# Seafood Watch
Seafood Report

MONTEREY BAY AQUARIUM®

# U.S. Farmed Rainbow Trout
*Oncorhynchus mykiss*

(Picture courtesy of the Idaho Department of Agriculture)

Final Report
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## About Seafood Watch® and the Seafood Reports

Monterey Bay Aquarium's Seafood Watch® program evaluates the ecological sustainability of wild-caught and farmed seafood commonly found in the United States marketplace. Seafood Watch® defines sustainable seafood as originating from sources, whether wild-caught or farmed, which can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems. Seafood Watch® makes its science-based recommendations available to the public in the form of regional pocket guides that can be downloaded from the Internet (seafoodwatch.org) or obtained from the Seafood Watch® program by emailing seafoodwatch@mbayaq.org. The program's goals are to raise awareness of important ocean conservation issues and empower seafood consumers and businesses to make choices for healthy oceans.

Each sustainability recommendation on the regional pocket guides is supported by a Seafood Report. Each report synthesizes and analyzes the most current ecological, fisheries and ecosystem science on a species, then evaluates this information against the program's conservation ethic to arrive at a recommendation of "Best Choices," "Good Alternatives," or "Avoid." The detailed evaluation methodology is available upon request. In producing the Seafood Reports, Seafood Watch® seeks out research published in academic, peer-reviewed journals whenever possible. Other sources of information include government technical publications, fishery management plans and supporting documents, and other scientific reviews of ecological sustainability. Seafood Watch® Fisheries Research Analysts also communicate regularly with ecologists, fisheries and aquaculture scientists, and members of industry and conservation organizations when evaluating fisheries and aquaculture practices. Capture fisheries and aquaculture practices are highly dynamic; as the scientific information on each species changes, Seafood Watch's sustainability recommendations and the underlying Seafood Reports will be updated to reflect these changes.

Parties interested in capture fisheries, aquaculture practices and the sustainability of ocean ecosystems are welcome to use Seafood Reports in any way they find useful. For more information about Seafood Watch® and Seafood Reports, please contact the Seafood Watch® program at Monterey Bay Aquarium by calling (831) 647-6873 or emailing seafoodwatch@mbayaq.org.

### Disclaimer

Seafood Watch® strives to have all Seafood Reports reviewed for accuracy and completeness by external scientists with expertise in ecology, fisheries science and aquaculture. Scientific review, however, does not constitute an endorsement of the Seafood Watch® program or its recommendations on the part of the reviewing scientists. Seafood Watch® is solely responsible for the conclusions reached in this report.

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## Executive Summary

The rainbow trout (*Oncorhynchus mykiss*) is a species of fish in the family Salmonidae, which is native to the Pacific drainages of North America. After many years of introductions and transfers the current distribution of rainbow trout now covers most of North America and many other parts of the world. In the United States, the practice of raising trout began in the late 1800s, with interest in both raising fish for recreational purposes as well as bringing fish to market. In the 1960s, commercial production of rainbow trout for the food fish market grew at a rapid rate and the industry is now the second largest finfish aquaculture industry in the U.S., with nearly three-quarters of the production coming from the state of Idaho. In the U.S., trout are farmed in flow-through systems, which consist of raceways, ponds, or tanks with continuously flowing water. These systems use well, spring, or stream water and can range in size from small farms producing just a few thousand pounds of trout to large facilities that may produce millions of pounds of trout each year.

Overall, U.S. farmed rainbow trout ranks as a "Best Choice" according to Seafood Watch® criteria. Advancements in feed formulations in recent years have led to improved feed conversion ratios and therefore less use of marine resources. With current production methods farms do not appear to be releasing any significant numbers of fish into the environment. There are potential risks, however, from the escape of farmed rainbow trout, and caution must be taken to ensure that the environment is not negatively impacted by such escapes. The discharge of wastes is not believed to be a concern, mainly because of solid waste collection and the development of low pollution feeds. However, there is some concern that disease and parasite interactions may affect wild fish populations since wastewater, which can include disease causing organisms, is constantly released and there is some indication that farms could act as incubators for disease. Management of the rainbow trout aquaculture industry is effective and well regulated and there appears to be widespread use of best management practices.

## Table of Sustainability Ranks

| | **Conservation Concern** | | | |
|---|---|---|---|---|
| **Sustainability Criteria** | **Low** | **Moderate** | **High** | **Critical** |
| Use of Marine Resources | | √ | | |
| Risk of Escaped Fish to Wild Stocks | √ | | | |
| Risk of Disease and Parasite Transfer to Wild Stocks | | √ | | |
| Risk of Pollution and Habitat Effects | √ | | | |
| Management Effectiveness | √ | | | |

**About the Overall Seafood Recommendation:**

- A seafood product is ranked **Avoid** if two or more criteria are of High Conservation Concern (red) OR if one or more criteria are of Critical Conservation Concern (black) in the table above.
- A seafood product is ranked **Good Alternative** if the five criteria “average” to yellow (Moderate Conservation Concern) OR if four criteria are of low concern and one is of high concern.
- A seafood product is ranked **Best Choice** if three or more criteria are of Low Conservation Concern (green) and the remaining criteria are not of High or Critical Conservation Concern.

## Overall Seafood Recommendation:

**Best Choice** 🟩 Good Alternative 🟨 Avoid 🟥

## Introduction

Rainbow trout (*Oncorhynchus mykiss*) is a species of fish in the family Salmonidae, which includes Pacific salmon and trout (genus Oncorhynchus), Atlantic salmon and brown trout (genus Salmo), char (genus Salvelinus, for example brook trout and Dolly Varden), and whitefishes and grayling (Behnke 2002). Behnke (1992) suggests that three types, or evolutionary groups, are included in what is commonly referred to as rainbow trout. These groups are: the redband trout of the Columbia River basin; the redband trout of the Sacramento River basin; and the coastal rainbow trout. Rainbow trout are found in cold, clear waters of rivers, streams, and lakes (Staley and Mueller 2000) and spawn in the spring when water temperature exceeds 42 to 44 degrees Fahrenheit (Behnke 2002). Steelhead, a type of rainbow trout, displays a migratory life history in which they spawn and spend their juvenile stages in coastal streams, but spend much of their lives in the ocean (Behnke 2002).

Native to the Pacific drainages of North America, the historic distribution of rainbow trout extended from Alaska to Mexico and included British Columbia, Washington, Oregon, California, Idaho, and Nevada. Their current distribution, however, now covers most of North America (Figure 1) and attempts have been made to introduce the species in nearly every state of the U.S. (Fuller 2004). Extensive stocking programs dating back to the late 1800s run primarily by state and federal authorities are responsible for the introduction of rainbow trout outside of its native range and the translocation of different strains of rainbow trout within its native range. Many stocking programs continue to this day, but they often have more stringent guidelines than previous efforts on where the fish can be stocked, keeping in mind potential impacts on native biota.

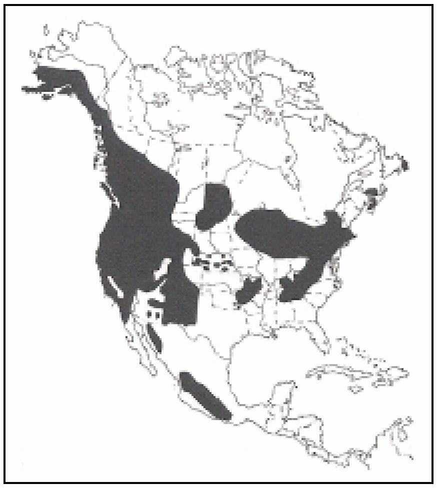

Figure 1: Current distribution of rainbow trout in North America (Staley and Mueller 2000).

### *Production*

In the United States, the practice of raising trout began in the late 1800s, with some interest in raising fish for recreational purposes as well as for bringing fish to market (Hardy et al. 2000). Throughout the last century there has been much interest in raising trout as a means of supplementing wild populations and for stocking for recreational fishing purposes. The early years of trout culture provided many years of refinement of techniques through trial and error and some of the techniques that were developed are still very much in use today. Commercial-scale production of rainbow trout for the food fish market began in the early 1900s, but stayed at very low levels until the 1960s, when production grew at a rapid rate (Hardy et al. 2000).

In 2004, sales of U.S. farmed food-size trout (note that sales of trout for stocking, fingerlings, and eggs are not included) reached 54,976,000 pounds and were ranked second in U.S. finfish aquaculture products, behind only farmed catfish (Harvey 2005). U.S. farmed trout production is centered in the Snake River region of Idaho (Hardy et al. 2000). Nearly 75% of all domestic farmed trout production, or 40,400,000 pounds, came from the state of Idaho in 2004 (Harvey 2005). Other states with relatively high levels of production in 2004 were: Washington, 4,050,000 pounds; North Carolina, 3,940,000 pounds; California, 2,200,000 pounds; and Pennsylvania, 1,150,000 pounds.

The U.S. accounts for a small amount of overall global farmed trout production. In 2000, total worldwide farmed trout production reached 511,000 metric tons (mt), or roughly one billion pounds (FAO 2002). The major producing countries include France, Chile, Denmark, Italy, and Norway (Hardy et al. 2000; FAO 2002). According to Hardy et al. (2000), the U.S. accounted for about 7% of global farmed trout production in 1995. This figure is likely lower today as global production increased approximately 150,000 mt between 1995 (358,456 mt) and 2000 (511,000 mt), but U.S. production increased only slightly over this same period of time. Although the U.S. contributes relatively little to the global supply of farmed trout, domestic production accounts for most of the trout consumed in the U.S. (Harvey 2005). At 8,573,000 pounds, imports of farmed trout in 2004 accounted for only about 15% of the market in the U.S.

### *Production methods*

In the U.S., trout farming takes place in flow-through systems (EPA 2002), which consist of raceways, ponds, or tanks with continuously flowing water. The systems are usually concrete or earthen troughs, with dimensions usually around 80 feet long, 8 feet wide, and 2.5 feet deep. Multiple raceways can be joined together, either in series or parallel; in series water flows downstream through one raceway and then into the next, while in parallel the source water is split among several raceways that flow alongside one another. Large farms can use a combination of these two types of systems and in many cases water is reused several times before it is discharged.

Flow-through systems use well, spring, or stream water and can range in size from small farms producing just a few thousand pounds of trout to large facilities producing millions of pounds of trout each year (EPA 2002). The amount of trout that a given raceway system can support is called the carrying capacity. The carrying capacity depends on water flow rate, volume, temperature, dissolved oxygen concentration, pH, and the size of the trout. Flow-through systems may require supplemental oxygen or mechanical or passive aeration to maintain high levels of dissolved oxygen in the water. Feeding in flow-through systems can be done in several ways, including by hand, with demand feeders, or through mechanical systems. Small farms typically feed by hand while larger operations tend to have mechanized systems to deliver feed to fish at the appropriate times.

Wastes in flow-through systems, including uneaten food, feces, and other metabolic wastes, are carried downstream by flowing water and the swimming action of fish (EPA 2002). Typically, at then end of raceways are areas that fish are excluded from, called quiescent zones, in which solid wastes settle to the bottom. Once wastes settle in the quiescent zones they can be collected and removed from the system. Flow-through systems may also use settling ponds to collect and store wastes until they can be disposed of.

Trout in raceways must be graded several times during production in order to maintain fish of similar size together in the same system and improve feeding efficiency (EPA 2002). This is usually done four times during a production cycle and is accomplished with a bar grader, which crowds large fish together so they can be removed and sorted into the appropriate raceways. Harvesting of fish is accomplished in a similar manner. Trout are usually harvested for market after a production cycle of 10 to 15 months (Hardy et al. 2000).

**Scope of the analysis and the ensuing recommendation:**
This analysis encompasses farm-raised rainbow trout from the U.S. that is farmed in flow-through systems, and that is available in the market to U.S. consumers. A relatively small amount of farmed rainbow trout is also imported, some of which is farmed in a similar manner and some of which is farmed using different techniques. This latter type of import is usually referred to and labeled as "steelhead" or "steelhead trout." Since the production techniques for this type of imported trout are significantly different from the domestic production techniques, it is not dealt with in this report.

## Availability of Science

There is a rich body of literature about many topics involved in the production of rainbow trout. Feed formulation and improvement, production methods, pollution control, and disease control are research areas that have received much attention. Research at academic institutions and government research stations will likely continue to supply the industry with scientific advances to improve production and help the industry progress in the coming years. As with many forms of aquaculture, little comprehensive research has been conducted and relatively little scientific literature is available on the environmental impacts of rainbow trout farming in the U.S.

## Market Availability

**Common and market names:**
Scientific name: *Oncorhynchus mykiss*
Common name: Rainbow trout
Market name: Farmed rainbow trout, farmed trout
Note: Farmed steelhead trout also is rainbow trout, but it is farmed in saltwater netpens in the same manner as Atlantic salmon in countries such as Chile and Norway. It is believed that imported farmed steelhead trout is usually labeled as such in the market and is generally recognizable by its larger fillet size, which sometimes is brightly pigmented. Due to the vast differences in production practices (coastal netpens versus landbased flow-through systems) it is recommended that a separate evaluation be completed for farmed steelhead trout.

**Seasonal availability:**
Farmed rainbow trout is available year-round.

**Product forms:**
Fresh and frozen whole fish and fillets, value-added products, as well as smoked products.

**Import and export sources and statistics:**
Imports of farmed trout make up about 15% of the market in the U.S. (Harvey 2005). Very little farmed trout, about 1 million pounds, is exported from the U.S. as nearly all of what is produced is consumed domestically.

## Analysis of Seafood Watch® Sustainability Criteria for Farmed Species

### Criterion 1: Use of Marine Resources

Worldwide aquaculture production includes a wide variety of species, ranging from autotrophic seaweeds, to filter-feeding shellfish and finfish, to omnivorous and carnivorous shellfish and finfish (FAO 2004). Several recent reports have raised concerns about the feed requirements of the carnivorous species used in aquaculture, specifically that they may be contributing to a net loss in fish protein (Naylor et al. 2000; Weber 2003). The dependence on wild fish for feed ingredients could result in increased pressure on wild fisheries used to make the feeds. While some economists, researchers, and activists have criticized aquaculture of carnivores as an inefficient use of resources, claiming that it takes several pounds of small forage fish to produce a single pound of farmed fish (Weber 2003; Naylor et al. 2000), other researchers and members of the aquaculture industry have pointed out that aquaculture systems are much more efficient than natural systems (Tidwell and Allan 2001). In terrestrial systems in nature, conversion efficiency from one trophic level to the next is believed to be around 10 to 1 and it has become common practice for those defending the farming of carnivores to favorably compare these seemingly inefficient natural systems with the feed conversion efficiency of aquaculture, generally in the range of 1:1-3:1. This may be an over-simplification, however, as it fails to take into account that aquaculture of carnivores is an industrial system that has externalized many of its costs, while the natural conversion from one trophic level to another forms an integral part of a functioning ecosystem, providing much more than food for human consumption. It also may not be a valid comparison because farmed carnivores often feed at a much higher trophic level than their wild counterparts (for example, farmed trout and salmon are provided a diet consisting mainly of other fish while in the wild they feed primarily on low trophic level organisms such as insects and crustaceans). Additionally, little is known about trophic conversion efficiencies in aquatic systems, though they are believed to be better than in terrestrial systems. Regardless, it is important to note that aquaculture is a very efficient means of producing protein, likely far more efficient than most other animal agriculture systems (Forster and Hardy 2001), though useful comparative measures of ecological efficiency have rarely been applied.

Much of the protein and fat in feeds for carnivorous fish are sourced from reduction fisheries for wild fish such as anchovy, herring, menhaden, and mackerel. These fisheries, like many around the world, are believed to be at their maximum sustainable levels, leading some to question the sustainability of further developing an industry based on feeding wild-caught fish to farmed fish

(Naylor et al. 2000; Weber 2003; Naylor and Burke 2005). Clearly, the issue of feeding wild fish to farmed animals is not isolated to the aquaculture industry. The fishmeal and fish oil obtained from these fisheries are in high demand and are used in many different feed applications, including poultry, pigs, and pet foods (IFFO 2001; Tacon 2005). In 2002, aquaculture used 46% and 81% of the global supplies of fishmeal and fish oil, respectively, though aquaculture feeds account for a small amount (3% in 2004) of total industrial feed production (Tacon 2005). Other agricultural uses, such as chickens and pigs, use a smaller amount of fishmeal and fish oil in their feed formulations, but since the industries are so large, they consume a large percentage of the overall supply. Future projections estimate that the aquaculture feed industry, led primarily by increases in marine production, will use an increasingly large share of the fishmeal and fish oil supply, possibly as high as 56% of the fishmeal and 97% of the fish oil in 2010 (IFFO 2001), though the trend in trout farming is toward lower inclusion levels of these feed ingredients.

Protein alternatives, including plant-based proteins and those derived from processing wastes, will have to be developed if aquaculture production of organisms requiring feeds is to expand (Tacon 2005; Hardy and Tacon 2002; Watanabe 2002). While there is a growing realization that this change will need to take place and much of the work has begun, it will be a major challenge for the aquaculture industry to continue to grow in the future while reducing its dependence on wild fish for feeds.

### ***Farmed rainbow trout feed use***

Farmed rainbow trout are carnivorous and require a high protein diet. Like many other aquaculture industries, feed costs in rainbow trout farming account for the largest proportion of variable costs (Hinshaw et al. 1990), which means that appropriate diets not only affect efficiency, but also profitability. Diet formulations and other areas of nutrition and feed science, including the use of alternative proteins, are areas of much research interest (for examples, see: Hardy 1996; Green et al. 2002; Cheng and Hardy 2002; Gomes et al. 1995; Thiessen et al. 2004).

#### *Rainbow trout feeding behavior*

After hatching, young trout live on nutrients in their yolk sacs. In the wild, these fish then shift to a diet consisting primarily of insects and crustaceans (Staley and Mueller 2000). When they reach larger sizes wild trout will also feed on small fish and fish eggs. When in the farm setting, rainbow trout can be trained to accept artificial feeds after seven to ten days (Hinshaw 1999). The feeds contain high levels of fishmeal and fish oil, essentially making the farmed fish piscivorous from the time of first feeding.

#### *Inclusion rates*

In a review of the culture of rainbow trout, Hardy et al. (2000) provide a generalized feed formulation for rainbow trout reared in freshwater aquaculture systems. According to their generalized formulation, fishmeal inclusion in farmed trout diets is about 33% and fish oil inclusion is about 18%. Other feed ingredients included in the generalized diet are poultry by-product meal, soybean meal, and wheat grain. Several studies indicate that high levels of alternative proteins can be included in diets for rainbow trout, potentially making the industry significantly less dependent on marine resources (Hardy 1996; Thiessen et al. 2004; Adelizi et al. 1998). Additional published references to actual commercial diets, especially more recent diets, are hard to obtain, possibly because of the proprietary nature of feed formulations. For example, Green et al. (2002), in a study of phosphorus utilization and excretion in rainbow trout, used a common "commercial diet" provided by Rangen, Inc., but instead of providing the specific diet formulation as they did with the experimental diets, the authors indicated that the commercial diet is a "closed formula." Other references to farmed trout diet formulations include: a reference diet used by Thiessen et al. (2004) containing 30% fishmeal and 10% fish oil that was formulated according to Bureau and Cho (1994), cited in Thiessen et al. (2004); a control diet used by Cheng and Hardy (2002) that contained 25% fishmeal and 19.5% fish oil; and a "standard commercial trout diet" referenced in Adelizi et al. (1998) that contained 30% fishmeal and 8% fish oil.

It should be noted that the apparent trend in farmed trout diets is to decrease the level of fishmeal and to increase the level of fish oil as this can lead to high energy feeds with improved feed conversion ratios and lower levels of pollution (Hardy et al. 2000). With the use of high energy diets with higher fish oil levels the dependence on wild fish for feed could increase. For the purpose of completing the calculations in this report, the generalized feed formulation as described by Hardy et al. (2000) with a fishmeal inclusion rate of 33% and fish oil inclusion rate of 18% is used.

*Feed conversion ratio (FCR)*

Feed conversion ratio (FCR), the ratio of feed inputs (dry weight) to farmed fish output (wet weight), for rainbow trout may vary considerably depending on the quality of feed and feeding practices. FCRs have improved greatly over the past couple of decades, especially with changes to high-energy feeds, and now stand at an impressive 0.8 to 1.2 units of feed for each unit of farmed trout production (Hardy et al. 2000). An FCR of 1.0:1 is used in this report, as this represents an average of the FCR range suggested by Hardy et al. (2000) when high energy diets and good feeding practices are used.

*Notes on feed calculations*

To avoid double-counting, calculations were performed separately for fishmeal and fish oil and the larger of the two final calculations are used to assess the fish-in to fish-out ratio. Some researchers have added the fishmeal and fish oil inclusion rates together for a total inclusion rate and then used this figure in calculating the fish-in to fish-out ratio, but this fails to take into account that reduction fisheries are for both fishmeal and fish oil. In other words, the same fish are used to produce fishmeal and fish oil, so adding the inclusion rates together ignores the fact that they are products from the same fisheries and in effect double-counts the amount of wild fish inputs consumed.

*Yield rates*

Other important figures for these calculations are the yield rates of fishmeal and fish oil from reduction fisheries. Yield rates can vary based on the species of fish, season, condition of fish, and efficiency of the reduction plants (Tyedmers 2000). For this report, a fishmeal yield rate of 22% is used. This has been suggested by Tyedmers (2000) as a reasonable year-round average yield rate and means that 4.5 units (kg, lb, mt, etc.) of wild fish from reduction fisheries are needed to produce 1 unit of fishmeal. For this report a fish oil yield rate of 12%, or 8.3 units of wild fish to produce 1 unit of fish oil, is used, which was suggested by Tyedmers (2000) as a representative year-round average for Gulf of Mexico menhaden.

*Ratio of wild fish to farmed rainbow trout*
Based on the figures above, the following calculations were completed to estimate the wild fish input to farmed fish output ratio for farmed rainbow trout (RBT):

<u>Conversion for fishmeal</u>

$$\frac{4.5 \text{ kg of wild fish}}{1 \text{ kg fishmeal}} \text{ X } \frac{.33 \text{ kg fishmeal}}{1 \text{ kg feed}} \text{ X } \frac{1.0 \text{ kg feed}}{1 \text{ kg RBT}} = 1.49 \text{ kg wild fish per kg of RBT}$$

<u>Conversion for fish oil</u>

$$\frac{8.3 \text{ kg of wild fish}}{1 \text{ kg of fish oil}} \text{ X } \frac{.18 \text{ kg fish oil}}{1 \text{ kg feed}} \text{ X } \frac{1.0 \text{ kg feed}}{1 \text{ kg of RBT}} = 1.49 \text{ kg wild fish per kg of RBT}$$

As noted above, these calculations are not added together, as that would result in double-counting the wild fish inputs required to grow the farmed fish. Instead, the larger of the two values (in this case is the two values are the same), 1.49, represents the ratio of wild fish input to farmed rainbow trout output.

***Stock status of reduction fisheries***
It is generally believed that populations of fish used in most reduction fisheries are stable (Hardy and Tacon 2002; Huntington et al. 2004), though concerns have been raised about the potential for increased demand from expanding industries for farmed carnivorous fish (Weber 2003) and in most cases the populations are classified as fully exploited (Tacon 2005). Additionally, concerns have been raised about the role of the fisheries in the ecosystem and how their removal could affect ecosystem dynamics, especially in regard to their importance as prey for predators such as birds and mammals (Huntington et al. 2004; Tacon 2005). Catches have been stable, with the exception of El Nino years when declines in catches, especially in fish off the western coast of South America, contribute to declines in overall availability of fish used for reduction (Hardy and Tacon 2002). Worldwide landings of fish for reduction have ranged from 19 million mt to 28 million mt in the past decade, yielding an annual average of 6-7 million mt of fishmeal and 1.2 million mt of fish oil (Hardy and Tacon 2002).

***Broodstock collection***
There are several lines of domesticated trout currently used in the rainbow trout aquaculture industry (Silverstein 2004). Domestication is a high priority in the industry and there is currently ongoing work to further domesticate rainbow trout to improve aquaculture characteristics. Broodstock for domesticated lines were collected 30 or more years ago and have undergone many generations of selection and improvement (Silverstein 2004). Commercial trout growers purchase eggs from established suppliers or maintain their own broodstock. No reports of broodstock collection in any significant numbers in recent years for commercial aquaculture could be found for this report and it is believed that any threatened or endangered populations would be protected from this type of commercial activity.

**Synthesis**

Farmed rainbow trout diets contain fishmeal and fish oil that is sourced from wild fisheries. Inclusion levels of fishmeal and fish oil in these diets are lower than some other farmed carnivorous fish, such as Atlantic salmon, but inclusion levels are higher than those for other popular farmed finfish, such as catfish and tilapia. The feed conversion ratio for rainbow trout is very low, occasionally cited below 1.0:1. It appears, however, that improvements in feed conversion may come with a tradeoff for higher levels of fish oil in feeds, and therefore could potentially result in increased dependence on wild fisheries for feed ingredients. Ongoing research to substitute fish oil in feeds may lower this dependence in the future. The overall ratio of wild fish used as feed to farmed fish produced, according to the calculations above, is 1.49 and, therefore, is considered a "moderate" conservation concern based on Seafood Watch® criteria.

**Use of Marine Resources Rank:**

Low 🟩 **Moderate** 🟨 High 🟥 Critical ⬛

## Criterion 2: Risk of Escaped Fish to Wild Stocks

Aquaculture has become one of the leading vectors of exotic species introduction (Carlton 1992; Carlton 2001), and concerns have been raised about the ecological impacts of escapes of farmed fish into the wild (Volpe et al. 2000; Weber 2003; Youngson 2001; Naylor et al. 2001). Most criticism has been directed at open aquaculture systems, primarily netpens and cages used in coastal waters, especially those used to farm Atlantic salmon. Myrick (2002) described six potential negative impacts of escaped farmed fish: genetic impacts, disease impacts, competition, predation, habitat alteration, and colonization. Escaped farmed fish can negatively impact the environment and wild populations of fish whether they are native or exotic to the area in which they are farmed, and the probability of significant ecological impact increases as the number of escaped individuals increases (Myrick 2002). Different aquaculture systems carry different levels of risk of escapes, with open systems such as netpen salmon farms carrying the greatest risk and more closed systems having lower risk. The risks of impact to the environment from escaped farmed organisms can be further reduced through proactive measures such as careful selection of sites, species, and systems; training of personnel; and development of contingency plans and monitoring systems (Myrick 2002).

***Frequency of rainbow trout escapes***

Due to the nature of U.S. trout farming facilities—inland raceways—the inherent risk of escapes from rainbow trout farms is considerably lower than from some other aquaculture systems, specifically netpens and cages. There is no evidence that escapes of rainbow trout from commercial aquaculture facilities occur often or in great numbers, and management practices such as barriers or screens at the end of raceways prevent fish from escaping. Escapes from commercial inland flow-through trout farms likely do not occur in numbers anywhere near what has been reported in other aquaculture systems; for example, escapes as large as 360,000 salmon from coastal salmon farms in Washington State, and escapes of over half a million salmon from farms in Norway (Gross 1998).

The amount of trout that could potentially escape from aquaculture facilities is also considerably smaller than the amount intentionally introduced through the large-scale stocking efforts by many government agencies. For example, in 1982, 200 million trout were intentionally stocked into inland waters of the United States by federal and state agencies (EPA 2002). More recently, over 125 million trout, including 10.2 million 12" or longer fish, 39.8 million 6"-12" fish, and 75.8 million fingerlings, were released for restoration, conservation, and recreational purposes, primarily by state and federal hatcheries (USDA 2005). Considering that today annual production of rainbow trout in commercial aquaculture facilities stands at about 55 million pounds (lbs) and that this is about equal to 55 million fish (55 million lbs production X 1 lb/fish) it becomes clear that the potential for large numbers of trout to escape from commercial farms is relatively small compared to the intentional stocking of trout carried out throughout the U.S. Hypothetically, even if a small portion of commercially farmed trout escaped into the wild it would be considerably less than the number of fish intentionally stocked into inland waters. Unfortunately, in some cases the damage to wild populations has already been done through many years of ill-advised introductions and transfers of trout and the fact is that modern commercial trout farming likely contributes very little in terms of harmful interactions with wild populations via escapes.

### *Impact of rainbow trout escapes*

Cultured rainbow trout are believed to have originated from various mixtures of coastal steelhead trout while redband trout contributed relatively little to hatchery strains (Behnke 1992). The hatchery strains of rainbow trout were rapidly domesticated. Behnke (1992) suggests that once trout have been domesticated and selected for traits to improve performance in the hatchery setting, they are less likely to survive under natural conditions, especially in competition with other species. Other researchers, however, have found that the interactions of hatchery trout (and salmonids in general) with wild trout, through intentional stocking, has caused ecological problems. Impacts associated with introduced species and strains of trout include competition with and displacement of native species, predation on native species, and genetic effects such as hybridization (Krueger et al. 1991; Dunham et al. 2004; Fuller 2004). Einum and Fleming (2001) reviewed differences between hatchery and wild salmonids and the implications for ecological interactions between the two. They found that artificial selection in hatcheries leads to phenotypic, genetic, and behavioral differences between hatchery and wild fish that can play an important role in interactions between them. The authors concluded that many current stocking practices may be detrimental to populations of native, wild salmonids. Escapes from rainbow trout aquaculture facilities could potentially carry similar risks, though it should be noted that unlike intentional introductions of trout, to date there is no evidence of negative impacts from commercially farmed rainbow trout escapes. As with all introductions and transfers, however, there are potential risks to the environment and wild populations of fish so caution should be taken to limit escapes and minimize their potential impacts.

### Synthesis

There is no evidence of frequent or large-scale escapes of rainbow trout from aquaculture facilities. The flow-through farming facilities used by the industry appear to be effective in containing fish and certainly have proven that, contrary to other systems (e.g., netpens and cages, where damage to facilities from weather related events or other causes has been responsible for the release of many farmed fish), they are not prone to massive escapes. The history of trout culture includes many years of transfers and introductions of trout and other salmonid species throughout North America, often in a haphazard manner with associated negative impacts on native biota. Most, if not all, of these introductions and transfers were made with the intent of improving or establishing recreational fisheries and are not something that the commercial trout aquaculture industry can or should be held responsible for. Many fishery managers are realizing that there are potential impacts associated with the introduction of salmonid species, and management practices (stocking, regulations, etc.) are being adapted to reflect the risks involved. While escapes from commercial trout aquaculture are not believed to currently be a major problem, there are potential risks and caution must be taken to ensure that the environment and wild populations of fish are not negatively impacted by escapes in the future.

**Risk of Escaped Fish to Wild Stocks Rank:**

**Low** 🟩 Moderate 🟨 High 🟥 Critical ⬛

## Criterion 3: Risk of Disease and Parasite Transfer to Wild Stocks

According to Blazer and LaPatra (2002), "intensive fish culture, particularly of non-native species, can and has been involved in the introduction and/or amplification of pathogens and disease in wild populations." In recent years, increasingly more concern has been raised over the spread of disease and parasites from aquaculture to wild fish populations, with the spread of parasitic sea lice from marine salmon farms gaining the most attention as of late (Krkosek et al. 2005; Weber 2003; Paone 2000; Carr and Whoriskey 2004). Like the issue of escapes, the risk of the spread of disease appears to be dependent on the type of aquaculture system used, with open systems carrying the greatest risk. Blazer and LaPatra (2002) identified three potential interactions of cultured and wild fish populations in terms of pathogen transmission: 1) introduction of new pathogens to an area via the importation of exotic organisms for culture; 2) introduction of new pathogens or new strains of pathogens via movement of cultured fish, native and non-native; and 3) amplification of pathogens that already exist in wild populations and transmission of these pathogens between wild and cultured populations via intensive fish culture, which can include crowding, poor living conditions, and other stressors.

Very little is known about the distribution and frequency of diseases in wild fish populations (Blazer and LaPatra 2002). Unlike aquaculture, where dead or dying fish are easily observed and diagnosed, sick fish in the wild often go unnoticed since they likely become easy prey for predators. Without the background knowledge of what diseases exist pre-aquaculture, it is difficult to determine whether aquaculture is responsible for introducing or transferring a disease to wild populations. Additionally, as with exotic species introduction, there are other means of disease introduction besides aquaculture, such as ballast water transfer, fish processing, and fish transport.

Closed and semi-closed aquaculture systems have the lowest potential for releasing pathogens into the environment (Blazer and LaPatra 2002). Wastewater from these systems can be treated and intermediate hosts and carriers, for example birds, snails, and worms, can be excluded from the culture facility. Pond and flow-through systems pose some risk of pathogen transfer to wild fish populations, as both can spread diseases through discharges of wastewater and escapes of farmed fish. Additionally, these systems are sometimes open to intermediate hosts, such as birds, which can transport pathogens from one farm to another and potentially between farms and the wild.

### *Diseases of rainbow trout*

Rainbow trout are susceptible to many disease-causing organisms including parasites, bacteria, viruses, and fungi, which account for most losses in trout culture (Roberts and Shepherd 1997; USDA 2005). (It should be noted that in some areas other types of losses, including to predators and drought, are very important.) Outbreaks of disease occur when fish are stressed or exposed to suboptimal living conditions (Hardy et al. 2000). Because of the difficulties and high costs involved with disease treatment, health management is based primarily on prevention. Hardy et al. (2000) state that elements of disease prevention and health management include: sanitation; high-quality feed; prevention of overcrowding; elimination of disease vectors (for example netting to restrict bird access); and vaccination. There are only two antibiotics (Terramycin and Romet-30) available to treat diseases in farmed trout and these are costly and may not be effective (EPA 2002; Hardy et al. 2000).

### *Potential for introduction, transfer, and amplification of diseases*

Introductions of diseases via aquaculture activities have been a problem in the past, but there are currently programs in place at the state, tribal, and federal levels to prevent disease introduction (LaPatra 2003). Little is known, however, regarding the role of aquaculture facilities in transferring and amplifying pathogens and the risks to wild fish populations. This is especially true regarding the significance of pathogens in aquaculture effluents (LaPatra 2003). Still, several diseases of trout serve as useful demonstrations of how culture facilities can play a role in transferring disease to wild fish and help illustrate the risks involved with trout culture in terms of disease transfer.

Whirling Disease, a disease caused by the parasite *Myxobolus cerabalis* has received much attention in the last few decades because it is a threat to populations of native trout (Nickum 1999). The disease is believed to have been introduced from Europe in the early 1950s with imports of European trout and it was first discovered at a trout hatchery in Pennsylvania (Nickum 1999). Soon after that discovery, the disease was found in several other states including Connecticut, Massachusetts, Nevada, and California and it has since been found in a total of 22 states. For many years Whirling Disease was believed to be a disease primarily of cultured trout and its spread to and impact on wild trout was not well understood. The disease has been found at various state and commercial aquaculture facilities and in wild fish, but impacts on wild fish appear to vary widely in different regions (Blazer and LaPatra 2002). It seems apparent that the most likely mode of introduction and transfer of Whirling Disease would be through intentional stocking; though commercial aquaculture certainly could play a role. One study in particular conducted in Michigan found that the parasite that causes Whirling Disease had become established in native trout found downstream of an aquaculture facility that contained infected fish (Yoder 1972, cited in Blazer and LaPatra 2002). However, because of the complex life cycle of the Whirling Disease parasite (it requires the death and decomposition of the host) it is likely to be less of a problem with the disease being in the effluent discharge but more of a problem if infected fish were to escape from aquaculture facilities and interact with wild fish in downstream environments (V. Blazer, USGS, personal communication).

Unlike diseases caused by parasites such as Whirling Disease, other diseases, especially those that are caused by microorganisms that can be shed from infected individuals, may be more likely to be spread through the effluent discharges from trout farming facilities. Infectious pancreatic necrosis virus (IPVN), a disease of salmonids, has also been detected in other fish species, invertebrates, and homeotherms (Blazer and LaPatra 2002). According to Blazer and LaPatra (2002), these isolations have "in part been attributed to contact with discharges or products of contaminated fish culture facilities" (Sonstegard and McDermott 1972, and Bucke et al. 1979, both cited in Blazer and LaPatra 2002). McAllister and Bebak (1997) conducted a study of the discharge of IPVN in effluents from trout hatcheries. The researchers found that, while no IPVN was present in water collected above hatcheries or in springwater supplies to hatcheries, the virus was detected for at least 19.3 km downstream of the point of discharge, and a small percentage of wild fish were found to be infected with the virus. McAllister and Bebak (1997) point out that the wild fish living downstream of the culture facilities were continuously exposed to the virus through discharges, but the risks to the wild fish may be small, possibly because the concentration of the virus in the water was too low or because of natural defense mechanisms.

Diseases of trout caused by bacteria are common, but vary widely in the degree to which they affect their host (Roberts and Shepherd 1997). Intensive farming can result in high loads of bacteria that are excreted or released from infected fish, but the risk of impacting wild fish through the discharge of bacteria from trout farms may be less than risks involved with other pathogens (Blazer and LaPatra 2002). The following have been suggested as reasons that the risk of bacterial diseases spreading from aquaculture facilities to populations of wild fish may be low: many bacteria are common in the aquatic environment and disease is often stress-mediated; and chemotheraputants and vaccines have been effective in treating and preventing bacterial diseases (Blazer and LaPatra 2002).

### Synthesis

Flow-through aquaculture systems, such as the type used by the U.S. trout farming industry, carry some inherent risk of spreading diseases and parasites to wild fish. There is evidence that trout culture activities, primarily stocking for recreational purposes, have been responsible for the spread of diseases and parasites, and there is additional evidence that untreated fish farm effluents can carry pathogens into the wild. While the significance of pathogens in effluents is unknown (Lapatra 2003), it appears that viruses and other pathogens that can be shed from cultured organisms and released to natural bodies of water in effluents may be the most problematic for populations of wild fish. Additionally, the spread of diseases to wild fish populations could occur through the escape of diseased fish. There currently are no consistently-used practices to control the discharge of pathogens in effluents, and there are many gaps in the scientific information regarding aquatic pathogens, including the distribution of aquatic pathogens in ecosystems and the role of aquaculture facilities in the amplification and discharge of pathogens (LaPatra 2003).

**Risk of Disease and Parasite Transfer to Wild Stocks Rank:**

Low 🟩 **Moderate** 🟨 High 🟥 Critical ⬛

**Criterion 4: Risk of Pollution and Habitat Effects**

Pollution from fish farming facilities is a concern as waste products from aquaculture have the potential to impact the surrounding environment (Gowen et al. 1990; Costa-Pierce 1996; Beveridge 1996). Like other forms of agriculture, aquaculture creates waste that can be released into the environment; however, wastes from some types of aquaculture systems are released untreated directly into nearby bodies of water. Pollution from aquaculture can take several forms, including nutrients, suspended solids, and chemicals. In recent years, biological pollution, including the release of farmed fish and diseases into the wild (addressed in other sections of this report), has also become recognized as an aspect of waste discharge (Byrd 2003).

The potential for impact from aquaculture wastes depends largely on the type of system used (Costa-Pierce 1996). Intensive systems, especially those that are open to the natural bodies of water, have the greatest potential for polluting the environment while there is little potential impact from closed or semi-closed systems, in which discharges are infrequent and wastes can be treated and disposed of (Costa-Pierce 1996). High volumes of effluent are discharged from flow-through aquaculture facilities, the primary means of producing trout, but the effluent contains low concentrations of pollutants (EPA 2002). The quality of effluents leaving flow-through facilities can vary widely depending on the activity that is taking place. During times of cleaning or other activities waste levels can be higher than under normal conditions. Most aquaculture waste is the result of excretion or excess feed (Beveridge 1996). The Environmental Protection Agency (EPA) lists several pollutants of concerns from aquaculture facilities, including: sediments and solids; nutrients; organic compounds and biological oxygen demand; and metals (EPA 2002).

***Solid wastes from trout farms***

When properly managed, flow-through systems employ means to capture solid wastes and dispose of them in an appropriate manner (EPA 2002). According to EPA (EPA 2002), many aquaculture facilities with National Pollution Discharge Elimination System (NPDES) permits must control and monitor their discharge levels of solids. In Idaho, where the majority of trout facilities are located, permits specify average monthly and maximum daily total suspended solids limits. All facilities that produce more than 20,000 pounds of trout per year must obtain NPDES permits in Idaho and those facilities must also develop and follow best management practices (BMPs) under the Idaho Waste Management Guidelines for Aquaculture Operations.

Generally, the approach to capturing solid wastes in flow-through systems is through settling, with quiescent zones and settling basins/ponds being the most common methods (Hinshaw and Fornshell 2002; EPA 2002). In EPA's recent review of the U.S. aquaculture industry as part of its effort to develop aquaculture effluent guidelines, five trout production facilities in Idaho were visited and their waste treatment systems observed (EPA 2002). All of the facilities visited by EPA employed quiescent zones in combination with off-line settling basins. Similar solid waste management techniques were observed at trout farming facilities in other states as well.

A quiescent zone is an area at the end of a raceway where a screen blocks fish from moving downstream, therefore excluding them from a section of the raceway (Hinshaw and Fornshell 2002). This allows solids to settle to the bottom of the raceway while still intact and large in size. Solid wastes in quiescent zones can be removed by vacuuming, sometimes with a connection to a standpipe that connects to an offline area where solids are collected. Solids in quiescent zones should be removed regularly and the raceways that are in the most downstream positions should be cleaned the most frequently. Settling ponds or basins are areas where solid wastes are collected. Off-line settling ponds are areas that receive the solids slurry from the quiescent zones and allow the solids to settle. Some trout farms, typically small facilities, use full-flow settling ponds, which collect solids from the water flow of the entire facility. Solid wastes can be removed from both types of settling ponds and used for fertilizer for crops, for composting, or, less frequently, disposed of in landfills (EPA 2002).

### *Nutrients from trout farms*

Rainbow trout retain about 45% of the nitrogen and 50% of the phosphorus in their diet, with the remainder being excreted as waste, though this is very much dependent on the quality of the feed (Gatlin and Hardy 2002). Significant changes in feed formulations and feeding practices have allowed the trout aquaculture industry to significantly reduce the amount of phosphorus (the nutrient of primary concern because of its potential to lead to eutrophication in freshwater) in effluents (Golburg and Triplett 1997; EPA 2002; Hinshaw and Fornshell 2002). In their review of effluents from flow-through aquaculture systems, Hinshaw and Fornshell (2002) report that between the early 1980s and the late 1990s phosphorus retention in commercial trout facilities improved from 19% to between 32% and 46%. Hinshaw and Fornshell (2002) suggest that increased nutrient retention efficiency and digestibility of diets (through improvements in feed formulations and feeding practices) are generally recognized as the most effective ways to reduce potential impacts from nutrients in flow-through trout aquaculture effluents.

### *Water use and habitat effects from rainbow trout farming*

Intensive water use in some areas where trout are farmed is a concern, for example in the Snake River area of Idaho, but trout farming is not considered a consumptive use of water so it is generally not considered part of this problem (EPA 2002). Instead, trout farming in flow-through systems, which can require high volumes of water, uses water from rivers, springs, or wells and then returns it to nearby bodies of water. It is also not believed that trout farming has any significant impact in terms of land use and habitat effects (Boyd et al. 2005). Small amounts of land are needed for trout farming because dense concentrations of trout can be grown in relatively small areas. For example, Boyd et al. (2005) state that a trout farm producing 1,000 mt/year would need about 3.33 hectares of culture area plus space for buildings and other activities.

**Synthesis**

Rainbow trout farming, as currently practiced in the U.S. poses a low risk to the environment through pollution and habitat effects. Through the capture and disposal or use of wastes and improvements in feed formulations and practices, the industry has been able to significantly reduce the two greatest potential impacts, the release of solids and nutrients in effluents. There does not appear to be significant habitat effects as a result of trout farming and the industry is not considered a consumptive user of water. Continued research and development to improve feeds and the continued application of best management practices should ensure that pollution and habitat effects from trout farming are kept to a minimum.

**Risk of Pollution and Habitat Effects Rank:**

**Low** 🟩 Moderate 🟨 High 🟥 Critical ⬛

## Criterion 5: Effectiveness of the Management Regime

Rainbow trout farming, like other forms of aquaculture in the U.S., falls under a wide range of regulatory regimes. Regulation, or more specifically over-regulation, has been identified as one of the main impediments to an expanded aquaculture industry in the United States and some have called for a clarification of agency roles and regulatory structures (Devoe 1999; Rychlak and Peel 1993). In addition to numerous state permits that are required to operate a rainbow trout farm, several federal agencies have some degree of oversight, including:

U.S. Department of Agriculture (USDA)

According to the Aquaculture Act of 1980, the USDA has the lead role in federal aquaculture policy and is responsible for coordinating national aquaculture policy (Buck and Becker 1993). USDA's role is primarily promotional, providing assistance to industry through research, information, and extension services.

Environmental Protection Agency (EPA)

Under recently established effluent limitation guidelines, EPA regulates discharges of wastes from aquaculture facilities (EPA 2004). EPA guidelines apply to rainbow trout facilities that produce at least 100,000 pounds a year in flow-through systems that discharge wastewater at least 30 days a year, though as described in the previous section, all facilities that produce over 20,000 pounds and discharge at least 30 days per year must obtain an NPDES permit. The rule requires the implementation of best management practices and requires that flow-through facilities minimize the discharge of solids such as uneaten feed, settled solids, and animal carcasses.

Fish and Wildlife Service (FWS)

The FWS regulates the introduction and transport of fish and shellfish through the Lacey Act (Buck and Becker 1993) and assists aquaculturists with the control of fish-eating birds through the issue of depredation permits (Curtis et al. 1996).

Food and Drug Administration (FDA)

The FDA Center for Veterinary Medicine is responsible for approving and monitoring the use of drugs and medicated feeds used in the aquaculture industry (Buck and Becker 1993).

### ***Best management practices***

Best management practices (BMPs) to address waste discharge are widely used in the U.S. trout aquaculture industry. Under the EPA effluent guidelines, facilities producing over 100,000 pounds of fish must develop BMPs for meeting the effluent requirements, and individual states may have other guidelines as well; for example, the state of Idaho has developed guidelines for the development of BMPs for trout aquaculture facilities (IDEQ 1997). The development of BMPs must be tailored for each facility and will vary based on specific site characteristics. The guidelines developed by the state are intended to be used by aquaculturists to develop BMPs with site-specific variables in mind. The BMP plans developed by aquaculturists must be approved by EPA. The stated objectives of waste management guidelines for aquaculture in Idaho are to:

- Design, build, and maintain aquaculture facilities in a manner that works towards the elimination of the release of nutrients and solids to surface or ground water;
- Operate aquaculture facilities in a manner that minimizes the creation of nutrients and solids while providing optimal fish rearing conditions; and
- Promote management of the collected biosolids as a resource, preferably in a manner that utilizes the available nutrients while minimizing the potential of the nutrient's impacting ground or surface waters.

### **Synthesis**

Rainbow trout farmers must comply with numerous regulations, both at the state and federal levels. The management of the rainbow trout aquaculture industry can be considered to be generally effective. There are no obvious gaps in management. The U.S. trout aquaculture industry, along with regulatory agencies, has led the way in developing and implementing BMPs, which appear to be environmentally protective.

**Effectiveness of the Management Regime Rank:**

[✓ **Highly Effective** 🟩] Moderately Effective 🟨 Ineffective 🟥

## Overall Evaluation and Seafood Recommendation

Overall, U.S. farmed rainbow trout ranks as a “Best Choice” according to Seafood Watch® criteria. There are no sustainability criteria that are of “High” or “Critical” concern for current production systems. Three sustainability criteria are of “Low” conservation concern, while two criteria are of “Moderate” concern. In terms of use of marine resources, there have been advancements in feed formulations in recent years, which have led to decreased feed conversion ratios and less dependence on wild fish inputs. There are potential risks from the escape of farmed rainbow trout, and caution must be taken to ensure that the environment and wild populations of fish are not negatively impacted by escapes. As currently practiced, however, trout farms do not appear to be releasing any significant numbers of fish into the environment. The discharge of wastes is not believed to be a concern, mainly because of solid waste collection and the development of low pollution feeds. However, there is some concern that disease and parasite interactions may affect wild fish populations since wastewater, which can include disease-causing organisms, is constantly released and there is some indication that farms could act as incubators for disease. Management of the rainbow trout aquaculture industry is effective and well regulated and the use of best management practices appears to be quite common.

## Table of Sustainability Ranks

| | **Conservation Concern** | | | |
|---|---|---|---|---|
| **Sustainability Criteria** | **Low** | **Moderate** | **High** | **Critical** |
| Use of Marine Resources | | √ | | |
| Risk of Escaped Fish to Wild Stocks | √ | | | |
| Risk of Disease and Parasite Transfer to Wild Stocks | | √ | | |
| Risk of Pollution and Habitat Effects | √ | | | |
| Management Effectiveness | √ | | | |

## Overall Seafood Recommendation:

**Best Choice** 🟩

Good Alternative 🟨

Avoid 🟥

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*Scientific review does not constitute an endorsement of the Seafood Watch® program, or its seafood recommendations, on the part of the reviewing scientists. Seafood Watch® is solely responsible for the conclusions reached in this report.*

## References

Adelizi, P.D., R. Rosati, K. Warner, Y. Wu, T. Muench, M. White, and P. Brown. 1998. Evaluation of fishmeal free diets for rainbow trout, *Oncorhynchus mykiss*. Aquaculture Nutrition 4:255-262.

Behnke, R.J. 2002. Trout and salmon of North America. The Free Press, New York, NY.

Behnke, R.J. 1992. Native trout of western North America. American Fisheries Society Monograph 6.

Beveridge, M.C.M. 1996. Cage aquaculture (2nd edition). Edinburgh, Scotland: Fishing News Books, 346 pp.

Blazer, V.S., and S.E. LaPatra. 2002. Pathogens of cultured fishes: potential risks to wild fish populations. Pages 197-224 *in* J. Tomasso, ed. Aquaculture and the Environment in the United States. U.S. Aquaculture Society, A Chapter of the World Aquaculture Society, Baton Rouge, LA.

Blazer, V. Fishery biologist, United States Geological Survey (USGS). Personal communication, January 5, 2006.

Boyd, C., A. Mcnevin, J. Clay, and H. Johnson. 2005. Certification issues for some common aquaculture species. Reviews in Fisheries Science 13:231–279.

Buck, E. and G. Becker. 1993. Aquaculture and the Federal Role. Report for Congress. Congressional Research Service, Library of Congress, Washington, DC. 15pp.

Byrd, S. 2003. U.S. PIRG v. Atlantic Salmon of Maine: Non-native fish as "biological pollutants" under the clean water act and the potential repercussions for Louisiana aquaculture. Louisiana Coastal Law 82:10-12.

Carlton, J. T. 1992. The dispersal of living organisms into aquatic ecosystems as mediated by aquaculture and fisheries activities. Pages 13-45 *in* A. Rosenfield and R. Mann, eds. Dispersal of living organisms into aquatic ecosystems. Maryland Sea Grant Publication, The University of Maryland, College Park, MD.

Carlton, J. 2001. Introduced species in U.S. coastal waters: Environmental impacts and management priorities. Pew Oceans Commission, Arlington, Virginia.

Carr, J. and F. Whoriskey. 2004. Sea lice infestation rates on wild and escaped farmed Atlantic salmon (*Salmo salar* L.) entering the Magaguadavic River, New Brunswick. Aquaculture Research 35:723-729.

Cheng, Z. and R. Hardy. 2002. Apparent digestibility coefficients and nutritional value of cottonseed meal for rainbow trout (*Oncorhynchus mykiss*). Aquaculture 212:361–372.

Costa-Pierce, B.A. 1996. Environmental impacts of nutrients from aquaculture: Towards the evolution of sustainable aquaculture systems. Pages 81-113 *in* D.J. Baird, ed. Aquaculture and water resource management. Blackwell Science, Oxford.

Curtis, K.S., W.C. Pitt, and M.R. Conover. 1996. Overview of techniques for reducing bird predation at aquaculture facilities. The Jack Berryman Institute Publication 12, Utah State University, Logan, 20pp.

DeVoe, M. R. 1999. Marine aquaculture in the United States: Current and future policy and management challenges. Pages 85-93 in B. Cicin-Sain, R. Knecht, and N. Foster, editors. Trends and future challenges for U.S. National ocean and coastal policy. National Oceanic and Atmospheric Administration, Silver Spring, MD.

Dunham, J., D. Pilliod, and M. Young. 2004. Assessing the consequences of nonnative trout in headwater ecosystems in western North America. Fisheries 29(6):18-26.

Einum, S. and I. Fleming. 2001. Implications of stocking: ecological interactions between wild and released salmonids. Nordic Journal of Freshwater Research 75:56-70.

Food and Agriculture Organization of the United Nations (FAO). 2002. The State of World Fisheries and Aquaculture 2002. Available online: www.fao.org/sof/sofia/index_en.htm

Food and Agriculture Organization of the United Nations (FAO). 2004. The State of World Fisheries and Aquaculture 2004. Available online: www.fao.org/sof/sofia/index_en.htm

Forster, J. and Hardy, R. 2001. Measuring efficiency in intensive aquaculture. World Aquaculture 32(2):41-45.

Fuller, P. 2006. *Oncorhynchus mykiss*. USGS Nonindigenous Aquatic Species Database, Gainesville, FL. <http://nas.er.usgs.gov/queries/factsheet.asp?SpeciesID=910> Revision Date: 12/8/2004

Gatlin, D.M. and R. Hardy. 2002. Manipulation of diets and feeding to reduce losses of nutrients in intensive aquaculture. Pages 155-165 *in* J. Tomasso, ed. Aquaculture and the Environment in the United States. U.S. Aquaculture Society, A Chapter of the World Aquaculture Society, Baton Rouge, LA.

Golburg, R. and T. Triplett. 1997. Murky waters: Environmental effects of aquaculture in the United States. The Environmental Defense Fund, New York, NY.

Gomes, E., P. Rema, and S. Kaushik. 1995. Replacement of fish meal by plant proteins in the diet of rainbow trout (*Oncorhynchus mykiss*): digestibility and growth performance. Aquaculture 130:177-186.

Gowen, R.J., H. Rosenthal, T. Makinen and I. Ezzi. 1990. The environmental impact of aquaculture activities. Pages 257-283 *in* N. De Pauw and R. Billard, eds. Aquaculture Europe '89 - Business Joins Science. Bredene, Belgium, European Aquaculture Society, Special Publication 12.

Green, J., E. Brannon, and R. Hardy. 2002. Effects of dietary phosphorus and lipid levels on utilization and excretion of phosphorus and nitrogen by rainbow trout. 2. Production-scale study. Aquaculture Nutrition 8:291-298.

Gross. M. 1998. One species with two biologies: Atlantic salmon (*Salmo salar*) in the wild and in aquaculture. Canadian Journal of Fisheries and Aquatic Sciences 55(Suppl. 1):131–144.

Hardy, R. 1996. Alternate protein sources for salmon and trout diets. Animal Feed Science Technology 59:71-80.

Hardy, R., G. Fornshell, and E. Brannon. 2000. Rainbow trout culture. Pages 716-722 *in* R. Stickney ed. Encyclopedia of Aquaculture. John Wiley & Sons, Inc., New York.

Hardy, R.W. and A. Tacon. 2002. Fish meal: historical uses, production trends and future outlook for supplies. Pages 311-325 *in* Stickney, R. and J. McVey, eds. Responsible Marine Aquaculture. CABI Publishing, New York. 391 pp.

Harvey, D. 2005. Aquaculture Outlook. United States Department of Agriculture Economic Research Service, Washington, DC. pp. 27.

Hinshaw, J. L. Rogers, and J. Easley. 1990. Budgets for Trout Production: Estimated Costs and Returns for Trout Farming in the South. Southern Regional Aquaculture Center Publication SRAC-221. pp. 8.

Hinshaw, J. 1999. Trout Production: Feeds and Feeding Methods. Southern Regional Aquaculture Center Publication SRAC-223. pp. 4.

Hinshaw, J. and G. Fornshell. 2002. Effluents from raceways. Pages 77-104 *in* J. Tomasso, ed. Aquaculture and the Environment in the United States. U.S. Aquaculture Society, A Chapter of the World Aquaculture Society, Baton Rouge, LA.

Huntington, T., C. Frid, R. Banks, C. Scott, and O. Paramor. 2004. Assessment of the Sustainability of Industrial Fisheries Producing Fish Meal and Fish Oil. Report to The Royal Society for the Protection of Birds. 119 pp.

Idaho Division of Environmental Quality (IDEQ). 1997. Idaho Waste Management Guidelines for Aquaculture Operations. IDEQ Publication. pp. 87.

International Fishmeal and Fish Oil Organization (IFFO). 2001. Sustainability of Fishmeal and Oil Supply. Paper presented at Scottish-Norwegian Conference on Sustainable Futures for Marine Fish Farming.

Krkosek, M., M. Lewis, and J. Volpe. 2005. Transmission dynamics of parasitic sea lice from farm to wild salmon. Proceedings of the Royal Society of London, Series B 272:689-696.

Krueger, C. and B. May. 1991. Ecological and genetic effects of salmonid introductions in North America. Canadian Journal of Fisheries and Aquatic Sciences 48(Suppl. 1):66-77.

LaPatra, S. 2003. The lack of scientific evidence to support the development of effluent limitations guidelines for aquatic animal pathogens. Aquaculture 226:191–199.

McAllister, P. and J. Bebak. 1997. Infectious pancreatic necrosis virus in the environment: relationship to effluent from aquaculture facilities. Journal of Fish Diseases 20:201-207.

Myrick, C.A. 2002. Ecological impacts of escaped organisms. Pages 225-245 *in* J. Tomasso, ed. Aquaculture and the Environment in the United States. U.S. Aquaculture Society, A Chapter of the World Aquaculture Society, Baton Rouge, LA.

Naylor, R. and M. Burke. 2005. Aquaculture and Ocean Resources: Raising Tigers of the Sea, Annual Review of Environment and Resources 30, in press.

Naylor, R.L, R.J. Goldburg, J. H. Primavera, N. Kautsky, M.C.M. Beveridge, J. Clay, C. Folke, J. Lubchenco, H. Mooney, and M. Troell. 2000. Effect of aquaculture on world fish supplies. Nature 405:1017–1024.

Naylor, R., S. Williams, and D. R. Strong. 2001. Aquaculture--A gateway for exotic species. Science 294:1655-1656.

Nickum, D. 1999. Whirling Disease in the United States: A Summary of Progress in Research and Management. Trout Unlimited, Arlington, VA.

Paone, S. 2000. Industrial Disease: The Risk of Disease Transfer from farmed Salmon to Wild Salmon. Friends of Clayoquot Sound, Tofino, BC, Canada. 16 pp.

Roberts, R. and C. Shepherd. 1997. Handbook of Trout and Salmon Diseases, 3rd Edition. Fishing News Books, Oxford, UK.

Rychlak, R. and E.M. Peel. 1993. Swimming past the hook: Navigating legal obstacles in the aquaculture industry. Environmental Law 23:837-868.

Silverstein, J., C. Rexroad, and T. King. 2004. Genetic variation measured by microsatellites among three strains of domesticated rainbow trout (*Oncorhynchus mykiss*, Walbaum). Aquaculture Research 35:40-48.

Staley, K. and J. Mueller. 2000. Rainbow trout. NRCS Fish and Wildlife Habitat Management Leaflet Number 13.

Tacon, A. 2005. State of information on salmon aquaculture feed and the environment. Report to the WWF Salmon Aquaculture Dialogue.

Thiessen, D.L., D.D. Maenz, R.W. Newkirk, H.L. Classen, and M.D. Drew. 2004. Replacement of fishmeal by canola protein concentrate in diets fed to rainbow trout (*Oncorhynchus mykiss*). Aquaculture Nutrition 10:379–388

Tidwell, J.H. and G.L. Allan. 2001. Fish as food: aquaculture's contribution. EMBO reports 2(11):958-963.

Tyedmers, P. H. 2000. Salmon and Sustainability: The biophysical cost of producing salmon through the commercial salmon fishery and the intensive salmon culture industry. Ph.D. Thesis. The University of British Columbia: 272 pages.

United States Department of Agriculture (USDA). 2005. Trout Production. Report by the National Agriculture Statistics Service. 20pp. February 2005.

United States Environmental Protection Agency (EPA). 2002. Development Document for Proposed Effluent Limitations Guidelines and Standards for the Concentrated Aquatic Animal Production Industry Point Source Category. U.S. EPA, Washington DC, Publication EPA-821-R-02-016. 571 pp.

United States Environmental Protection Agency (EPA). 2004. Effluent Limitations Guidelines and New Source Performance Standards for the Concentrated Aquatic Animal Production Point Source Category; Final Rule. 40 CFR Part 451. 40pp.

Volpe, J., E.B. Taylor, D.W. Rimmer, and B. Glickman. 2000. Evidence of natural reproduction of aquaculture escaped Atlantic salmon (*Salmo salar*) in a coastal British Columbia river. Conservation Biology 14:899-903.

Watanabe, T. 2002. Strategies for further development of aquatic feeds. Fisheries Science 68:242–252.

Weber, M. L. 2003. What price farmed fish: a review of the environmental and social costs of farming carnivorous fish. SeaWeb Aquaculture Clearinghouse, Providence, RI. 52 pp.

Youngson, A., A. Dosdat, M. Saroglia, and W. C. Jordan. 2001. Genetic interactions between marine finfish species in European aquaculture and wild conspecifics. Journal of Applied Ichthyology 17:155-162.