PAPERS ON THE USE OF SUPPLEMENTAL OXYGEN TO INCREASE HATCHERY REARING CAPACITY IN THE PACIFIC NORTHWEST

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PAPERS ON THE USE OF SUPPLEMENTAL OXYGEN TO INCREASE HATCHERY REARING CAPACITY IN THE PACIFIC NORTHWEST

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AN INTRODUCTION TO

WATER QUALITY **MANAGEMENT** IN INTENSIVE AQUACULTURE

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INTRODUCTION

Increasing fish density or reuse of hatchery water can significantly increase the production capacity **of hatcheries. Generally, dissolved oxygen is the most limiting environmental parameter and** reaeration can allow reuse. Several types of aerators can be used for hatchery applications but pure oxygen systems may be the most economically method for many existing hatcheries. Limited documentation is available at this time on the optimum type of pure oxygen system or the effects of increased density or water reuse on adult return. Prior to the widespread implementation of intensive aquaculture systems, it will be necessary to clearly define the engineering solutions and biological needs at each location.

INTENSITY OF A HATCHERY

The intensity of a hatchery can be described by several parameters. The most common parameters are:

$$\text{Density } (lb/ft^3) = \frac{\text{mass of fish (lb)}}{\text{volume of Eating unit } (ft^3)}; \quad (1)$$

$$\text{Loading (lb/gpm)} = \frac{\text{mass of fish (lb)}}{\text{flow to rearing unit (gpm)}}; \quad (2)$$

$$\text{Exchange rate (number/h)} = \frac{(60)(\text{flow to rearing unit in gpm})}{(\text{volume of rearing unit in gallons})} \quad (3)$$

Loading, exchange rate, and density are related by

$$\text{Loading} = \frac{8.02 \text{ (Density)}}{\text{Exchange Rate}} \quad (4)$$

Typical densities used for salmon and trout fry range from 0.20 to 0.60 lb/ft^3, but may range from 0.60 to 2.50 lb/ft^3 for larger fish. If loading rates are maintained low (high exchange rate), densities in experimental systems have been as high as 34 lb/ft^3. Loading rates in production typically range from 4 to 10 lb/gpm. The maximum density will depend on both water quality considerations and the ability of the particular species to tolerate crowding.

IMPACT OF FISH ON WATER QUALITY

The metabolic activities of fish result in significant changes in water quality. For fed fish, some of the most important metabolic processes are shown in Figure 1. In flow-through systems, typically only dissolved oxygen and ammonia may need to be considered. As the intensity of a hatchery is increased it may be necessary to consider the impact of carbon dioxide, uneaten feed, and fecal solids. Fecal matter and uneaten feed contains high levels of bacteria and release small amounts of soluble organic compounds.

Both ammonia excretion, oxygen consumption, and carbon dioxide. excretion rates show a significance die1 fluctuation, depending primarily on the time of feeding. If feeding is stopped, the oxygen consumption, carbon dioxide excretion, and ammonia excretion rates will decrease to baseline values.

PROCESS CRITERIA

Density, loading, and exchange rate are the most important process criteria needed for the design and operation of fish culture systems. These parameters can be estimated from either empirical or mass-balance considerations.

Empirical Approach Typically, fish culture facilities have been design by selecting a density and exchange rate based on past experience (Leitritz and Lewis, 1976; Piper et al., 1982; Shepherd, 1984). The total volume of rearing units needed is equal to production objective/density and water flow rate is equal to production objective x loading rate.

This approach works well in areas with an ample water supply at an acceptable water temperature. Generally, this approach wiII result in a conservatively designed hatchery. as many state and federal hatcheries were located on the sites with excellent water supplies. Application of these process criteria to areas of limited water supply may result in very high capital and operating costs. In addition, the applicability of empirical process criteria depends on how the new conditions compare to the conditions under which the original criteria were developed. For example, many trout hatcheries have pHs in the range of 6.5 to 7.0. Published process criteria would not be valid at a site with a pH of 8.4 and could result in significantly reduced production capacity.

Mass-balance Approach. This method is based on identification of the critical environmental parameters that may limit the growth of fish. These may include, dissolved oxygen, carbon dioxide, ammonia, and solids. Based on laboratory and production experiments, a water quality criterion is set for each parameter. Then the water flow required to maintain each parameter is computed for the specific hatchery conditions. In many cases, the largest flow required will be for maintaining the dissolved oxygen.

This method is quite flexible, especially when the dissolved gas concentrations, pH, salinity (or total dissolved solids), and temperature at a new site significantly different from previous sites. The major advantage of this method is that is allow one to estimate the effect of water treatment on the overall water requirement. For example, what effect will addition of 5 - 1 hp aerators have on water requirement? Most of the remainder of this article will discuss the mass-balance approach to the design of flow-through systems for the culture of salmon and trout.

LIMITING FACTORS

Four environmental parameters may influent the growth of fish in flow-through systems: dissolved oxygen, carbon dioxide, ammonia, and fecal solids. Temperature will also strongly influence growth, but under production conditions, it is generally not economically feasible to heat or cool water. This section will use growth as the biological endpoint. Ideally, either adult return or some

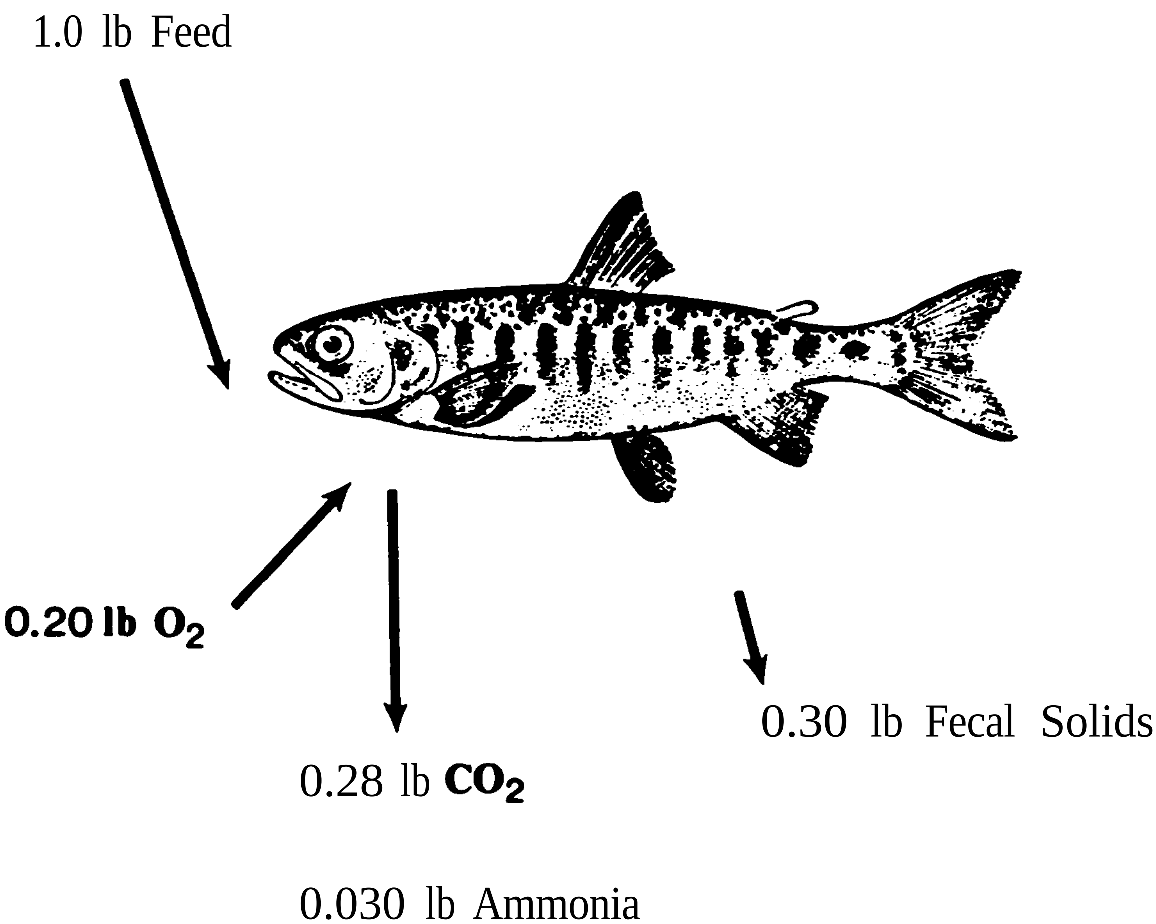

Figure 1 Impact of Fish on Water Quality

physiological quality index that is highly correlated with adult return should be used.

Dissolved oxygen. The mass of dissolved oxygen in equilibrium with air decreases with increasing temperature:

Equilibrium Concentration of Dissolved Oxygen

Temperature		Dissolved oxygen (mg/l)	
C	F	Saturation	Available
0	32	14.60	8.60
5	41	12.56	6.56
10	s o	11.28	5.28
15	59	10.07	4.07
20	68	9.08	3.08

Any reduction in dissolved oxygen concentrations below 5 to 6 mg/l will decrease the growth of salmon and trout. Assuming a dissolved oxygen criteria of 6.00 mg/l, the difference between the saturation concentration (above table) and the criteria is the dissolved oxygen available for the fish and is presented the previous table. Increasing the water temperature from 41 to 59 F, decreases the available dissolved oxygen by 38 %. The actual carrying capacity will be decreased even more because the oxygen consumption rate of the fish will also significantly increase due the temperature change. This would be reflected by increased feeding levels.

The flow requirement for maintaining the dissolved **oxygen** concentration (Westers, 1981) for a raceway system (Figure 2) is equal to

$$Q_{oxygen}\ (lpm) = \frac{(K_{oxygen})(R)}{(DOin - 6.00\ mg/l)} \qquad (5)$$

where

K_{oxygen} = 200 g oxygen /kg feed

R = total ration, kg/d

DO_{in} = influent dissolved oxygen concentration. mg/l

Assuming 5,000 kg (11,000 lb) of fish fed 2% of body weight per day and influent dissolved of 11.00 mg/l, the required flow (Q_{oxygen}) is equal to 4,000 lpm (1100 gpm). The observation that

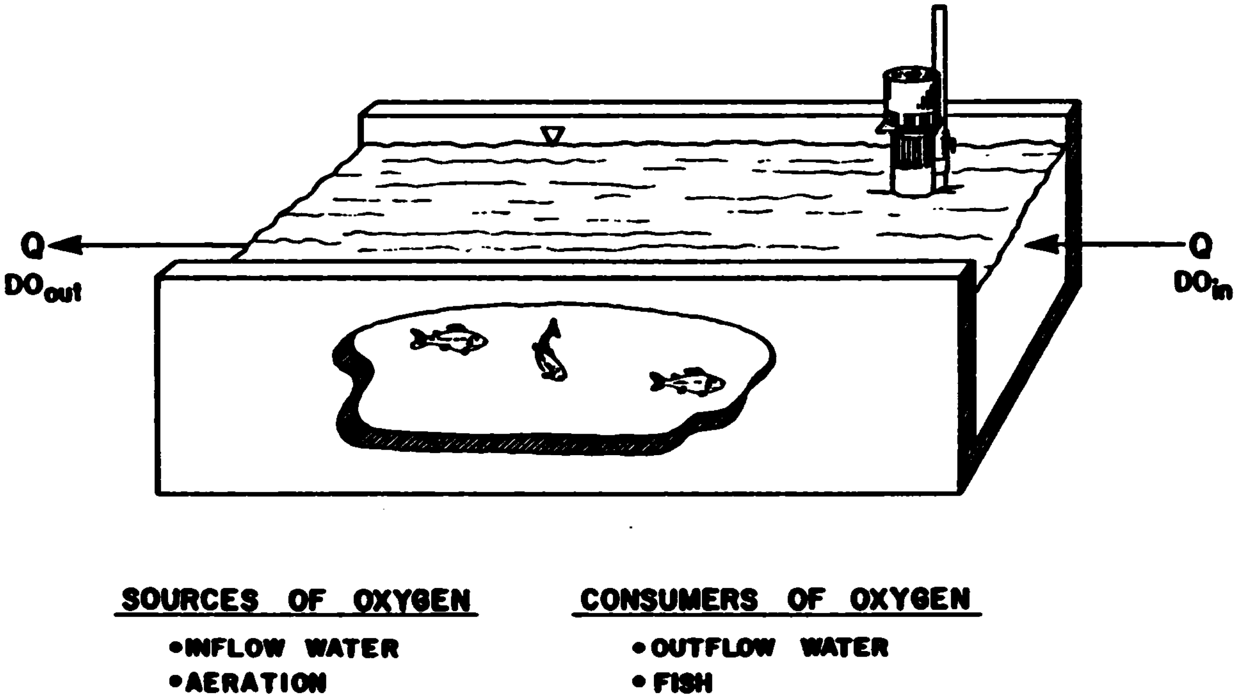

Figure 2 Oxygen Balance in a Raceway

oxygen consumption is proportional to feed consumption has been the basis for several procedures for the computation of loading rate or flowrate (Haskell, 1955; Westers and Pratt, 1977; Willoughby 1968).

Carbon dioxide. The carbon dioxide production of fish is equa1 to

$$\text{Carbon dioxide Production (mg/d)} = 1.375(RQ)(T') \qquad (6)$$

where

RQ = respiratory quotient (approximately 1 .0 under most conditions)

T = oxygen consumption, mg/d

The build-up of carbon dioxide can result in reduced metabolic activity and increased disease problems. Carbon dioxide concentrations should be maintained less than 20 mg/l. although higher levels can be tolerated depending on the dissolved oxygen concentration and temperature. If it assumed that all the excreted carbon dioxide remains in the water **as** dissolved carbon dioxide, then the flow required to maintain the carbon dioxide concentration below 20 mg/l is equal to

$$Q_{carbon\ dioxide}\ (lpm) = \frac{(1.375)(RQ)(K_{oxygen})(R)}{(20.0\ mg/l - C_{in})} \qquad (7)$$

where

C_{in} = influent **concentration** of carbon dioxide, mg/l

For RQ = 1 and C_{in} = 0.50 mg/l, Q_{carbon} dioxide = 1,400 lpm for the previous example. The assumption that all the carbon dioxide remains in solution as free carbon dioxide produces a very conservative estimate of Q_{carbon} dioxide. A better estimate of Q_{carbon} dioxide will require information on alkalinity and pH of the water.

Ammonia (NH_3) is end-product of protein metabolic and is excreted primarily across the gills. As the ambient ammonia concentration builds-up, the rate of ammonia excretion decreases and feeding is reduced.

Ammonia **is** weak base and exists both as an un-ionized (NH_3) and ionized (NH_4^+) form. The un-ionized form is much more toxic than the ionized form and water quality criteria are written in terms of the un-ionized form (NH_3).

The concentration of both unionized and ionized ammonia are expressed on a nitrogen basis and the sum of both forms is the total ammonia nitrogen and can be measured by standard chemical tests. The concentration of un-ionized ammonia depends on total ammonia nitrogen, pH, temperature, and salinity (or total dissolved solids). The mole fraction (percent ammonia/100) of un-ionized ammonia for freshwater conditions is presented below:

Mole Fraction of Un-ionized Ammonia (α_{NH3})

PH	Temperature, C (F)		
	5(41 F)	lO(5OF)	15(59F)
6.0	0.000124	0.00186	0.000273
6.5	0.00393	0.000587	0.000862
7.0	0.00124	0.00185	0.00272
7.5	**0.00392**	0.00584	0.0856
8.0	0.0123	0.0182	0.0266
8.5	0.0379	0.0555	0.0794
9.0	0.111	0.157	0.214

The concentratiou of un-ionized ammonia is equal to the mole fraction **(above** table) time the total ammonia nitrogen:

$$NH_3\text{-}N = \text{(mole fraction)(total ammonia nitrogen)} \quad (8)$$

If the concentration of total ammonia nitrogen is express in mg/l, then **NH_3-N** will also be expressed in mg/1. Total ammonia nitrogen may be abbreviated as TAN. A change of one pH unit will change the concentration of un-ionized ammonia by **a** factor of 10 over the normal pH range. Westers (1981) proposed a maximum un-ionized ammonia concentration of 0.010 mg/l **NH_3-N** for salmon and trout. **A truly safe,** maximum acceptable concentration of un-ionized ammonia is not known at this time (Meade, 1985). Additional research is needed to increase our understanding of ammonia excretion and excretion products, to define the effect of ionic compound on ammonia toxic, and to determine the chronic effects of ammonia toxicity on several fish species.

As the intensity of culture is increased there is increasing incident of gill hyperplasia and more serve gill damage (peters et al., 1984). Recent research indicates that ammonia alone is probably not the cause of gill hyperplasia (Meade, 1985). Fecal solids, bacterial solids, or other by-products of metabolism may contribute to the tissue damage attributed to ammonia

Assuming that the concentration of ammonia in the influent water is zero, the flow require to maintain 0.010 mg/l or 10.0 **µg/l** NH3-N is equal to

$$Q_{ammonia} = \frac{(1319)(\alpha_{NH3})(K_{ammonia})(R)}{10.0\ \mu g/l} \quad (9)$$

where

α_{NH3} = mole fraction of unionized ammonia (see above table)

$K_{ammonia}$ = ammonia excretion rate (30 g TAN/kg feed)

R = ration, kg/d

At pH equal to 6.5 and temperature equal 10 C, only 232 lpm (62 gpm) would be needed to maintain the ammonia criteria **for** the previous example. Equation 9 does not consider the effect of respiratory carbon dioxide on the pH of the culture water. In waters of low alkalinity (and hardness), the accumulation of carbon dioxide may result in significant reduction in Qammonia.

Fecal Solids. The effect of solids strongly depends on the size, shape, and texture. Both uneaten feed and fecal matter may contain high levels of potentially pathogenic bacteria. Water quality criteria for fecal solids and uneaten feed are not well defined at this time. Since these solids can settle out in the rearing unit, the concentration of solids may significantly increase during cleaning. grading, or harvesting.

Cumulative Loading. Repeated reaeration and reuse can result in adverse **physiological changes.** such a reduced growth or tissue damage. For Lake Trout, this occurs at a cumulative loading of SO lb/gpm (Meade, 1985) and may be due the synergistic effects of a number of metabolites.

Density. As the density is increased, the fish growth may decrease. Much of this effect is related to the impact of density on loading, rather than the biological impact of crowding on the culture animal. Increased incident of fin damage has been observed at higher density.

REUSE OF WATER

In the previous section, the following flows were needed to maintain the water quality criteria **for the specific** parameters:

Limiting Water Flows

Parameter	Flow (lpm)
Dissolved oxygen	4,000
carbon dioxide	**1,400**
Un-ionized ammonia	232

Therefore, if additional oxygen was added to the water, the water flow could be reduced to only 1,400 Ipm If both dissolved oxygen and carbon dioxide were controlled, then the water flow could be reduced to only 232 lpm Conversely, if the water flow was maintained at 4,000 Ipm and aeration used to maintain the dissolved oxygen at excess of 6.0 mg/l, the carrying capacity of the hatchery could be increasd by 2.9 times. Theoretical, if both dissolved oxygen and carbon dioxide were controlled by aeration, the carrying capacity of the hatchery could be increased by 17 times. A number of production hatchery have been designed for up to 5 or 6 reuses.

Control of Reuse. It most cases, the reuse of water will be controlled by the dissolved oxygen and unionized ammonia criteria. The reuse ratio for oxygen and ammonia is equal to

$$RR_{OXY/AMM} = \frac{Q_{oxygen}}{Q_{ammonia}} \tag{10}$$

and is presented in Figure 3 as a function of pH and influent dissolved oxygen. This parameter is equal to the number of times the water can be reused before the un-ionized ammonia criteria is exceeded. At low pHs, the water requirement is control by the dissolved oxygen and the water can be reused following reaeration. At higher pHs, ammonia becomes the limiting parameter and the water can not be reused as the ammonia criteria has already been exceeded.

Aeration. Under those conditions where the reuse ratio is greater than 1.0, reaeration can bc used to increase production in hatcheries. Four common types of aerators are surface aerators, subsurface aerators. gravity aerators, and pure oxygen aerators (Colt and Tchobanoglous, 1981). One to 2 hp surface aerators can be easily mounted in raceways or ponds. This type or aerator may result in ice hazard in cold weather. Subsurface aerator such as diffused aeration or jet aerator are more efficient than surface aerators, but can result in gas supersaturation problems (Colt and Westers, 1982). Gravity aerators can be used to reaerate water if l-3 feet of head is available between the individual rearing units. These units will consist of horizontal perforated screens or high-surface area trickling filter media These type of systems will require periodic cleaning.

Depending on the production schedule of a particular hatchery, aeration may only be required during the latter stages of the production cycle when the water temperature and biomass are high. In some newer hatcheries with higher densities, aeration may be required continuously.

The efficiency of aerators decreases as the dissolved oxygen concentration approaches saturation (Colt and Tchobanoglous, 1981). Pure oxygen system can be used to achieve dissolved oxygen concentration above the air saturation values. U-tube, down-flow bubble contractors, pressurized packed columns, and atmospheric pressure packed columns have been used in hatcheries. The build-up of carbon dioxide may be a serious problem with some of these units and require installation of small surface aerators or gravity aerator to strip off carbon dioxide.

Ammonia Renoval. Removal of ammonia is not economically feasible in flow- through systems. The effects of **pH** on carrying capacity should be considered in the site selection process. The accumulation of carbon dioxide in hatchery water due to fish respiration may reduce the pH in waters with low hardless and significantly decrease the concentration of un-ionized ammonia.

Solids Removal. Depending on the velocity and geometry, the fecal solids can keep suspended or allowed to settle in the rearing unit. Some type of settling will typically be required prior to for discharge. In some cases, the fish will be removed from the last raceway section, and the solids allowed to settle out there.

While the effects of fecal solids are not well-defined, they may have a major impact on the operation of reuse systems. Operationally, it is highly desirable to have self-cleaning rearing units. From a fish health view, this may be highly undesirable. Rather than pass all the fecal solids through the overall raceway, it is desirable to remove the solids from each section independently (Boersen and Westers, 1986). This will result in better solids removal, as the settling velocity of fresh fecal solids is higher than solids that have resuspended many times as they move down the raceway.

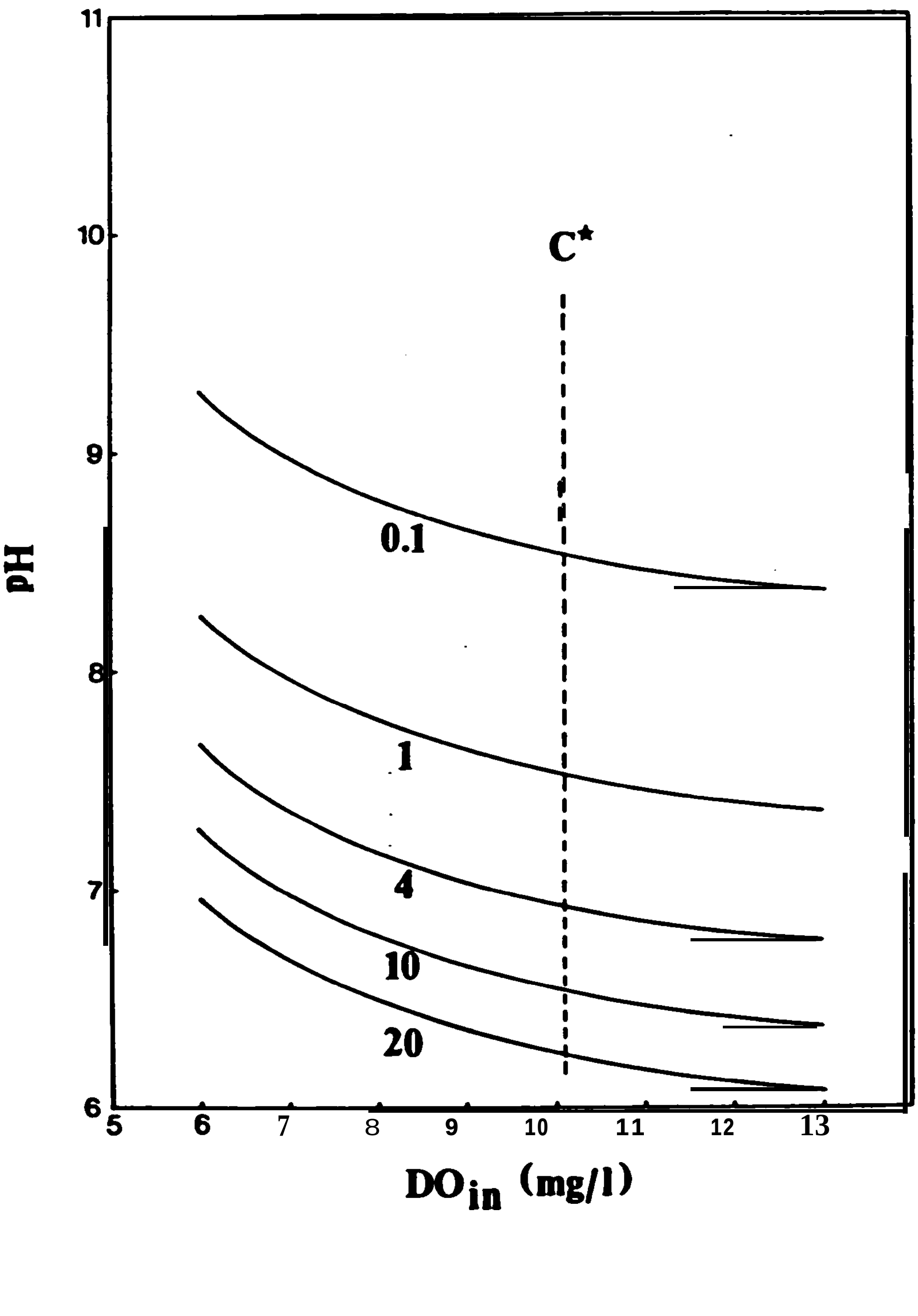

Figure 3 Oxygen-Ammonia Reuse Ratio

DEVELOPMENT OF NEW SYSTEMS

Increasing the intensity of hatcheries in the Columbia River basin can result in significant increase in existing smolt or fry production with small increases in capital and operating expenditures. The installation of pure oxygen or improved solids removal systems into existing hatcheries will require modification of both the physical plant and hatchery operations. Additional pilot-scale work is needed to evaluate the performance, operating characteristics, and economics of the most promising systems.

The impact of increased intensity on adult return is difficult to estimate at this time and will require pilot-scale evaluation. Ideally, this work should be conducted at a full-scale production hatchery with existing hatchery personnel. This will allow clear definition of the economic advantages of this approach to increasing the adult return of salmonid species in the Columbia River Basin.

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Michigan's Experience with Supplemental Oxygen in Salmonid Rearing

by

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presented at
The 37th Annual Northwest Fish Culture Conference
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Springfield, Oregon

Introduction

From 1978 through 1983 three new salmonid production hatcheries came on line in Michigan. All three facilities provide for incubation (Heath incubators), indoor rearing and outdoor rearing. These units were built on spring and/or well water sources.

Basic designs include rectangular concrete tanks for indoor rearing with rearing volumes of 105; 210 and 420 cubic feet (3, 6 and 12 M^3) plumbed for a water exchange rate of four per hour. The outdoor raceways are all rectangular, concrete ponds approximately 9' x 90' x 3' deep, with an operational depth of 26" (60 Ma). These raceways are arranged in a three-pass serial reuse fashion and operate at four water exchanges per hour (1000 gpm). Baffles keep the ponds self cleaning and permit deposit of solids in a 9' x 9' feet section immediately behind the fish barrier.

The water quality at all three units meet or exceed aquaculture water quality parameters except for dissolved oxygen. (Daily and Economon, 1983)

The first two hatcheries were equipped with 15 feet deep aeration chambers into which a combination of air and water was introduced through special nozzles located on a manifold near the bottom of the chamber. Although very effective and efficient, this system is prone to cause high levels of dissolved nitrogen gas unless carefully controlled (Colt and Westers, 1982). For this reason, the third hatchery was designed with packed columns for initial as well as reuse aeration. Subsequently, the other two hatcheries were also changed over to packed columns. Despite the packed columns, all units experienced low level nitrogen gas supersaturation. Although no obvious gas bubble disease symptoms were observed, abnormally high mortalities were indicative of problems, suspected to be related to water quality (Westers, 1983).

After many diagnostic investigations it was concluded that the low level nitrogen gas supersaturation (101-103X) played a major role in the poor rearing performance of the fry and fingerling Rainbow and Brown trout, in particular at the Harrietta State Fish Hatchery (Figure 1). It was at that time the decision was made to reduce nitrogen gas levels to 100 percent or less! This would eliminate gas supersaturation as a variable in future evaluations of problems. It was decided to replace the packed columns with vacuum degassers.

In the interim, the Marquette State Fish Hatchery personnel experimented with pure oxygen and learned by trial and error that by injecting oxygen into a sealed packed column, nitrogen gas can be forced out of solution and be displaced with the oxygen. A means was now available to bring nitrogen below 100 percent while simultaneously increasing the dissolved oxygen to 100 percent saturation or higher. The advantage over the vacuum degasser was obvious, since with pure oxygen degassing and oxygenation were accomplished in a one step operation. Of further significance was the fact that industrial PSA (Pressure Swing Adsorbtion) oxygen generators of various generating capacities had been developed during the past decade. This made a practical technology available to aquaculture, as oxygen can now be generated on-site in the proper quantities required. A number of Michigan's state fish hatcheries were equipped with Xorbox oxygen generators with capacities from 75, 200, to 400 cubic feet per hour, and combinations thereof.

Trial and error in design, such as sizing the column relative to flow, partial vacuum levels, packing materials, water distribution patterns (nozzles, etc.), oxygen injection location as well as rate of oxygen introduction per unit of water flow, etc., is still continuing. However, Michigan did derive at workable design parameters. These, along with some economic considerations, are covered in some detail in the paper "Engineering Considerations in Supplemental Oxygen" presented at this conference by Gary Boersen.

Although Michigan purchased oxygen generators for four hatcheries two years ago, not all installations have been completed. However, at Harrietta, where the installation is now complete for both the indoor and outdoor rearing, the positive results have been dramatic, as reflected in Figure 1. The vastly improved survival rate of Rainbow and Brown trout coinciding with the application of pure oxygen is most significant. Of interest is also a much improved growthrate for the Rainbow trout in particular.

Unfortunately, this information covers only one year of oxygen application for indoor rearing at the Harrietta hatchery, and just the beginning of this year's outdoor rearing cycle. Survival and growthrates continue to be very good, especially with the Rainbow trout with a rate of .5 inch per month, at a 1.2 conversion for a constant temperature of 45°F. It appears that the application of pure oxygen had its greatest impact on the Rainbows, however, the fourfold improvement in survival of the Brown trout certainly indicates a highly significant advantage for this species as well.

At the Wolf Lake State Fish Hatchery, where the application of pure oxygen has been in place to one degree or another for at least two years, the results have been equally encouraging. At this station the oxygen is also used to increase production. Dissolved oxygen levels have been tested as high as 180 percent saturation without obvious ill effects on the fish. It has allowed reduction of heated water requirements by nearly 50 percent for esocids (Northern pike and Muskies). Furthermore, the first pass in the three-pass series is operated at very high D.O. levels (135-150 percent) to conserve energy otherwise needed for reaeration of the second and third pass during much of the rearing cycle. Of interest and concern to all of us are the effects of supersaturated D.O. levels on fish quality relative to their ability to survive after their release into the natural environment. Research will be conducted at Lake Superior State College in Michigan, to determine the effects on blood chemistry, composition and cardio-vascular development.

Because of the relative newness of the application of the PSA oxygen generator technology to aquaculture, many questions remain yet unanswered. The need for research, both with respect to the technology and the biology, is obvious. It is our hope that Federal Fish Technology Centers will take on some of these tasks. As far as the state of Michigan is concerned, we are sufficiently convinced of the positive benefits that we will equip yet another hatchery this fiscal year with a Xorbox system. We further believe that Michigan's hatchery design and operational modes are uniquely suited to take advantage of this technology.

Michigan's Hatchery Design and Operational Mode

I believe that a brief discussion relative to Michigan's hatchery design **is in** order. The three new hatcheries are all designed as three-pass serial reuse facilities and operate at four water changes per hour through rectangular, linear raceways. The raceways are equipped with baffles to make them totally self cleaning and to provide high velocities for fish to select (Boersen & Westers, 1986). Production capacity and their relationships in terms of flow (lbs/gpm) and space **(lbs/ft^3)** can be expressed as follows:

lbs/gpm = 8/R x **lbs/ft^3** and **lbs/ft^3** - R/8 x lbs/gpm

where R represents the hourly exchange rate and 8 equals the number of cubic feet per 1 gpm for one hour. For an exchange rate of four (Michigan's design) we obtain:

lbs/gpm = 2.0 x **lbs/ft^3,** and **lbs/ft^3** = .5 x **lbs/gpm**

For salmonids, Michigan uses a loading formula (lbs/gpm) based on an oxygen consumption of about 95 g per pound of feed. The formula is:

$$\text{lbs/gpm} = \frac{4 \times \text{D.O. avail.}}{\text{\% B.W.}}$$

At 2% feeding and 4.0 ppm D.O. available, the loading equals 8 lbs/gpm. At an exchange rate of 4.0 per hour, the corresponding density is 4 **lbs/ft^3.** At an exchange rate of 1.0 per hour this would be 1.0 **lb/ft^3.** We do produce densities of up to 10 **lbs/ft^3.** Finally, I like to make these observations:

1. Operational modes of four changes per hour, under optimum loadings (lbs/gpm), require but one fourth the raceway (concrete) space, compared to hatcheries designed on the basis of one exchange per hour.

2. Four changes per hour make baffles very effective, and provide for excellent solid control and interception (NPDES - Permit requirements).

3. Four changes per hour produce superior pond hydraulics and, therefore, a healthier rearing environment.

4. Baffles create high velocities, locally up to over .5 feet per second. The fish can, and will, select these areas (flush their gills?)

5. Relative high densities may change the behavior of fish from one of territorial (stress) *to* schooling (submissive). This needs to be explored and density thresholds should be identified for each species.

6. The use of pure oxygen offers the opportunity to maintain optimum D.O. levels throughout the raceway, including the effluent water.

7. Number of possible reuses, based on unionized ammonia toxicity (.02 mg/l) is determined with:

$$\text{lbs/gpm} = \frac{80}{\text{\%U.A.} \times \text{\%B.W.}}$$ (Westers, 1986)

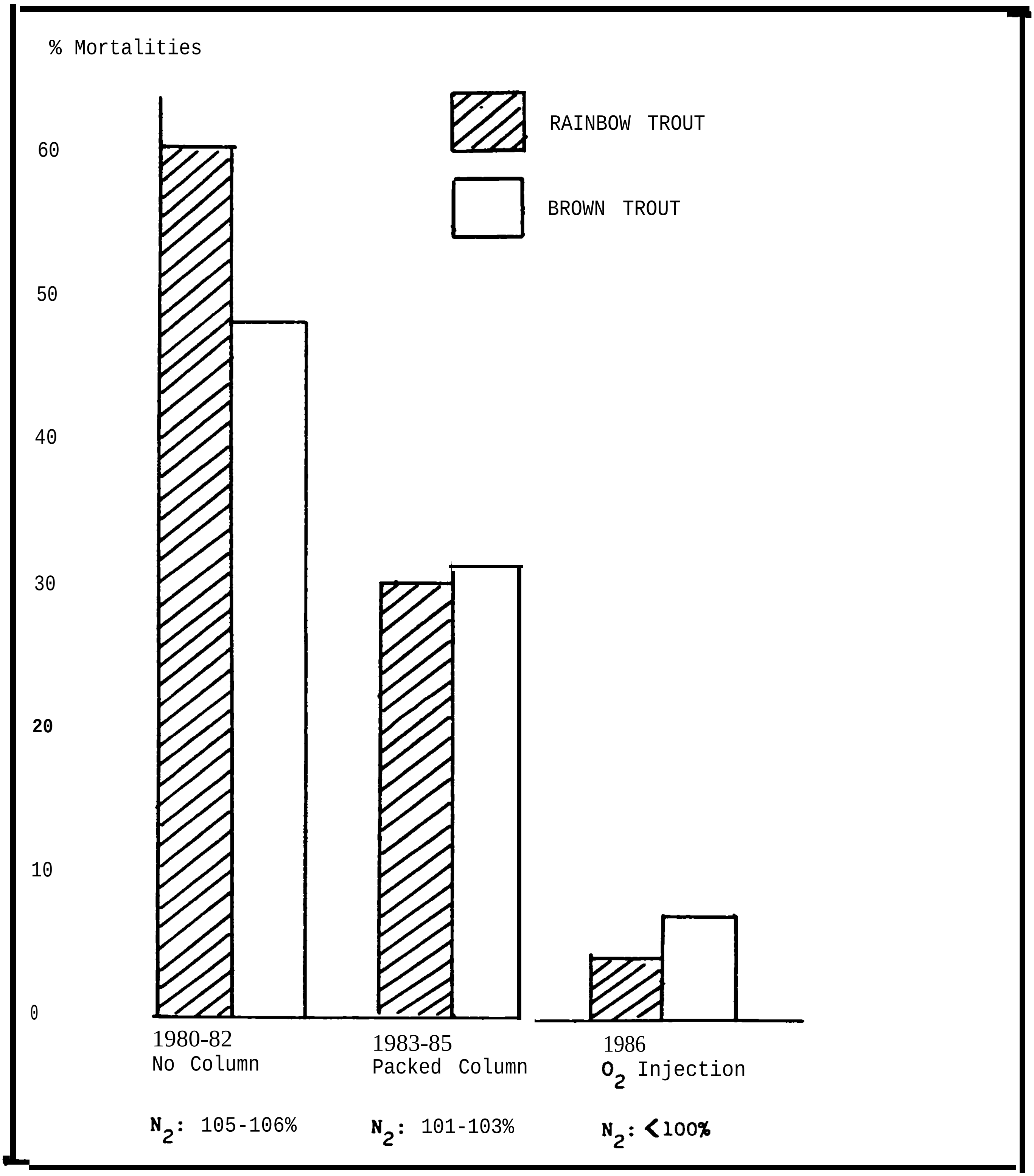

Figure 1. Average indoor rearing mortalities of Rainbow and Brown trout at Harrietta State Fish Hatchery under various nitrogen gas levels from 1980 through 1986.

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Engineering Considerations in Supplemental Oxygen

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Abstract

Michigan has experienced stress and mortality problems over the past several years due to total gas pressures greater than 100 percent. Pure oxygen has been found to be an effective means of controlling total gas pressure and increasing dissolved oxygen concentration. In selecting an oxygen source, several considerations as: facility location, capital cost, operating cost, existing facilities and the length of time oxygen is required must be evaluated. Pressure-Swing Adsorption systems were selected as the best option for a oxygen source. Several types of oxygen absorption structures have been developed. The use of pure oxygen has allowed facilities to realize their design potential at reasonable cost.

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Introduction

The Michigan Department of Natural Resources has recently completed a hatchery renovation program. With the completion of that program, rather severe stress and mortality problems started to occur with small salmonid fingerlings. After several years of investigations, gas supersaturation was identified as the suspected culprit (cause). All hatcheries with gas. supersaturation problems were equipped with packed columns to degas the water. The packed columns provided adequate dissolved oxygen and reduced Total Gas Pressure (TGP) to 101-103 percent. Although these low super-saturation levels were not creating acute mortalities, it was assumed they caused stresses resulting in secondary problems, often leading to death. A vacuum degasser was built, which proved to be a costly failure apparently due to poor design. Experiments with adding oxygen to a packed column demonstrated that TGP could be reduced to less than 100 percent with the added benefit of increased oxygen levels. This was a successful method to control TGP, but how to economically obtain and use oxygen was another problem. Basically two options were available for pure oxygen, an on-site generator or purchase of bulk oxygen.

On-Site vs. Bulk Oxygen

Not long ago, bulk oxygen was the only choice available for fish culture. Until rather recently on-site generating oxygen systems required a monthly use of 8-10 million cu ft per month. This greatly exceeded the demands of almost all fish culture operations, where only 0.5 million cu. ft. would be required. Recently small on-site generation systems have become available which produce oxygen in quantities which meet fish hatchery requirements. A number of factors are involved in selecting whether bulk or on-site oxygen generation is best for a facility. Economic considerations include capital and operating costs. Other factors include backup system requirements such as standby power and alarms. These costs depend whether the oxygen is made into a life support system or is used as a supplementary system. It further depends on the existing facilities at the hatchery itself.

The maintenance requirements of both systems is minimal. On-site systems require occasional maintenance such as compressor lubrication and air filter changes.

System Design

The State of Michigan selected the Pressure-Swing Adsorption (PSA) system for its oxygen source. Table 1 shows a cost comparison between on-site and bulk oxygen systems. As a public agency the Fisheries Division decided to go with the up front capital costs, so that operational costs will not be a problem during tight budget years. A commercial application might obviously reach a different conclusion.

Figure 1 shows a schematic of a PSA-oxygen generating system. The primary components are a compressor to force air through the molecular sieve material. The molecular sieve is a ceramic material that adsorbs nitrogen gas, but not oxygen, so what exists the generating unit is nearly pure oxygen with some argon. This goes to a storage tank. The

TABLE 1

COSTS OF OXYGEN SYSTEMS

PRESSURE SWING ABSORPTION[1]		BULK OXYGEN	
CAPITAL COST		CAPITAL COST	
40 HP Compressor	$10,000		
80 KW Standby Power	$15,000		
600 cfh PSA System	$30,000	Concrete Pad	$4,000
	$55,000		$4,000
OPERATING COST[2]		OPERATING COST	
Electricity	25¢/100 CU FT	Oxygen Cost	25-30¢/100 CU FT[3]
		Storage Tank Rental	$500/Month[4]
		Evaporation Lost	.25%/Day of Tank Volume

Other Considerations

1) Existing facilities

2) Length of time oxygen required

3) Equipment

   a) Absorption column
   b) Alarm systems
   c) Piping for oxygen conveyance

[1] Assuming a use of 10,000 cu ft/day.

[2] 25 kw/hr X 6¢/kw X 24 hr ÷ 14,400 cu ft.

[3] Cost does not include transportation, cost of delivery depends on distance from air separator, ranges from 3-15¢/50 miles, at a use of 10,000 cu ft/day, delivery cost would probably be 3-6¢/50 miles.

[4] Length of contract for rental from 3-5 years for 6,000 gallon tank.

sieve material is purged of nitrogen by decompressing and backwashing with some oxygen from the storage tank on a timed basis. The sieve material, if treated properly (moisture, oil kept to a minimum) should last indefinitely.

Three hatcheries now use the PSA systems. Each one applies the oxygen at their facility somewhat differently. All use oxygen to remove excess nitrogen, some increase DO levels while one facility supersaturates with oxygen.

At the Harrietta State Hatchery a specific room was available to install the oxygen generators. This room has 3-200 cfh oxygen generators and storage tanks. The compressors at Harrietta are housed in the mechanical room. The 40 hp compressor produces about 90,000 BTU per day and the fan from the compressor has been tied into the forced air heating system. Location of the compressor at this location has solved a couple problems that have developed at the another hatchery. At the Wolf Lake State Fish Hatchery the compressors and PSA systems are located adjacent to each other in a separate building. This has caused both the compressors and the oxygen generators to operate at elevated temperatures. The compressor at Harrietta is located about 150 ft. from the oxygen generators which apparently allows the air to cool prior to entering the generators.

Air enters the oxygen generators at about 60 psi and exits at 55 psi. A pressure regular maintains a constant 45 psi to the distribution system. Galvanized pipe and copper tubing is used in the distribution system. Three-quarter inch piping is used on trunk lines and l/2" tubing to individual oxygen absorption columns.

At the Harrietta Hatchery both the indoor and outdoor absorption columns (Figures 2 and 3) are designed with the basic design criteria of 250 **gpm/ft^2** (1 **lpm/cm^2).** A water seal is maintained at the bottom of the columns and the water falling into the column develops a vacuum of 3-4 inches mercury* The indoor absorption column is 55 inches high and 12 inches in diameter. Water flow rates through the column range from 50 to 200 gpm (200 to 800 lpm). Oxygen is added to the column at a rate of 1.5 lpm under all flow conditions. Oxygen in the water increases about 1.2 ppm from 10.0 ppm to about 11.2 ppm at **46°F.** Total gas pressure of 102 to 103 percent is decreased to less than 100%.

The outdoor absorption columns are 38 inches in diameter and 72 inches high. The tanks are currently constructed of welded steel, but switching to aluminum in the future is anticipated. The steel tanks cost about $200 each as compared to $1700 for an aluminum tank. These tanks are going to be used in two different ways. The columns on the first pass water are used primarily to degas water. Oxygen is being added at about 15 lpm. TGP is decreased to less than 100% and oxygen concentrations are slightly increased. Oxygen absorption efficiency is about 50 percent.

The columns on reuse water will be used only to reoxygenate the water and the operating criteria have yet to be developed. Use of the columns **seem** to indicate poorer absorption than on the first pass columns. The exact reason is unclear. The design of these columns to develop a vacuum may be part of the problem. Design of efficient oxygen absorption columns under varying conditions is one area where research is needed.

The indoor columns presently have 1½ inch media in them. Experiments with columns without media have not demonstrated better efficiencies. The outdoor columns have been built without media. It has been a major objective to have columns without media to reduce maintenance requirements.

The general maintenance on the system is minimal and has been incorporated into the hatcheries preventive maintenance program. Water condensate from the compressor is drained daily and the filters are cleaned on the oxygen generators weekly. The compressor operating gauges and the oxygen purity from the generators is checked dally. Because of the routine maintenance checks alarms have only been added at two locations. A pressure gauge from the compressor to the oxygen generator and another pressure gauge leading from the oxygen generator. Both of these are tied into the hatcheries alarm system.

Other systems for oxygen absorption have and are being developed at other state hatcheries. Figure 4 is from the Marquette Hatchery. A flow of 9000 gpm creek water needed treatment with only about 2 ft of head available. A slide was fitted on the weir boards of the dam. The water goes down this slide and enters boxes with an opening at the top of one side. The opening is too small to permit all the water to enter so the water helps form a seal at the top. The bottom of the box is below the water level. The oxygen with this system is added through a grid arrangement at the bottom with media in the intermediate area. The system has been able to reduce TGP's but not below 100 percent. The D.O. concentrations are increased from 10 mg/l to 14 mg/l. The oxygen absorption efficiency is about 40 percent. Oxygen is added to three boxes at a rate of 300 cu ft/hr.

The Wolf Lake Hatchery absorption system has two 18 inch corrugated pipes about 4 foot long with no media. The pumped water is discharged through a nozzle and also develops a slight vacuum. By adding 20 lpm oxygen, the D.O. level can be increased from 0 to 14 mg/l at a TGP of less than 100 percent for a flow of 300 gpm (1100 lpm). On reuse water, concentrations are increased from 7 to 14 mg/l with 12 lpm of oxygen.

Other equipment is also being developed. One example is the Aquatector. This device highly oxygenates a side stream which is then mixed with other water. This device is just being tested and many questions remain unanswered. Other techniques for adding oxygen such as U-Tubes and down flow bubble coatactors may have their applications in specific cases. (Richard E. Speece, "Management of Dissolved Oxygen and Nitrogen in Fish Hatchery Waters," Proceedings of the Blo-Engineering Symposium for Fish Culture, Traverse City, Michigan, American Fisheries Society, FCS Publ. 1)

Costs

The cost per pound of fish produced with oxygen is not an appropriate assessment at this time. The use of oxygen allows the facilities to realize their design potential. For example, at the Harrietta Hatchery it was believed the hatchery could produce 200,000 pounds per year. Prior to the use of oxygen, production of only 120,000 pounds was realized. This year, with oxygen applied, production is expected to reach 200,000 pounds for the first time. The capital cost of oxygen generators and compressors at Harrletta was about $40,000. Oxygen costs about 25¢ per 100 cu ft or about $36.00/day at maximum use. Installation of the compressor, oxygen generators and oxygen absorption columns was preformed by hatchery personnel.

How oxygen can enhance production and at what cost with a given volume of flow can be calculated readily. At an elevation of 800 ft., 50°F water at 90% saturation has a dissolved oxygen concentration of about 10 ppm. If that oxygen concentration is increased to 100 percent the oxygen is increased by 1.1 ppm to 11.1 ppm. If 6 mg/l is the lower limit for oxygen, the production potential based on an additional 1.1 ppm D.O. increases by about 25 percent (ll.l-6/10-6 = 125%). At a flow rate of 4000 gpm and a loading of 5 pounds/gpm the peak load at a facility is increased from 20,000 pounds to 25,000 pounds. The amount of oxygen required for this increased production potential is about 53 pounds of oxygen per day (5.76 mgd x 8.34 x 1.1). Should oxygen absorption be only 25 percent, 212 pounds (53 x 4) of oxygen is required, which is equal to 2800 cf of oxygen per day. At an oxygen cost of 25¢/100 cuft, the operating cost to increase production by 5000 pounds would be $7.00 per day.

Conclusion

Michigan's use of pure oxygen in fish culture was facilitated by clrcumstances which art probably unique. First, high mortalities were occurring which were believed to be related to low level nitrogen gas supersaturation, something needed to be done. Secondly, the hatcheries had several items as alarms and standby power incorporated into their design, so using advanced technology was not a new concept. Thirdly, because Michigan had built "high tech" fish hatcheries a number of the components necessary for moving into the use of pure oxygen were already in place. For instance, alarm systems and standby power had already been provided for in the new hatcheries. These three factors, made moving into the use of pure oxygen a much easier process.

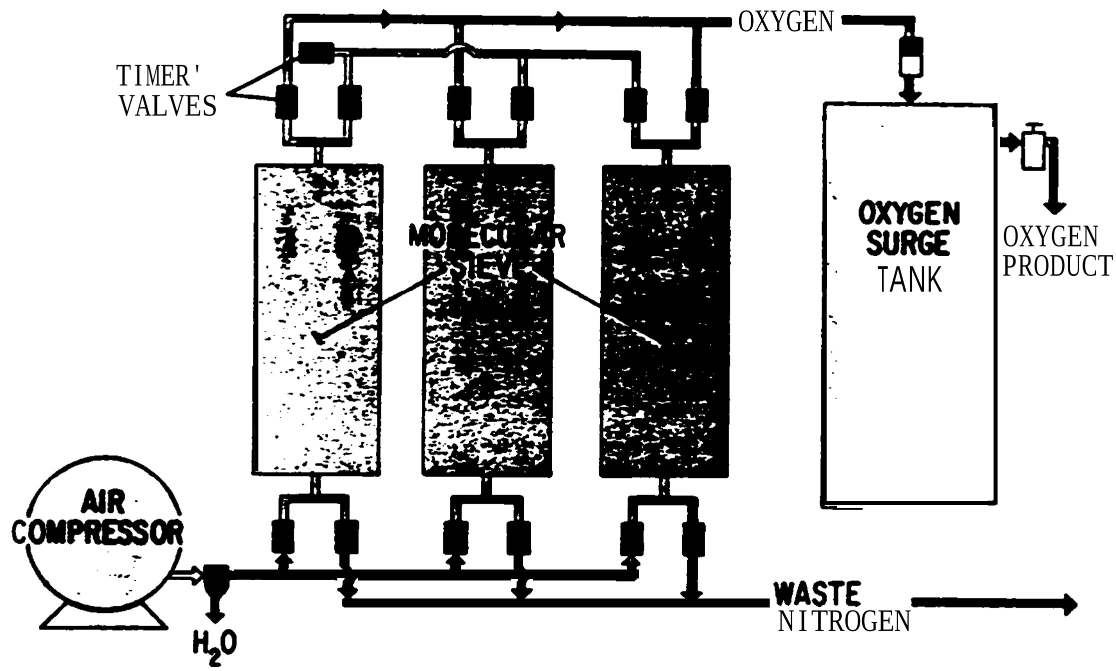
Appendix A
Common Conversions
Weight = Volume Equivalents of Oxygen

1 lb. (liquid) = 0.1371 gal (liquid) = 0.5190 (liquid)
1 lb (liquid) = 13.35 cu ft (gas) or 377.9 liters (gas)
1 gal (liquid) = 97.33 cu ft (gas) or 2756 liters (gas)
1 cu ft (gas) = 28.3 liters (gas)
1 liter (liquid) = 25.7 cu ft (gas) or 728.1 liter (gas)

Liquid is volume at normal boiling point
Gas is volume at 70°F and 14.696 PSIA

FIGURE 1

PSA-OXYGEN GENERATING SYSTEM



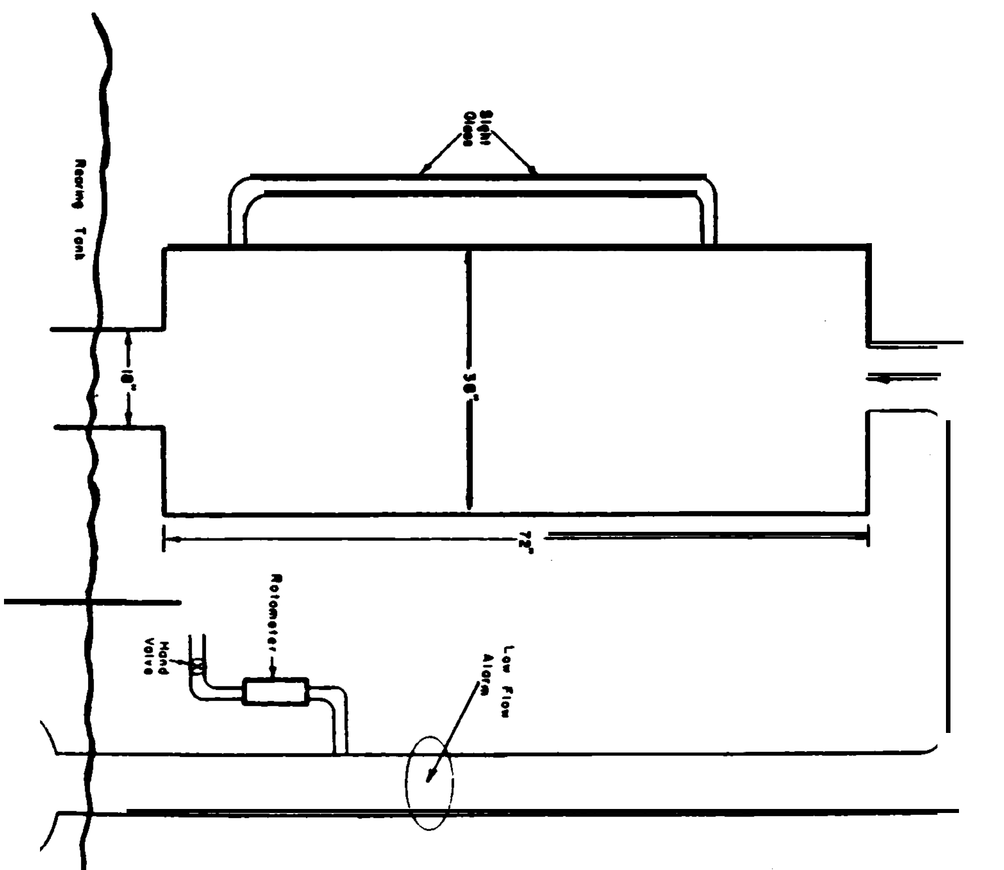


FIGURE 2

Harrie tU Fish HQchery
Out oo Rearing Tanks
Ox yde nAbsorption lu mn

FIGURE 3

Ho..ietta Fish Hatchery
Indoor Rearing Tanks
Oxygen Absorption Column

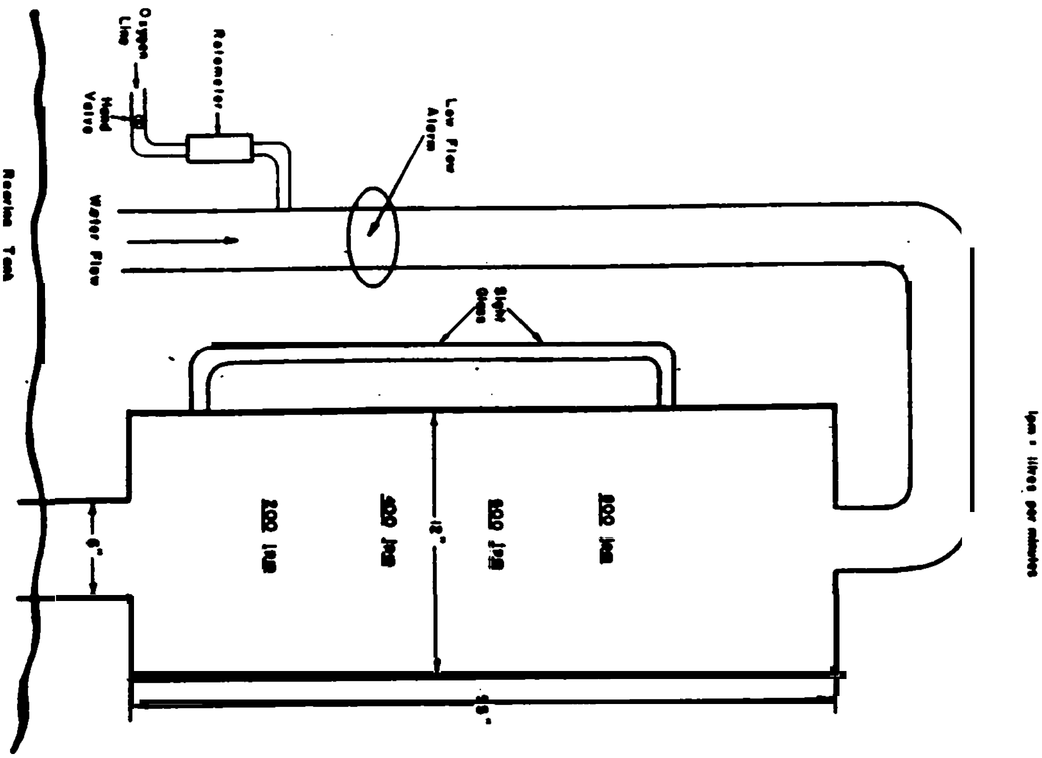
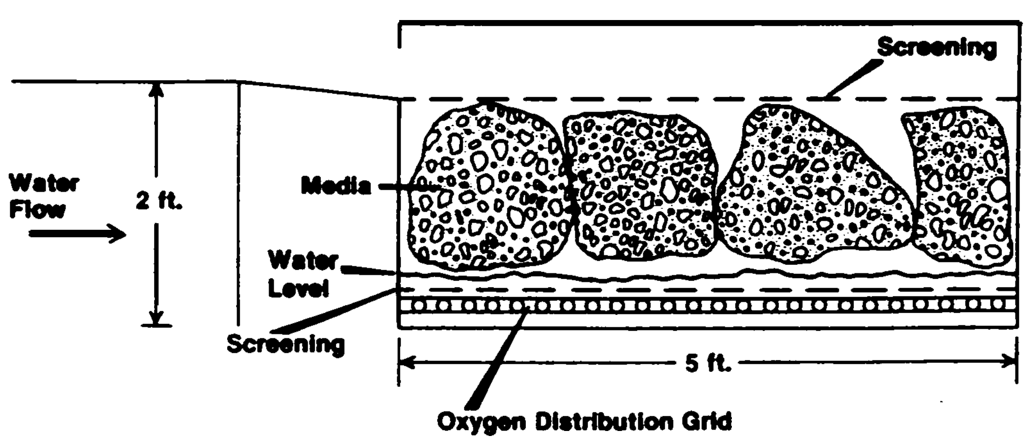


FIGURE 4

MARQUETTE FISH HATCHERY
Instream Oxygen Absorption Structure



USE OF OXYGEN TO COMMERCIALLY REAR COHO SALMON

by

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In 1977, Oregon Aqua-Foods, Inc. constructed a salmon hatchery on the McKenzie River near Springfield, Oregon. Among the unique features of the hatchery are: (1) the application of industrial waste heat to promote fish growth (from nonprocess plant cooling water effluent from a neighboring pulp and paper mill); (2) water disinfection by chlorination and its removal by sulphonation for all incoming hatchery water supplies; and (3) the use of pure oxygen to supplement natural oxygen levels in water.

The hatchery's production capability consists of 36 raceway ponds totaling 385,000 cubic feet of available rearing space. The production plan objectives require a maximum rearing density of 1.5 lbs. of coho salmon per cubic foot. A combination of the mill heated water and McKenzie River ambient water provide a total flow of 32,000 gallons per minute to the hatchery. Operating experience during 1978 and 1979 revealed that the relationship between flow capacity and available rearing capacity was disproportionate; that is, production capacity was limited by the oxygen which could be provided via available water flows.

When effluent dissolved oxygen (O_2) levels were near or at 5 mg/liter, the average loading density for the facility was only 0.7 lbs/cubic foot.

Alternative ways were explored to provide additional oxygen to the fish, which in turn would allow an increased average loading density of 1.0 lbs of fish/cubic foot of water. This average loading further assumes that peak biomass within an individual raceway may experience up to the 1.5 lbs/cubic foot design capacity and would therefore require increased oxygen to sustain such loadings. Without supplemental oxygen, the hatchery could only produce approximately 6.5 million coho smolt, and this would underutilize the hatchery's rearing capacity by 50 percent. A secondary objective was to reduce dissolved nitrogen (N_2) gas supersaturation because symptoms of low level gas embolism had been observed in alevin (yolk-sac fry) during the winters of 1978 and 1979.

The first task was to determine the quantity of oxygen required to support the additional biomass at peak load conditions. Next, we determined the amount of oxygen in the water coming into the hatchery, and by subtraction determined how much additional oxygen would be needed. Subsequent computations which considered gas transfer efficiency were provided by Dr. R. E. Speece, Professor of Environmental Engineering at Drexel University, and these determined that our additional oxygen requirement was 747 kg/day.

OXYGEN SYSTEM DESIGN ASSUMPTIONS

• Predicted peak biomass	165,000 kg
• Flow capacity	32,000 gpm
• Body weight/day feed rate	3.5 percent
• Water temperature	13.5°C
• Oxygen consumed/kg feed metabolized (fed)	0.22 kg

1. Total Oxygen Requirement

165,000 kg. fish x 0.035 kg feed/kg fish day = 5,775 kg feed/day

5,775 kg feed/day x 0.22 kg O_2/kg feed = 1,270 kg O_2/day

Oxygen Transfer and Consumption Efficiency Safety Factor:

1.33 x 1,270 kg O_2/day = 1,689 kg O_2/day.

2. Oxygen Available in Incoming Water Supply

32,000 gpm x 1,400 min/day x 3.785 l/gal x (10.4 - 5.0 mg/l) @ l,OOO,OOO mg/kg = 942 kg O_2/day.

3. Additional Oxygen Requirement

1,689 kg O_2/day - 942 kg O_2/day = 747 kg O_2/day

Oxygen consumption was determined taking into account fish food consumption and temperature. A factor of 1.33 (75 percent efficiency) serves to take into account reductions in metabolic oxygen requirements at night, loss of a portion of the oxygen to the atmosphere as it enters the ponds and other miscellaneous inefficiencies (either in the gas absorption in the water supply or in oxygen consumption rate of the fish).

Several alternatives were explored to provide the additional oxygen:

1. Increase fresh water flow by 12,760 gpm.

2. Add oxygen at the raceways through diffusers.

3. Add oxygen at the raceways through mechanical aerators.

4. Provide oxygen through high pressure side-stream injection at the raceways.

5. Inject 02 at the River pumps or in ambient water pipelines after the water disinfection treatment.

6. Provide oxygen through a side-stream packed column with counter-current oxygen injection after the water disinfection treatment.

Option Number 1 was not practical due to hydraulic limitations in the pipeline (influent and effluent capacities from the river intake station to the hatchery) and the prohibitive cost of expanding the water treatment capabilities. The latter option also implied an expansion of the hot water sys terns.

Options 2, 3, 4, and 5 were discarded because of the inefficiencies of oxygen gas transfer, high energy and maintenance costs and/or high capitalization costs and other considerations.

Option Number 6 was selected as the most efficient and cost effective. This alternative was based on the principle of a counter-current exchange process of oxygen and water creating an oxygen supersaturated solution and eliminating nitrogen gas supersaturation. Weyerhaeuser Aquaculture R&D evaluated the alternatives, Dr. R. E. Speece developed the criteria for design, and CH2M Hill provided the engineering.

Description of System

Construction was completed in March of 1980 on a counter-current supplemental oxygenation system. This comprised three, 11 foot high by 5 foot diameter packed columns containing diffusers covering all four quadrants, a diffuser plate supporting 6 feet of pall rings (118 $ft.^3$), and a water supply distribution plate. Each column is fitted with a 15 h.p. vertical pump and during combined operation will pump approximately 9,300 gpm or 30 percent of the total hatchery ambient water supply (Figure 1).

The oxygen supply system consists of a 6,000 gallon liquid oxygen storage tank, vaporization unit, and flow meters. The oxygen supply system is supplemented with an ITT Barton differential pressure (D/P) sensing system. The D/P sensing system can be calibrated to acknowledge interruptions in oxygen flow below 75 percent of normal operations, such as low storage tank level and/or leaks in the oxygen delivery line.

System operation is accomplished by filling the pall ring packed columns with water and controlling overflow via a by-pass valve located on the vertical pump. Once a volume (plug) of water is formed over the distribution plate, the water level within the column, rotometer pressure, and discharge volume can be controlled by a 16 inch column effluent gate valve. Liquid oxygen flows through the vaporization unit and then in a gaseous state, travels to a column by way of a four-place manifold. The individual locations on the manifold are connected to a Fisher and Porter flow meter. Regulated oxygen then flows into distribution diffuser pipes within the lower portion of the column where oxygen transfer occurs. Supersaturated side-stream water at 25-30 mg/l of oxygen travels out of the packed columns and is blended back into the main stream water supply which supplies the hatchery's needs.

Performance Testing

After the start-up of the oxygen system, performance testing was conducted to compare the effective supply of supplemental oxygen under varying operating modes. Variables included: (1) quantity of oxygen supplied to column diffusers; (2) percent operating capacity of any individual column; and (3) number of columns in operation. In the interest of accuracy, two YSI Model 57 oxygen meters were utilized to measure oxygen levels during the testing.

Performance testing was initiated by starting up one of the three columns. Rotometers on the test column were set at 90 percent operating capacity, and pressurized oxygen was injected into the column at 20, 25, 30, 35, and 40 psi increments. Increases in oxygen levels (mg/l) at the influent raceway headbox were documented between each pressure change. In a second test, two packed columns were initiated and rotometers on both test columns were set at 45 percent operating capacity. Pressurized oxygen (30 psi) was injected into the columns and dissolved oxygen levels were recorded. Finally, all three columns were tested at 30 percent operating capacity and pressurized oxygen supply was set at 30 psi.

Results from the first test indicated that optimum oxygen pressure to the packed columns was 30 psi. Supply pressures greater than 30 psi increased dissolved oxygen levels by only 0.4 mg/l at a substantial increase in cost. Supply pressures lower than 30 psi caused several column rotometers to malfunction. Test results also indicated that operation of two columns at 45 percent versus one column at 90 percent showed no significant increase in efficiency or operational cost savings. It should be noted that operation of three columns at 30 percent of operating capacity versus two columns at 45 percent showed no significant difference. Although there was no difference in efficiency of oxygen gas absorption between the three tests, it was more cost efficient to operate one column rather than splitting the requirement between two or three (assuming the total requirement could be met with one column or less) due to the electrical cost of one pump versus two or three.

The efficiency of gas transfer has been measured from time to time at the column's discharge and compared with measurements taken in the headbox to the raceways. Based on these measurements, the system was estimated to be 73 percent efficient in oxygen gas transfer to the water supply. The actual consumption, however, of the added oxygen was estimated at 75 percent as discussed previously in the theoretical demand computation. Oxygen values measured at the head of the raceways are shown in Figure 2 in relationship to various percent use of the supplemental oxygen system.

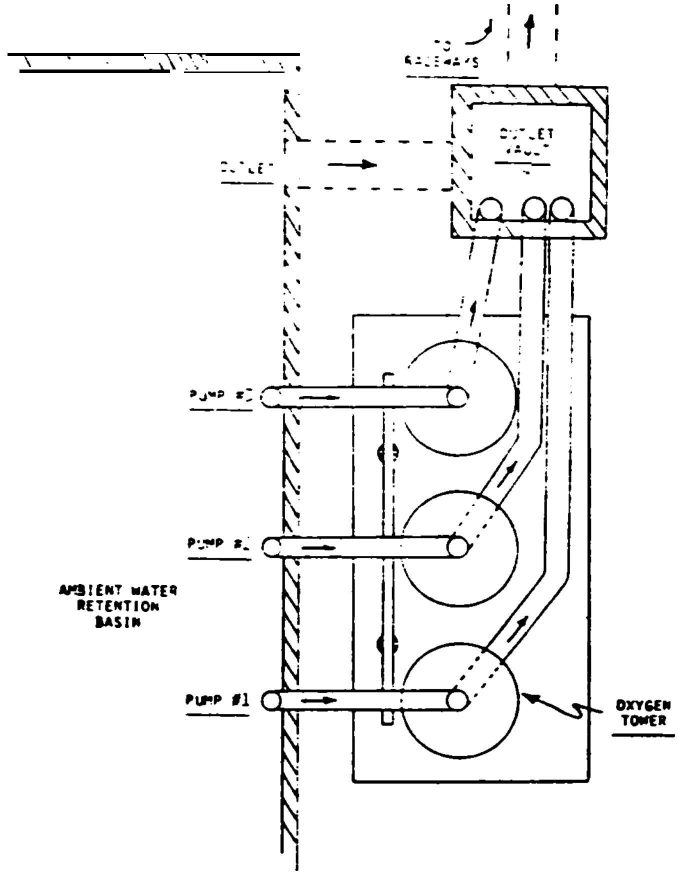
Operating Experience

Since March of 1980, Oregon Aqua-Foods has operated the supplemental oxygen system with measureable success. The Springfield hatchery water supply of 32,000 gallons per minute can support a biomass of 100,000 kg (220,000 lbs.) consisting primarily of zero-age coho salmon smolt with an average weight of 10 g (45/lb.). When the hatchery biomass exceeds 100,000 kg, typically about mid-April, supplemental oxygen is required. The need for supplemental oxygen will often extend until mid-July and may extend into August, depending on the level of chinook production following the coho.

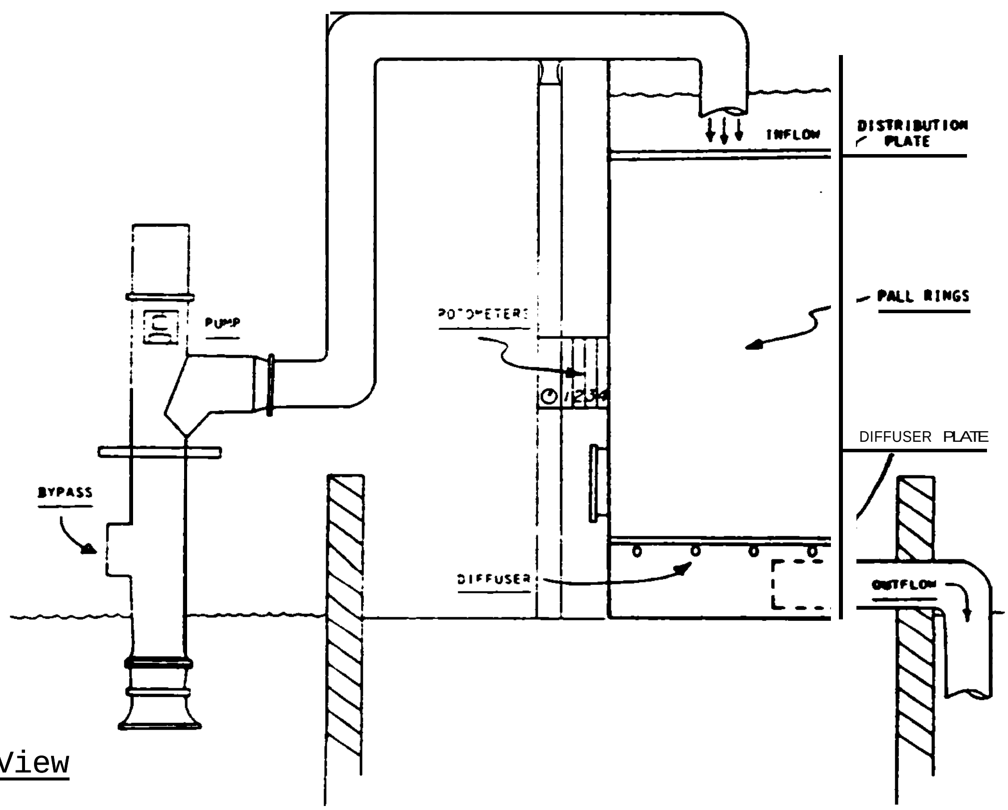
Additional performance testing has been conducted during the past 7 years to evaluate cost/benefit of the oxygen system. However, operating experience has provided the best source of information to measure the effective benefit of supplemental oxygen. There are a number of variables which determine the amount of additional production which supplemental oxygen will provide, not the least of which are related to temperature and feed. Under accelerated rearing conditions which implies temperatures in the range of 12-15°C and maximum feed rate, a doubling in capacity can be expected with addition of supplemental oxygen.

Influent dissolved oxygen levels to the raceways can be increased up to 200 percent of saturation depending on the percent of the oxygen system used. Management objectives require that the hatchery system be operated to maintain an effluent dissolved oxygen level of 5 mg/1. For example, at an operating temperature of 13.5°C, oxygen saturation of influent water into the raceways would be approximately 10.4 mg/l. Assuming the maximum flow of 32,000 gals/minute and 100 percent use of all three oxygen chambers, influent dissolved oxygen at the raceways can obtain 21 mg/l (Table 1).

The economic benefit derived from the use of supplemental oxygen is quite dramatic, particularly in light of the fact that approximately 50 percent or more of available oxygen present in the incoming water supply to a hatchery is not useable for fish production.



Plan View



Design View

Figure 1. Counter-Current Supplemental Oxygen System

For example:

Influent Dissolved Oxygen	10.4 mg/1
Effluent Dissolved Oxygen	5.0 mg/l
Useable for Fish Production	5.4 mg/1

In other words, approximately 50 percent of the cost of pumping water goes directly toward fish production and the remainder of those costs virtually go down the drain. On the other hand, each dollar spent to supplement the oxygen in the incoming water supply is returned directly to fish production. This is illustrated in Figure 2 which also demonstrates the relationship of oxygen demand (based on actual operating experience) compared to the theoretical demand.

Experience at the Springfield hatchery strongly indicates that supplemental oxygen is cost effective in increasing production capacity. For example, the operating cost ratio associated with pumping additional water versus oxygen addition is approximately 2.5:1. This, includes the cost of water treatment which would not be associated with most hatcheries. Disregarding water treatment, the ratio would still approximate 1.6:1 in favor of supplemental oxygen (Table 2). The capital costs associated with the oxygen system are also favorable compared to additional pumping or other mechanical means of aeration. Capital costs for the oxygen system at Springfield compared to the construction cost of a pump station and pipelines favor supplemental oxygen by a cost ration of 1:4.2.

An additional benefit of the oxygen system is the reduction in nitrogen gas saturation and to some extent, total dissolved gas. Nitrogen (N_2) gas saturation of incoming water can approach 103.5 percent which, under chronic conditions, can cause nitrogen gas bubble disease symptoms. Testing for nitrogen gas at varying oxygen flow rates of O-100 percent has shown a reduction in room 103.5 percent down to 82 percent (Table 3). One management practice has been to increase oxygen during the winter months when flow rates in the River are at their highest and nitrogen levels are higher than at other times of the year and production in the hatchery is most vulnerable and susceptible to gas bubble disease. Since practicing this procedure of nitrogen stripping, we have not observed any signs of gas bubble disease in our product ion.

Table 3

Effect of Oxygen on Nitrogen and
Total Dissolved Gas at 13.5°C

02 Gas Flow	% O2	Headbox % N2	TDG
100%	162%	92-92%	102.5%
40%	127%	96-98%	102.5%
0%	107%	l00-103.5%	103.0%

Note : % N_2 in discharge of sidestream system is . 72%.

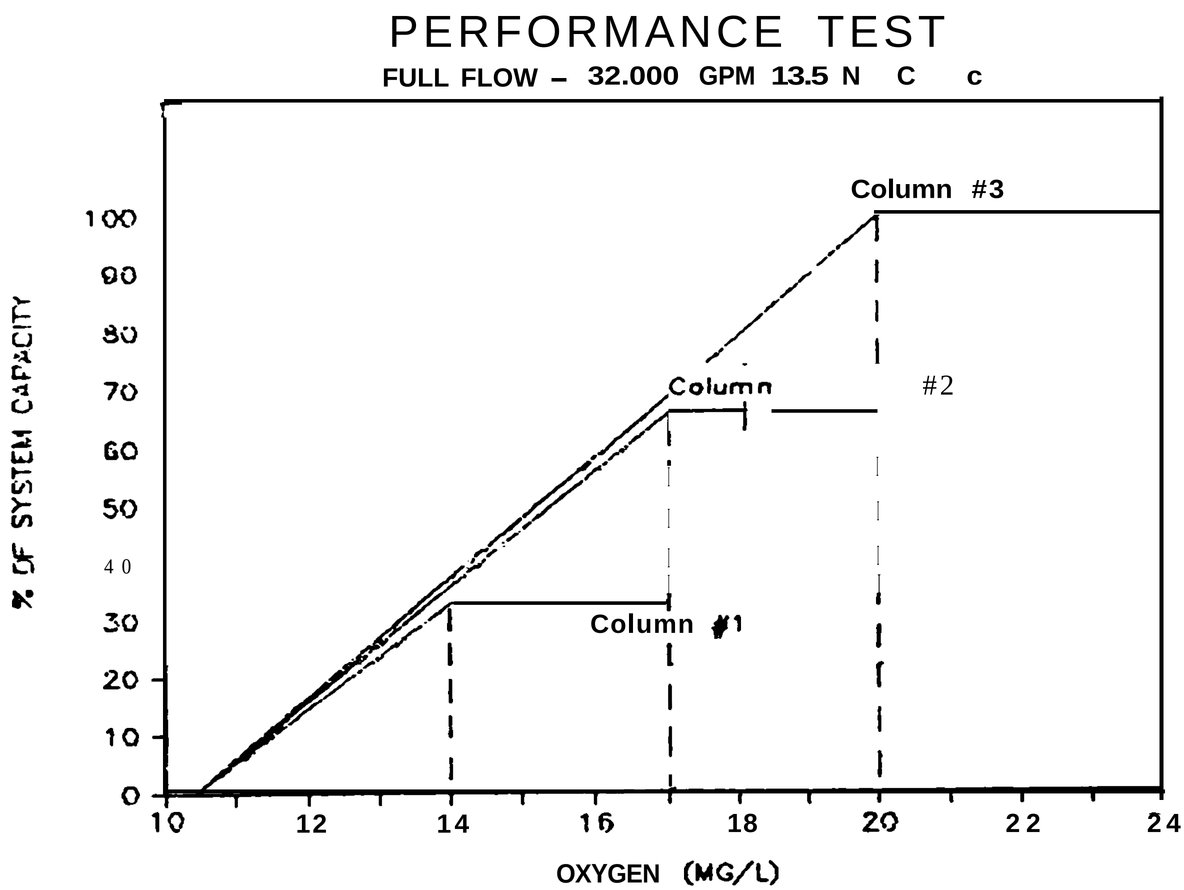


Figure 2.

Oxygen Level of Inflow to Raceways at Various Operating Percent of Oxygen System

Table 1. OXYGEN DEMAND AND SUPPLEMENTATION FOR ZERO-AGE COHO PRODUCTION

Required Biomass (1,000's kg)	Ambient Water Supply (gpm)	Influent Oxygen (mg/l)	Effluent Oxygen (mg/l)	Available Oxygen to Fish (kg O_2/day)	Additional Oxygen Required (kg O_2/day)	Total Oxygen Available to Fish (kg O_2/day)	Oxygen Use in SCF/day-1/
25	5,750	10.4	5.0	169		169	
50	11,500	10.4	5.0	338		338	
75	17,250	10.4	5.0	507		507	
100 (220 k lbs.)	23,000	10.4	5.0	676		676	
125	32,000	11.5	5.0	941	191	1,133	5,080
150	32,000	13.8	5.0	941	593	1,534	15,792
175	32,000	16.1	5.0	941	994	1,936	26,478
200	32,000	18.4	5.0	941	1,395	2,337	37,160
225	32,000	20.7	5.0	941	1,796	2,738	47,844

1/ Standard cubic feet

Conclusions

Our experience has shown that supplemental oxygen is a benefit not only to the economics of fish production, but also as it relates to fish health and quality of smolt. Although these benefits are less tangible, they can be measured over time by better survival and growth performance in the hatchery, and better marine survival. Supplemental oxygen is particularly advantageous under conditions in which a hatchery's rearing capacity is disproportionate to its water flow capacity as is the case at Springfield. If a hatchery is underutilizing its rearing volume due to lack of water flow, supplemental oxygen will more than likely be the least expensive alternative as it compares both in operating and capital costs.

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USE OF SUPPLEMENTAL OXYGEN TO REAR CHINOOK IN SEAWATER

by

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Introduction

Anadromous, Inc. is an ocean ranching company with a freshwater rearing facility near Klamath Falls, OR and a salt water rearing facility at Coos Bay, OR. The Company rears and releases coho, spring and fall chinook. In past years the company has released up to 2 l/2 million chinook smolts annually and will release over 5 million in 1987.

Two general rearing strategies are used for spring chinook. In the first strategy, spring chinook are raised to 4 grams in freshwater and then moved to seawater at Coos Bay, OR, in Play-June. Thence, smolts are grown to a size of 45 g in seawater and released in mid-August. In the second strategy, the fish are transported to seawater as 25-35 g smolts in July through September, held for 30 days in seawater, and released at 45-55 g.

The Coos Bay facility is on an estuary and uses pumped seawater; tidal cycles cause salinity, temperature, and raceway flows to change through the day. Pump output at low tide is less than at high tide. In a 24-hour period, salinity can vary between 10 and 33 parts per thousand (°/oo), temperature from 8 to 16 C, and flow from 20-40,000 liters per minute. As a result of tide cycles, the amount of disolved oxygen (D.O.) available to the fish from the pumped seawater also varies substantially within each day.

High biomass loads (rearing densities) are used at the Coos Bay facility, and supplemental oxygen is used to rear all species. The oxygen system used at the Coos Bay site is an injection system (Figure 1) and has been in use since May 1984.

The main supply of seawater is pumped from a depth of 15-25 feet (depending on the tide). The pumped seawater passes through an aspirator basin to strip off nitrogen. The flow out of the aspirator basin is at saturation or above, and receives the supersaturated oxygen flow from the injector. Oxygen is bled off as a gas from the liquid oxygen tank and is injected into a 4″ PVC water line. The water in the line is at 80 PSI, and the oxygen is at 100 PSI; the pressure differential prevents water from entering the oxygen line. Thence, oxygen goes through an orifice plate which serves to maintain back pressure in the line until just prior to entering the injector. The advantage of the high back pressure is the larger amount of oxygen that can be held in solution.

In addition to the main oxygen injector line there is a second injection line which has six injectors, one for each raceway. The raceway injectors are at the midpoint of the raceways and are individually adjusted for the biomass load in each raceway.

Effects of Dissolved Oxygen of Carrying Capacity

The amount of biomass which a hatchery can sustain is limited by the dissolved oxygen which is available for metabolic usage. To estimate the carrying capacity, one must estimate the flow, the initial D.O. and the effluent D.O. In our case, D.O. ranges from 7-11 mg/l when it leaves the aspirator basin. If an effluent D.O. of 5 mg/l is desired, then only 2 to 6 mg/l of oxygen are available for rearing fish. Note that it is the lowest available influent D.O. that is important because this determines how much supplemental oxygen is needed for any given time. Conversely, the mean influent D.O. determines the total daily requirement.

The maximum biomass load that could be carried at the Coos Bay site without supplemental 02 was estimated as follows:

Total oxygen in hatchery water supply = Flow/day x D.O. =

= 30,400 x lpm (7 mgO_2/l) x (60 min/hour) x (24 hour/day) x (1 $kg/1x10^6$ mg)

= 306 kg O_2/day.

And total oxygen in the hatchery effluent =

= 30,400 lpm x 5 mg O_2/l x 60 min/hour x 1 kg/lx 10^6mg.= 219 kg O_2/day

If an effluent D.O. of 5 mg/l is desired, then 219 kg O_2/day is "lost" or unused in the hatchery effluent. Therefore the oxygen available for rearing fish =

=306 kg O_2/day - 219 kg O_2/day = 87 kg O_2/day.

We assume that each kg of biomass requires 150 mg 02 per hour or about 3,600 ❑ g 02 per kg[2] fish per day (see appendix).

The maximum fish biomass which could be supported concurrently (without supplemental oxygen) is:

$$\frac{(87 \text{ kg } 02) \text{ X } (1\text{x}10^6 \text{ mg/kg})}{3{,}600 \text{ mg } O_2/\text{kg fish/day}} =$$

= 24,166 kg (53,166 lbs).

Therefore the available D.O., in our situation limited rearing densities to only 7.4 kg/m3 (0.47 lbs/ft^3), or less.

Because increased fish production was desired, two alternatives were possible: pump more water to provide the oxygen, or provide supplemental oxygen. The latter alternative was selected because it was the least expensive means of achieving the same biological goal.

In July 1984 a supplemental oxygen system was installed, and 68,000 kg (149,600 lbs) of chinook and coho were reared at the same site. The chinook rearing densities for the month ranged from 15 to 22 kg/m^3. The loading density increased as the fish grew and averaged 20.8 kg of fish per cubic meter or (1.33 pounds per cubic feet) over the rearing period. The amount of supplemental oxygen used by the system during that period was 37,636 kg (82,000 lbs).

Cost of Supplemental Oxygen

The cost of liquid 02 for the month of July 1984 was $7,500 ($.75/100 ft^3). Therefore, the cost to rear the additional 44,000 kg (96,800 lbs) of fish for 1 month was $7,500 or 7.8 cents per pound of fish per month.

Estimation of Efficiency

The efficiency of the supplemental oxygen system can be estimated by dividing the estimated oxygen consumption by the actual oxygen used, as follows:

$$\text{Efficiency} = \frac{\text{estimated } O_2 \text{ consumed by fish/day}}{\text{observed mean } O_2 \text{ usage/day}} =$$

$$= \frac{258 \text{ kg } O_2}{2{,}254.5 \text{ kg } O_2} = 0.126$$

(Note : This assumes that 150mg 02 is used per day per kg of fish)

This is a very emperical estimate whose value is uncertain. However it is fair to say that there is ample room for improving the efficiency of the system.

Reasons for Apparent Inefficiency

Several factors contribute to inefficient utilization of the supplemental oxygen which is being provided via our system. While this list is not exhaustive , it covers the main problems. These are:

1. The system is said to be 80 percent efficient at delivering O_2 into solution, so 20 percent is lost inmediately after injection.

2. The system is not self regulating; it has to be adjusted manually. Due to the high variability in inflow, the system is always set high as a safeguard. Peak oxygen utilization by the fish also varies with feed rate and activity; although it can be reduced by continual feeding.

3. The length of the raceways (420') is such, that some injected 02 is lost to the atmosphere. The amount of oxygen lost is uncertain, but it takes 40 minutes for the water to travel from the first injector to the second.

4. The second injection line does not distribute the O_2 evenly. The first injector in the line gets more O_2 than the next and so on. That means that the line has to be adjusted upward in order to get sufficient O_2 to the last raceway.

5. There is some oxygen leakage from the tank.

1984 was the first year that we used the supplemental oxygen supply system. At present we are using a more extensive monitoring system to reduce consumption. In October 1986, we carried a slightly larger biomass at Coos Bay for an 02 cost of $4,000, which gives an overall efficiency of 24 percent. We hope to improve upon that with better equipment and more intensive monitoring of water quality parameters. Still, we feel that the advantages of supplemental 02 systems far outweigh the disadvantages.

Appendix

Empirical Calculation of 02 Consumption

On 24 and 25 November 1986, oxygen consumption was measured in one raceway section at Coos Bay. The inventoried biomass was 14,000 kg of coho salmon with a mean weight of 180 g. The mean flow into the raceway was 5646 lpm. Oxygen levels were measured before and after the first injector, at the head of raceway, and just prior to the second injector, producing the following data:

	Tide and Time			
Dissolved oxygen:	Low High 4:38p,24 Nov	Low Low 11:47p,24 Nov	High High 7:03a,25 Nov	High Low 12:45p,25 Nov
before injection (mg/l)	10.1	10.0	9.4	9.8
after injection (mg/l)	16.6	15.5	15.4	16.0
top of raceway (mg/l)	15.8	14.8	13.8	15.3
middle raceway (mg/l)	11.3	10.5	9.5	9.9
Oxygen consumption:				
ΔO_2 (mg/l)	4.5	4.3	4.3	5.4
mg O_2/kg fish	108.6	104.0	104.0	130.9
Temp. (C)	11	10	11	11
Salinity (O/00)	18.8	17.9	31.5	18.8

The 02 consumption by smaller fish would be considerably higher. Oregon Aqua Foods estimates 02 consumption at 350 mg O_2/kg fish/hour for 10 g. coho in freshwater (Dick Severson, Oregon Aqua Foods, Springfield, OR). The 150 mg O_2/fish/hour figure is a rough composite of several values in the literature.

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EFFECTS OF RACEWAY INFLOW AND REARING DENSITY INTERACTIONS ON ADULT RETURNS OF COHO AND SPRING CHINOOK SALMON

by

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Raceway rearing density studies were conducted at Willard National Fish Hatchery using **1981** and 1982-brood coho salmon and are being conducted at Carson National Fish Hatchery using **1982** through 1985-brood spring chinook salmon. Objectives of these tests are to study the effects of different raceway loadings on: **(1)** fingerling performance, physiology, and disease status during hatchery residence and (2) post-release survival and adult contribution. At Willard, coho fingerlings were reared for approximately one year at densities of 25,000, 50,000, and 75,000 fish per raceway at water inflow rates of 200, 400, and 600 gallons per minute in a two-way factorial design with two replicate raceways per cell. A similar design is being used with spring chinook at Carson. Fingerling densities have been established at 20,000, 40,000, and 60,000 fish per raceway at inflows of 200, 400, and 600 gallons per minute. Treatment effects on post-release survival are being determined through evaluation of catch-release ratios of coded wire-tagged subpopulations from each raceway. Recovery data from the coho studies are limited to hatchery rack returns and non-finalized ocean recoveries. Spring chinook recovery data are from partial returns from **1982** brood tests.

Raceway loadings at release in pounds of smolts per gallon per minute inflow and pounds per cubic foot of rearing space are shown in Tables l-4. At Willard, coho smolts ranged from1.8 to approximately 16.0 pounds of fish per gallon per minute of inflow. Crowding levels varied from 0.9 to 2.9 pounds per cubic foot of rearing space. Similar loadings were obtained at release in the spring chinook tests at Carson.

Experimental treatment effects on percent recovery of coded-wire-tagged groups are summarized in Tables 5 and 7. Adult contributions (Tables 6 and 8) were determined by multiplying catch-release ratios of wire-tagged fish (within raceway) by total smolts released (within-raceway). The following observations are based on these data:

1. Percent recovery and adult contribution of coho was not affected by raceway inflow rates (Tables 5 and 6). This may have been a reflection of the year-around cold water temperatures **(39-45°F)** at Willard. Inflowing dissolved oxygen was **11.9** and 11.5 ppm at smolt release for the **1981** and **1982** broods, while variation in raceway effluent oxygen was limited to 8.6 to 11.4 ppm between treatment cell extremes.

2. Although coho survival rates were reduced somewhat as rearing densities increased (Table 5), adult returns (Table 6) increased by a factor of 2.3 as fish reared per raceway increased from 25,000 to 75,000.

3. Results from tests of spring chinook suggested a trend of increased survival rate and contribution with increased inflow (Tables 7 and 8). At smolt release, dissolved oxygen at raceway inflows was recorded at 12.2 ppm. Effluent oxygen levels ranged from 7.0 ppm to 11.7 ppm between treatment cell extremes. The divergent response of coho and spring chinook to different levels of inflow may have been a reflection of variations in species tolerance to loading or the result of subtle differences between the two hatcheries or their water supplies.

4. Survival rates of spring chinook decreased significantly as rearing densities increased (Table 7). As a result, raceways with 20,000 smolts have produced as many returning adults to date as raceways where 60,000 fish were reared (Table 8).

The effects of dissolved oxygen on adult returns cannot be directly assessed within these studies. Although oxygen levels differed between rearing environments, direct oxygen effects were obscured by simultaneous variations in water inflow rates. Oxygen, however, may have been a contributor to the inflow-related differences in survival observed in the spring chinook tests.

The studies reported here were conducted at hatcheries with year-around cold water temperatures. Different results might be expected, however, from similar tests conducted at hatcheries with warmer water where the oxygen metabolism of fish is higher and oxygen carrying capacity of water is reduced.

TABLE 1. Pounds of smolts per gallon per minute inflow at release in 1981- and 1982-brood coho rearing tests at Willard National Fish Hatchery.

Inflow (gpm)	Race-way	1981 brood year Fish per raceway at start				1982 brood year Fish per raceway at start			
		25000	50000	75000	Mean	25000	50000	75000	Mean
200	A	5.9	12.6	17.6		5.0	11.3	14.8	
	B	5.9	13.0	17.8	12.1	5.7	11.6	14.9	10.6
400	A	2.9	6.3	8.9		2.7	6.0	7.7	
	B	2.8	6.0	9.0	6.0	2.8	5.9	7.5	5.5
600	A	1.8	4.0	6.0		1.8	3.5	5.3	
	B	2.1	3.9	6.3	4.0	1.8	3.6	5.3	3.6
	Mean	3.6	7.6	11.0		3.3	7.0	9.3	

TABLE 2. Pounds of smolts per gallon per minute inflow at release in 1982-brood spring chinook tests at Carson National Fish Hatchery.

Inflow (gpm)	Race-way	Fish per raceway at start 20000	40000	60000	Mean
200	A	5.5	10.9	16.0	
	B	5.9	11.3	15.9	10.9
400	A	2.8	5.6	8.1	
	B	2.6	5.4	8.0	5.4
600	A	1.9	3.5	5.5	
	B	1.8	3.4	5.6	3.6
	Mean	3.4	6.7	9.9	

TABLE 3. Pounds of smolts per cubic foot of rearing space at release in 1981- and 1982-brood coho rearing tests at Willard National Fish Hatchery.

Inflow (gpm)	Raceway	1981 brood year, Fish per raceway at start: 25000	50000	75000	Mean	1982 brood year, Fish per raceway at start: 25000	50000	75000	Mean
200	A	0.91	1.97	2.74		0.78	1.76	2.32	
	B	0.93	2.02	2.78	1.89	0.89	1.81	2.32	1.65
400	A	0.90	1.96	2.77		0.85	1.87	2.39	
	B	0.88	1.88	2.81	1.87	0.87	1.84	2.34	1.69
600	A	0.86	1.87	2.82		0.82	1.65	2.50	
	B	0.97	1.85	2.93	1.88	0.86	1.71	2.49	1.67
	Mean	0.91	1.93	2.81		0.85	1.77	2.39	

TABLE 4. Pounds of smolts per cubic foot of rearing space at release in 1982-brood spring chinook tests at Carson National Fish Hatchery.

Inflow (gpm)	Race-way	Fish per raceway at start 20000	40000	60000	Mean
200	A	0.92	1.81	2.66	
	B	0.98	1.87	2.64	1.81
400	A	0.92	1.86	2.67	
	B	0.87	1.77	2.66	1.79
600	A	0.93	1.73	2.71	
	B	0.91	1.71	2.80	1.80
	Mean	0.92	1.79	2.69	

TABLE 5. Percent recovery of **1981-** and **1982-brood** coded-wire-tagged coho from raceways within treatment groups at Willard National Fish Hatchery (Based on partial returns only).

Inflow (gpm)	Race-way	1981 brood year Fish per raceway at start 25000	50000	75000	Mean	1982 brood year Fish per raceway at start 25000	50000	75000	Mean
200	A	0.31	0.29	0.27		0.44	0.44	0.26	
	B	0.31	0.33	0.27	**0.30[c]**	0.42	0.37	0.38	**0.39[c]**
400	A	0.27	0.28	0.23		0.30	0.35	0.36	
	B	0.34	0.29	0.21	**0.27[c]**	0.43	0.44	0.29	**0.36[c]**
600	A	0.31	0.24	0.25		0.44	0.27	0.40	
	B	0.47	0.29	0.28	**0.31[c]**	0.41	0.32	0.37	**0.37[c]**
	Mean	0.33"	**0.29[ab]**	**0.25[b]**		**0.41[a]**	**0.36[a]**	**0.35[a]**	

ab Within brood years, column means with different letters in their superscripts are significantly different **(P<.05).**

c Within brood years, row means were not significantly different **(P<.05).**

TABLE 6. Adult contribution of 1981- and 1982-brood coho from raceways within treatment groups at, Willard National Fish Hatchery (Based on partial returns only).

Inflow (gpm)	Raceway	1981 brood year Fish per raceway at start 25000	50000	75000	Mean	1982 brood year Fish per raceway at start 25000	50000	75000	Mean
200	A	72	141	185		87	185	147	
	B	74	158	184	136[d]	89	159	215	147d
400	A	63	131	159		63	151	204	
	B	79	138	148	120d	98	187	163	144[d]
600	A	71	115	177		91	104	243	
	B	110	136	198	135[d]	84	123	224	145[d]
	Mean	78"	137b	175[c]		85[a]	152[b]	199[c]	

abc Within brood years, column means with different superscripts are significantly different (P<.05).

d Row means within brood year are not significantly different (P<.05).

TABLE 7. Percent recovery of 1982-brood coded-wire-tagged spring chinook from raceways within treatment groups at Carson National Fish Hatchery (Based on partial returns only).

Inflow (gpm)	Race-way	Fish per raceway at start 20000	40000	60000	Mean
200	A	0.057	0.057	0.007	
	B	0.041	0.017	0.011	0.032[c]
400	A	0.068	0.032	0.027	
	B	0.053	0.032	0.028	0.040[cd]
600	A	0.094	0.037	0.027	
	B	0.082	0.034	0.034	0.051[d]
	Mean	0.066[b]	0.035[a]	0.022[a]	

ab Colunn means with different superscripts are significantly different (P<.05).

cd Row means with different letters in their superscripts are significantly different (P<.05).

TABLE 8. Adult contribution of 1982-brood spring chinook from raceways within treatment groups at Carson National Fish Hatchery (Based on partial returns only).

Inflow (gpm)	Raceway	Fish per raceway at start 20000	40000	60000	Mean
200	A	11	23	4	
	B	8	7	6	10[b]
400	A	14	12	16	
	B	10	12	17	14[bc]
600	A	18	15	16	
	B	16	14	20	17[c]
	Mean	13[a]	14[a]	13[a]	

a Column means are not significantly different ($P<.05$).

bc Row means with different letters in their superscripts are significantly different ($P<.05$).