APPENDIX A – FISH CULTURE GUIDELINES

Yakama Nation Fisheries Resource Management

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I. ***SUMMARY***

The pre-smolt and acclimation rearing environments have a large impact on survival to adulthood. Densities, flow rates, water temperatures, water quality, feeding methods, and rearing unit conditions are important aspects of those environments. Due to the high value of returning adults to the coho reintroduction program, emphasis is placed on maximizing adult return rates.

Optimal coho culturing guidelines for the Mid-Columbia Coho Reintroduction Plan (MCCRP) are selected based on reviews of the scientific literature and discussions with fish culturists. Successful systems described by researchers include very low rearing densities, large volume rearing units, natural water temperatures, limited fish transportation in the pre-smolt or smolt stages, low flow densities, and limited predation. Specific culturing conditions are proposed to approximate those conditions:

- *First and second winter water temperatures*: 33° to 40° F.
- *Summer water temperature*: daily peak of 65° F and maximum daily average of 62° F. Minimum of 55° F.
- *Water pathogen load*: minimized for as long as possible—priority for incubation and early rearing.
- *Maximum volume density*: a maximum of 0.3 lb/cft for fish larger than 100/lb; 0.1 lb/cft for facilities with less reliable water supplies (acclimation sites).
- *Maximum flow density*: water temperature and fish size dependent: 9 lbs/gpm for 20/lb fish in 50º F water.
- *Main rearing units*: large ponds or constructed natural habitat for fish larger than 100/lb, with minimum dimensions of 30 feet wide by 100 feet long by 4 feet deep.
- *Trucking*: no movement after fish begin smolting (assumed to begin at a size larger than 40/lb in March). No transport between watersheds is preferred.
- *Acclimation period*: 6 or more months for sites that can function through the winter; 6 weeks for those that cannot.

Practical considerations may not allow all of these conditions to be met. Water and space availability, construction costs and operational considerations may place limits on facility options.

II. ***INTRODUCTION***

Studies (discussed in the following sections) demonstrate the impact of specific changes in individual culturing parameters on smolt to adult survival rates. Insight into the general importance of the rearing environment can also be obtained by comparing the adult return rates of wild and hatchery reared smolts. Data on adult survival rates (Chandler to Prosser) has been collected on the Yakima River for the past 4 years (see Bosch et al. 2005). Naturally produced smolts had 3.5 to over 16 times higher survival rates. Because the genetics of the hatchery and naturally produced fish in the Yakima are similar, differences in the egg to smolt rearing environment explains much of the large survival advantage of natural fish. Other data show similar results. For example, Johnson (1996) estimated survival to be two to three times higher for wild Oregon coastal stocks than for hatchery smolts with similar genetics. Culturing conditions are proposed for MCCRP production that attempt to produce smolts with “wild” characteristics.

III. *WATER*

The availability of both ground and surface water supplies at rearing sites adds flexibility and reliability. The preferred supply for most of the rearing cycle is surface water, with ground water providing a low-pathogen source for early rearing and a stable back-up.

A. TEMPERATURES

A natural water temperature profile may be important to producing quality fish. It is clear from the literature that low second winter water temperatures improve smolt characteristics. Studies that demonstrate the importance of cold winter temperatures and a natural fish growth profile include:

- Steelhead held in <u>4 to 10° C (39 to 50° F) water</u> for several months prior to release had higher survivals than fish reared in constant 15° C (59° F) water (Bjorn and Ringe 1984).
- Spring chinook at Columbia River hatcheries had adult survivals that were positively correlated with <u>fast growth rates</u> during the 1-2 months prior to release (Dickoff et al. 1995).
- Atlantic salmon reared in <u>natural water temperatures</u> (winter temperatures down to 42° F), survived at higher rates than fish reared on a constant winter temperature of 52° F, when transferred to seawater (Dickoff et al. 1998). The authors concluded that increasing late winter temperatures are important to the smolting process.
- Recent research indicates that <u>spring growth rates</u> are important to adult survival. Beckman et al. (1999) state: *"Maintaining fish at a relatively small size initially, then inducing rapid growth in the final spring, may result in high-quality smolts…".* Small size until the final spring is optimally managed with low incubation and second winter temperatures. Growth manipulation can be done by adjusting feed rates, but low ration in warm water may cause nutritional stress.
- Compensatory growth following <u>winter starvation</u> has been demonstrated (Griffioen 1976) for coho and fish condition is not impaired (Larsen et al. 2001).

Clear beneficial results from rearing on cold winter temperatures have not been demonstrated in all cases. Appleby et al. (2002) in a study of spring chinook at the Klickitat hatchery, showed that adult survivals were not increased with 6-week-long exposure to cold acclimation water. However, other investigators, as cited in the paper, did find that winter temperature fluctuations enhanced smoltification and emigration of salmonid juveniles.

Low first winter temperatures are also important. Chilling incubation water is relatively inexpensive and helps match the hatchery growth profile to that of natural fish. Rapid growth in the summer and second spring can then be used to attain smolt size targets. Keeping fish small as they enter the first summer also keeps pond flow and volume densities low, minimizing stress.

There were no peer-reviewed studies found that evaluate the impact of warm summer temperatures. However, the Samish, Puyallup, and Toutle Washington Department of Fish and Wildlife (WDFW) hatcheries have some of the highest adult coho return rates in the state, although these facilities all see occasional temperatures in the low 70s F in summer months (Harry Senn, Fish Management Consultants, personal communication, 2002).

There is conflicting information on the upper limit for rearing temperatures in coho facilities. For the purposes of this siting work, an upper limit for the daily maximum is 65° F and for the daily average, 62° F. The Wenatchee River near Wenatchee and the Columbia River at Rock Island Dam are above this value; both supplies are generally considered too warm for yearling salmonid culture. Cascade Hatchery (Eagle Creek) in Oregon is just below this value and at the upper limit of temperature for coho. These numbers are general guidelines only and are site- and facility-specific. Hatcheries that have recurring disease problems, high rearing volume densities, and/or low flow volumes require reduced upper limits.

B. DISEASE

The fish pathogen load of the water supply is another consideration when choosing a rearing site. The prevalence of certain pathogens may impact fish transportation restrictions between watersheds and the operation of rearing facilities. The most serious of these are the "regulated" diseases (from Northwest Indian Fish Commission(NWIFC) and WDFW 1998):

- Viral Infectious Hematopoietic Necrosis virus (IHNV)
- Viral Infectious Pancreatic Necrosis virus (IPNV)
- North American Viral Hemorrhagic Septicemia virus (VHSV)
- Viral pathogens not known to exist in Washington
- Myxobolus cerebralis parasite

Currently the entire Columbia is one Fish Health Management Zone, and transfers anywhere in the drainage are allowed. In the future, smaller Columbia Basin zones may be created to minimize disease transfers (personal communication, Kevin Amos, WDFW/NMFS, 1999; the possibility of this as a restriction is a siting consideration. Egg Health Management Zones may remain large due to the effectiveness of egg disinfection methods. Facilities that use pathogen-free water supplies exclusively are not subject to the same transfer restrictions that untreated surface supplies are.

C. FLOW DENSITY

Flow densities, if kept above minimum values, do not appear to have a large impact on survival rates. In a study of pond vs. raceway rearing for cutthroat (Tipping 1998), the flow densities in pond groups were higher than in raceway groups that survived at lower rates (see Table 1). The Banks (2002) density study (Figure 2) did not show any survival differences for flow densities in the range from 3 to 8 lbs/gpm. In general, water supply systems are expensive components of hatcheries. As a result, flow densities at these low values are not proposed.

The method used for calculating water requirements used by WDFW is described in Piper (1982). It assumes that water temperatures, elevations, and fish size impact the amount of water needed per unit weight of fish being reared. A flow index number taken from a table for a given water temperature and elevation is multiplied by the fish length in inches to yield the water requirement in lbs/gpm. Specifically, standard WDFW tables for 50° F and 1,000 feet of elevation yield a flow index of 1.7. A 20/lb coho is 5.5 inches, resulting in a flow density of 9.6 lbs/gpm. This calculation is performed for changing water temperatures and fish sizes to predict water needs for potential hatchery sites. A safety factor would also be applied that varies depending on water quality considerations and on supply reliability.

D. WATER CHEMISTRY

Other quality parameters considered when evaluating the rearing environment include turbidity, dissolved gases, heavy metals, hardness, pH, and miscellaneous contamination potential. Very high turbidity levels (above 100,000 ppm) may cause problems such as gill irritation for fry; reduced growth rates when fish visibility is reduced; and silt removal problems. Air super-saturation downstream of dams, high dissolved carbon dioxide/low oxygen levels in groundwater (assumed for all supplies and easily corrected), and the presence of dissolved hydrogen sulfide are potential gas issues. Heavy metals are generally introduced to water through improper facility construction; however, natural supplies can also contain them. Sensitivity of fish to toxic pollutants, including metals, increases at low alkalinity. Chemical spills from truck accidents, agricultural pesticides, and herbicide applications are other sources of water supply contamination. Suggested upper limits for many of these quality parameters are listed in Piper (1982) and in the Alaska Fish Culture Manual (ADFG 1986). Due to the interactive aspects of chemical reactions in water, developing specific criteria is difficult. Most water supplies have some values outside these limits, yet coho are successfully reared in a variety of conditions throughout the Northwest. The standards can be used as general guidelines, but quality determinations should not be made until testing with live fish for a full rearing cycle is completed.

IV. REARING UNITS

Various options exist for rearing unit designs. Ponds, circular tanks, and raceways are among the types of systems in which fish are cultured. The use of different rearing units for fish at different stages of development is a standard practice. Concrete raceways have operational advantages which are important for small fish that need to be fed frequently and handled for activities like tagging. Moving fish from raceways to ponds for grow-out may improve adult survival rates (see Table 1 and discussion below).

A. VOLUME DENSITY

Rearing volume density appears to be one of the most important variables impacting adult survivals. Numerous studies (discussed below and summarized in Table 1) have demonstrated significant impacts. Many of these studies included compounding experimental variables such as water flow rates and rearing environment. However, volume density is an important and common difference between controls and experimental groups in the studies.

Table 1. Summary of Rearing Studies

Author	*Comparison*	*Species*	*Study Volume Density (lbs/ft³)*	*Control Volume Density (lbs/ft³)*	*Study Flow Density (lbs/gpm)*	*Control Flow Density (lbs/gpm)*	*Study Length (mo)*	*Avg. Survival*	*Survival Advantage of Study Groups*
COHO									
Banks, 1995	Rwys (Willard)	Coho	0.87	2.59	3.5	8.1	12	0.5%	23%
Fuss, 2002	Ponds (Elochoman)	Coho	0.19	3.30	1.0	11.8	10	1.5%	270%
Ewing, et al, 1995	Rwys (Washougal)	Coho	0.21	0.52	6.2	14.7	6	2.0%	23%
	Rwys (Cowlitz)	Coho	1.31	2.27	11.0	23.0	7	1.4%	0%
	Rwys (Sandy)	Coho	0.72	2.59	14.7	12.8	12		0%
	Rwys (Capilano)	Coho	0.34	0.57	3.3	5.7	12	13.0%	0%
	Ponds (Clatsop)	Coho	0.07	0.14			4	2.2%	500%
OTHER SPECIES									
Tipping, 1998	Rwys vs pond	Cutthroat	0.02	1.12	14.5	5.7	7		60%
Banks, 2002	Rwys vs. rwys	S. Chnk.	1.0	3.0	2.5	7.5	9.5		300%
Ewing, 1995	Rwys vs. rwys (Elk)	S. Chnk.	0.6	1.0	4.7	8.5	10		170%
Ewing, 1995	Circs vs. circs (Deer)	S. Chnk.	0.4	2.0	1.8	8.1	9.5		600%
Beckman,1999	Rwys vs pond	S. Chnk.	0.1	1.0			4.5		60%

A study that showed a large survival advantage due to changes in rearing conditions was done by Fuss and Byrne (2002). They compared coho reared in a large “natural” pond at low densities for 10 months to fish reared in conventional raceways for 6-9 months and then transferred to hatchery ponds for the final 2-3 months of rearing. Volume density was one of the significant differences between the test groups. Important compounding variables included the mechanical introduction of feed, the presence of rock and large woody debris, and high predation rates (50%) in the treatment pond. Survivals were 140% higher for the natural pond than for the controls or for other coho releases in the region.

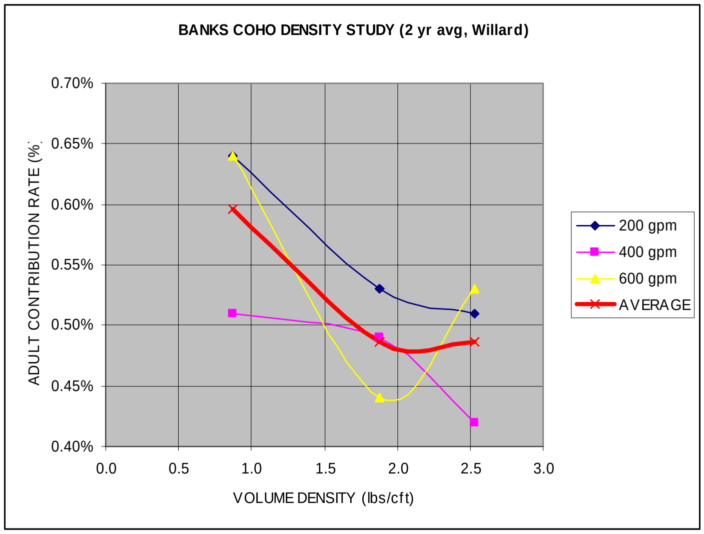

Figure 1. Coho volume density and adult coho contribution rate

(adapted from Banks (2002))

Data from Banks (2002) coho density study is plotted in Figure 1. It shows an increase in adult survivals with reduced densities in raceways.

Ewing (1995) found that in 7 of 20 brood years for coho salmon, increased rearing density resulted in a reduced percent survival to adulthood. Most of these evaluations were done in conventional hatchery raceways at different facilities at relatively high densities. Data from two of the study locations are plotted in Figure 2. Results from Washougal show that at very low densities, there was a survival advantage for lower densities, but at higher densities at Cowlitz, there was not.

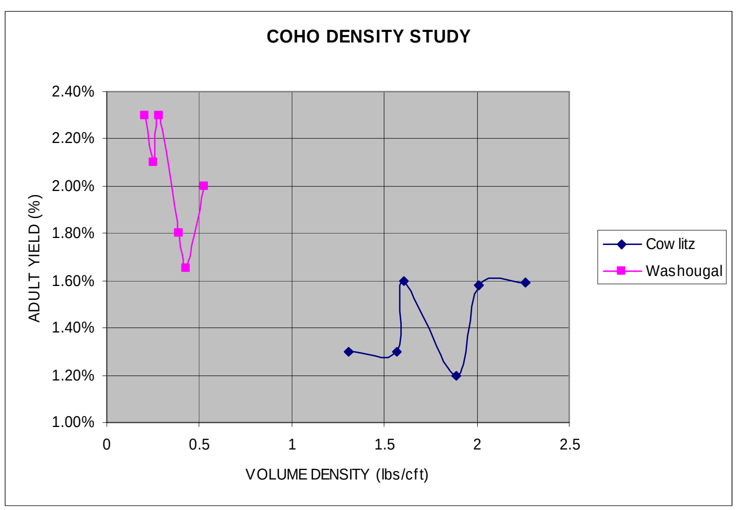

Figure 2. Coho volume density and adult yield

(adapted from Ewing (1995))

The duration of time salmonids spend in large volume rearing units may be important as well. Tipping (2001a) found that cutthroat showed a 31% improvement in survival for 4-7 months of rearing in a large pond vs. 1 month.

Natural smolt densities are much lower than those used in fish culture. A study of western Washington streams (Sharma and Hilborn 2001) evaluated smolt densities in pool habitats. In an engineered habitat experiment, fish were allowed to emigrate out of the system voluntarily at any life stage. Smolts remained at low densities even where feed was not a limiting factor. Comparative density data (Table 2) indicate that coho choose densities that are two orders of magnitude lower than standard hatchery values.

Table 2. Rearing Density Comparison

	Smolts /Acre
Natural Ponds and Side Channels	3,460
Engineered Habitat, Voluntary Out Migration	6,100
Low Density Pond, 3' Deep, 18/lb, 0.3 lbs/cft	706,000
Standard Raceway, 3' Deep, 18/lb, 1.0 lbs/cft	2,353,000

B. REARING UNIT SIZE

Studies have shown an additional survival benefit when comparing pond rearing to raceways. The benefits of pond rearing have been demonstrated for coho salmon (Fuss 2002), cutthroat trout (Tipping 1998), and spring chinook salmon (Beckman 1999).

It is unclear why large rearing units perform well. They may reduce stress by providing escape areas when fish perceive threats. The relationship between stress and disease (Wedemeyer 1984) and the impact of stress on growth rates (McCormick et al. 1998) have been described. There may also be a relationship between stress and survival fitness.

There are practical limits to the size of rearing ponds. One limitation on width is the distance that feed can be thrown. For example, fry typically may be ponded after tagging in June at approximately 250/fpp. The 3.5 mm pellets that are fed to fish of this size can be spread up to 30 feet. Also, the length-to-width ratio affects pond hydraulics: long and narrow increases flow velocities. The final determination of overall rearing unit dimensions will be based on the size of evaluation tag groups.

Water depth may also be an important consideration, as it provides security from predators and moderates water temperatures in both winter and summer. However, where depth needs to be limited by human safety considerations, it should be kept to less than 4 feet.

Large ponds do increase the cost of disease treatments that are applied to water. They also make removal of all fish by seining more difficult and reduce the ability to visually monitor fish. Yet advantages beyond that of increasing adult survivals include:

- Large oxygen reserves, which provide back-up in case of emergency water flow interruptions.
- Room for exercise and for schooling. Exercise may be beneficial to smolt quality (Khovanskiy et al. 1993).
- Reduced disease problems due to the low stress environment and low pathogen density.
- Low construction costs, with large water volume to pond bottom and side surface ratios.

C. ENVIRONMENT

Natural rearing environments in artificial production systems have been proposed. Flagg et al. (1999) propose a strategy for conservation hatcheries that emphasizes the production of fish with "wild-like" attributes. Some testing of this concept has occurred, with varying degrees of success. Large scale experiments with spring chinook at the Cle Elum Supplementation Hatchery have not demonstrated advantages in survival due to the use of some natural rearing strategies. Painted walls, floating covers, and subsurface feed introduction did not substantially improve adult survivals when compared with standard raceways.

Maynard (2004) describes a Puget Sound coho study currently underway that looks at the impact on coho adult survival rates of bottom substrate, fir tree structure, and camouflage net covers in a raceway environment. Adult return data show that these features have little impact.

Tipping (2001b) demonstrated that for cutthroat, fish fed with demand feeders had a 10% higher survival rate to adulthood. Similarly Fuss (2002) also used mechanical feeding. Based on this evidence, there may be a small advantage to avoiding hand feeding methods.

Water flow patterns in streams and rivers are different than in the controlled environments of ponds and raceways. A key difference is that wild fish are faced with a high degree of hydraulic complexity; including turbulence, eddies, high shear, and very low flow velocities. Fish react to changes in flow conditions (Smith 2003 and Goodwin et al. 2004), and behavior learned in the captive environment may affect success in the wild.

Noise levels in fish hatcheries are another area of recent interest. Acoustic noise can be 20 to 50 dB higher than in natural habitats (Browman et al. 2005). Frequencies (a typical source is electric motors at 60 Hz) are also much different. The impacts of artificial noise on fish are not understood.

Other new rearing unit designs and practices are showing some value, primarily involving water temperature profiles and growth rates, volume density, and rearing unit sizes, as discussed above. Strategies that have less of an impact or that are just starting to receive interest also have been identified. Where research gives clear direction, mimicking natural conditions has been shown to improve adult survival rates. Where it does not, the assumption will be made that natural conditions are the default, wherever possible.

V. TRUCKING

Fish reared at lower Columbia River hatcheries and transported to upper watersheds in the mid-Columbia region may be in haul trucks for up to 8 hours. Several authors have evaluated the response of salmonids to hauling activities (see Specker 1908; Schreck et al. 1988; and Maule et al. 1989). They concluded that the greatest stress occurs during loading and during the first few hours of transportation. Fish transported 4 hours or 12 hours did not show large differences in overall stress levels. Also, elevated levels of stress are reduced to pre-transportation levels within periods of days. If fish are given adequate time to recover, there does not appear to be a significant stress-related decrease in survival for hauling fish long distances.

Other transportation issues need to be considered when selecting the program design. Fish should not be hauled during or after the smolting period. High stress levels and handling during this critical time may reduce survival. For example, scales become loose during smolting, and loading fish into trucks and confining them in tanks causes scale loss. There may be unknown impacts to the smolting process itself. In addition, long trucking distances increase the chances of smolt loss due to mechanical failures.

Disease considerations may affect transportation plans. As discussed previously, stress is a contributing factor in disease epizootics and fish are stressed during trucking. Also, there are diseases that can prevent the transportation of fish between watersheds. Disease transfer is one of the motivations for policies limiting the movement of fish between Puget Sound basins (see NWIFC 1998). Such policies may be developed for the Columbia region in the future. The existence of certain diseases in hatcheries (viruses such as VHS, for example) would prevent the movement of fish to upstream release sites under current conditions.

In summary, the impact of hauling on smolting, in addition to the risks due to disease, means that the preferred system would involve no hauling. Fish reared and released at the same location would eliminate many of these potential problems. Operational and cost considerations make this impractical. Reducing the requirement to transport fish between watersheds and moving fish well prior to release is the next best alternative.

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