A PROFILE OF THE AQUACULTURE OF TROUT IN THE UNITED STATES

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Introduction

The culture of rainbow trout *Oncorhynchus mykiss* (Figure 1) in the United States takes place in a mature and relatively stable industry. Rainbow trout constitute the overwhelming majority of trout produced on commercial facilities, but other species such as the eastern brook trout *Salvelinus fontinalis* (Figure 2) and the European brown trout *Salmo trutta* (Figure 3) are also produced in limited numbers on U. S. trout farms. According to the 1998 Census of Aquaculture (NASS 2000), the U.S. trout industry consists of 561 farming operations located in 42 states. Major producing states include Idaho (70-75% of domestic production), North Carolina, Pennsylvania, California, and Colorado. The majority of the farms are small, family-operated businesses with average sales per farm of $129,473 nationally. However, the largest ~20% of the trout farming operations (108) actually account for over 85% of the total sales. This dichotomy in farm sizes exists within most states, with a few large companies or farms producing most of the fish in those areas.

Figure 1. Rainbow trout *Oncorhynchus mykiss*.

Figure 2. Brook trout *Salvelinus fontinalis*.

Figure 3. Brown trout *Salmo trutta*.

Figure 4. Commercial trout production in the U.S. *Source: NASS 1994 - 2004.*

As with other agriculture, trout aquaculture can be a risky business. But many of the initial challenges to trout production have been addressed through proper location and water supply, planning and management of production, and where appropriate, application of technological solutions to counter risks such as drought and diseases. The relative stability of the trout industry during the past decade attests to the capability of the farmers to minimize risks and losses while maintaining a reasonable level of profitability. Production of food size rainbow trout over the past decade has changed little, averaging 56 million pounds per year and ranging from 52.1 million pounds up to a peak of 60.2 million pounds (Figure 4). Unfortunately, increasing threats from low-cost imports, aggressive environmentalism, and competition for limited water resources may prove much greater challenges to the future of trout farming in the U.S. than the actual husbandry and marketing of the animals.

History of Trout Production in the U. S.

Rainbow trout are native to North America extending throughout the eastern Pacific coastal regions from Mexico northward to the Aleutian Islands, and southward on the western

Pacific rim from the Kamchatka Peninsula to the Amur River of Siberia (Behnke 1992). At the end of the last ice age, they were distributed in the U. S. and Canada throughout the region west of the Continental Divide. The first stocks of rainbow trout propagated in a hatchery are believed to have originated from coastal strains from the San Francisco Bay area about 1870-1873 (Needham and Behnke 1962; Behnke 1990). Facilities for hatching rainbow trout eggs were first located in the basement of the San Francisco City Hall and on campus at the University of California at Berkeley. Livingston Stone, reportedly one of the foremost salmonid breeders of his time, established the first U. S. Fish Commission trout spawning station on a tributary of the McCloud River in California in 1879 (Gall and Crandell, 1990). Supported by the U.S. Commission of Fish and Fisheries, eggs from this station were shipped throughout the country with subsequent establishment of rainbow trout culture in a number of federal hatcheries. The first shipment of rainbow trout eggs outside the country is believed to have been to Japan in 1877. In 1883, trout eggs were shipped from a private hatchery in California to New Zealand, and in 1885, eggs were sent to the National Fish Culture Association in England, which subsequently established a breeding stock. Shortly thereafter, farming of rainbow trout began in Denmark. Many of the rainbow trout stocks currently cultured worldwide probably originated from resident McCloud River populations, populations of steelhead trout from tributaries of San Francisco Bay, or the cross breeding of those fish (Behnke 1992).

In Idaho, the first rainbow trout farm was established in 1909 at Devil's Corral, just east of Twin Falls. In 1914, Warren Meader of Pocatello established a brood stock facility, which by 1940 was supplying up to 60 million eggs seasonally to private and public hatcheries throughout the country (Brannon and Klontz, 1989). In addition to trout having relatively large eggs with abundant yolk, the manipulation of their breeding cycle to make eggs available year-round has been a major contribution to their success as a farmed fish. Rainbow trout naturally spawn in the spring, but spawning time can be manipulated through genetic selection and photoperiod adjustment. Selection for early winter spawning on a particular strain in

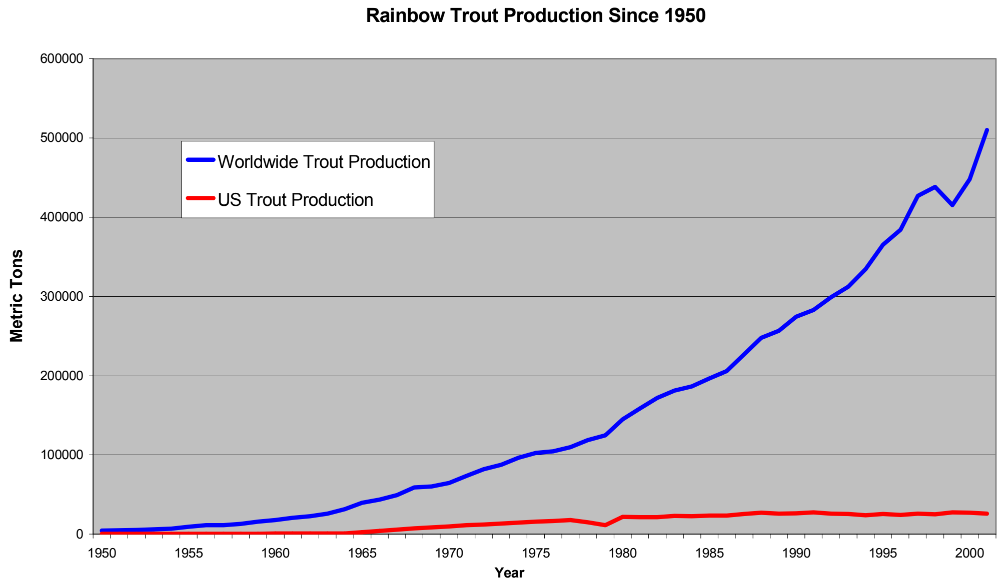

Figure 5. Production of trout worldwide since 1950. *Sources: Hardy et al. 2000; FAO 2003; NASS 1987 - 2003.*

California began during the 1930s. The median time of spawning for this strain was shifted from March in 1880 to October by 1940, and further work several decades later moved the median time to August in 1980. By 1970, eggs were available all year, and contributed to a rapid increase in world trout production over the last three decades (Figure 5). Another technological advance that many trout growers adopted was the use of all female stocks. The use of all female stocks reduces performance variability and eliminates the occurrence of sexually precocious males, which are economically undesirable because of poor flesh quality. Trout eggs can now be purchased as mixed-sex, all-female, or all-female sterile fish at any time of year.

Although rainbow trout farming had started in Idaho and other states on a limited scale in the early 1900's, significant expansion of the U. S. trout industry didn't occur until the 1970's and 1980's. Of the factors that contributed to the growth of the trout industry, perhaps the most significant advance was the development of pelleted feeds in the early 1950s. The U.S. Fish and Wildlife Service was primarily responsible for identification of the nutritional requirements of rainbow trout, which was followed soon afterward by the development of dry, pelleted feeds. Pelleted feeds reduced the cost of production and stimulated further development in the industry by eliminating the need to prepare fresh feeds onsite and making feeding less labor intensive. The first major rainbow trout processing plant was constructed in Idaho also during the mid-1950's by the Snake River Trout Company (Brannon and Klontz, 1989), allowing product diversification and greater potential for distribution. Soon thereafter, automated processing equipment was developed, followed quickly by development of automatic feeders, graders, and fish pumps. Concurrent with broodstock manipulation and pelleted feed development, the evolution of trout production from simple earthen ponds to concrete raceway production systems also increased production significantly, while reducing labor for cleaning, grading, moving, and harvesting. Depending upon the individual site, the switch from earthen ponds to concrete raceways can increase production by 25-40% with same quantity of water. Although many earthen ponds remain in commercial trout culture, well over 90% of production is estimated to come from concrete raceways.

Characteristics of the U.S. Trout Industry

Production of food size rainbow trout in the U.S. between 1988 and 2002 averaged 56 million pounds per year, ranging from a low of 52.1 million pounds to a high of 60.2 million pounds . Trout growers reported sales in 2003 of $66.4 million, compared to an average value of $72.2 million from 1988 to 2002 (NASS 1989 - 2003; H.M. Johnson & Associates 2002; Figure 6). This includes sales of food fish, fish for stocking, fingerlings, and eggs. The fluctuation of total sales from year to year reflects varying production, especially from Idaho, market price, and the proportion of sales coming from the different sectors within the industry. These sales are ex-farm and are the gross value received by the producer. Food size fish comprised 84% of total sales in 2002.

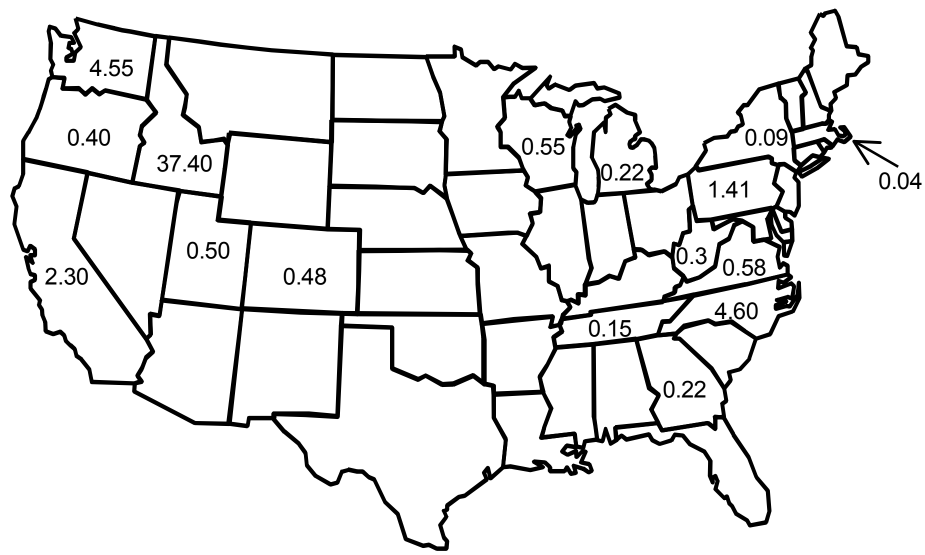

Figure 6. 2002 U.S. commercial trout sales in millions of pounds, foodfish $\geq$ 12", by state for major trout production states. *Source: NASS 2003*.

According to the 1998 U.S. Department of Agriculture Census of Aquaculture, nearly 60% of food-size trout were sold to processors. Total sales of food-size trout (> 30 cm and 340 g) averaged $58.9 million from 1991 through 2002, followed by stockers (15-30 cm and < 340 g) at $7.06 million, eggs at $5.06 million and fingerlings at $ 1.53 million. Market outlets vary in different states related to the scale of the industry. In 2002, Idaho trout growers relied on processors for nearly all their sales of food-size trout (99%), whereas Colorado growers sold most of their fish to fee fishing operations (81%). California trout growers sold nearly all their fish (92%) to fee fishing outlets. In the eastern half of the U.S., direct sales (New York – 37%) and fee fishing operations (Massachusetts – 81%) are important market outlets, however, in North Carolina 87% of the trout were sold to processors. In general, the greater the amount produced, the higher the percentage sold to processors.

Table 1. Water quality parameters for trout hatchery water supplies. *From Piper et al. 1982.*	
Dissolved oxygen	5 mg/L to saturation
Temerature	45-65N F
pH	6.5-8.0
Total alkalinity (CaCO3)	10-400 mg/L
Calcium	4-160 mg/L
Manganese	0-0.01 mg/L
Iron (total)	0-0.15 mg/L
Zinc	0-0.05 mg/L
Nitrogen gas	Less than 100% saturation
Carbon dioxide	10 mg/L or less
Hydrogen sulfide	0.1 ppb or less

Production Practices and Systems

Production of trout in the U. S. is typically equated with culture of fish in flow-through systems. Water for trout production is usually diverted from streams, springs or artesian wells to flow onto the farm via gravity. Pumping water from wells or other water sources to the production units is more costly and is not often used in the industry other than for operating small hatcheries. Use of water from wells, springs, or surface flows for trout facilities is regulated by various public agencies depending upon the specific water laws of each state, and is considered a non-consumptive use.

Water supply

Water for trout production must be cold and pure (Table 1), though various species of trout can be acclimated to a wide range of water chemistries ranging from soft, fresh

Table 2. Effects of water temperature on spawning, survival and growth of trout. *From Piper et al. 1982.*

Species	**Spawning Frequency**	**Survival (°F)**	**Optimum Growth (°F)**	**Optimum Spawning (°F)**	**Eggs per pound of fish**
Ranbow Trout	Annual	33-78	50-60	50-55	1000
Brook Trout	Annual	33-72	45-55	45-55	1200
Brown Trout	Annual	33-78	48-60	48-55	1000

waters to sea water. Water quality and quantity will determine the carrying capacity and production potential of trout production systems. Incoming water provides oxygen and outgoing water removes metabolic and solid wastes from the production unit. Temperature is also a critical water quality parameter because it directly affects survival, growth, and will impact the quality of egg production (Table 2). When available, groundwater sources are preferable to surface waters because they have more stable temperatures and reduced risk of contamination from wild fish or pathogens. However, groundwater in some areas may be relatively low in dissolved oxygen, and high in carbon dioxide, nitrogen, or hydrogen sulfide.

Trout Farming Systems

Trout production farms in the U. S. evolved from earthen pond systems, the most popular shape of which was long and narrow with sufficient slope to allow for aeration by gravity between ponds. Earthen ponds are still in use today, particularly on small farms (Figure 7). Pond size varies depending on available water, topography, soil type, production goals and other factors. A primary disadvantage of earthen ponds is erosion of the banks when

Figure 7. A trout farm using earthen production ponds.

Figure 8. Circular tanks used for rainbow trout broodstock production.

water flows are maintained at the desired rates. Compared to tanks, water velocities must be kept lower in earthen ponds to minimize erosion. Rocks, wood, or concrete structures are sometimes used to stabilize the banks. Other disadvantages of earthen ponds for rearing trout include more difficult fish management and harvesting. Lower fish densities associated with earthen ponds may result in a healthy and colorful appearance of the fish. The low capital investment makes earthen ponds systems popular for culture on smaller trout farms supplying live fish markets. Circular tanks are also used to raise trout on U. S. trout farms, but relatively few are in use compared to the number of these facilities in Europe. Circular tanks can provide relatively uniform water quality throughout the rearing unit and many are designed to be self-cleaning (Figure 8). Smaller quantities of trout are also produced in net pen systems in fresh and saltwater in the U. S., including some by public fisheries agencies (Figure 9).

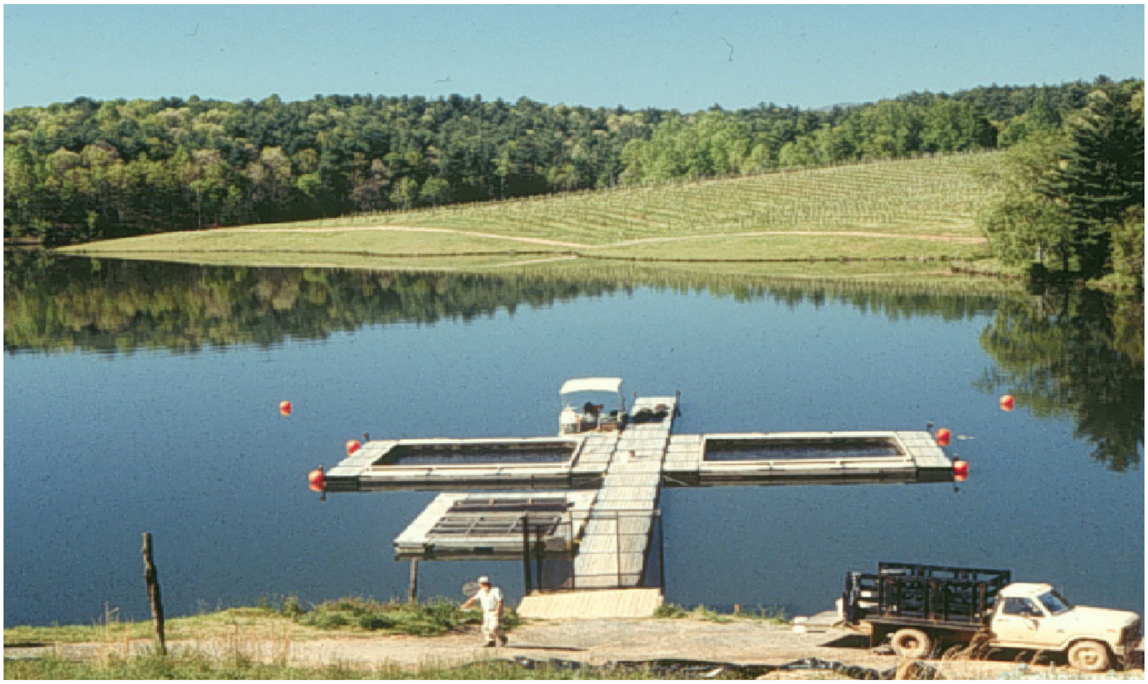

Figure 9. Net pens used for rainbow trout culture in a small impoundment.

Most commercially and publicly produced trout in the U. S. are grown on trout farms with concrete raceways. A typical raceway-based trout farm consists of a series of tanks, usually rectangular with water flow along the long axis (Figure 10). General recommendations for concrete raceways are 30:3:1 length, width and depth ratios. Dimensions for raceways are highly variable and can range from 6 to 18 feet wide and from 60 to 180 feet long. Water depth is usually between 2.5 to 3.5 feet to facilitate management of the fish.

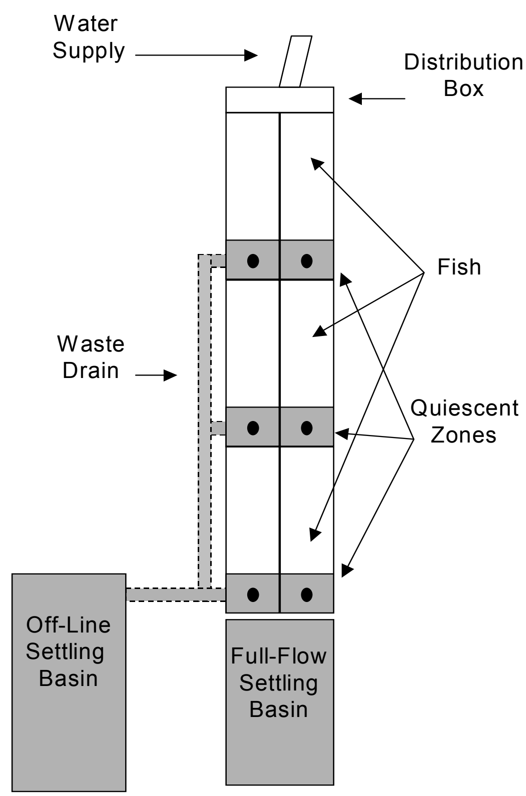

Figure 10. Schematic of a raceway production system.

Flow-through systems can be classified as primarily in series or parallel in reference to the rearing units, but typically contain features of both approaches. A system is in series where water flows from one rearing unit to the next one below. With parallel systems, the rearing units are adjacent to each other and discharge directly into the receiving waters. Available space, topography, and water flow will influence whether to construct a flow-through system with rearing units in series or parallel. Most trout farms are a combination of series and parallel production units. The raceways on most trout farms are divided into two or more tanks at each step in the series, but on smaller farms the tanks are usually in pairs for ease of access (Figure 11). Larger farms may construct vehicle access on the tanks and have multiple raceways in parallel series (Figure 12).

Figure 11. Paired concrete raceway systems for trout production on smaller farms.

The water in raceway production systems is rarely recirculated, but is 're-used' serially with aeration or oxygenation between tanks. The water in linear raceways exhibits plug flow, making the tanks relatively easy to keep clean, and

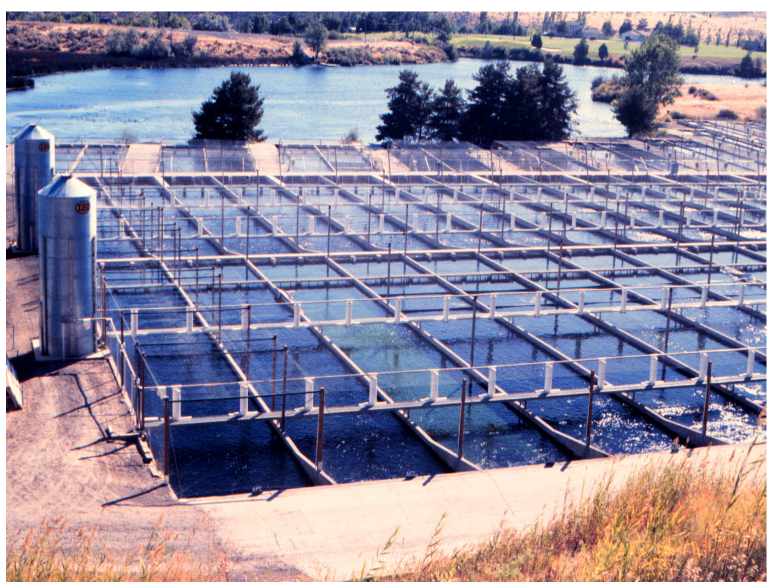

Figure 12. Parallel raceways for trout production on a larger trout farm. Note only three serial uses of the water.

easier to manage than earthen ponds. A minimum of four volume exchanges or 'turnovers' per hour are recommended with minimum water velocity of 0.1 feet per second to maintain good water quality within fish rearing units. Thorough reviews of physical design, construction, and operational parameters of raceways can be found in Burroughs and Chenoweth (1955), Wheaton (1977), Klapsis and Burley (1984), and Timmons and Youngs (1991).

For trout farms with serial water reuse, sufficient slope is necessary to ensure a minimum of 18 to 24 inches of drop between each rearing unit. Dissolved oxygen is the first limiting factor affecting production within a rearing unit, and the fall of the water between units allows passive aeration and oxygen recharge between uses. The intensity of water use, *i.e.* number of reuses and fish density, is determined by incoming water quality and topography of the site. In areas where the source water has high alkalinity and hardness, with a basic pH, the number of uses (*i.e.*, tanks in series) will typically be limited to four to six due to the accumulation of un-ionized ammonia. In low alkalinity and soft waters with neutral to acidic pH, virtually all the ammonia is ionized and has little impact on the number of times the water is 'used'. In these waters the number of tanks in series is often ten or more, and will be limited by accumulated carbon dioxide or particulate wastes.

Reproduction

Most trout eggs are produced on broodfish farms separate from farms that produce fish for food or stocking. This is due to the high cost of maintaining broodstock and the skill and labor required to produce high-quality disease-free eggs. Rainbow trout in nature are spring spawners, while brook and brown trout spawn in the fall. However, due to selective breeding and photoperiod manipulation, salmonid eggs are available all year.

Rainbow trout sexually mature between 2 to 3 years of age, although under fast growing conditions trout as young as 1 year old may spawn. Rainbow trout are typically spawned artificially by manual stripping or expelling the eggs with pressurized air. An anesthetic

Figure 13. Manually stripping eggs from a trout.

Figure 14. Fertilizing trout eggs.

such as MS-222 is used to calm the fish to reduce stress, minimize any potential handling injury and to avoid damaged eggs. Manually collecting eggs from a ripe female can be done by a single individual, but it is easier to use two people to spawn larger fish. One person gently holds the female near the head with one hand and with the other just above the tail. The female is held with her vent pointing down toward a pan used to collect the eggs. The second person gently massages the abdomen using his thumb and forefinger beginning above the vent and working toward it to express the eggs. If the female is ripe (has ovulated), the eggs will freely flow from the vent (Figure 13). Sperm from the male is obtained in a similar manner (Figure 14).

With air spawning, a hypodermic needle connected by a hose to a low-pressure (2-3 psi) air compressor or air cylinder is inserted about ½ to 1 inch into the female body cavity, depending on the size of the fish. The needle is inserted in the depression under a pelvic fin for best results. The air pressure will expel the eggs with minimal stress to the fish. Air spawning generally produces cleaner eggs and no broken shells, and fewer eggs remain in the body cavity compared to manual stripping.

Either the wet or dry methods can be used to fertilize the eggs. With the wet method, a pan is partially filled with water, then the eggs added with the milt added shortly after. The dry method allows more time between collecting eggs and milt from several fish. Once the eggs and milt are collected in a pan both are thoroughly mixed to increase fertilization and then water is added. After fertilization the eggs are rinsed and allowed to water harden. The eggs can be disinfected with an iodine solution, such as Argentyne®, Betadine®, or Wescodyne®. The eggs are treated for 10 minutes at 100 ppm active iodine. In poorly buffered (alkalinity < 35 ppm) or low pH waters sodium bicarbonate is added to the water before disinfecting at approximately 0.5 grams per gallon to prevent pH reduction. The eggs and disinfectant are gently mixed to ensure all egg surfaces are treated. Once disinfection is completed the eggs are rinsed with clean water and ready to be counted and placed into incubators.

Water hardened eggs can be transported from 1 to 48 hours after fertilization, but after 48 hours the eggs are very sensitive to any movement and should not be moved until they reach the eyed stage, when the eye pigment is clearly visible. During spawning and incubation the eggs are also sensitive to light and should be shielded from direct sunlight and intense artificial light. Time to 'eye-up' and subsequent hatching depends on the water temperature (Table 3).

Most trout growers receive eyed eggs shipped from egg producers. The eggs typically arrive in a styrofoam container packed with a small amount of ice and cheesecloth or paper towels to keep the eggs cool and moist. The eggs are tempered gradually over a 30 to 60 minute period to the hatchery water temperature. The tempering process should not be done in the hatch house to avoid possible contamination with pathogens.

Table 3. Number of days from fertilization until hatching. *From Piper et al. 1982.*

Species	Water Temperature					
	35°F	40°F	45°F	50°F	55°F	60°F
Rainbow Trout	---	80	48	31	24	19
Brown Trout	156	100	64	41	---	---
Brook Trout	144	103	68	44	35	---

Shipping containers should also be destroyed to avoid contamination. Although the eggs were probably disinfected by the egg supplier it is good hatchery management to disinfect prior to placing them in the incubators. If the eggs have begun to hatch, do not disinfect as significant mortality will occur.

Eyed trout eggs purchased from a commercial supplier will usually contain a very small percentage of dead eggs, and may not require treatment for fungus. However, if the eggs are more than 3 days from hatching, any dead eggs should be removed regularly to limit fungal infections. Removing dead eggs is more effective than chemical treatment at controlling fungus, but can be very time consuming. If it becomes necessary to chemically control fungus, formalin or hydrogen peroxide can be used to treat the eggs. Trout eggs should not be treated with formalin within 24 hours of hatching. Trout eggs and sac fry should not be treated with any chemicals during the hatching process.

Hatching rate depends on water temperature, but will usually be completed within 2 to 4 days after commencing. If the eggs are incubated separately from the rearing troughs, the sac fry should be transferred into shallow fry troughs within approximately one week after hatching is complete, depending on the incubators used and available water flow. When about 50 percent of fry swim up, or approximately two weeks after hatching commenced, fish can be trained to feed on a prepared diet using a small particle starter mash on the surface at least three to four times daily, until active feeding has begun by most of the fish. Automatic feeders usually are better and certainly are more convenient than feeding by hand, but many are not well suited to distributing the smallest feed sizes. Many hatchery operators choose to feed by hand for the first 2 to 3 weeks, or until fry are about 1" long (approximately 0.5 grams or 1,000 fish per pound). At this point, fish can be fed using automatic feeders and rates according to a published feeding chart, or ad libitum as water quality allows. The rearing troughs must be cleaned regularly to maintain a healthy environment for the fish.

The fry will be ready to move from the troughs into small production tanks in the hatchery or outdoors when they grow to approximately 2 grams, or 200 to 250 fish per pound. Trout are kept in the smaller systems until they are 100 to 120 days old (post-hatch), and reach 4 to 6 grams in size (three to four inches; 80 to 100 fish per pound). At this size, they may be moved to larger raceway production systems on-site, or may be sold to farms that do not operate their own hatchery. In areas where *Yersinia ruckeri*, the causative agent of enteric redmouth disease (ERM), has been detected, the fish should be vaccinated 2 weeks before moving them to a production facility. The recommended minimum size for immersion vaccination of trout against ERM is 4.5 grams, or approximately 100 fish per pound. Vaccine development is a critical need for trout growers to prevent losses from several other diseases for which treatments are limited or nonexistent, including coldwater disease caused by (*Flavobacterium psychrophilium*), and two viral diseases, infectious hematopoietic necrosis, and infectious pancreatic necrosis.

Growout

Depending on the water temperature rainbow trout can grow from 0.5 to slightly over an inch in length per month (Table 4). A typical production schedule at a trout farm using spring water at a constant temperature of 15° C (59° F) is as follows:

Receive 12 batches of eyed eggs/year, 30 days apart	day 1
(20,000 eyed eggs per up-well incubator, 1 week to hatch)	
Move 1: Sac fry emptied into nursery troughs	day 1 - 7
(20,000 per trough, begin feeding)	day 15
Move 2: 25,000 per small production tanks	day 55
(Indoor or outdoor)	
Move 3: 18,000 per large production raceway	day 120
Move 4: 11,000 per large production raceway	day 220
Move 5: Harvest fish at 300 - 400 grams, about 0.8 pounds	day 250-300

(Harvest takes place over a three month period, with the majority harvested between 8.5 and 10.5 months after hatching.)

Table 4. Temperature-based growth rate potential (mm per day length increase). *From Klontz, 1988.*

T (C)	T (F)	Rainbow Trout	Brook Trout	Brown Trout
20	68.0	0.746	0.480	0.470
19	66.2	0.851	0.558	0.536
18	64.4	0.956	0.637	0.602
17	62.6	1.060	0.715	0.668
16	60.8	1.165	0.793	0.734
15	59.0	1.270	0.872	0.800
14	57.2	1.165	0.950	0.734
13	55.4	1.006	0.872	0.668
12	53.6	0.956	0.793	0.602
11	51.8	0.851	0.715	0.536
10	50.0	0.746	0.637	0.470
9	48.2	0.641	0.558	0.404
8	46.4	0.537	0.480	0.338
7	44.6	0.432	0.401	0.272
6	42.8	0.327	0.323	0.206
5	41.0	0.222	0.245	0.140
4	39.2	0.117	0.166	0.074

On facilities with water temperatures that are above or below 15^{o} C, the total production period for this size fish will be extended, and may reach 14 to 16 months.

Farm Inventory and Carrying Capacity

As the trout grow, the groups are split into more tanks to maintain fish densities within levels acceptable for efficient fish production. The carrying capacity of each tank depends on several factors including: water flow, tank volume, exchange rate, water temperature, oxygen content, pH, fish species and size, production targets (feeding rates), and accumulation of waste products. Using tolerance limits for available oxygen of 5 mg/L minimum and 0.0125 mg/L un-ionized ammonia maximum (Smith and Piper 1975), Westers and Pratt (1977) presented a synthesis of flow-through system design criteria that still reflects the existing U.S. trout industry, based on metabolic characteristics of trout. Much of the commercial industry still operates within the range of productivity outlined by Westers and Pratt, normally carrying between 20 and 80 kg fish per cubic meter of water volume (approximately 2 to 5 pounds per cubic foot) with water exchange rates per tank of three to six times per hour. The water is re-used serially four to six times or until ammonia becomes limiting (*e.g.*, un-ionized ammonia approaches 0.0125 mg/L), then is discharged. In areas where the waters are acidic, ten or more uses are typical, and other factors such as carbon dioxide or suspended solids may become limiting before ammonia. Colt *et al.* (1991) describe methods for calculating carrying capacity in culture systems where oxygen is not a limitation such as when pure oxygen is added in a trout farm. Total annual production or yield is generally 2 to 3 times the total farm carrying capacity.

Piper *et al.* (1982) recommend using flow and density indices to calculate carrying capacity. The flow index (an index of weight of fish per unit fish size and water) is calculated as follows: F = W/(L*I), where F = flow index, W = known permissible weight of fish, L = length of fish in inches, and I = water flow in gallons per minute. Standard flow index tables are available that have calculated the flow index at various temperatures and elevations, with the assumption the incoming water is at or near 100% saturation. By rearranging the formula to: W = F*L*I, the permissible weight can be calculated. The total fish biomass per unit water flow in a tank is referred to as the tank 'loading'. The density index calculates the maximum weight of fish per unit volume. The density index is calculated as: W = D*V*L, where W = permissible weight of fish, D = density index, V = volume in cubic feet, and L = fish length in inches. The recommended flow and density indices are from 0.5 to 1.0 when pure oxygen is not used.

The flow and density indices were developed at state and federal hatcheries where production goals differ from commercial facilities and are very conservative relative to potential carrying capacity. Most trout farmers base their carrying capacity on empirical observations relative to available oxygen, where a predetermined limit of dissolved oxygen flowing out of one raceway into the next raceway is established. For example, incoming water to the first tank is 100% saturation and the predetermined limit of outgoing water is set at 70% of saturation. The available oxygen is calculated based on the water flow and the incoming concentration of dissolved oxygen. The allowable biomass is calculated by dividing the available oxygen by the metabolic oxygen consumption of the fish. Typical carrying capacities range from 2.5 to 5.5 pounds of fish per gallon of water inflow per minute for each use of the water on the farm. Carrying capacities are even higher with supplemental oxygen and may reach 10 to over 15 pounds of fish per gallon of water inflow per minute for each tank in the system. As described previously, the number of times this can be repeated in the system is a function of water chemistry (4 - 6 times in more alkaline waters, 10 - 20+ in acidic waters), temperature, and available slope for reaeration/oxygenation.

Inventory

During the production cycle, trout groups are usually ‘split’ and moved three or four times, and may be sorted according to size (graded) at that time to maintain size uniformity. The frequency of grading will vary according to individual circumstances, but is generally not done with trout smaller than five inches in length. The simplest graders, called bar graders, are made of wooden frames that are as long as the tank is wide, and slightly taller than the water is deep. Bar graders have vertical pieces of aluminum tubing, PVC pipe or smooth wood spaced at regular intervals across the frame. These graders can be constructed on-site to fit snugly within the tank, and to match the sizes of fish to be routinely graded. The grader is put in the top (inflow) of the tank and is used to crowd the fish toward the tailscreen (outflow). Fish too large to pass through the bars remain at the bottom of the tank, where they can be harvested or moved to another tank. The smaller fish swim through the bars and remain in the same tank, although 10 percent or more usually remain behind the grader. Mechanized graders are available, and function by pumping the fish onto rotating grader bars. Mechanized systems are very effective when properly sized for the fish to be graded, but are difficult to justify economically for smaller trout farms.

Fish populations in each tank on the farm are monitored to assure that the fish are growing as expected and to keep track of ‘loading’ rates (loading = fish biomass per unit water inflow) and density. This is often accomplished using the initial sizes and numbers stocked into the tanks, then using records of mortalities, removals, and feed inputs to calculate fish biomass. From the calculated fish growth, loadings can be adjusted when necessary and feed allotments determined. Fish may also be sampled to estimate population growth. With the fish loosely crowded at the head end of the tank, a sample of fish is netted into a bucket of water suspended from a scale. The weight is recorded and the fish are counted as they are poured back into the tank. If fish are well-graded, three or four samples are sufficient. Fish size (expressed as number per pound) is calculated by dividing the number of fish in each sample by the total sample weight. The average of all samples for each tank is then used to estimate the weight of fish in the entire tank. Some mechanized grading systems incorporate electronic fish measurement systems, but their use is not widespread in the trout industry.

Earthen pond systems present much more of a challenge in managing trout populations than tank systems. Most often, fish are stocked into earthen pond systems at 100 grams (four fish per pound) or larger and are not split or graded before harvest for market. The carrying capacity of an earthen pond can be estimated similarly to a tank system if the water exchange rate is approximately 30 minutes or less. If turnover rate is longer than this, the capacity is a function of the ratio of surface area to water volume, inflow rate and oxygen demand of the sediments. The carrying capacities of earthen ponds are best determined by measuring the oxygen content of the pond and outflow waters, and maintaining good production records.

Other routine activities include removing any mortalities from each tank on a daily basis and recording the numbers. Dead fish left in tanks are a potential source of disease and are indicative of poor farm hygiene. Analyzing mortality rates in each tank may identify developing fish health problems before they become severe. Mortalities can be subtracted each month from estimated population totals to maintain an accurate inventory.

Waste Management

Settling basins are commonly used to remove solids and solids-bound nutrients prior to discharge into receiving waters. Stechey and Trudell (1990) found sedimentation to be the most widely applicable and inexpensive method for removing solids from flow-through trout farms. Gravitational settling can provide a simple, low-maintenance, and only moderately expensive method of removing a high percentage of the solids and accompanying nutrients from raceway effluents, but may require a larger flat area (Summerfelt 1999) and must be properly designed. Within raceway production systems, three types of settling basins are used to settle solids: 1) a quiescent zone, 2) a full-flow settling basin, and 3) an off-line settling basin (see Figure 10). A quiescent zone is an area downstream of the rearing area of each tank for initial separation of settleable solids from the water. A screen prohibits fish from entering the quiescent zone allowing the solids to settle undisturbed. Ideally, quiescent zones should be installed in every raceway, but it is essential that the last tanks of each raceway series have quiescent zones to settle solids before the water is discharged into receiving waters. A common misconception is that the water velocity within raceway systems serves to 'flush' solids from the tanks. In fact, water velocities in virtually all commercial raceway systems are below 3.7 cm/s, suggested as the minimum flow required for self-cleaning (Youngs and Timmons 1991). Fecal solids and waste feeds will accumulate nearly anywhere in the system that fish are not present.

Quiescent zones serve as the pre-treatment system for solids, which are then either pumped or transported by gravity flow to off-line settling basins. Off-line settling basins receive the concentrated solids removed from quiescent zones, but not the full flow of the water from the facility. The combination of quiescent zones and off-line settling basins is the most commonly used system of treatment with concrete raceways in the U. S. to capture and remove solids. Full-flow settling basins receive the entire flow of a facility and are generally used where total facility flow is considered small, generally less than 283 L/sec, and level area is not limiting. Quiescent zones may or may not be included with full-flow basins depending upon the intensity of water use. The sludge from the settling basins can be

Table 5. Expected trout losses at different life stages. *From Klontz 1998.*		
Life Stage	Percent Loss	Initial Number
Green Eggs	7	1,000,000
Eyes Eggs	5	930,000
Hatch-out	6	883,500
Swim-up	1	848,160
Grow-out	25	839,678
Processing	5	629,759
Distribution		598,271

land applied or composted. Design criteria for aquaculture settling basins can be found in Wheaton (1977), Stechey and Trudell (1990), IDEQ (1997), and Summerfelt (1999).

Identification and Prevention of Fish Loss

Trout growers indicate that from 2.0 to 3.5 eggs are required to get one fish to market. Brannon and Klontz (1989) estimated losses of 5 to 25% during egg incubation, sac-fry and fry losses at 10 to 20% and losses among fingerlings and stockers ranging from 1 to 15 %, with losses generally decreasing as the fish reach larger sizes. Mortality during incubation is usually associated with infertility. Sac-fry and fry losses are often associated with respiratory diseases. Klontz (1998) suggested approximately 1.7 eggs are required to produce one market fish, slightly higher survival than reported by growers (Table 5).

The NASS Trout Production report lists seven categories of loss, including disease, predation, theft, chemicals, drought, flood and other. The majority of losses from 1997 through 2002 were from disease (range 72.5% - 84.5%), followed by predation (range 7.8% - 19%). Total number of trout lost per year from 1997 through 2002 ranged from 28,856,000 to 44,603,000. The number of pounds lost per year during this period ranged from 5,791,000 to 7,836,000. The average size of fish lost ranged from 0.130 pounds up to 0.235 pounds (Table 6).

Disease is consistently responsible for the highest percentage of losses to the

Table 6. Total number, pounds, and average fish size lost: 1997-2002. *Source: NASS 1998 - 2003.*					
Year	**Number (1,000s)**	**Pounds (1,000s)**	**Fish Weight (lbs.)**	**Fish Weight (grams)**	**Fish/Pound**
2002	34,968	6,611	0.189	85.8	5.3
2001	44,603	5,791	0.130	58.9	7.7
2000	29,662	6,639	0.224	101.6	4.5
1999	33,791	6,023	0.178	80.9	5.6
1998	34,248	7,836	0.229	103.9	4.4
1997	28,856	6,790	0.235	106.8	4.2

industry on a national basis (Figure 15), although the distribution of losses from different causes varies considerably from state to state (Figure 16). Widespread adoption of a change in management or technology can result in dramatic shifts in the relative importance of diseases as a cause of loss in a relatively short period of time, *e.g.*, change in vaccination practices in North Carolina (Figure 17). Diseases known to cause significant losses in the U. S. trout industry include those caused by viral pathogens (*e.g.* Infectious Hematopoietic Necrosis - IHN; Infectious Pancreatic Necrosis - IPN), bacterial pathogens (*e.g.*, coldwater disease caused by *Flavobacterium psychrophilium,* enteric redmouth disease caused by *Yersinia ruckeri,* and columnaris caused by *Flavobacterium columnare*), and an assortment of primarily protozoal parasites (*e.g.*, *Ichthyopthirius multifilis, Ichthyobodo sp., Episylis sp.*). Fungal diseases can cause

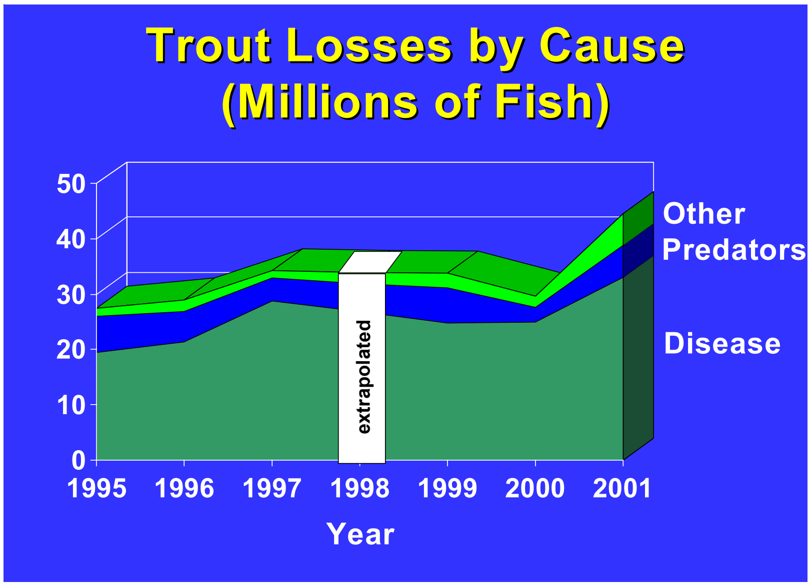

Figure 15. Reported causes of trout losses in the U.S. *Source: NASS 1996 - 2003.*

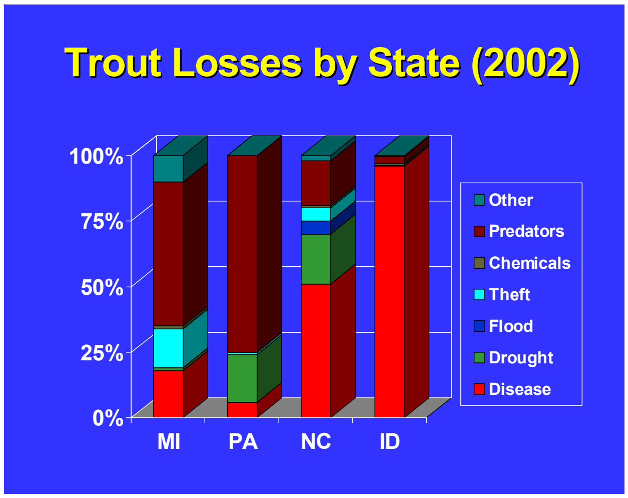

Figure 16. Sources of trout loss by state in four major producing states. *Source: NASS 2003.*

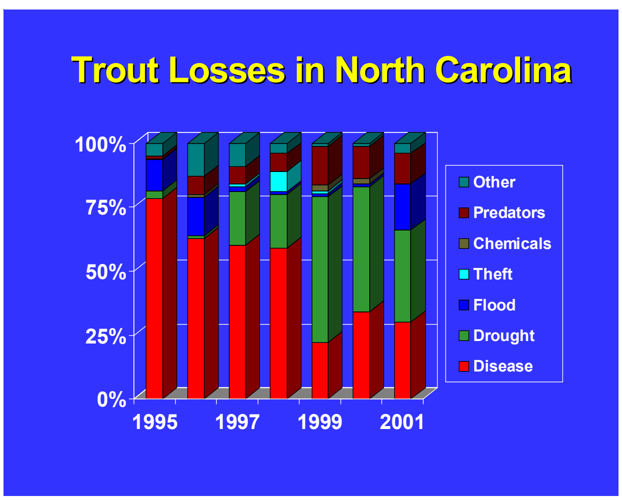

Figure 17. Example of management change resulting in decline of disease as a source of trout loss. Injection vaccination was demonstrated in 1995 with increasing usage by industry inclde about 60% of all trout produced commercially in North Carolina by 2000. Total losses declined concurrently. *Source: NASS 1996 - 2002.*

severe losses of fish eggs and occasionally larger fish, but don't frequently result in significant losses outside of the hatchery.

Predators can also cause severe losses, and are the primary cause of loss reported in many states. The majority of predators include mink, otters, and birds. In 2002 Pennsylvania and Michigan reported losses due to predation at 75% and 55% respectively. However, in Idaho predation accounted for only 3% of total losses in 2002. One reason predation is so much lower in Idaho is that most farms are covered with bird netting. Bird netting is very effective in keeping out birds and other predators when properly constructed and maintained. Chicken wire, plastic mesh and nylon netting are commonly used materials. Keeping the area around the facility free from garbage, mortalities and spilled feed also reduces the number of predators.

Chemical losses include mortalities from pesticides or therapeutants or other chemicals. Fortunately, chemical losses are extremely rare, accounting for only 0.1% of all losses in 2002. Still, trout growers should still be knowledgeable about the appropriate and approved uses and handling of chemicals on trout farms. Water quality influences the toxicity of certain chemicals and may also be adversely affected by some chemicals. Detailed knowledge of water quality and chemistry is critical before using any chemical treatment. Before application, farmers should test any chemical treatment on a small group of fish before treating an entire raceway. Fish should be observed for symptoms of toxicity throughout any treatment. In some situations chemical losses may stem from an upstream source. In particular, farms that use surface waters in their facilities must be vigilant to ensure that chemicals added to the water supply intentionally (*e.g.*, herbicides in irrigation canals) or indirectly (runoff or overspray) do not harm their fish or contaminate their facilities.

Losses from theft include acts of vandalism in the NASS Trout Production reports. Losses from theft in 2002, like losses from chemicals, are relatively minor for the entire U.S. trout industry, accounting for 0.4% of all losses. However, Michigan reported a 14% loss from theft in 2002. Living on site can minimize the risk of theft and vandalism. Besides acting as a deterrent to predators, bird netting or other fence enclosures can also serve to reduce vandalism and theft. At minimum, facilities should have a gate and lock on roads leading into the farm. Larger facilities might consider employing security guards.

Reduction of water supply due to drought can directly reduce production on a trout farm. Little can be done to avoid diminished production due to drought, although the impact can be ameliorated through oxygenation technologies, particularly in acidic waters. In more alkaline and basic waters, oxygenation provides little benefit due to the toxicity of unionized ammonia. During a drought or anytime when water flows are reduced, direct mortalities can be avoided by adjusting feeding and stocking rates to reflect the reduced flow rather than the tank volume and normal flows. Losses due to drought in 2002 were 4.1% of all losses reported and higher than in previous years. In 2002 states with particularly high losses due to drought included Colorado and Utah in the west (35% and 29% respectively) and North Carolina and Pennsylvania in the east (19% and 18% respectively).

Floods caused relatively minor losses between 1998 and 2002, averaging slightly over 0.3% of total losses, although North Carolina reported losses of 18% in 2001. Facilities that divert water from surface sources such as streams have a higher risk of flood damage compared to those facilities that use more stable ground water sources. Preventative measures to reduce the risk from floods include avoiding flood zones as farm sites and water diversion structures that allow control of flow rates into the farm.

The NASS Trout Production report does not specifically define losses associated with the "other" category. There are, however, catastrophic events that can cause severe losses to a trout farm. One such event is flow interruption where the water supply does not reach all or some part of the farm. In many instances where the water delivery system to a farm has failed, severe losses have occurred. For example, debris or other objects within the water delivery system can obstruct the flow and may result in losses. If the flow is interrupted to a facility reaction time is limited to approximately 30 minutes or less before losses begin to occur, dependent upon loading rates and temperature. To prevent such a catastrophe intake structures and the water delivery system should be properly constructed, and an alarm system may be set up as part of the system. Screens, trash racks and moss collectors should also be cleaned on a regular basis.

Another catastrophic event is the detection of a reportable pathogen on a facility that requires a disease-free certification to market its fish. For example, trout growers in Colorado depend primarily on selling their fish to stock into recreational or fee fishing ponds and are required to be free of the pathogen, *Myxobolus cerebralis*, that causes whirling disease. If the pathogen is detected on the farm the grower can no longer sell fish until the farm is re-certified whirling disease free, a process that requires considerable time and expense putting the farm at risk of bankruptcy. Implementing a good biosecurity plan can lessen the risk.

The key to minimizing losses from disease begins with good management. Good management includes obtaining certified disease-free eggs or fingerlings, maintaining proper water quality, proper handling to prevent injury and minimization of stress, providing good nutrition and following sanitation procedures. Specific good management practices to minimize disease losses include:

Fish Health

- Obtain certified disease-free eggs or fingerlings.
- Vaccinate fish as appropriate to prevent disease.
- Monitor fish health through observation and examine the lethargic or erratic fish for potential clinical signs. Respond rapidly when problems first occur.
- Obtain a diagnosis before treatment and follow treatment recommendations completely.

Water quality

- Do not exceed the carrying capacity; maintain appropriate fish densities and adequate water flow.
- Monitor water quality, especially temperature and dissolved oxygen (maintain above 70% saturation).
- Prevent the accumulation of organic debris (clean raceways regularly).
- Maintain other important water quality parameters within recommended limits, including concentrations of ammonia, carbon dioxide or pH.

Handling and transportation

- Withhold feed prior to handling fish; 24 hours before grading or inventory, and 2 to 3 days before harvesting.
- Keep fish in the water as much as possible and work quickly, but gently.
- Use handling methods and equipment that minimize injury and stress.
- Maintain optimum water quality when handling fish. Keep dissolved oxygen levels high.
- Increase the chloride level by adding salt (NaCl) to the water in hauling tanks or culture tanks during hauling and after handling to minimize the effects of stress.

Nutrition

- Feed a high quality diet that meets the nutritional requirements for each life stage.
- Feed the appropriate rate and feed size for each life stage. Avoid overfeeding and underfeeding.
- Never feed spoiled or moldy feed.
- Properly store feed in a cool dry place and use before the manufacturer's expiration date.

Sanitation

- Disinfect eggs with an iodine solution.
- Prevent feral or wild fish from residing in the hatchery water supply.
- Remove mortalities as soon as they are observed and dispose of properly to prevent the spread of pathogens.
- Provide footbaths outside of hatch houses, limit personnel access and maintain separate equipment for the hatch house.
- Disinfect and clean equipment, hauling tanks and rearing containers on a regular basis.
- Quarantine and/or observe all new fish for mortality and disease symptoms.

Production Economics and Market Structure

A wide range of water sources are used for growing trout including springs, lakes, streams, and wells. The average flow rate for sources used by small trout producers in the north central U.S. is 383 gpm, medium trout producers 1,958 gpm, and large trout producers 3,833 gpm (Brown 1994). Not all trout producers in the region with these water sources fall within these criteria, however. Some trout producers with low flow rates have learned to fully optimize their water resources and could be economically classified as large trout producers. To supplement water supplies, 38% of all trout producers in the region pumped at least part of their water and 19% pumped all of the water used. All of the large producers in the north central U.S. reported that they did not pump any significant amount of water (Brown 1994). In other trout producing regions of the U.S., water is rarely pumped for trout production on commercial facilities with the exception of a limited number of farms in northeastern states.

For 1991 the average investment made by midwestern trout farmers was $82,000 for a small facility, $333,000 for a medium facility, and $500,000 for a large facility. The total costs to produce a pound of trout for midwestern trout farmers in 1991 was $3.07 for a small facility, $1.57 for a medium facility, and $1.39 for a large facility with an overall average cost of $1.53/lb (Brown 1994). Hinshaw *et al*. (1990) compiled prices and operating costs for trout producers in North Carolina, classifying as small trout farms those producing up to 100,000 pounds per year and large farms as those expecting to produce from 100,000 to over 500,000 pounds per year. Costs associated with land or interest on land purchases were excluded from his analyses. Variable costs for both classes of trout farms ranged from $0.61 - $0.75 per pound, while total production costs ranged from $0.89 - $1.07 per pound for smaller facilities and $0.82 - $0.99 for larger facilities. Klontz (1991) reported that the production costs for a family owned and operated trout farm (in Idaho) producing 30,000-100,000 lbs per year under typical circumstances are approximately $0.80-$1.10/lb. In rare circumstances and under extremely well managed conditions, he stated that production costs could be in the range of $0.53-$0.86/lb. The suggested breakdown of these production costs for a family owned and operated trout farm were eggs (3.21%), feed (57.05%), labor (11.11%), therapeutic treatment (4.70%), mortality (6.41%), and overhead (17.52%).

Engle *et al*. (2004 DRAFT MANUSCRIPT) surveyed trout producers of various sizes in North Carolina and Idaho, following the size classifications established by the U.S. Environmental Protection Agency in the effluent guidelines development process (see USEPA 2002), classifying trout farms as medium (100,000 to 475,000 pounds/year) or large (>475,000 pounds per year). Smaller farms were not included in the survey. In their analyses, variable costs of trout production on medium farms in North Carolina averaged $0.93 per pound compared to $0.66 per pound in Idaho for medium farms and $0.60 per pound for large farms. Total costs of production for trout in North Carolina averaged $1.04 per pound, with total costs per pound in Idaho averaging $0.77 for medium farms and $0.69 for the large Idaho facilities. Nu San *et al.* (2001) developed enterprise budgets for trout farms in West Virginia corresponding to sizes of 20,000, 50,000, and 100,000 pounds per year. They estimated total production costs of $0.98, $0.93, and $0.90 per pound for the respective sizes of farms using typical raceway production systems, and $1.12, $1.22, and $1.21 per pound respectively for trout farms producing fish in circular, flow-through tank systems.

In Idaho feed costs are generally around 50% of variable costs (G. Fornshell, University of Idaho Extension, Twin Falls, personal communication). Brannon and Klontz (1989) found that feed was 46% and labor was 9% of production costs for trout culture in Idaho when processing labor was excluded. Klontz (1991) reported that feed costs constitute 57% of the production costs for a family owned and operated trout farm producing 30,000-100,000 lbs per year and they are not static. Hinshaw *et al.* (1990) found that feed costs made up 63% of the variable costs for inexperienced producers on both small and large trout farms. Conversely, they found that feed costs made up 59% of the variable costs for experienced producers on both small and large trout farms. Engle *et al.* (2004 DRAFT MANUSCRIPT) reported the primary costs of producing trout consisted of feed (36% in North Carolina; 44-50% in Idaho) and labor (15% in NC and 11% in smaller Idaho farms). On the largest farms in Idaho, depreciation was a slightly greater cost than labor (12% vs. 11%).

Johnson and Talhelm (1978) reported on economics of the aquaculture industry in Michigan, comprised mostly of rainbow trout operations at that time. They found that feed costs represented 48% and labor 8% of total variable costs. These low labor costs stemmed from the fact that small to medium size operations reported no to very little labor costs as compared to the larger operations. They concluded that the smaller farm owners did a greater percentage of the labor while not taking a wage, while the larger firms had a tendency to employ hired labor.

Brown (1994) found that in general, variable costs represent 81% of total costs for trout production in the north central region. Variable costs for small, medium, and large producers were 65%, 84%, and 83%of total costs, respectively. The main variable costs in order of greater to lesser magnitude are feed, labor, electricity, repair and maintenance of buildings and equipment, and eggs. Johnson and Talhelm (1978) findings in Michigan were similar as they reported that average variable costs were 82% of total costs. For 1975 they reported the size of the fish farms surveyed based on average gross revenue and it was delineated by mean sizes of $6,000, $27,000, and $93,000 for small, medium, and large operations, respectively. They found that variable costs for producers to be 72%, 84%, and 86% of total costs, respectively.

Hinshaw *et al*. (1990) reported the variable costs for an inexperience farmer on a small trout farm to be 70% with the remaining 30% in fixed costs. For an experienced producer on a small trout farm they found variable costs to be 68% and fixed costs to be 32%. For an inexperienced producer on a large farm the variable costs were 75% and fixed costs 25%, with 74% variable and 26% fixed costs for an experienced producer on a large farm. Again these estimates assumed prior ownership of the land. Comparisons of variable costs and total costs per pound showed slight economies of scale between small inexperienced and large inexperienced and also between small experienced and large experienced trout producers.

Knowledge of aquaculture as part of agriculture has grown across the U.S., resulting in more traditional agriculture businesses exploring the incorporation of aquaculture into their already established businesses. Bacon *et al.* (1994) used a comprehensive farm-level stochastic and dynamic capital budgeting simulation model (AQUASIM) to evaluate the economic benefits of incorporating a small-scale trout enterprise with a grain and broiler farm. All the scenarios they completed resulted in a 100% probability of economic survival for the representative farm. This means that the producer has a very good chance of remaining financially solvent over the 10-year planning horizon. In contrast, none of the scenarios produced 100% probability of economic success. Across multiple test scenarios, the representative farm was not able to consistently generate more than 8% return over the entire planning horizon. Bacon *et al.* (1994) noted that the introduction of the small-scale trout technology to the base farm as well as proper use of debt significantly increased the probability that the farming operation would generate the desired rate of return. The proposition that using debt capital is better than using equity capital is likely to be true only for operations that could generate positive returns over the planning horizon.

The literature on economics of production of trout presented here is representative of the patchwork of studies conducted in individual states and regions at various time scenarios. These studies have also been reported in different formats, making difficult a comparison of different aspects of trout production costs. A national study on the costs of trout production focusing on the top trout producing states would be necessary to make comparisons across the different segments of the industry.

Crop Pricing

Scientific literature is lacking on specific crop pricing mechanisms for rainbow trout in most regions of the United States and comprehensive research should be devoted to this area at a national level. The price paid to farmers for their trout has changed little in the past decade, with the national average ranging from $1.14 to $1.30 per pound (Figure 18). This price includes trout of all sizes and markets, but excludes sales of trout eggs. In a survey of Michigan fish marketing businesses, Chopak and Kevern (1994) found few market coordination mechanisms being used that would improve marketing of aquacultural products. In general, fish growers were found to have little information available about product markets, a poor history of cooperation, and few sales that were contracted directly. The authors also found that the price of food fish sold by growers varied by both species and the level of processing. Rainbow trout, the species most commonly sold in Michigan by fish growers, was sold whole ($1.40 to $3.00 per pound), dressed ($2.90 to $3.15 per pound), butterfly filleted ($3.35 per pound), filleted ($3.30 to $4.50 per pound), and filleted and boned ($4.62 per pound). Of the other species, brook trout was sold primarily dressed ($2.50 per pound) and filleted and boned ($2.50 to $5.22 per pound). Brown trout was sold whole ($1.60 per pound).

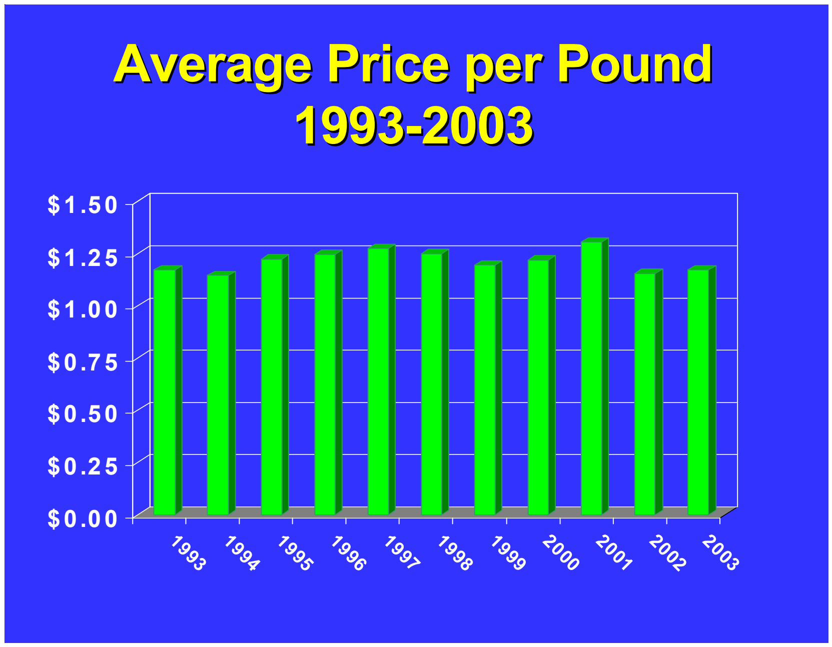

Figure 18. Average price per pound paid to trout farmers for trout 1993 - 2003. The price includes payments for trout of all sizes sold to processors and sold live for any purpose. Source: *NASS 1994 - 2004.*

Industry sources in Michigan reported that farm-raised fish products (primarily rainbow trout) have a better appearance and texture than similar products from other states. Yet brokers, wholesalers, and retailers stated that Michigan aquacultural products are priced too high compared with other fish and shellfish products they handle, including Idaho farm-raised rainbow trout (Chopak and Kevern 1994). They recommended that a promotional campaign highlighting the non-price advantages of locally-grown aquacultural products, such as taste and freshness, would help growers differentiate their products. Still, retailers expressed interest in local farm-raised rainbow trout, even at premium prices (Chopak and Newman 1992).

Demand Elasticity

Fisheries economists have largely neglected aquaculture issues, despite the fact that most of the growth in fish supply over the past two decades has been the result of aquaculture development (Anderson 2002). Research has been lacking on the potential interdependencies of finfish and shellfish consumption with other products such as beef and poultry. Little information also exists on demand parameters for disaggregate species of fish and shellfish, especially at the retail level. Cheng and Capps (1988) attempted to fill this void by investigating the at-home demand for several fresh and frozen finfish and shellfish species in the U.S. They found that the demand for fresh and frozen seafood commodities was inelastic, except for oysters. In general, household expenditures for fresh and frozen fishery products consumed at home were more sensitive to changes in their own price than to changes in prices of poultry and red meat. Household expenditures for fresh and frozen fishery products consumed at home were more sensitive to changes in household size than to changes in income. The presence of children was negatively associated with expenditures for all fresh and frozen fishery products. They reported that households in the South spent significantly more on fresh and frozen seafood commodities than did households located in other regions of the U.S. Households with religious affiliation spent significantly less on total finfish than did households with no religious affiliation. Cheng and Capps' study also showed that nonwhite households expended significantly more on most fresh and frozen fishery products than did white households. Significant differences related to season also existed for expenditures on total finfish and shellfish. Coupon value had significant positive effects on household expenditures for all categories of fresh and frozen seafood products, except for oysters. Although their study focused on commercially caught seafood, the findings in their study regarding the demographic demand for fish should have application to aquaculture products such as trout.

Robinson *et al*. (1991) reported that seafood is relatively price inelastic and income elastic for demand. For instance, during a recession either the price or consumption will go down, as consumers will turn to other low cost substitutes such as chicken or other fish. This also means that if the U.S. supply increases because of imports or increased domestic production, there will be a resultant reduction in price unless U.S. income, and therefore demand, rises. Robinson *et al*. (1991) indicated that many fish harvested or produced on a large scale are also fungible goods, almost commodities. Therefore, to a certain extent, the species of fish which is chosen for production will dictate whether you will have to settle for the "going rate" pricing (market taker) or "perceived value" pricing (market-setter). In some situations customers interpret a product's quality by its price level, but different elasticities may vary in different market segments.

Characteristics of Trout Consumers and Markets

Chopak (1992b) indicated that marketing business operators' awareness of the U.S. aquaculture industry was high, but their awareness of aquaculture in his state (Michigan) specifically varied across the types of marketing businesses. Almost all wholesalers and restaurant operators were aware that some farmers in Michigan raised fish for food, but brokers and retailers in general were not aware of the Michigan aquaculture industry. A majority of all marketing businesses, except brokers, had sold farm-raised fish, primarily trout and catfish. The number of businesses in Michigan that carried farm-raised fish varied by the marketing business type. Chopak also found that more than half of the wholesalers interviewed carried farm-raised fish products, primarily rainbow trout and catfish. Almost all retail stores sold fresh farm-raised fish that included rainbow trout. Less than a quarter sold frozen farm-raised fish. About a quarter of the restaurant operators offered farm-raised fish meals that were mostly rainbow trout at the time of the survey.

In a survey of consumers in Michigan Chopak and Kevern (1994) found that more than half indicated that the fish products they demanded were not always available. Almost 40% of the consumers reported that they do not eat fish often because it is too expensive. Chopak (1992a) previously had assessed Michigan consumer preferences for farm-raised fish, given its limited availability in stores and restaurants. An overwhelming majority (82%) stated that they would purchase local farm-raised fish if it were available. Consumers specified the following reasons to eat farm-raised fish:

-Products contaminant-free (18%)

-Want to support Michigan businesses and farms (15%)

-Believe these products would be of superior quality (14%)

-Products are healthy and nutritious (12%)

-Want to try them (8%)

-Products would be less expensive (4%)

-Products would be fresher (4%)

Chopak (1992a) found that Michigan consumers who would not purchase farm-raised products if they were available would not because of the following reasons:

-Don't like fish (34%)

-Prefer to catch own (28%)

-Expect that they would be of poor quality (10%)

-Would not taste as good (6%)

-Don't eat fish (6%)

Hushak *et al*. (1993) investigated market presence and species demand for trout among wholesalers, specialty retailers, and grocery retailers in the north central U. S. Respondents were asked to select, from a list of freshwater fish and shellfish species, all species they would like to sell if available as farm-raised products. They found that trout had high market presence index and demand values and was a popular product that sold almost exclusively as farmed. However, quantities produced were limited because of scarcity of the specific environmental resources required for profitable trout culture. Hushak also stated the cost of systems that provide necessary conditions for trout is quite high compared to prices paid to the producer.

Goff *et al*. (1979) found that individual trout producers in western North Carolina, eastern Tennessee, and northern Georgia could not adequately provide trout in quantities that restaurants and supermarkets require for consistent marketing. The producers' reliance on small local outlets for their trout depressed the price and subsequently their returns. This situation has changed somewhat with the addition of several larger processors in North Carolina in the past decade. A market survey of retail, wholesale, and institutional outlets in North Carolina, South Carolina, and the Washington D.C. area found that the most common concern in the marketing of trout was low consumer demand at prevailing retail prices (Goff *et al*. 1979). These marketers believed that trout producers had not been adequately involved in market promotion activities designed to encourage greater consumption of trout. Retailers in particular felt that a market promotion campaign, similar to campaigns of the milk and egg industries and including media advertisements as well as restaurant and supermarket displays, would stimulate consumer demand for trout.

Chopak (1992a) reported that the 10 fish or shellfish types reported by Michigan households as being most frequently purchased or ordered in restaurants included rainbow trout (5%). However, the relative order of species preference in Michigan differed from nationwide preferences in two ways. First, species of freshwater fish in Michigan were consumed more often due to better availability and lower cost. Secondly, trout were preferred over catfish because it was more available and due to historical anti-catfish consumer biases in northern states. Additional research is needed at the national level on trout demand elasticity with a focus on the potential interdependencies of trout consumption with other fishery products, and competing non-fishery products such as beef, pork, and poultry.

Two separate University of Idaho studies surveyed rainbow trout buyers and consumers to determine marketing attributes and perceptions. The objective of the first study, a survey of wholesale and retail distributors of rainbow trout, was to better understand how intermediaries perceive rainbow trout as a product line (McCain and Guenthner, 1991).

Very little was known about the decision making process when distributors and retailers decided what types of trout products and quantities to purchase. In developing an effective marketing plan, trout processors/marketers must understand the way wholesalers and retailers operate and make purchasing decisions. Trout processors usually sell their products to seafood wholesalers, however, McCain and Guenthner (1991) reported distributors felt the trout processing industry was less supportive of promotional activities than other seafood suppliers. Distributors indicated a desire for market support materials such as pamphlets, recipes, posters and table displays. The majority of distributors purchased trout from more than one processor indicating a willingness and ability to shift from one supplier to another to purchase the type of products that met their needs at the best price. Competitive marketing strategies addressing the distributor's needs and market could result in market share shifting.

Distributors agreed that the supply of trout and trout price levels were stable. McCain and Guenthner (1991) found distributors rate consistent quality as the most important attribute, followed by competitive price, and consistent supply. A majority of the distributors thought trout has a unique flavor and that trout processors provided a consistently high-quality product. Their study also reported distributors perceive trout as attractive in restaurants and retail stores. Distributors did not believe trout is difficult to prepare, however some thought retail consumers had greater difficulty preparing trout than other fish. They also believed retail and restaurants preferred fresh product over frozen. Distributors preferred boned trout products.

Retailers responded similarly, rating consistent quality as the top attribute, followed by competitive price, but ranked shelf life third. Appearance and shelf life are more important attributes for retailers than for wholesalers. Retailers in the study included specialty fish markets, seafood departments in grocery stores, and grocery meat departments that carry fish as part of their product line. Retailers also agreed that the supply of trout and trout price levels were stable. Compared to distributors, more retailers considered trout a high-price product. A higher proportion of retailers compared to distributors believe trout has a unique flavor. Like distributors, a high percentage of retailers (71.4%) agreed trout suppliers provide consistently high-quality products. Retailers more than distributors see red-fleshed trout as a better product compared to white-fleshed trout and are more likely to use red-fleshed trout as a substitute for pan-sized salmon. But overall distributors and retailers felt that red-fleshed trout and pan-sized salmon were not readily substitutable. Retailers also agreed with distributors that consumers prefer boned trout and consumers do not find it difficult to prepare trout.

The McCain and Guenthner (1991) study reported more than half of the retail respondents did not believe trout suppliers provided useful sales support materials. They strongly agreed that there is a need for more sales support material and they would gladly welcome more industry advertising support. This conclusion agrees with the assessment previously reported by Goff *et al*. in 1979. Both wholesalers and retailers conduct little consumer research, but the attributes they themselves value most relate to product quality. They consistently gave lower ratings to attributes related to marketing activities such as sales and advertising, indicating that the trout industry cannot depend upon wholesalers and retailers to promote the industry. However, individual businesses usually are unable to conduct regional or national marketing research at the level necessary to develop strategies that will expand industry sales. Marketing programs to increase the sale and consumption of trout will need to originate at the producer/processor level (McCain and Guenther 1991).

The second University of Idaho study investigated consumer perceptions of trout as a food item (Foltz, 1997). Four focus groups were conducted, two each in Los Angles and two each in Chicago. Each of the regional focus groups was broken down into trout eaters and non-trout eaters. The key findings were that taste and freshness are two key qualities involved in the purchasing decision. Ninety-one percent of the respondents ranked taste as a “very important attribute” influencing their fish purchase decision. This was followed by freshness (90.8%), appearance (84.2%), and then smell (83.5%). Product form was also important, with boneless fillets being especially desirable due to their greater convenience in preparation. Interestingly, 40.4 % of consumers that purchase whole trout filet the fish prior to cooking. Non-trout eaters responding to an open-ended question about product form indicated that having to purchase a whole fish inhibited their purchase of trout. They also included color, skin, bones, eyeballs, and head as reasons not to purchase trout. Trout were perceived to be more expensive than other meats, but relative to other fish, survey respondents felt that trout was about the same price. Trout was an impulse item for most shoppers. This observation has important implications for increasing sales through the use of eye catching slogans, in-store advertising, recipes, coupons, and other methods to attract shoppers within the store to purchase trout. Coupons and newspaper advertising could also be used to get retail customers to add trout to their shopping lists.

Chopak (1992b) found that most marketing business operators indicated their costumers wanted fresh (not frozen) fish or meals prepared from fresh fish. The businesses purchased fresh fish because their customers perceive them as having better taste and texture. Brokers wanted uniform-sized fish that range from 4 to 12 ounces per portion, while wholesalers were less concerned about fish size unless they were selling to a restaurant that was concerned with portion control. About half of retail stores wanted a variety of sizes in the fish they received to give their customers more choice, while the other half wanted uniform-sized fish to simplify the purchasing decisions of customers and for display purposes. Restaurants had the strictest size requirements that included 3 to 6 ounce portions for lunches and 8 to 10 ounce portions for dinners, depending on the species. He also indicated that most marketing businesses operators, except brokers, want fish growers to provide them with a more diversified line of fish species. Most marketing business operators indicated that they would like to receive most of the fish they purchase as fillets, but demand did exist for a small amount to be received whole or gutted to be used either for specific market segments or for businesses that do their own portion control. These businesses wanted fish delivered on a schedule that was consistent with their costumers' purchasing patterns. They also wanted the fish growers to maintain a regular schedule of contact and to be flexible about delivery schedules. All business operators wanted the fish they purchased to be available year round. This especially applied to brokers because of concerns regarding warehouse space cost. Approximately half of wholesalers would purchase fish with seasonal availability if the product was of high quality and had a fair price. Most retail store and restaurant operators indicated they would purchase seasonally available products to run as a special only if the quality was high and it had a good price.

Other marketing research has shown that trout are widely accepted among wholesalers, specialty retailers, and grocery retailers in the midwestern U.S. Hushak *et al*. (1993) found that trout was one of the four freshwater species that were most frequently sold in the region. Trout was handled by 67% of wholesalers, specialty retailers, and grocery retailers contacted. Product forms sold included fresh, frozen, and live. Fresh product was the most popular (79%) followed by frozen product (43%). Product forms for trout handled included fillets (70%), whole (51%), and gutted (56%).

In contrast to the studies of the early 1990's, in recent marketing research in the midwestern US, only 14% of supermarket managers responding to a seafood survey listed trout as one of their best selling species in the region (Riepe 1999b). But 28% of the restaurants listed salmon as one of their best selling species, while trout was not even listed. This result demonstrates the impact that increasing availability of low-cost imported salmon and the concurrent salmon marketing efforts has had on its popularity in both urban and rural restaurants. The fact that trout did not make the list of best selling species in any of these restaurants indicates that marketing efforts directed at this food establishment sector should be undertaken to help increase sales volumes. Chopak (1992b) surveyed marketing business operators in Michigan and found some key areas where fish growers could provide better service. These areas included maintaining a consistent product, reasonable price, consistent delivery schedule, variety in fish product form, improved communications, customer education, and product promotion.

Production Constraints and Marketing

A major limiting factor that will hinder future growth of trout aquaculture in the United States, based on existing practices, is availability of adequate water supplies at the proper temperature and adequate quantity. The amount of available water remaining for trout production development is limited and thus large increases in production are not anticipated (Flick 2002). Environmental regulations will likely limit the use of additional surface waters and thus fish farmers will have to use their current water resources more intensively in order to expand. Also, groundwater restrictions are anticipated in the future due to increasing competition for that resource from consumer and industrial demands. Environmental regulations are stringent for addressing the water quality of discharges from flow-through aquaculture systems, and could become even more restrictive. With limited water resources in many parts of the United States, it will be necessary to capitalize on production scenarios that can help support the viability of regional trout industries. Trout producers will be required to run very efficient operations to make a profit. Value-added products and marketing will need to be enhanced in order to keep trout production profitable, particularly production of rainbow trout for foodfish. Competition from low-cost imports of trout and other salmonids has increase significantly in recent years and is expected to continue and expand. Trout producers will be required to acquire added marketing skills to help tap into new and emerging markets as well as maintain their current sales opportunities.

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