A Survey of Chemical Constituents in National Fish Hatchery Fish Feed

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Abstract

Recent studies have demonstrated that various fish feeds contain significant concentrations of contaminants, many of which can bioaccumulate and bioconcentrate in fish. It appears that numerous organochlorine (OC) contaminants are present in the fish oils and fish meals used in feed manufacture, and some researchers speculate that all fish feeds contain measurable levels of some contaminants. To determine the presence and concentration of contaminants in feeds used in National Fish Hatcheries managed by the U.S. Fish & Wildlife Service, we systematically collected samples of feed from 11 hatcheries that raise cold-water species, and analyzed them for a suite of chemical contaminants. All of the samples (collected from October 2001 to October 2003) contained measurable concentrations of at least one dioxin, furan, polychlorinated biphenyl (PCB) congener, or dichlorodiphenyltrichloroethane (DDT) metabolite. All samples which were assayed for all contaminants contained one or more of those classes of compounds and most contained more than one; dioxin was detected in 39 of the 55 samples for which it was assayed, 24 of 55 contained furans and 24 of 55 samples contained DDT or its metabolites. There with 10- to 150-fold differences in the range in concentrations of the additive totals for PCBs, dioxins, furans and DDT. Although PCBs were the most commonly detected contaminant in our study (all samples in which it was assayed), the concentrations (range: 0.07 to 10.46 ng g^{-1} wet weight) were low compared to those reported previously. In general, we also found lower levels of organochlorine contaminants than have been reported previously in fish feed. Perhaps most notable is the near absence of OC pesticides—except for DDT (and its metabolites) and just two samples containing benzene hexachloride (Lindane). While contaminant concentrations were generally low, the ecological impacts can not be determined without a measure of the bioaccumulation of these compounds in the fish and the fate of these compounds after the fish are released from the hatcheries.

Table of Contents

List of Tables

List of Figures

List of Appendices

Introduction

Fish can bioaccumulate, biomagnify and bioconcentrate contaminants that they ingest with their food or take up directly from the water via diffusion across the gills and skin (Gobas et al., 1999). The rate of accumulation is based in part on the quantity and form of the contaminants (Watanabe et al., 1997; Carline et al., 2004), water quality variables, and the age, size and nutritional status of the fish (Patrick and Loutit, 1978; Schaperclaus, 1986; Sorensen, 1991). A wide range of organochlorine chemicals (OCs) and metals have been documented in wild fish populations (deWit et al., 2003; Evenset et al., 2004), and more recently contaminants have been found in fish in aquaculture (Horst et al., 1998; Hites et al., 2004). Horst et al. (1998) found OCs, specifically chlordane compounds, in farmed salmon as well as fish meal, oil and food products made from those fish. Easton et al. (2002) found that the levels of OCs, polybrominated diphenyl ethers (PBDE; flame retardants) and metals detected in farmed salmon were likely a consequence of elevated levels of contamination found in commercial salmon feeds. Several researchers concluded that there was no salmon feed that did not contain significant levels of contaminants, that farmed salmon showed consistently higher levels of contaminants than did wild salmon from the Pacific Coast, and that there may be safety concerns for individuals who regularly consume farmed salmon produced with contaminated feed (Horst et al., 1998; Easton et al., 2002; Hites et al., 2004).

Contaminants enter the aquatic environment from a variety of sources. Many pesticides (including those that are banned in the USA) become bound to the soil and enter the aquatic environment in precipitation run-off or as aerially transported dust (MacLeod and Mackay, 2004; VanCuren, 2003). Other contaminants result from industrial chemicals (including byproducts of incineration), which can enter the atmosphere and be transported throughout the globe before deposition (deWit et al., 2003; Breivik et al., 2004). Many of the contaminants entering freshwater and marine ecosystems are persistent in the environment and, because they are also lipid soluble, tend to accumulate in the lipid depots of animals, and are passed from prey to predators (Muir et al., 1992). This accumulation leads to organisms at higher trophic levels having relatively higher levels of OCs and other lipophilic contaminants through the process of biomagnification. Thus, hatchery diets that contain a high percentage of meal and oil from pelagic, ocean fish will likely contain high amounts of contaminants of global concern.

Hatchery-raised fish might, in effect, be moved to a higher trophic level on the food chain than their wild counterparts by consuming feeds made from oil and meal derived from marine fish, as opposed to their natural food, which is comprised of, at least in part, freshwater invertebrates.

Organochlorine residues have been found in fish oil (Jacobs et al., 1997; Jimenez et al., 1996) and fish meal (Rumsey, 1980) used in fish food. Salmon feed can contain up to 30 % fish oil and 50 % fish meal, while trout feed generally contains less of both constituents (Horst et al., 1998). A pilot study by National Oceanic and Atmospheric Administration (NOAA) Fisheries measured relatively high levels of selected OCs, especially hexachlorobenzene, in pollock oil that was tested prior to being used as a carrier fluid in a blue mussel contaminant exposure study (G. Ylitalo, NOAA Fisheries, personal communication). Polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) have been found in soybean meal (Rappe et al., 1998). Mac et al. (1979) found polychlorinated biphenyls (PCBs) and metabolites of dichlorodiphenyltrichloroethane (DDT), namely dichlorodiphenyltrichloroethylene (*p*, *p* DDE), in fish feeds. The levels detected in the feed varied with some lots having almost undetectable amounts while other lots contained levels of concern (R. Carline, USGS-BRD, personal communication). The NOAA Fisheries Science Center in Seattle, Washington, while trying to conduct an organochlorine-dosed feeding study to look at immune suppression in fish by contaminants, detected elevated levels of PCBs in fish feed received directly from the manufacturer (T. Collier, NOAA Fisheries, personal communication).

There are several reasons to be concerned about contaminants in fish feed. The primary concern is the possibility of human health impacts. The concentrations of contaminants in the fish and feeds reported by Hites et al. (2004) were not considered acutely toxic by the Food & Drug Administration (FDA). The Code of Federal Regulations, 21 CRF 109.30, states that the temporary tolerance for residues of PCBs in finished feed for food producing animals is 0.2 ppm; tolerance levels for edible portions of the fish is 2.0 ppm. However, the U.S. Environmental Protection Agency (EPA) guidelines and assumptions used by Hites et al. (2004) are designed to manage human health risks by providing risk-based consumption advice regarding contaminated fish. The combined concentrations of contaminants in the fish are what trigger the EPA consumption recommendations. To determine this, the EPA uses a toxic equivalency quotient (TEQ) or cumulative approach when assessing risk from compounds with similar modes of action. Concern for human health arises primarily over fish released for immediate catch and consumption, fish held for broodstock then released to the public, or returning adult salmon consumed by Native Americans whose diets may contain more fish than other segments of the USA population. It is also likely that the accumulation of contaminants will reduce the quality of the fish in the hatchery and their survival after release, as exposure to certain persistent organic pollutants in urban Puget Sound estuaries have been linked to reduced growth rate and reduced disease resistance in juvenile salmon (Arkoosh et al. 1998, 2001).

The objective of the current study was to determine if fish feed used in some cold-water U.S. Fish & Wildlife Service (FWS) National Fish Hatcheries (NFHs) across the country contained measurable levels of contaminants. Even though it is possible that contaminants could be found in the water or physical structures of the hatcheries, feeds were chosen because the literature indicated they are a potential point source and they are universally used, i. e. more than one hatchery may use the same feed. Therefore, to reach the objective of this study, we collected samples of feed from six manufacturers used at 11 NFHs; samples were collected quarterly for two years and were assayed for a variety of OC pesticides, metals, PCBs, dioxins and furans. This work was not meant to be a comparison of feed companies but a survey of feeds that are used by the FWS at some of its facilities.

Materials and Methods

Sample collection and handling

We collected samples of feeds from 11 NFHs in U.S. Fish & Wildlife Service in the Pacific, Great Lakes, Northeast and Mountain-Prairie Regions (Table 1) over a two year period. All of the diets tested were made at commercial feed mills except the kelt diet (designated feed "C"). This diet was handmade at the hatchery (North Atteboro NFH) using shrimp paste, fish paste, beef liver, a commercial starter diet and the appropriate vitamins and minerals. The large quantity of raw materials gives this diet higher moisture content than the other commercial diets tested. All feeds were sampled according to the Association of Official Analytical Communities (AOAC) guidelines (Horwitz, 2000). Once each quarter beginning in October 2001 through October 2003, a pallet of feed bags (40 bags) was randomly selected at each NFH for sampling. Approximately 50-100 g of feed was collected from every fourth bag from the same lot of feed; thus, 10 samples were collected each quarter from each NFH. To sample bulk feeds, 10 samples were collected from different parts of the load. A 99-cm (39-inch) Seeburo® chrome-plated trier was used for each bulk feed sampling. After sampling, the trier was disassembled, cleaned with soap and warm water, rinsed thoroughly and allowed to air dry. Each quarter the hatcheries were also provided with 10 chemically clean jars with labels for the feed samples. Samples of frozen fish feeds were placed in water tight containers (e.g., a Styrofoam box) with ice, sealed and placed in a cardboard box for shipping.

For each group of samples the fish-feed-sample analysis form provided by the Abernathy Fish Technology Center (Center) (Figure 1) was completed and included. Feed bag labels were supplied by the NFH when possible. All samples were shipped to the Center where one composite sample per NFH was made by pooling the 10 samples from each NFH and grinding them with a mortar and pestle. The mortar and pestle were cleaned by washing with enzyme soap, rinsing with water, washing with Acitionox soap, rinsing with water, rinsing twice with 10% HCl, and finally rinsing with acetone. This protocol was followed twice. Each composite feed sample was divided into four glass jars coded with the identifying NFH abbreviation, sample period (i.e., 1 through 8), and sample weight. One of these sub-sample jars was given a composite, as well as, a random number code, and was sent to a certified laboratory for contaminant analyses. The three remaining jars were placed in a -20º C freezer at the Center, where one jar of feed was used to determine proximate analysis. The two remaining jars are being stored as spare, archival samples.

Analytical methods

The feed sub-sample retained for proximate composition was analyzed at the Center for protein, lipid, moisture and ash according to the AOAC methods (Horwitz, 2000). A total of 101 other variables (including the totals of some classes of compounds, and metabolites) were measured on samples collected. Samples were sent to the USGS National Water Quality Laboratory (USGS Lab) for measurement of OC pesticides and trace metals (Table 2). Metals were assayed using the US EPA Method 3052 microwave-assisted, nitric acid digestion procedure (Hoffman, 1996). Aluminum, barium, boron, chromium, copper, iron, magnesium, manganese, strontium and zinc were determined by inductively coupled plasma atomic emission spectrometry (ICP-OES). Arsenic, beryllium, cadmium, lead, molybdenum, nickel, selenium and vanadium were determined by inductively coupled plasma mass spectrometry (ICP-MS).

Mercury was determined by cold vapor atomic fluorescence (CVAF) following US EPA Method 7474. The analysis of fish feed samples for organochlorine pesticides was accomplished by gas chromatography with electron capture detection (GC/ECD) by USGS Laboratory Schedule 2101 (Leiker et al., 1995). Severn Trent Laboratories, Inc., Sacramento, CA (Severn) analyzed the feed for dioxins and furans (EPA method 8290, US EPA, 1995). Severn Trent Laboratories, Inc., Knoxville, TN (Severn) also assayed some of the feed samples. Severn analyzed for the same suite of OCs and metals as the USGS Lab (Table 2) using standard methods, including metals (except Hg) by US EPA method 6010B (US EPA 1996a), mercury by method 7471A (US EPA, 1995), 14 PCB congeners by US EPA method 1668 (US EPA, 1999), and OC pesticides by EPA SW 846 (US EPA, 1996b). Difficulty with the matrix (fish feed) was noted by both the USGS Lab and Severn.

Data analyses

We sampled different brands and different batches of feed to obtain an overall view, seasonally and through time, of contaminant levels in the feed. The feeds collected were formulated for several different fish life-stages (e.g., fry, parr, and broodstock) and have different compositions. All data were summarized by determining means (+/- 1 standard deviation, SD) based on the NFH where the samples were collected and by the manufacturer. We also determined the total contents of dioxins, furans, PCBs and DDT metabolites by summing the values from the congener-specific analyses. Our objectives in this study were to determine the presence and concentrations of contaminants in a cross-section of fish feeds used at NFHs. We were not interested in comparing between NFHs or manufacturers; therefore, we did not conduct statistical analyses to identify differences between mean concentrations of contaminants.

In our analyses we do not consider the detection limits of the assays; that is, only assay results that were above detection limits were included in this report and we did not speculate as to the significance of values below the detection limits. Our data summaries contain only positive values when there were often values that may equal “0” (i.e. non-detects). We do present the detection limits for the assays conducted and our tabular results do indicate total number of samples assayed as well as the number of positive values (i.e., sample size, N) used in the calculations. Furthermore, Severn attached qualifiers to some values when, after adjusting for the dilution factor, those values were below the estimated minimum level (EML) or above the upper calibration level (UCL); these values are estimates. We included these values in our analyses. In order to compare our results to others in the literature, we calculated the toxic equivalency quotients (TEQ) for dioxin congeners found in our samples for which there are toxic equivalent factors (TEF) (i.e., 1, 2, 3, 4, 6, 7, 8-HpCDD; OCDD). Similar TEQs were calculated for furans (congeners: 2,3,7,8-TCDF; OCDF) and dioxin-like PCBs (congeners: DL-PCB -77, -105, -114, -118, -123, -126, -156, -157, -167, -189) and the total TEQ based on the World Health Organization's established TEFs for fish (Van den Berg et al., 1998).

Results

A total of 77 samples were collected all of which were assayed for proximate analysis (i.e., ash, lipids, moisture and protein content). The disparity in the number of samples received verses the 88 identified in the original design was due to the fact that some hatcheries either did not have fish all year or they did not feed their fish all year so they did not have new feeds to sample every quarter. Metals and other contaminants were measured in 46 to 55 samples (Table 3). Not all samples collected were assayed for all contaminants due to budget constraints. The remaining feed samples are archived at the Center. Detectable values were obtained for 55 of the 101 variables (Table 3). As indicated above, in our results we include only values that were greater than detection levels (Table 4). Excluding the values for proximate analyses and the totals that were the sums of other variables measured (e.g., Total PCBs = sum of the 14 congeners measured) there were 41 contaminants detected in the samples (Table 5). All of the samples contained measurable concentrations of at least one dioxin, furan, PCB congener, or DDT metabolite expressed per wet weight of feed. All samples assayed contained one or more of those compounds; 39 of 55 samples contained dioxins, 24 of 55 contained furans and 24 of 55 samples contained DDT or its metabolites (Table 6). Most of the samples contained more than one of these classes of compounds. There were 10- to 150-fold differences in the range in concentrations of the additive totals for PCBs, dioxins, furans and DDT (Table 6). In addition to DDT and its metabolites, the only pesticide detected was benzene hexachloride (BHC, also known as Lindane) found in two samples. Differences in the number of samples between the assayed total values and the additive totals are the result of some samples in which assay results are positive for totals in a class of compounds, but either none of the individual congeners were above detection limits, and/or homologous congeners were detected. In order to compare our results to others in the literature, we calculated TEQs for dioxins (2,3,7,8, TCDD; 1,2,3,7,8 PeCDD; 1,2,3,4,6,7,8 HpCDD; and OCDD) and furans (2,3,7,8-TCDF and OCDF), and dioxin-like PCBs (Table 7). Metals were also present in all 55 samples for which they were assayed (Table 8). Beryllium (Be) was the only metal not found in any sample, and 12 of the other 18 metals were found in all 55 samples (Table 8).

In general, the proximate composition of feed (protein, moisture, lipid, ash) adds up to approximately 100 %. However, in some cases, the fiber and nitrogen-free extract (e.g., sugars, starches) that were not measured were in the feed at significant levels and, therefore, made up the difference seen in the proximate compositions (Tables 9 and 10). Table 9 summarizes the concentrations of components and contaminants based on the NFH from which the feed samples were collected, and Table 10 summaries components and contaminants based on the feed manufacturer. As we were not concerned with comparing manufacturers, we have coded the names (A through F). Rather than show all congeners and metabolites in these tables, we present the additive totals for dioxins, furans, PCBs, DDT metabolites and BHC, as well as mean percent composition of ash, lipids, moisture and protein, and mean concentrations of each of the metals. We also compared the results of our study to those reported previously by Mac et al. (1979) and Easton et al. (2002) in Table 11. All individual assay results above the minimum detection levels for the various contaminants are listed by NFH and date that they were received at the Center in Appendix A.

Discussion

OC contaminants in fish feed

In this study we have shown that some form of chemical contaminant occurred in all samples. In general, we found lower levels of OC contaminants than have been reported previously in fish feed. Perhaps most notable is the almost total lack of pesticides—except for DDT (and its metabolites) and just two samples containing BHC. Hites et al. (2004) reported detectable levels of dieldrin and toxaphene in 13 feed samples, which included six from Canada but none from the USA. Jacobs et al. (2002) found hexachlororobenzene (HCBs) and BHCs in eight feed samples of European manufacture. Hilton et al. (1983) formulated five test feeds using fish meal from several sources, and all of the resulting feeds had detectable concentrations of dieldrin, heptachlor and chlordane. Our samples contained lower concentrations of total DDTs (range: 3.3 to 31.0 ng g^{-1} wet weight; Table 6) than were reported by Mac et al. (1979) for several lots from one commercial feed manufacturer (means: 80 to 340 ng g^{-1} wet weight), but our samples contained about the same concentration of DDT as another feed manufacturer they examined (means: 13 to 51 ng g^{-1} wet weight). Feeds manufactured in Scotland reportedly had levels of total DDT (range: 34 to 52 ng g^{-1} lipid adjusted; Jacobs et al., 2002), which would be three- or four-fold greater than ours if expressed as wet weight. It appears that the concentrations of DDT metabolites we found in feeds from three manufacturers were lower than those observed by Mac et al. (1979) and Easton et al. (2002) in samples from the same manufacturers several years previous (Table 11).

Although PCBs were the most commonly detected contaminant in our study (46 of 46 congener-specific analyses), the additive total concentrations of 14 dioxin-like PCB congeners ranged from 0.07 to 10.46 ng g^{-1} wet weight (Table 6). These were low compared to total PCBs reported by Hites et al. (2004; range: ~10 to 95 ng g^{-1} wet weight), Carline et al. (2004; range: 69 to 126 ng g^{-1} wet weight), and Mac et al. (1979; means: 54 to 230 ng g^{-1} wet weight). Hilton et al. (1983) also reported high concentrations of PCBs (100 to 2,120 ng g^{-1}) but these were expressed in dry weight of feed. It is, however, important to note that these values are probably not directly comparable as the methods used in these other studies considered more PCB congeners than the 14 in our additive totals. Easton et al. (2002) presented data on the same 14 PCB congeners as our study and are thus directly comparable, as is the total PCBs reported for various feeds in the Mac et al. study (1979). The range of total PCBs in feed from manufacturer A sampled in 1999 and reported by Easton et al. (2002) is less than that reported by Mac et al. (1979) (Table 11). Easton et al. (2002) also presented the sums of 14 PCBs for the same feeds and these were greater than what we assayed in our samples (Table 11). Furthermore, the maximum TEQ for PCBs in our samples was about one-half those in Easton et al. (2002) and from one- to two-orders of magnitude less that those reported in European fish feeds (Bell et al., 2005; Isosaari et al., 2004). In fact, the highest value from our samples (0.44 pg TEQ g^{-1}) was less than the lowest value (0.62 pg TEQ g^{-1}) reported in either of the European studies.

Bell et al. (2005) and Isosaari et al. (2004) combined TEQs for dioxins and furans in fish feeds and reported a range of 0.16 to 4.9 pg TEQ g^{-1} in eight samples. In the present study, the mean dioxin plus furan TEQ was 0.227 and the maximum value was 3.98 pg TEQ g^{-1} (Table 7).

It should be noted, however, that these values are skewed by two samples (out of 42) that contained 2.5 and 3.9 pg 1,2,3,7,8 PeCDD g^{-1}, which has a toxic equivalent factor of 1.0 (fish TEF value), as compared to TEFs ≤ 0.05 (Van den Berg et al., 1998) for all other dioxin and furan congeners in our samples. For example, one sample had an absolute concentration of 350 pg OCDD g^{-1} but because its TEF = 0.0001, it contributes 0.035 pg TEQ g^{-1}. If these two PeCDD values are excluded, the mean dioxin/furan TEQ is 0.077 pg TEQ g^{-1} and the maximum value is 0.581 pg TEQ g^{-1}. Bell et al. (2005) reported that the European Union allows up to 2.25 pg TEQ g^{-1} in fish feed. Hites et al. (2004) presented combined dioxin, furan and dioxin-like PCB TEQs in 13 fish feed samples collected from Scotland, Canada and Chile. He reported TEQs of about 0.5 to 7.0 pg TEQ g^{-1}, as compared to our range of 0.0005 to 3.98 pg TEQ g^{-1}. Again, in the present study, two samples with PeCDD skew these comparisons.

Metals in fish feed

Metals found commonly in fish feed are contributed by the ingredients and by a mineral pack added by the manufacturer. Shearer et al. (1994) analyzed eight feeds from a Norwegian feed manufacturer for select metals. Generally, their results [Cu, 1.3-29.2 ppm (i.e., $\mu g\, g^{-1}$); Fe, 68.7-353 ppm; Mg, 1860-2100 ppm; Mn, 5-120 ppm; Zn, 170-380 ppm] were slightly higher than the values we report here (Table 7). In addition, guidelines from the Association of Feed Control Officials Official Publication (Hanks, 2000) indicate the maximum tolerable levels are for Cd, 0.5 ppm; Hg, 2.0 ppm; Se, 2.0 ppm; Cu, 25 ppm; and Pb, 30.0 ppm. These dietary levels in the feed, for a limited period, will not affect animal performance and should not produce unsafe residues in human food derived from the animal. Generally, our metal results fall below these tolerable levels. Many gaps exist in our understating of essential minerals for fish (i.e., without them there are clinical signs of deficiency); however, it appears that B, Ca, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, P, Se, and Zn are essential. The levels of these metals required by each species fish have not been defined.

Ecological implications

The presence of OCs and heavy metals (e.g., mercury) in fish food is of great concern because of human health implications, but also because of the effects of these compounds on the survival of fish after release from hatcheries, and impacts on the ecosystem into which they are released. Millions of dollars are spent each year in US Fish & Wildlife Service hatcheries to provide fish for recreational and commercial fisheries, and to supplement natural production of stocks listed under the Endangered Species Act. Most of the compounds measured in this study, including some of the metals, are known to bioaccumulate and biomagnify up the food web. However, to determine the level of bioaccumulation or the effects of these feeds on the fish, we would need information about the specific amounts of each feed fed to a specific group of fish throughout their life cycle and the levels of contaminants in the fish tissues. Macek (1968) reported that brook trout (*Salvelinus fontinalis*) fed DDT (2 mg kg^{-1} body weight $week^{-1}$) for 31 weeks had 20-fold greater accumulated DDT than did control fish. Isosaari et al. (2004) reported that from 43% to 83% of the total mass of dioxins, furans, and PCBs fed to Atlantic salmon (*Salmo salar*) over 30 weeks accumulated in the tissue of the fish.

The majority of OCs are persistent in the environment and, because they are lipid soluble, tend to accumulate in the lipid depots of animals, and biomagnify up the food chain. Because of this biomagnification, hatchery fish that are fed for 6 to 24 months in a hatchery may accumulate OC concentrations in their flesh that are significantly higher than that in the feed (Isosaari et al., 2004; Lundebye et al., 2004). Well-fed fish will accumulate these lipophilic contaminants in fat depots in muscle and viscera where the toxic effects are muted. When fish stop feeding, however, the lipids are mobilized as an energy source and the OCs are redeposited in vital organs (e.g., brain, liver, heart, kidney; Jørgensen et al., 2002). Recent work with Arctic charr dramatically illustrates the impacts of this mobilization of OCs on physiological processes. Anadromous charr normally feed for only 6 to 8 weeks in the ocean—where they can accumulate OCs—and fast for the remaining 10 months of the year in freshwater. In a series of experiments, Jørgensen and colleagues contaminated charr with PCBs, fasted or fed the fish for 5 months, and then measured physiological responses. Contaminated charr had impaired responses to stress (Jørgensen et al., 2002), reduced immune responses leading to decreased disease resistance (Maule et al., 2005), and reduced growth and survival in saltwater a year after contamination (Jørgensen et al., 2004). It appeared that one mechanism of PCB's effect is interference with hormonal regulation of physiological processes at the level of the brain or pituitary (Aluru et al., 2004). These results suggest strongly that PCBs will reduce the fitness and survival of fish in the wild.

Hatchery fish released into the wild can be caught immediately in recreational fisheries or survive to grow. Grown fish might either be caught in tribal, commercial or recreational fisheries, or survive to reproduce. Feeding these fish contaminated food can have negative impacts on the success of NFH operations, and the health of the ecosystem. For example, in the Pacific Northwest salmon are raised in hatcheries for 6 to 18 months and are released to emigrate to the ocean. Survival of these hatchery fish may be < 0.1% as compared to estimated survival as high as 10% in some emigrating wild salmon stocks. Upon release from hatcheries, these salmon do not feed while they adjust to the new environment and new food resources in rivers and streams. Lipid reserves in these fish decline for at least the first month after release possibly due to less efficient prey capture but also metabolic and biochemical changes due to smoltification (Rondorf et al. 1985; Hoar 1988). If there are OCs in lipid depots, they will be mobilized and re-deposited in organs where they will impair physiological functions necessary for survival (e.g., respond to stresses such as dam passage, entering the saltwater, resisting fish pathogens). If the availability of food is reduced—for example if poor ocean upwelling reduces nutrients available for the near-shore food web—more fats will be mobilized, increasing the deposition of contaminants in the organs, leading to greater physiological dysfunction and reduced survival. Some hatchery fish also become prey when released and will add any contaminants they contain to the food web—expanding the ecological impacts of these contaminants.

There are several experiments that could address the ecological impacts of exposing soon-to-be-released salmonids to contaminants: (1) measure the flow of contaminants from food to fish by assaying body burdens in fish during hatchery rearing; (2) measure contaminants in other parts of the rearing environment and determine the fish's uptake of them; (3) measure flow of contaminants within fish by simulating the period of fasting after release and measuring contaminants in muscle, brain, liver, and kidney over several months; (4) determine the impact of observed body burdens and organ levels of contaminants by conducting performance tests (i.e., predator avoidance, saltwater growth and survival, stress challenge and disease challenge) and measuring physiological functions (e.g., osmoregulation, physiological stress responses, immune responses); (5) determine the impact of contaminants on migration rates and survival after fish are released; (6) assess the movement of contaminants in the ecosystem.

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Table 1. U.S. Fish and Wildlife Service Region, National Fish Hatchery (NFH) and fish species reared and fed at those hatcheries during the two-year study.

FWS Region	**NFH**	**Species**
Pacific	Coleman	Steelhead Fall Chinook
	Hagerman	Rainbow trout, Steelhead
	Spring Creek	Fall Chinook
	Quilcene	Coho, Chum
	Leavenworth	Spring Chinook, Steelhead
Mountain-Prairie	Garrison Dam	Pallid sturgeon, Walleye, Pike, Smallmouth bass
	Ennis	Rainbow trout
Great Lakes	Genoa	Lake trout, Brook trout, Bass, Bluegill, Sturgeon, Pike
	Jordan River	Lake trout
Northeast	North Attleboro	Atlantic salmon
	White Sulphur Springs	Rainbow trout

Table 2. Metals and other contaminants assayed by the National Water Quality Laboratory or Severn Trent Laboratories, Inc.; proximate contents assayed by Abernathy Fish Technology Center in fish feed samples collected from 11 National Fish Hatcheries between October 2001 and October 2003.

Percent Ash	PCB 77	Aldrin
Percent Lipids	PCB 81	Chlordane (technical)
Percent Moisture	PCB 105	DCPA (Dacthal)
Percent Protein	PCB 114	Dieldrin
1,2,3,4,6,7,8-HpCDD	PCB 118	Endosulfan I
1,2,3,4,6,7,8-HpCDF	PCB 123	Endosulfan II
1,2,3,4,7,8,9-HpCDF	PCB 126	Endosulfan sulfate
1,2,3,4,7,8-HxCDD	PCB 156	Endrin
1,2,3,4,7,8-HxCDF	PCB 157	Endrin aldehyde
1,2,3,6,7,8-HxCDD	PCB 167	alpha-BHC
1,2,3,6,7,8-HxCDF	PCB 169	beta-BHC
1,2,3,7,8,9-HxCDD	PCB 170	delta-BHC
1,2,3,7,8,9-HxCDF	PCB 180	gamma-BHC (Lindane)
1,2,3,7,8-PeCDD	PCB 189	cis-Chlordane
1,2,3,7,8-PeCDF	PCB-Total	cis-Nonachlor
2,3,4,6,7,8-HxCDF	Aluminum (Al)	o,p'-Methoxychlor
2,3,4,7,8-PeCDF	Arsenic (As)	p,p'-Methoxychlor
2,3,7,8-TCDD	Barium (Ba)	trans-Chlordane
2,3,7,8-TCDF	Beryllium (Be)	trans-Nonachlor
OCDD	Boron (B)	Toxaphene
OCDF	Cadmium (Cd)	Heptachlor
Total HpCDD	Chromium (Cr)	Heptachlor Epoxide
Total HpCDF	Copper (Cu)	Hexachlorobenzene (HCB)
Total HxCDD	Iron (Fe)	Methoxychlor
Total HxCDF	Lead (Pb)	Mirex
Total PeCDD	Magnesium (Mg)	Oxychlordane
Total PeCDF	Manganese (Mn)	Pentachloroanisole (PCA)
Total TCDD	Mercury (Hg)	Decachlorobiphenyl
Total TCDF	Molybdenum (Mo)	4,4'-DDD
	Nickel (Ni)	4,4'-DDE
	Selenium (Se)	4,4'-DDT
	Strontium (Sr)	Total DDT
	Vanadium (V)	
	Zinc (Zn)	

Table 3. Number of samples distributed to Abernathy Fish Technology Center (Center), National Water Quality Laboratory (USGS Lab) or Severn Trent Laboratory, Inc. (Severn) for analyses of lipids, moisture, ash and protein (proximate analysis), organochlorine pesticides (OCs), polychlorinated biphenyls (PCBs), dioxins, furans, and metals.

	Center	USGS Lab	Severn		Total Samples
Proximate analysis	77	--	--	--	77
PCB congeners	--	--	46	--	46
OCs	--	29	26	--	55
Dioxins, Furans	--	--	55	--	55
Metals	--	29	26	--	55
Sample not analyzed	--	--	--	22	22
No sample received	--	--	--	11	11

Table 4. Detection limits of assays performed on feed samples collected from 11 National Fish Hatcheries between October 2001 and October 2003. Detection limits of dioxins, furans and PCBs vary between assays; values shown are the highest minimum detection limits for all assays performed. Values for metals and OC pesticides are minimum detection limits for all assays. Assays were conducted at the National Water Quality Laboratory (USGS) or Severn Trent Laboratories, Inc (Severn).

				Detection Limits					
Severn		Severn			Severn	USGS		Severn	USGS
	(pg g^{-1})		(ng g^{-1})		(µg g^{-1})			(µg kg^{-1})	
1,2,3,4,6,7,8-HpCDD	2.40	PCB 77	0.028	Aluminum (Al)	3.30	1.00	Aldrin	3.7	5.0
1,2,3,4,6,7,8-HpCDF	3.60	PCB 81	0.025	Arsenic (As)	0.46	0.10	Chlordane	35.0	
1,2,3,4,7,8,9-HpCDF	4.20	PCB 105	0.023	Barium (Ba)	0.11	0.10	DCPA (Dacthal)		5.0
1,2,3,4,7,8-HxCDD	1.80	PCB 114	0.023	Beryllium (Be)	0.02	0.10	Dieldrin	5.5	5.0
1,2,3,4,7,8-HxCDF	1.50	PCB 118	0.024	Boron (B)	0.47	0.20	Endosulfan I	3.1	
1,2,3,6,7,8-HxCDD	1.50	PCB 123	0.023	Cadmium (Cd)	0.08	0.10	Endosulfan II	3.9	
1,2,3,6,7,8-HxCDF	1.40	PCB 126	0.030	Chromium (Cr)	0.40	0.50	Endosulfan sulfate	6.3	
1,2,3,7,8,9-HxCDD	1.60	PCB 156	0.035	Copper (Cu)	0.10	0.50	Endrin	5.1	5.0
1,2,3,7,8,9-HxCDF	1.70	PCB 157	0.035	Iron (Fe)	2.40	1.00	Endrin aldehyde	8.8	
1,2,3,7,8-PeCDD	2.30	PCB 167	0.027	Lead (Pb)	0.13	0.10	alpha-BHC	5.7	5.0
1,2,3,7,8-PeCDF	1.60	PCB 169	0.041	Magnesium (Mg)	1.80	0.008*	beta-BHC	5.7	5.0
2,3,4,6,7,8-HxCDF	1.80	PCB 170	0.046	Manganese (Mn)	0.07	0.10	delta-BHC	5.3	5.0
2,3,4,7,8-PeCDF	2.60	PCB 180	0.044	Mercury (Hg)	0.01	0.01	gamma-BHC	5.6	5.0
2,3,7,8-TCDD	0.98	PCB 189	0.032	Molybdenum (Mo)	0.21	0.10	cis-Chlordane		5.0
2,3,7,8-TCDF	0.64			Nickel (Ni)	0.34	0.10	cis-Nonachlor		5.0
OCDD	5.10			Selenium (Se)	0.25	0.10	o,p'-Methoxychlor		5.0
OCDF	4.40			Strontium (Sr)	0.04	0.10	p,p'-Methoxychlor		5.0
Total HpCDD	2.40			Vanadium (V)	0.21	0.10	trans-Chlordane		5.0
Total HpCDF	4.20			Zinc (Zn)	0.21	0.50	trans-Nonachlor		5.0
Total HxCDD	1.80						Toxaphene	150	200.0
Total HxCDF	3.40				* mg L^{-1}		Heptachlor	4.6	5.0
Total PeCDD	10.00						Heptachlor Epoxide		5.0
Total PeCDF	7.60						Hexachlorobenzene		5.0
Total TCDD	0.98						Methoxychlor	6.0	
Total TCDF	2.50						Mirex		5.0
							Oxychlordane		5.0
							Pentachloroanisole		5.0
							4,4'-DDD	5.3	5.0
							4,4'-DDE	4.7	5.0
							4,4'-DDT	4.8	5.0

Table 5. Metals and other contaminants for which there was at least one value above detection limits when assayed by the National Water Quality Laboratory or Severn Trent Laboratories, Inc. in fish feed samples collected from 11 National Fish Hatcheries between October 2001 and October 2003. Total DDT, Total Dioxins, Total Furans and Total PCBs were determined by summing within classes of compounds. All other totals were determined by independent assays.

1,2,3,4,6,7,8-HpCDD	PCB 156	Lead (Pb)
1,2,3,7,8-PeCDD	PCB 157	Magnesium (Mg)
2,3,7,8-TCDD	PCB 167	Manganese (Mn)
2,3,7,8-TCDF	PCB 170	Mercury (Hg)
OCDD	PCB 180	Molybdenum (Mo)
OCDF	PCB 189	Nickel (Ni)
Total HpCDD	Aluminum (Al)	Selenium (Se)
Total HpCDF	Arsenic (As)	Strontium (Sr)
Total PeCDD	Barium (Ba)	Vanadium (V)
Total PeCDF	Boron (B)	Zinc (Zn)
Total TCDD	Cadmium (Cd)	alpha-BHC
Total TCDF	Chromium (Cr)	delta-BHC
PCB 77	Copper (Cu)	4,4'-DDE
PCB 81	Iron (Fe)	Total DDT
PCB 105		Total Dioxins
PCB 114		Total Furans
PCB 118		Total PCBs
PCB 123		
PCB 126		

Table 6. Summary of dioxins, furans (total samples assayed = 55), PCBs (total samples assayed = 46) and organochlorine pesticides (total samples assayed = 55) detected in fish feed samples assayed by the USGS National Water Quality Lab or Severn Trent Laboratories, Inc. in fish feed samples collected from 11 National Fish Hatcheries between October 2001 and October 2003. DDT contains data from the two labs using different assays (see Methods). Total DDT, Total Dioxins, Total Furans and Total PCBs were determined by summing across classes of compounds. All other totals were determined by independent assays. Differences in the number of samples between the assayed total values and the additive totals are the result of some samples in which assay results are positive for totals in a class compounds, but none of the individual congeners were above detection limits, and vice-versa.

Compound	1,2,3,4,6,7,8 HpCDD	1,2,3,7,8 PeCDD	2,3,7,8 TCDD	2,3,7,8 TCDF	OCDD	OCDF	Total HpCDD	Total HpCDF	Total PeCDD	Total TCDD	Total TCDF	Total Dioxin	Total Furans	Total PCB	Total DDT	Total BHC
Units	pg g^{-1}	pg g^{-1}	pg g^{-1}	pg g^{-1}	pg g^{-1}	pg g^{-1}	pg g^{-1}	pg g^{-1}	pg g^{-1}	pg g^{-1}	pg g^{-1}	pg g^{-1}	pg g^{-1}	ng g^{-1}	µg kg^{-1}	µg kg^{-1}
Mean	10.4	3.2	0.55	1.29	36.2	10.00	16.93	3.00	12.80	0.69	1.33	38.08	1.76	1.94	11.33	21.50
SD	12.6	1.0		0.82	67.5		19.25		6.30	0.19	0.82	74.25	2.40	2.42	7.97	3.54
N	10	2	1	22	38	1	10	1	3	2	23	39	24	46	24	2
SE	4.0	0.7		0.17	11.0		6.09		3.64	0.14	0.17	11.89	0.49	0.36	1.63	2.50
Max value	44.0	3.9	0.55	3.80	350.0	10.00	66.00	3.00	19.00	0.82	3.80	394.00	12.30	10.46	31.00	24.00
Min Value	3.1	2.5	0.55	0.64	5.2	10.00	3.10	3.00	6.40	0.55	0.64	2.50	0.64	0.07	3.30	19.00

SD = standard deviation; N = number of samples with detectable values; SE = standard error of the mean

Table 7. World Health Organization (WHO) toxic equivalents (TEQ; pg g^{-1}) for dioxins (congeners: heptachlorodibenzo-p-dioxin, octachlorodibenzo-p-dioxin, pentachlorodibenzo-p-dioxins, tetrachlorodibenzo-p-dioxin), furans (congeners: tetrachlorodibenzo furan, octachlorodibenzo furan) and PCBs (congeners: PCB -77, -105, -114, -118, -123, -126, -156, -157, -167, -189) detected in 55 fish feed samples assayed by Severn Trent Laboratories, Inc. in fish feed samples collected from 11 National Fish Hatcheries between October 2001 and October 2003. Toxic equivalent factors for fish were used in the calculations (Van den Berg et al., 1998).

	Mean	SD	N	SE	Min	Max
Dioxin TEQ	0.208	0.739	39	0.1183	0.0005	3.9486
Furan TEQ	0.064	0.041	22	0.0087	0.0320	0.1900
PCB TEQ	0.061	0.085	46	0.0125	0.0026	0.4144
Dioxin + Furan	0.227	0.708	42	0.1092	0.0005	3.9486
Total TEQs	0.237	0.647	52	0.0897	0.0006	3.9811

SD = standard deviation; N = number of samples with detectable values, each of the 52 total samples could contain 1, 2 or 3 of the classes of contaminants; SE = standard error of the mean; Min = minimum value detected above detection limits; Max = maximum value detected.

Table 8. Summary of metals detected in 55 fish feed samples assayed by Severn Trent Laboratories, Inc. and the National Water Quality Laboratory in fish feed samples collected from 11 National Fish Hatcheries between October 2001 and October 2003. The labs used different assay methods (see Methods).

Metal	Al	As	Ba	B	Cd	Cr	Cu	Fe	Pb	Mg	Mn	Hg	Mo	Ni	Se	Sr	V	Zn
Units	$\mu g\ g^{-1}$	$\mu g\ g^{-1}$	$\mu g\ g^{-1}$	$\mu g\ g^{-1}$	$\mu g\ g^{-1}$	$\mu g\ g^{-1}$	$\mu g\ g^{-1}$	$\mu g\ g^{-1}$	$\mu g\ g^{-1}$	$\mu g\ g^{-1}$	$\mu g\ g^{-1}$	$\mu g\ g^{-1}$	$\mu g\ g^{-1}$	$\mu g\ g^{-1}$	$\mu g\ g^{-1}$	$\mu g\ g^{-1}$	$\mu g\ g^{-1}$	$\mu g\ g^{-1}$
Mean	61.50	2.62	6.67	5.28	0.39	1.50	10.54	353.9	0.78	1763	84.31	0.03	0.76	2.35	2.48	45.94	2.07	142.76
SD	50.30	1.37	3.97	2.23	0.21	0.74	5.43	134.9	1.11	429	45.94	0.03	0.52	1.39	0.68	26.06	1.78	42.36
N	55	55	55	55	41	53	55	55	25	55	55	52	47	55	55	55	54	55
SE	6.78	0.18	0.54	0.30	0.03	0.10	0.73	18.2	0.22	58	6.19	0.00	0.08	0.19	0.09	3.51	0.24	5.71
Max value	226.00	8.17	15.30	9.80	0.89	4.70	29.83	622.0	5.82	2640	196.00	0.12	2.28	7.80	3.80	117.00	9.44	258.54
Min value	1.94	0.25	0.20	0.63	0.08	0.67	1.20	15.0	0.10	212	3.60	0.01	0.16	0.42	0.25	4.52	0.22	14.20

SD = standard deviation; N = number of samples with detectable values; SE = standard error of the mean

Table 9. Mean + standard deviation (SD) of constituents found in fish feed samples collected from 11 National Fish Hatcheries between October 2001 and October 2003. Results for metals and DDT contain data from the two labs using different assays (see Methods). Total DDT, Total Dioxins, Total Furans and Total PCBs were determined by summing across classes of compounds. All other variables were determined by independent assays. Numbers (n) of samples positive for the variable are in parentheses.

Hatchery	Ash (%)	Lipids (%)	Moisture (%)	Protein (%)	Total Dioxins ($pg\ g^{-1}$)	Total Furans ($pg\ g^{-1}$)	Total PCB ($ng\ g^{-1}$)	Total DDT (μg/kg)	BHC (μg/kg)
Coleman (6)	8.4 ± 0.4 (6)	18.7 ± 2.3 (6)	13.4 ± 9.4 (6)	45.9 ± 2.0 (6)	9.50 ± 4.04 (3)	0.92 (1)	1.24 ± 0.89 (4)	8.00 ± 0.57 (2)	--
Ennis (8)	8.5 ± 1.1 (8)	12.9 ± 1.0 (8)	9.0 ± 0.7 (8)	43.9 ± 2.7 (8)	13.05 ± 4.16 (4)	0.73 (1)	0.53 ± 0.42 (5)	4.90 ± 0.71 (2)	--
Garrison Dam (6)	8.5 ± 0.4 (6)	19.5 ± 0.7 (6)	11.7 ± 7.1 (6)	47.1 ± 1.0 (6)	168.9 ± 171.5 (4)	0.96 ± 0.33 (3)	1.86 ± 1.58 (3)	25.00 ± 5.66 (2)	--
Genoa (6)	8.2 ± 0.9 (6)	17.0 ± 1.8 (6)	8.1 ± 1.0 (6)	44.7 ± 2.3 (6)	19.82 ± 7.87 (5)	1.15 ± .07 (2)	1.59 ± 1.49 (5)	6.90 (1)	--
Hagerman (8)	8.5 ± 1.7 (8)	15.5 ± 2.8 (8)	7.6 ±1.3 (8)	47.5 ± 3.4 (8)	34.5 ± 40.3 (4)	1.17 ± 0.30 (3)	2.17 ± 1.70 (5)	11.37 ± 7.87 (3)	24.0 (1)
Jordan River (7)	9.0 ± 0.9 (7)	14.8 ± 2.6 (6)	7.4 ± 1.2 (6)	47.4 ± 3.6 (6)	7.51 ± 1.61 (3)	0.64 (1)	0.24 ± 0.10 (4)	5.83 ± 0.67 (3)	--
Leavenworth (8)	7.9 ± 1.5 (8)	18.9 ± 3.7 (8)	15.2 ± 8.5 (8)	48.3 ± 3.4 (8)	39.75 ± 29.34 (2)	0.74 ± 0.08 (3)	1.88 ± 0.59 (4)	20.47 ± 10.81 (3)	--
North Attleboro (5)	6.7 ± 0.3 (5)	9.5 ± 0.7 (5)	42.8 ± 1.6 (5)	34.8 ± 2.3 (5)	35.45 ± 40.7 (2)	0.72 ± 0.06 (2)	1.43 ± 0.37 (4)	--	19.0 (1)
Quilcene (8)	8.3 ± 1.2 (8)	20.4 ± 2.3 (8)	6.0 ± 1.0 (8)	51.0 ± 1.6 (8)	5.7 ± 3.3 (3)	--	1.73 ± 0.90 (4)	4.00 (1)	--
Spring Creek (7)	8.5 ± 1.1 (7)	17.5 ± 2.5 (7)	12.7 ± 6.8 (7)	48.1 ± 1.3 (7)	6.33 ± 0.81 (3)	1.80 (1)	1.09 ± 1.92 (4)	9.77 ± 5.69 (3)	--
White Sulphur Springs (8)	7.7 ± 1.2 (8)	17.0 ± 2.4 (8)	7.5 ± 2.0 (8)	43.2 ± 18 (7)	60.25 ± 91.2 (4)	5.18 ± 4.84 (4)	9.87 ± 0.52 (3)	10.75 ± 5.88 (4)	--

Table 9. Continued

Hatchery	Aluminum ($\mu g\ g^{-1}$)	Arsenic ($\mu g\ g^{-1}$)	Barium ($\mu g\ g^{-1}$)	Boron ($\mu g\ g^{-1}$)	Cadmium ($\mu g\ g^{-1}$)	Chromium ($\mu g\ g^{-1}$)	Copper ($\mu g\ g^{-1}$)	Iron ($\mu g\ g^{-1}$)	Lead ($\mu g\ g^{-1}$)
Coleman	67.58 ± 61.88 (4)	2.35 ± 0.43 (4)	5.65 ± 3.22 (4)	5.61 ± 2.04 (4)	0.38 ± 0.17 (3)	1.43 ± 0.67 (4)	8.55 ± 1.82 (4)	271.5 ± 150.7 (4)	0.62 ± 0.40 (3)
Ennis	82.00 ± 41.74 (7)	1.85 ± 0.54 (7)	11.96 ± 2.1 (7)	7.51 ± 1.28 (7)	0.32 ± 0.24 (4)	1.52 ± 0.61 (7)	10.11 ± 1.87 (7)	370.9 ± 73.3 (7)	0.78 ± 0.05 (2)
Garrison Dam	67.18 ± 62.50 (4)	2.92 ± 0.18 (4)	5.88 ± 2.69 (4)	5.21 ± 2.48 (4)	0.42 ± 0.29 (3)	1.32 ± 0.29 (3)	7.07 ± 1.49 (4)	414.3 ± 38.3 (4)	0.39 ± 0.17 (2)
Genoa	92.45 ± 61.23 (58)	1.81 ± 1.02 (5)	7.80 ± 4.43 (5)	6.75 ± 3.56 (5)	0.09 ± 0.01 (2)	2.60 ± 1.40 (4)	8.40 ± 4.89 (5)	400.0 ± 221.3 (5)	--
Hagerman	56.43 ± 46.69 (5)	2.66 ± 0.76 (5)	4.33 ± 2.19 (5)	4.03 ± 1.69 (5)	0.53 ± 0.40 (3)	1.53 ± 0.56 (5)	8.92 ± 1.82 (5)	398.8 ± 60.8 (5)	0.46 ± 0.38 (2)
Jordan River	60.02 ± 25.19 (5)	2.34 ± 1.15 (5)	9.30 ± 3.03 (5)	6.09 ± 1.70 (5)	0.31 ± 0.12 (4)	1.43 ± 0.51 (5)	12.55 ± 4.75 (5)	388.7 ± 109.6 (5)	1.06 ± 0.42 (4)
Leavenworth	15.75 ± 9.62 (4)	2.73 ± 0.81 (4)	2.83 ± 1.28 (4)	2.96 ± 0.70 (4)	0.46 ± 0.30 (4)	1.09 ± 0.47 (4)	7.65 ± 1.63 (4)	275.8 ± 115.9 (4)	0.46 ± 0.08 (2)
North Attleboro	26.50 ± 5.33 (4)	6.19 ± 2.23 (4)	1.75 ± 0.33 (4)	3.64 ± 0.75 (4)	0.37 ± 0.07 (4)	1.54 ± 1.21 (4)	25.68 ± 5.42 (4)	202.3 ± 134.1 (4)	0.10 ± 0.01 (2)
Quilcene	16.94 ± 8.89 (7)	1.89 ± 0.46 (7)	2.91 ± 0.58 (7)	3.96 ± 1.42 (7)	0.48 ± 0.11 (7)	1.01 ± 0.21 (7)	8.89 ± 2.49 (7)	206.9 ± 51.6 (7)	0.29 ± 0.02 (2)
Spring Creek	73.42 ± 23.47 (5)	2.98 ± 0.92 (5)	9.02 ± 1.32 (5)	4.76 ± 1.87 (5)	0.33 ± 0.17 (5)	1.89 ± 0.66 (5)	9.71 ± 3.50 (5)	474.8 ± 95.8 (5)	0.40 ± 0.15 (3)
White Sulphur Springs	128.45 ± 76.41 (4)	2.44 ± 0.53 (4)	10.43 ± 1.19 (4)	7.11 ± 1.00 (4)	0.34 (1)	1.38 ± 0.57 (4)	10.94 ± 4.95 (4)	444.0 ± 35.4 (4)	2.39 ± 2.98 (3)

Table 9. Continued

Hatchery	Magnesium ($\mu g\ g^{-1}$)	Manganese ($\mu g\ g^{-1}$)	Mercury ($\mu g\ g^{-1}$)	Molybdenum ($\mu g\ g^{-1}$)	Nickel ($\mu g\ g^{-1}$)	Selenium ($\mu g\ g^{-1}$)	Strontium ($\mu g\ g^{-1}$)	Vanadium ($\mu g\ g^{-1}$)	Zinc ($\mu g\ g^{-1}$)
Coleman	1639 ± 116 (4)	38.20 ± 10.43 (4)	0.02 ± 0.01 (4)	0.50 ± 0.15 (4)	2.54 ± 0.91 (4)	2.26 ± 0.33 (4)	36.9 ± 14.39 (4)	3.09 ± 0.47 (3)	115.41 ± 12.4 (4)
Ennis	2221 ± 238 (7)	122.06 ± 44.2 (7)	0.02 ± 0.01 (6)	0.80 ± 0.24 (7)	2.52 ± 1.05 (7)	2.40 ± 0.50 (7)	34.34 ± 8.82 (7)	1.70 ± 0.85 (7)	186.30 ± 27.8 (7)
Garrison Dam	1550 ± 92 (4)	107.1 ± 56.29 (4)	0.07 ± 0.05 (4)	0.44 ± 0.22 (3)	1.91 ± 0.25 (4)	3.20 ± 0.54 (4)	58.4 ± 38.22 (4)	1.06 ± 0.19 (4)	155.81 ± 11.7 (4)
Genoa	1564 ± 811 (5)	52.72 ± 28.26 (5)	0.01 ± 0.00 (3)	0.98 ± 0.35 (4)	1.87 ± 0.86 (5)	2.15 ± 1.07 (5)	20.26 ± 9.3 (5)	0.89 ± 0.38 (5)	119.44 ± 59.2 (5)
Hagerman	1447 ± 246 (5)	85.02 ± 39.24 (5)	0.06 ± 0.03 (5)	0.52 ± 0.43 (5)	2.03 ± 1.46 (5)	2.40 ± 0.46 (5)	60.36 ± 32.8 (5)	1.76 ± 1.99 (5)	136.9 ± 25.58 (5)
Jordan River	2108 ± 312 (5)	120.20 ± 6.14 (5)	0.02 ± 0.01 (5)	1.16 ± 0.74 (4)	3.00 ± 0.75 (5)	2.10 ± 0.65 (5)	37.79 ± 9.12 (5)	2.42 ± 0.94 (5)	158.17 ± 10.4 (5)
Leavenworth	1513 ± 152 (4)	66.33 ± 37.73 (4)	0.05 ± 0.02 (4)	1.28 ± 0.43 (2)	2.33 ± 1.35 (4)	2.46 ± 0.82 (4)	65.81 ± 24.2 (4)	2.21 ± 1.82 (4)	111.36 ± 16.5 (4)
North Attleboro	1742 ± 548 (4)	79.65 ± 22.88 (4)	0.05 ± 0.02 (4)	0.31 ± 0.04 (2)	2.95 ± 3.30 (4)	2.86 ± 0.95 (4)	91.64 ± 28.9 (4)	0.75 ± 0.61 (4)	198.00 ± 63.8 (4)
Quilcene	1775 ± 394 (7)	31.49 ± 12.81 (7)	0.03 ± 0.02 (7)	0.33 ± 0.07 (7)	1.43 ± 0.66 (7)	2.67 ± 0.59 (7)	47.07 ± 13.1 (7)	1.71 ± 1.22 (7)	105.55 ± 17.0 (7)
Spring Creek	1953 ± 324 (5)	130.66 ± 50.1 (5)	0.02 ± 0.01 (5)	0.82 ± 0.28 (5)	3.75 ± 1.90 (5)	2.62 ± 0.67 (5)	41.52 ± 12.1 (5)	5.34 ± 3.10 (5)	168.63 ± 30.4 (5)
White Sulphur Springs	1609 ± 287 (4)	92.38 ± 14.06 (4)	0.01 ± 0.00 (4)	1.55 ± 0.81 (4)	1.90 ± 0.36 (4)	2.19 ± 0.66 (4)	21.42 ± 4.32 (4)	2.15 ± 0.88 (4)	108.60 ± 23.1 (4)

Table 10. Mean + standard deviation (SD) of constituents found in fish feed samples from six manufacturers collected from 11 National Fish Hatcheries between October 2001 and October 2003. Results for metals and DDT contain data from the two labs using different assays (see Methods). Total DDT, Total Dioxins, Total Furans and Total PCBs were determined by summing across classes of compounds. All other variables were determined by independent assays. Numbers (n) of samples positive for the variable are in parentheses.

Feed Manufacturer	Ash (%)	Lipids (%)	Moisture (%)	Protein (%)	Total Dioxins ($pg\ g^{-1}$)	Total Furans ($pg\ g^{-1}$)	Total PCB ($ng\ g^{-1}$)	Total DDT ($ng\ g^{-1}$)	BHC ($ng\ g^{-1}$)
A (10)	8.9 ± 1.0 (10)	17.2 ± 2.3 (10)	22.8 ± 2.0 (10)	46.9 ± 2.7 (10)	28.52 ± 19.34 (6)	1.04 ± 0.43 (6)	2.56 ± 1.07 (6)	18.83 ± 9.18 (7)	--
B (14)	7.8 ± 1.1 (14)	20.8 ± 2.5 (14)	6.6 ± 1.2 (14)	49.9 ± 2.7 (14)	5.83 ± 2.71 (4)	--	1.32 ± 0.84 (7)	4.00 (1)	--
C (5)	6.7 ± 0.3 (5)	9.5 ± 0.7 (5)	42.8 ± 1.6 (5)	34.8 ± 2.3 (5)	36.20 ± 39.60 (2)	0.72 ± 0.06 (2)	1.02 ± 0.57 (4)	--	--
D (21)	8.8 ± 1.0 (21)	16.8 ± 2.3 (21)	7.9 ± 1.3 (21)	46.6 ± 2.8 (19)	54.83 ± 106.48 (15)	0.93 ± 0.42 (10)	1.85 ± 1.38 (14)	8.97 ± 5.69 (6)	24.0 (1)
E (19)	8.4 ± 0.9 (19)	15.2 ± 2.5 (19)	8.2 ± 2.1 (19)	46.1 ± 3.3 (19)	20.95 ± 37.70 (7)	0.64 (1)	0.41 ± 0.52 (12)	6.57 ± 3.80 (6)	19.0 (1)
F (8)	7.7 ± 1.3 (8)	17.0 ± 2.5 (8)	7.5 ± 2.0 (8)	43.2 ± 1.8 (8)	60.25 ± 91.19 (4)	5.18 ± 4.84 (4)	9.87 ± 0.52 (3)	10.75 ± 5.88 (4)	--

Table 10. Continued

Feed Manufacturer	Aluminum ($\mu g\ g^{-1}$)	Arsenic ($\mu g\ g^{-1}$)	Barium ($\mu g\ g^{-1}$)	Boron ($\mu g\ g^{-1}$)	Cadmium ($\mu g\ g^{-1}$)	Chromium ($\mu g\ g^{-1}$)	Copper ($\mu g\ g^{-1}$)	Iron ($\mu g\ g^{-1}$)	Lead ($\mu g\ g^{-1}$)
A	45.14 ± 51.55 (7)	3.11 ± 0.30 (7)	4.93 ± 3.31 (7)	4.33 ± 2.36 (7)	0.48 ± 0.26 (6)	1.54 ± 0.60 (6)	6.57 ± 1.06 (7)	374.29 ± 91.71 (7)	0.53 ± 0.19 (5)
B	16.12 ± 9.34 (10)	1.90 ± 0.40 (10)	2.93 ± 0.52 (10)	3.86 ± 1.20 (10)	0.45 ± 0.13 (10)	1.03 ± 0.24 (10)	9.18 ± 2.10 (10)	190.70 ± 49.96 (10)	0.29 ± 0.10 (4)
C	28.75 ± 3.88 (4)	5.66 ± 3.09 (4)	4.18 ± 4.69 (4)	4.82 ± 1.77 (4)	0.37 ± 0.07 (4)	3.40 ± 3.23 (4)	21.98 ± 8.95 (4)	267.8 ± 119.0 (4)	0.10 ± 0.01 (2)
D	89.88 ± 48.72 (15)	2.34 ± 0.86 (15)	7.44 ± 4.18 (15)	6.19 ± 2.85 (15)	0.35 ± 0.36 (7)	1.92 ± 0.93 (14)	8.60 ± 3.01 (15)	395.13 ± 124.34 (15)	0.67 ± 0.33 (4)
E	61.89 ± 29.69 (15)	2.39 ± 0.97 (15)	8.87 ± 3.21 (15)	5.40 ± 1.71 (15)	0.32 ± 0.17 (13)	1.42 ± 0.60 (15)	12.06 ± 5.09 (15)	411.0 ± 131.2 (15)	0.80 ± 0.46 (7)
F	128.45 ± 76.41 (4)	2.44 ± 0.53 (4)	10.43 ± 1.19 (4)	7.11 ± 1.00 (4)	0.34 (1)	1.38 ± 0.57 (4)	10.94 ± 4.95 (4)	444.00 ± 35.36 (4)	2.39 ± 2.98 (3)

Table 10. Continued

Feed Manufacturer	Magnesium ($\mu g\ g^{-1}$)	Manganese ($\mu g\ g^{-1}$)	Mercury ($\mu g\ g^{-1}$)	Molybdenum ($\mu g\ g^{-1}$)	Nickel ($\mu g\ g^{-1}$)	Selenium ($\mu g\ g^{-1}$)	Strontium ($\mu g\ g^{-1}$)	Vanadium ($\mu g\ g^{-1}$)	Zinc ($\mu g\ g^{-1}$)
A	1579 ± 158 (7)	91.84 ± 49.93 (7)	0.06 ± 0.04 (7)	0.93 ± 0.62 (4)	2.38 ± 1.27 (7)	2.71 ± 0.89 (7)	65.58 ± 29.26 (7)	2.56 ± 2.35 (7)	129.71 ± 26.62 (7)
B	1737 ± 333 (10)	31.04 ± 10.70 (10)	0.03 ± 0.02 (10)	0.41 ± 0.21 (10)	1.75 ± 0.92 (10)	2.54 ± 0.56 (10)	47.76 ± 12.18 (10)	2.06 ± 1.27 (9)	106.80 ± 14.27 (10)
C	2099 ± 552 (4)	113.95 ± 57.64 (4)	0.05 ± 0.02 (3)	0.51 ± 0.36 (3)	1.65 ± 0.91 (4)	2.99 ± 0.82 (4)	86.37 ± 36.19 (4)	1.22 ± 0.77 (4)	208.74 ± 53.69 (4)
D	1629 ± 526 (15)	67.56 ± 29.43 (15)	0.04 ± 0.03 (13)	0.68 ± 0.36 (13)	2.14 ± 0.98 (15)	2.39 ± 0.65 (15)	36.57 ± 27.54 (15)	1.31 ± 0.84 (15)	147.14 ± 48.68 (15)
E	1953 ± 391 (15)	123.02 ± 33.86 (15)	0.02 ± 0.01 (15)	0.88 ± 0.46 (13)	3.26 ± 1.90 (15)	2.35 ± 0.65 (15)	40.68 ± 12.49 (15)	2.80 ± 2.48 (15)	160.00 ± 21.47 (15)
F	1609 ± 287 (4)	92.38 ± 14.06 (4)	0.01 ± 0.00 (4)	1.55 ± 0.81 (4)	1.90 ± 0.36 (4)	2.19 ± 0.66 (4)	21.42 ± 4.32 (4)	2.15 ± 0.88 (4)	108.60 ± 23.06 (4)

Table 11. Total PCBs, 14 dioxin-like PCBs (DL-PCBs), toxic equivalents (TEQ; pg g^{-1}) for the DL-PCBs, and DDT metabolites (ng g^{-1} wet weight) in feed from specific manufacturers (A, B and D) as reported in three studies spanning about 25 years. Values for Pre-1979 are the range of means from Mac et al. (1979); values for 1999 are data from 1 or 2 assays presented in Easton et al. (2002); values for 2001-2003 are ranges of results from this report, not including those below detection levels. Sample sizes are in parentheses; for this report, we also report total number of samples examined.

	Pre-1979	1999	2001-2003
A			
Total PCBs	100 - 230 (n = 3-4)	43 & 107 (2 samples)	ND
14 DL-PCBs	ND	6.7 & 4.4	1.4 - 4.0 (n = 6 of 10)
TEQ	ND	0.312 & 0.261	0.046 to 0.135
DDT metabolites	10 - 340 (n = 3-4)	50 & 50 (2 samples)	8.4 - 31.0 (n = 7 of 10)
B			
Total PCBs	ND	90.2 (1 sample)	ND
14 DL- PCBs	ND	5.2	0.4 - 3.0 (n = 7 of 14)
TEQ (mean $\pm$ SE)	ND	0.177	0.015 to 0.041
DDT metabolites	ND	30.7 (1 sample)	4.0 (n = 1 of 14)
D			
Total PCBs	54 - 60 (n = 3)	ND	ND
14 DL-PCBs	ND	ND	0.6 - 4.8 (n = 14 of 19)
TEQ	ND	ND	0.004 to 0.125
DDT metabolites	13 - 51 (n = 3)	ND	4.4 - 20.0 (n = 6 of 19)

ND – no data available

Figure1. Fish feed quality control sample analysis form.

Abernathy Fish Technology Center Nutrition Program Fish Feed Quality Control Sample Analysis Form	
Hatchery Name:	**Hatchery Contact Person:**
Today's Date:	**Feed Manufacturer:**
Date of Feed Manufacture:	**Date Feed Received:**
Lot Number (if any):	**Size of Feed:**
Comments (i.e. Have any problems been observed with the fish? Why are you sending this sample in?): **Please provide the name of the feed.**	

Appendix A

Raw Data from Contaminants Assays of Feed
Collected from National Fish Hatcheries

(values > minimum detection levels; assays conducted at several laboratories, some using different methods; please see Methods)

DATE*	HATCHERY (NFH)	HpCDD pg g^{-1}	PeCDD pg g^{-1}	TCDD pg g^{-1}	TCDF pg g^{-1}	OCDD pg g^{-1}	OCDF pg g^{-1}	Tot HpCDD pg g^{-1}	Tot HpCDF pg g^{-1}
11/09/01	Coleman								
02/01/02	Coleman					14.000			
05/23/02	Coleman				0.920	8.300			
09/12/02	Coleman					6.200			
02/19/03	Coleman								
05/07/03	Coleman								
10/16/01	Ennis				0.730	17.000			
12/19/02	Ennis					11.000			
04/08/02	Ennis								
06/22/02	Ennis								
10/30/02	Ennis					8.200			
02/10/03	Ennis								
	Ennis					16.000			
07/30/03	Ennis								
11/19/01	Garrison Dam	3.100			1.300	31.000		3.100	
11/19/01	Garrison Dam	3.300			0.930	33.000		3.300	
09/13/02	Garrison Dam								
12/23/02	Garrison Dam	44.000			0.640	350.000		66.000	
07/14/03	Garrison Dam	11.000				200.000		19.000	
12/19/03	Garrison Dam								
10/25/01	Genoa	3.300			1.100	20.000		6.100	
09/26/02	Genoa				1.200	17.000			
09/26/02	Genoa								
02/14/03	Genoa					12.000			
02/14/03	Genoa					15.000			
07/12/02	Genoa	4.800				27.000		8.000	
12/31/01	Hagerman				1.100	12.000			
01/02/02	Hagerman				0.890	19.000			
04/19/02	Hagerman								
06/28/02	Hagerman				1.600	16.000			
11/18/02	Hagerman	6.400				100.000		11.000	3.000
02/18/03	Hagerman								
07/02/03	Hagerman				1.100	19.000			
08/08/03	Hagerman								

* Date sample received at Abernathy

HATCHERY (NFH)	Tot PeCDD pg g^{-1}	PCB105 ng g^{-1}	PCB114 ng g^{-1}	PCB118 ng g^{-1}	PCB 123 ng g^{-1}	PCB 126 ng g^{-1}	PCB 156 ng g^{-1}
Coleman		0.094		0.210			
Coleman		0.220		0.560			0.065
Coleman		0.260		0.840			0.100
Coleman		0.120		0.310			0.049
Coleman							
Coleman							
Ennis							
Ennis		0.089		0.290			0.049
Ennis							
Ennis		0.069		0.180			0.029
Ennis		0.046		0.130			
Ennis				0.071			
Ennis		0.120		0.330			0.057
Ennis							
Garrison Dam							
Garrison Dam		0.410	0.050	1.400			0.180
Garrison Dam							
Garrison Dam		0.120		0.340			0.048
Garrison Dam		0.110		0.360			0.048
Garrison Dam							
Genoa		0.410		1.400	0.028		0.180
Genoa		0.095		0.320			0.063
Genoa							
Genoa		0.064		0.200			
Genoa		0.130		0.410			0.063
Genoa	6.400	0.071		0.230			0.029
Hagerman		0.480	0.034	1.500	0.046		0.230
Hagerman		0.360		1.100			0.170
Hagerman		0.052		0.140			
Hagerman		0.220		0.600			0.074
Hagerman		0.089		0.270			0.043
Hagerman							
Hagerman		0.240		0.730	0.015		0.087
Hagerman							

HATCHERY (NFH)	PCB 157 ng g^{-1}	PCB 167 ng g^{-1}	PCB 77 ng g^{-1}	Tot PCB ng g^{-1}	Ash %	Lipids %	Moisture %	Protein %	Aluminum µg g^{-1}
Coleman				0.434	8.600	20.600	8.400	49.400	5.610
Coleman	0.065			1.370	8.400	16.800	24.400	45.400	140.000
Coleman	0.100	0.061	0.036	2.437	8.100	18.000	9.100	44.500	96.600
Coleman	0.049			0.708	7.800	22.400	6.300	45.200	28.100
Coleman					8.900	16.800	26.400	43.900	
Coleman					8.600	17.700	5.500	47.000	
Ennis					9.400	14.700	8.800	45.800	110.000
Ennis	0.049			0.828	9.200	13.400	10.000	45.600	137.000
Ennis				0.000	7.500	12.800	9.800	42.000	47.900
Ennis	0.029			0.447	7.600	11.400	8.400	42.700	76.700
Ennis				0.227	7.200	12.100	9.400	41.200	29.900
Ennis				0.071	8.400	12.900	9.300	40.300	49.500
Ennis	0.057			1.074	8.500	12.800	8.400	47.500	123.000
Ennis					10.300	13.000	7.900	46.300	
Garrison Dam					8.500	19.200	20.700	46.000	14.100
Garrison Dam	0.180	0.068		3.688	8.800	18.600	20.900	46.300	12.600
Garrison Dam					9.100	19.500	6.300	46.400	
Garrison Dam	0.048			0.932	8.600	20.300	8.100	48.500	129.000
Garrison Dam	0.048			0.956	8.400	19.200	8.500	47.800	113.000
Garrison Dam					7.800	20.400	5.800	47.500	
Genoa	0.180	0.090	0.060	4.208	7.400	17.900	8.400	42.200	1.940
Genoa	0.063			1.011	9.100	18.700	6.400	48.000	167.000
Genoa					8.400	15.500	7.700	44.100	
Genoa				0.572	7.300	16.400	9.000	43.600	76.600
Genoa	0.063	0.037		1.393	9.300	19.000	8.200	47.100	124.000
Genoa	0.029	0.027		0.772	7.400	14.700	9.100	43.100	92.700
Hagerman	0.230	0.100	0.130	4.809	8.600	16.800	8.800	45.700	16.500
Hagerman	0.170	0.087		3.527	8.700	17.700	7.300	46.300	9.600
Hagerman				0.341	8.300	17.000	6.900	45.500	30.300
Hagerman	0.074			1.428	10.300	14.700	7.900	53.000	83.800
Hagerman	0.043			0.887	8.100	16.000	8.600	46.200	131.000
Hagerman					8.200	16.000	7.100	46.800	
Hagerman	0.087	0.035		2.004	10.900	16.600	8.800	52.600	67.400
Hagerman					9.000	16.700	5.100	43.800	

HATCHERY (NFH)	Arsenic $\mu g\ g^{-1}$	Barium $\mu g\ g^{-1}$	Copper $\mu g\ g^{-1}$	Iron $\mu g\ g^{-1}$	Lead $\mu g\ g^{-1}$	Magnesium $\mu g\ g^{-1}$	Manganese $\mu g\ g^{-1}$	Mercury $\mu g\ g^{-1}$
Coleman	2.087	2.500	10.475	153.000	0.164	1798	25.900	0.014
Coleman	2.983	9.200	6.732	447.000	0.795	1654	50.600	0.019
Coleman	2.220	7.500	7.293	347.000	0.911	1545	41.400	0.015
Coleman	2.100	3.400	9.700	139.000		1560	34.900	0.029
Coleman								
Coleman								
Ennis	2.724	10.400	6.745	368.000	0.819	2158	85.800	0.018
Ennis	2.207	15.300	8.902	450.000	0.746	2229	79.100	0.020
Ennis	2.193	13.500	11.928	324.000		2312	130.000	0.010
Ennis	1.500	9.200	9.500	454.000		1890	155.000	0.033
Ennis	1.600	11.200	11.300	344.000		2640	196.000	
Ennis	1.200	13.100	10.600	249.000		2290	130.000	0.018
Ennis	1.500	11.000	11.800	407.000		2030	78.500	0.014
Ennis								
Garrison Dam	3.111	3.600	5.328	412.000	0.269	1488	144.000	0.099
Garrison Dam	2.876	3.500	6.336	364.000	0.512	1671	166.000	0.122
Garrison Dam								
Garrison Dam	2.700	8.100	8.400	425.000		1470	52.900	0.031
Garrison Dam	3.000	8.300	8.200	456.000		1570	65.400	0.034
Garrison Dam								
Genoa	0.246	0.200	1.203	15.000		212	3.600	
Genoa	2.800	9.900	8.200	487.000		1690	56.000	0.016
Genoa								
Genoa	1.900	9.600	14.800	547.000		2180	70.400	0.010
Genoa	2.600	7.900	7.800	535.000		1540	61.200	0.016
Genoa	1.500	11.400	10.000	416.000		2200	72.400	
Hagerman	4.064	2.200	7.206	429.000		1346	130.000	0.096
Hagerman	2.903	2.300	7.778	328.000	0.187	1766	98.200	0.055
Hagerman	2.118	7.300	9.935	477.000	0.727	1749	119.000	0.032
Hagerman	2.600	4.000	12.100	384.000		1200	85.400	0.068
Hagerman	2.100	6.700	7.900	442.000		1320	44.400	0.019
Hagerman								
Hagerman	2.200	3.500	8.600	333.000		1300	33.100	0.082
Hagerman								

HATCHERY	Molybd	Nickel	Zinc	alphaBHC	DeltaBHC	4,4-DDE	p,p-DDE	Tot DDT
(NFH)	μg g^{-1}	μg g^{-1}	μg g^{-1}	μg kg^{-1}	μg kg^{-1}	μg kg^{-1}	μg kg^{-1}	μg kg^{-1}
Coleman	0.416	3.084	108.478					
Coleman	0.699	2.757	132.932				8.400	8.400
Coleman	0.550	3.112	115.246				7.600	7.600
Coleman	0.350	1.200	105.000					
Coleman								
Coleman								
Ennis	0.877	3.162	216.390				5.400	5.400
Ennis	0.919	4.439	210.827				4.400	4.400
Ennis	0.283	1.317	164.900					
Ennis	0.710	1.600	164.000					
Ennis	0.920	2.600	184.000					
Ennis	0.980	2.100	161.000					
Ennis	0.910	2.400	203.000					
Ennis								
Garrison Dam		1.640	149.761				21.000	21.000
Garrison Dam	0.178	1.784	172.479				29.000	29.000
Garrison Dam								
Garrison Dam	0.540	2.000	146.000					
Garrison Dam	0.590	2.200	155.000					
Garrison Dam								
Genoa		0.464	14.205				6.900	6.900
Genoa	0.600	2.700	142.000					
Genoa								
Genoa	1.100	2.000	155.000					
Genoa	0.800	1.800	138.000					
Genoa	1.400	2.400	148.000					
Hagerman		1.559	139.286				20.000	20.000
Hagerman	0.158	1.776	139.114				9.500	9.500
Hagerman	1.008	4.923	150.785				4.600	4.600
Hagerman	0.230	1.200	175.000	24.000				
Hagerman	0.980	1.800	107.000					
Hagerman	0.220	0.910	110.000					
Hagerman								
Hagerman								

DATE*	HATCHERY (NFH)	HpCDD pg g^{-1}	PeCDD pg g^{-1}	TCDD pg g^{-1}	TCDF pg g^{-1}	OCDD pg g^{-1}	OCDF pg g^{-1}	Tot HpCDD pg g^{-1}	Tot HpCDF pg g^{-1}
12/19/01	Jordan River					8.300			
12/19/01	Jordan River			0.550	0.640	8.300			
04/08/02	Jordan River					7.700			
09/19/02	Jordan River					5.200			
07/23/03	Jordan River								
07/23/03	Jordan River								
07/29/03	Jordan River								
01/23/02	Leavenworth				0.700				
04/22/02	Leavenworth								
05/08/02	Leavenworth	6.500			0.690	54.000		11.000	
06/21/02	Leavenworth								
10/30/02	Leavenworth								
02/06/03	Leavenworth				0.830	19.000			
04/30/03	Leavenworth								
07/29/03	Leavenworth								
01/16/02	North Attleboro				0.760				
04/16/02	North Attleboro				0.670				
06/25/02	North Attleboro								
01/23/03	North Attleboro					6.700			
07/15/03	North Attleboro	4.300	3.900			56.000		9.800	
10/05/01	Quilcene								
02/22/02	Quilcene								
04/10/02	Quilcene					5.500			
06/25/02	Quilcene					9.100			
10/29/02	Quilcene								
02/27/03	Quilcene								
05/23/03	Quilcene								
07/29/03	Quilcene		2.500						
12/31/01	Spring Creek				1.800	7.200			
01/21/02	Spring Creek					5.600			
04/04/02	Spring Creek								
12/14/02	Spring Creek								
02/04/03	Spring Creek					6.200			
04/29/03	Spring Creek								
12/27/03	Spring Creek								

* Date received

HATCHERY (NFH)	Tot PeCDD $pg\ g^{-1}$	Tot TCDD $pg\ g^{-1}$	Tot TCDF $pg\ g^{-1}$	Tot dioxin $pg\ g^{-1}$	Tot Furans $pg\ g^{-1}$	PCB105 $ng\ g^{-1}$	PCB114 $ng\ g^{-1}$	PCB118 $ng\ g^{-1}$	PCB 123 $ng\ g^{-1}$	PCB 126 $ng\ g^{-1}$	PCB 156 $ng\ g^{-1}$
Jordan River				8.300		0.038		0.120			
Jordan River		0.550	0.640	8.850	0.640						
Jordan River				7.700		0.036		0.074			
Jordan River				5.200		0.073		0.160			0.023
Jordan River								0.073			
Jordan River											
Jordan River											
Leavenworth			0.700		0.700	0.230		0.690			0.086
Leavenworth						0.190		0.450			0.077
Leavenworth			0.690	60.500	0.690	0.350	0.024	0.940			0.130
Leavenworth											
Leavenworth											
Leavenworth			1.600	19.000	0.830	0.260		0.750			0.100
Leavenworth											
Leavenworth											
North Attleboro			0.760		0.760	0.190		0.570			0.063
North Attleboro			0.670		0.670	0.220		0.580			0.080
North Attleboro											
North Attleboro			0.870	6.700		0.260		0.780	0.013		0.094
North Attleboro	19.000			64.200		0.130		0.410			0.043
Quilcene											
Quilcene											
Quilcene				5.500							
Quilcene				9.100		0.130		0.380			0.050
Quilcene											
Quilcene						0.120		0.320			0.087
Quilcene						0.170		0.430	0.021		0.082
Quilcene	13.000			2.500		0.180		0.470			0.070
Spring Creek			1.800	7.200	1.800	0.590	0.040	1.600			0.190
Spring Creek				5.600							
Spring Creek								0.051			
Spring Creek											
Spring Creek				6.200		0.043		0.110			
Spring Creek						0.030		0.061			
Spring Creek											

HATCHERY (NFH)	PCB 157 ng g^{-1}	PCB 167 ng g^{-1}	PCB 170 ng g^{-1}	PCB 180 ng g^{-1}	PCB 189 ng g^{-1}	PCB 77 ng g^{-1}	Tot PCB ng g^{-1}	Ash %	Lipids %	Moisture %	Protein %	Aluminum µg/g
Jordan River				0.120			0.278	10.400	20.500	6.100	55.200	103.000
Jordan River								8.200	14.900	8.400	45.100	46.500
Jordan River				0.072			0.182	8.900	13.200	9.200	44.800	42.900
Jordan River	0.023			0.086			0.365	7.700	13.700	7.200	45.700	45.500
Jordan River				0.064			0.137	9.100	13.900	7.000	47.000	62.200
Jordan River								9.400	13.100	7.600	48.100	
Jordan River								9.300	14.400	6.000	45.600	
Leavenworth	0.086	0.035	0.130	0.340			1.597	7.900	17.000	23.000	48.700	9.600
Leavenworth	0.077		0.110	0.310			1.214	7.200	19.400	8.700	49.800	8.880
Leavenworth	0.130	0.071	0.190	0.730			2.565	8.100	18.400	24.400	43.300	14.900
Leavenworth								7.100	19.500	7.700	51.300	
Leavenworth								7.300	26.800	6.300	43.600	
Leavenworth	0.100	0.043	0.220	0.670			2.143	11.100	13.900	21.500	51.700	29.600
Leavenworth								8.300	16.700	23.500	46.800	
Leavenworth								5.800	19.200	6.700	51.100	
North Attleboro	0.063	0.029	0.110	0.310			1.335	6.800	9.300	41.900	37.000	23.600
North Attleboro	0.080	0.038	0.140	0.380			1.518	6.400	8.900	42.100	35.400	32.900
North Attleboro								6.300	10.800	42.400	36.200	
North Attleboro	0.094	0.034	0.150	0.460			1.885	7.100	9.400	42.100	34.400	20.900
North Attleboro	0.043	0.024	0.085	0.260			0.995	6.800	9.200	45.700	31.200	28.600
Quilcene								7.600	19.700	7.400	49.300	10.400
Quilcene								7.000	24.900	6.200	53.900	8.850
Quilcene								7.800	21.900	5.400	49.600	9.710
Quilcene	0.050		0.084	0.210			0.904	7.200	19.300	6.600	51.600	14.000
Quilcene								7.900	19.800	5.900	49.700	
Quilcene	0.087	0.062	0.520	1.800			2.996	9.000	21.600	4.000	50.600	33.200
Quilcene	0.082	0.033	0.210	0.590			1.618	9.100	18.000	5.800	52.800	22.700
Quilcene	0.070	0.033	0.140	0.420			1.383	10.400	17.900	6.900	50.600	19.700
Spring Creek	0.190	0.088	0.270	1.000			3.968	9.100	21.400	20.300	46.800	95.200
Spring Creek								7.100	19.400	15.500	46.300	89.600
Spring Creek				0.042			0.093	7.800	17.200	7.600	48.200	45.200
Spring Creek								10.100	13.600	22.700	50.400	
Spring Creek				0.043			0.196	7.900	18.400	7.300	48.400	50.900
Spring Creek							0.091	8.200	16.300	8.300	48.100	86.200
Spring Creek								9.600	16.100	6.900	48.300	

HATCHERY (NFH)	Arsenic $\mu g\ g^{-1}$	Barium $\mu g\ g^{-1}$	Boron $\mu g\ g^{-1}$	Cadmium $\mu g\ g^{-1}$	Chromium $\mu g\ g^{-1}$	Copper $\mu g\ g^{-1}$	Iron $\mu g\ g^{-1}$	Lead $\mu g\ g^{-1}$	Magnesium $\mu g\ g^{-1}$	Manganese $\mu g\ g^{-1}$	Mercury $\mu g\ g^{-1}$
Jordan River	4.205	4.200	3.383	0.445	2.217	5.195	374.000	1.142	1601	123.000	0.037
Jordan River	1.988	11.600	5.929	0.371	1.334	16.086	470.000	0.623	2247	119.000	0.013
Jordan River	2.584	9.600	7.238		0.891	17.362	527.600	0.860	2424	110.000	0.019
Jordan River	1.500	9.500	6.100	0.180	1.100	12.100	330.000		2060	125.000	0.030
Jordan River	1.400	11.600	7.800	0.250	1.600	12.000	522.000	1.600	2210	124.000	0.016
Jordan River											
Jordan River											
Leavenworth	3.118	2.600	2.282	0.886	1.801	6.966	319.000		1536	90.700	0.064
Leavenworth	1.615	3.000	3.048	0.380	0.901	9.331	167.000	0.402	1593	29.200	0.029
Leavenworth	3.489	1.300	2.594	0.177	0.852	5.715	198.000	0.513	1293	39.400	0.051
Leavenworth											
Leavenworth											
Leavenworth	2.700	4.400	3.900	0.380	0.810	8.600	419.000		1630	106.000	0.037
Leavenworth											
Leavenworth											
North Attleboro	8.174	1.800	3.863	0.446	0.800	28.900	119.000	0.104	2168	100.000	0.064
North Attleboro	7.970	2.200	4.504	0.422	3.317	29.826	381.100	0.096	2258	98.900	0.071
North Attleboro											
North Attleboro	3.700	1.500	2.700	0.300	0.740	26.100	82.200		1210	58.800	0.042
North Attleboro	4.900	1.500	3.500	0.320	1.300	17.900	227.000		1330	60.900	0.028
Quilcene	1.517	2.300	4.037	0.396	0.894	5.332	202.000	0.273	1777	25.800	0.010
Quilcene	1.803	2.500	2.017	0.513	1.024	6.074	123.000		1374	15.400	0.034
Quilcene	2.392	3.500	3.445	0.467	1.290	8.848	195.000	0.308	1822	27.100	0.019
Quilcene	1.200	2.800	3.300	0.290	0.670	9.400	277.000		1280	18.700	0.026
Quilcene											
Quilcene	2.300	3.300	3.600	0.540	1.200	12.100	261.000		1750	42.700	0.036
Quilcene	1.700	2.300	4.700	0.480	1.100	11.300	213.000		1940	44.600	0.029
Quilcene	2.300	3.700	6.600	0.640	0.920	9.200	177.000		2480	46.100	0.065
Spring Creek	3.485	9.900	7.316	0.290	1.774	6.335	461.000	0.568	1784	46.200	0.016
Spring Creek	2.440	6.800	3.288	0.610	3.048	6.051	506.000	0.306	1514	137.100	0.044
Spring Creek	4.260	10.100	3.573	0.352	1.538	10.754	405.000	0.319	2366	147.000	0.007
Spring Creek											
Spring Creek	1.900	9.000	3.400	0.160	1.400	11.100	380.000		1980	143.000	0.027
Spring Creek	2.800	9.300	6.200	0.240	1.700	14.300	622.000		2120	180.000	0.012
Spring Creek											

HATCHERY (NFH)	Molybd $\mu g\ g^{-1}$	Nickel $\mu g\ g^{-1}$	Selenium $\mu g\ g^{-1}$	Strontium $\mu g\ g^{-1}$	Vanadium $\mu g\ g^{-1}$	Zinc $\mu g\ g^{-1}$	alphaBHC $\mu g\ kg^{-1}$	DeltaBHC $\mu g\ kg^{-1}$	4,4-DDE $\mu g\ kg^{-1}$	p,p-DDE $\mu g\ kg^{-1}$	Tot DDT $\mu g\ kg^{-1}$
Jordan River		3.671	2.858	53.168	3.049	164.271				6.400	6.400
Jordan River	0.698	3.900	1.377	32.643	3.376	155.884				5.100	5.100
Jordan River	2.250	2.151	1.458	36.230	2.072	141.701				6.000	6.000
Jordan River	0.690	2.600	2.300	29.600	0.980	160.000					
Jordan River	1.000	2.700	2.500	37.300	2.600	169.000					
Jordan River											
Jordan River											
Leavenworth		1.814	3.312	99.560	1.161	120.733				9.400	9.400
Leavenworth	0.976	3.231	1.862	55.083	2.943	115.706					
Leavenworth	1.591	3.608	1.672	43.284	4.403	86.998				21.000	21.000
Leavenworth											
Leavenworth											
Leavenworth		0.680	3.000	65.300	0.330	122.000			31.000		31.000
Leavenworth											
Leavenworth											
North Attleboro	0.278	1.665	3.559	117.004	1.344	247.400					
North Attleboro	0.332	1.933	3.798	116.369	1.216	258.539					
North Attleboro											
North Attleboro		7.800	2.000	65.900	0.230	141.000		19.000			
North Attleboro		0.420	2.100	67.300	0.220	145.000					
Quilcene	0.432	2.622	2.008	24.925	3.638	92.332					
Quilcene	0.299	1.633	2.727	63.789	1.571	84.973					
Quilcene	0.208	1.598	1.877	52.252	1.396	126.222				4.000	4.000
Quilcene	0.310	1.400	3.600	45.700	2.700	87.300					
Quilcene											
Quilcene	0.360	0.770	2.900	37.900	0.310	121.000					
Quilcene	0.370	0.580	2.600	45.800	0.280	116.000					
Quilcene	0.340	1.400	3.000	59.100	2.100	111.000					
Spring Creek	1.258	4.371	1.861	42.303	6.949	123.033				12.000	12.000
Spring Creek	0.566	2.961	3.549	52.479	5.694	158.321				3.300	3.300
Spring Creek	0.693	3.323	2.105	32.614	9.438	173.798				14.000	14.000
Spring Creek											
Spring Creek	0.640	1.500	2.800	53.900	1.800	184.000					
Spring Creek	0.950	6.600	2.800	26.300	2.800	204.000					
Spring Creek											

DATE*	HATCHERY (NFH)	HpCDD pg g^{-1}	PeCDD pg g^{-1}	TCDD pg g^{-1}	TCDF pg g^{-1}	OCDD pg g^{-1}	OCDF pg g^{-1}	Tot HpCDD pg g^{-1}	Tot HpCDF pg g^{-1}
11/14/01	Wt. Sulphur Springs				1.600	15.000			
02/27/02	Wt. Sulphur Springs	17.000			2.300	180.000	10.000	32.000	
05/06/02	Wt. Sulphur Springs				3.800	17.000			
09/16/02	Wt. Sulphur Springs								
11/22/02	Wt. Sulphur Springs								
02/13/03	Wt. Sulphur Springs				3.000	12.000			
05/21/03	Wt. Sulphur Springs								
10/14/03	Wt. Sulphur Springs								

* Date received at Abernathy FTC

HATCHERY (NFH)	Tot PeCDD pg g^{-1}	Tot TCDD pg g^{-1}	Tot TCDF pg g^{-1}	Tot dioxin pg g^{-1}	Tot Furans pg g^{-1}	PCB105 ng g^{-1}	PCB114 ng g^{-1}	PCB118 ng g^{-1}	PCB 123 ng g^{-1}	PCB 126 ng g^{-1}	PCB 156 ng g^{-1}
Wt. Sulphur Springs			2.200	15.000	1.600						
Wt. Sulphur Springs			2.300	197.000	12.300	0.940	0.067	3.600	0.068		0.370
Wt. Sulphur Springs			3.800	17.000	3.800	0.930	0.059	3.700	0.053		0.380
Wt. Sulphur Springs											
Wt. Sulphur Springs											
Wt. Sulphur Springs			3.000	12.000	3.000	1.000	0.064	4.100	0.063	0.017	0.370
Wt. Sulphur Springs											
Wt. Sulphur Springs											

HATCHERY (NFH)	PCB 157 ng g^{-1}	PCB 167 ng g^{-1}	PCB 170 ng g^{-1}	PCB 180 ng g^{-1}	PCB 189 ng g^{-1}	PCB 77 ng g^{-1}	Tot PCB ng g^{-1}	Ash %	Lipids %	Moisture %	Protein %	Aluminum µg g^{-1}
Wt. Sulphur Springs								6.800	11.500	10.200	41.100	83.800
Wt. Sulphur Springs	0.370	0.230	0.890	2.900	0.057	0.140	9.632	8.200	17.200	9.300	42.400	150.000
Wt. Sulphur Springs	0.380	0.220	0.880	2.800		0.120	9.522	8.300	17.200	9.000	42.600	226.000
Wt. Sulphur Springs								10.300	17.400	7.800	40.700	
Wt. Sulphur Springs								7.100	19.600	4.300	44.000	
Wt. Sulphur Springs	0.370	0.240	0.930	3.100	0.040	0.170	10.464	7.100	17.900	5.600	45.300	54.000
Wt. Sulphur Springs								6.900	17.700	6.700	44.300	
Wt. Sulphur Springs								6.900	17.800	6.900	45.400	

HATCHERY (NFH)	Arsenic µg g^{-1}	Barium µg g^{-1}	Boron µg g^{-1}	Cadmium µg g^{-1}	Chromium µg g^{-1}	Copper µg g^{-1}	Iron µg g^{-1}	Lead µg g^{-1}	Magnesium µg g^{-1}	Manganese µg g^{-1}	Mercury µg g^{-1}
Wt. Sulphur Springs	2.146	10.100	6.782		1.891	17.452	485.000	0.435	1970	105.000	0.014
Wt. Sulphur Springs	2.590	12.100	8.398		1.857	5.790	461.000	0.920	1618	81.700	0.011
Wt. Sulphur Springs	1.908	9.300	7.259	0.344	0.926	8.929	422.000	5.815	1577	78.800	0.009
Wt. Sulphur Springs											
Wt. Sulphur Springs											
Wt. Sulphur Springs	3.100	10.200	6.000		0.860	11.600	408.000		1270	104.000	0.012
Wt. Sulphur Springs											
Wt. Sulphur Springs											

HATCHERY (NFH)	Molybd $\mu g\ g^{-1}$	Nickel $\mu g\ g^{-1}$	Selenium $\mu g\ g^{-1}$	Strontium $\mu g\ g^{-1}$	Vanadium $\mu g\ g^{-1}$	Zinc $\mu g\ g^{-1}$	alphaBHC $\mu g\ kg^{-1}$	DeltaBHC $\mu g\ kg^{-1}$	4,4-DDE $\mu g\ kg^{-1}$	p,p-DDE $\mu g\ kg^{-1}$	Tot DDT $\mu g\ kg^{-1}$
Wt. Sulphur Springs	2.279	2.109	1.690	26.451	3.267	138.886				5.100	5.100
Wt. Sulphur Springs	2.044	2.201	1.563	21.862	1.813	93.257				9.800	9.800
Wt. Sulphur Springs	0.478	1.878	2.714	21.455	2.333	88.250				9.100	9.100
Wt. Sulphur Springs											
Wt. Sulphur Springs											
Wt. Sulphur Springs	1.400	1.400	2.800	15.900	1.200	114.000			19.000		19.000
Wt. Sulphur Springs											
Wt. Sulphur Springs											