH = 4.6, max pH = 9, and at salt contents up to 10%. *Clostridium botulinum* type E and nonproteolytic B and F grow at 3.5 to 45°C, $A_w >$ 0.97, min pH = 5, max pH =9 and at salt content up to 5%. *Clostridium sporogenes* PA 3679 is not pathogenic but is physiologically similar to

Clostridium botulinum and serves as a model organism in shelf stability and sterilization processes for low acid foods in place of *C. botulinum* (Sanchez et al., 1995). Both *C. botulinum* and *C. sporogenes* produce heat resistant spores, which can germinate and grow in a food.

A heat sterilization process cannot be performed on caviar alone to inhibit spore germination of *C. botulinum*. Caviar can only be heated to less than 80°C before the protein irreversibly denatures, similar to what is observed when chicken eggs are cooked. Therefore, preservatives must be added to inhibit the germination of spores. The Russian market uses borax as a preservative in caviar when sold in their domestic market. North American or Western European authorities do not legally permit this preservative. Potassium nitrate is legal for use in cod roe as a curing agent (21 Code of Federal Regulations ß 172.60) but not for other roe products. There are no listed permissible preservatives for ikura, sturgeon roe, or for the roe of other fish species permitted in the U.S., which would inhibit spore germination and toxin production, and permit the development of a shelf stable caviar product.

C. Thermal Processing of Caviar Pasteurization Processes

International markets for caviar are demanding pasteurized products as a means of reducing the risk of food borne illness. Pasteurization is the destruction of pathogenic vegetative cells. Thermal pasteurization processes have been used to extend the shelf life of caviar. Batch pasteurization of airtight containers or vacuum packaged containers of caviar have been attempted with limited success.

Caviar pasteurization is executed at mild temperatures (50 to 70°C) due to the sensitivity of the product to heat. Within this range of temperature, the fish egg proteins do not undergo substantial coagulation and the appearance of the product remains visually the same. However, as a result of pasteurization, salmon caviar becomes slightly paler and soft, and immature salmon eggs lose their shape. The temperature during pasteurization must remain below 70°C. At 56 to 60°C, only slight changes in pink salmon caviar color are noticeable (Sternin and Dore, 1993). At 71°C, all the eggs appear dull; at 72°C, the egg yolk is completely coagulated and the caviar converts into a chewy, boiled egg mass (Sternin and Dore, 1993). Development of a high temperature-short time pasteurization may be possible by using dielectric heating methods. Pasteurization extends the shelf life of the caviar, and allows short-term storage at refrigeration temperature (2 to 3 weeks). This food processing technique does not assure quality at abusive temperatures such as room temperature.

The D values of *Listeria* spp. for roe are within the range for meat and eggs products. The $D_{60°C}$ value for *L. innocua* is 10 min for chum salmon (*Oncorhychus keta*) caviar (0.5% salt), 4.8 min for 2.5% salt. The $D_{60°C}$ for white sturgeon caviar (*Acipenser transmontanus*) (approx. 3% salt) range from 10 to 19 min.

CONCLUSION

Caviar and products made from the roe of aquatic animals besides sturgeon are becoming increasingly popular in both domestic and international markets. The roe of literally dozens of aquatic animals are used for food. Most of these roe products are brined or cured. Some are flavored or colored. The appearance, flavor and texture are all important sensory characteristics for these foods. Roe products are most commonly used in relatively small quantities as a condiment and are often served with rice or in preparations with other aquatic foods. However, despite the importance of these products in international commerce, there is relatively little technical information available about their chemical composition, product quality, and food safety attributes.

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