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Analyses of Potential Factors Affecting Survival of Juvenile Salmonids Volitionally Passing Through Turbines at McNary and John Day Dams, Columbia River

Open-File Report 2011–1227

U.S. Department of the Interior
U.S. Geological Survey

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KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2011

Suggested citation:
Beeman, J.W., Hansel, H., Perry, R.W., Hockersmith, E., and Sanford, B., 2011, Analyses of potential factors affecting survival of juvenile salmonids volitionally passing through turbines at McNary and John Day Dams, Columbia River: U.S. Geological Survey Open-File Report 2011-1227, 124 p.

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

SI to Inch/Pound

Multiply	By	To obtain
kilometer (km)	0.6214	mile (mi)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32.$$

Datums

Horizontal coordinate information is referenced to the World Geodetic System of 1984 (WGS84).

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Abbreviations and Acronyms

AICc Akaike Information Criterion adjusted to reflect the effects of sample size
BIOP Biological opinion
FCRPS Federal Columbia River Power System
NOAA National Oceanic and Atmospheric Administration
rkm river kilometer
USACE U.S. Army Corps of Engineers
USGS U.S. Geological Survey

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Executive Summary

This report describes analyses of data from radio- or acoustic-tagged juvenile salmonids passing through hydro-dam turbines to determine factors affecting fish survival. The data were collected during a series of studies designed to estimate passage and survival probabilities at McNary (2002–09) and John Day (2002–03) Dams on the Columbia River during controlled experiments of structures or operations at spillways. Relatively few tagged fish passed turbines in any single study, but sample sizes generally were adequate for our analyses when data were combined from studies using common methods over a series of years. We used information-theoretic methods to evaluate biological, operational, and group covariates by creating models fitting linear (all covariates) or curvilinear (operational covariates only) functions to the data. Biological covariates included tag burden, weight, and water temperature; operational covariates included spill percentage, total discharge, hydraulic head, and turbine unit discharge; and group covariates included year, treatment, and photoperiod. Several interactions between the variables also were considered. Support of covariates by the data was assessed by comparing the Akaike Information Criterion of competing models. The analyses were conducted because there was a lack of information about factors affecting survival of fish passing turbines volitionally and the data were available from past studies. The depth of acclimation, tag size relative to fish size (tag burden), turbine unit discharge, and area of entry into the turbine intake have been shown to affect turbine passage survival of juvenile salmonids in other studies.

This study indicates that turbine passage survival of the study fish was primarily affected by biological covariates rather than operational covariates. A negative effect of tag burden was strongly supported in data from yearling Chinook salmon at John Day and McNary dams, but not for subyearling Chinook salmon or juvenile steelhead. The negative effect of tag burden in data we examined from yearling Chinook salmon supports the recent findings from laboratory studies of barotrauma effects. A curvilinear (quadratic) effect of turbine unit discharge was weakly supported in data from subyearling Chinook salmon at John Day Dam. The maximum survival from those data was estimated to occur at a discharge of 15.9 thousand cubic feet per second, but the estimate was imprecise (95 percent confidence interval of -1.7–33.7 thousand cubic feet per second). This estimate is within the range of 1 percent of peak turbine operating efficiency (12.0–21.6 thousand cubic feet per second), but is lower than the 17.2 thousand cubic feet per second discharge at peak operating efficiency (at a head of 102 feet near the median in the data we examined). Effects of water temperature were supported in four of the five examined data sets and were strongly supported in all but one. Spill percentage, head, and total discharge received weak or moderate support in some cases.

The results are consistent with those of several controlled field experiments of turbine discharge. Studies based on the Hi-Z Turb'N tag (balloon tag) often show small, generally statistically insignificant, differences in survival at different turbine discharge levels. Some studies also show that a quadratic equation can be well fit to the relation of survival and turbine unit discharge. The lack of support for the operational covariates in most of the data sets we examined may be due to the small effect turbine discharge has even in controlled studies, the observational nature of the data we used, and the evaluation method. We assessed support of the data for models of linear and quadratic effects, whereas controlled experiments often statistically compare the point estimates of survival from each operational treatment studied. The results of our analyses suggest tag burden should be minimized or controlled for in analyses of future studies of passage survival and that water temperature also should be considered as a factor. This study may be the first to use data from juvenile salmonids entering turbines volitionally to assess factors affecting their turbine passage survival. Analyses of other data sets from fish with similar attributes should be conducted to corroborate these results.

Introduction

Hydroelectric dams are often cited as one cause of reductions in populations of anadromous salmonids (National Research Council, 1996). Adult anadromous fish in rivers with hydroelectric dams often must cross dams as they migrate upstream to spawn and their offspring must cross them as they migrate to the ocean to rear. The use of fish ladders generally has been a successful means of providing upstream passage for adult salmonids, resulting in little passage delay and high passage survival (Keefer and others, 2004). Cumulative survival of juveniles during their downstream migration, however, is lower, and has been a focus area for improvements (Muir and others, 2001; Williams and others, 2001). As a result, a recent biological opinion (BIOP) for the Federal Columbia River Power System (FCRPS) set minimum standards for dam passage survival of juvenile salmonids (National Oceanic and Atmospheric Administration’s National Marine Fisheries Service, 2008).

Actions to improve dam passage survival of juvenile salmonids in the FCRPS have traditionally focused on reducing passage through routes with low survival and increasing passage through routes with high survival. Generally, juvenile salmonid survival is highest through spillways, intermediate through turbine bypass systems, and lowest through turbines (Muir and others, 2001). As such, efforts to improve survival of juvenile salmonids since about 1995 have primarily focused on improving the probability of passage and survival through the spillways at FCRPS dams (Swan and others, 1997; Hansel and others, 2004; Johnson and others, 2005; Beeman and others, 2010).

Little effort has been directed toward improving survival of juvenile salmonids passing turbines relative to the other routes. This is unfortunate, because it may be more cost-effective to make improvements in turbine design or operation than to structures or operations of bypass systems or spillways. Turbines at several FCRPS dams are nearing their replacement age, and new fish-friendly designs may be beneficial to both fish and power generation (Odeh, 1999; Cada, 2001; Cada and others, 2006). Causes of mortality during turbine passage include exposure to shear, strike, and rapid pressure changes. Odeh (1999) and Cada (2001) provide descriptions of potential sources of mortality during turbine passage.

One management action intended to maximize turbine passage survival is the BIOP mandate to operate Kaplan turbines within 1 percent of their peak efficiency. This is based on data from Bell (unpub. data), suggesting this would provide the greatest survival. Several studies conducted to test this premise have shown that the peak survival does not always coincide with the “1 percent rule”, and is often associated with higher discharges (Mathur and others, 2000; Skalski and others, 2002a; Normadeau Associates and others, 2003, 2008). These results, and supporting results from physical models of turbines, have prompted further research into the relation between turbine operating conditions and fish survival. The goal of this research is to determine the turbine operating criteria, or “operating point,” that optimizes survival of juvenile salmonids passing through them. Such information could be used to design new turbine operating conditions and potentially new turbine designs.

Most studies of juvenile salmonid turbine passage survival have been based on surface-acclimated fish fitted with the Hi-Z Turb’n tag (balloon tag; Heisey and others, 1992; Mathur and others, 1996, 2000; Normadeau Associates and others, 2003, 2008).

These studies were based on juvenile salmonids, often taken directly from a hatchery, fitted with an externally attached radio transmitter and an externally attached small inflatable balloon. The fish are passed through a hose directly into the turbine intake or runner after injecting the balloon with a liquid to cause it to inflate shortly after release. The balloon facilitates recapture following passage after locating fish visually and with radio telemetry. These studies have been useful for testing the effects of various turbine-operating conditions on fish survival. However, results from these studies show that the elevation of entry into the turbine intake can affect turbine passage survival, and results from Brown and others (2009), and Carlson and others (2010) show that depth of acclimation is also an important factor. Therefore, it is beneficial to have data from depth-acclimated volitionally passing fish from which to draw inference. This report describes analyses of such data.

Data from volitionally passing juvenile salmonids are available from many studies conducted to estimate dam passage and survival probabilities. These studies are common in the FCRPS and typically are conducted to assess changes in operations or structures at passage routes other than turbines (see Skalski and others, 2002b; Axel and others, 2004a, 2004b; Counihan and others, 2006a, 2006b; Adams and Liedtke, 2010; Beeman and others, 2010). Fish with attached negatively buoyant transmitters must add air to their swim bladders to regain neutral buoyancy, a process that may take several hours (Fried and others, 1976). The fish in the studies we used were held 12–24 hours after tagging and were released into the Columbia River about 10–20 km upstream from the dams and are assumed to be neutrally buoyant at the time of release. Few fish from individual studies pass turbines, due to the structures and operations designed to minimize turbine passage, and thus individual annual studies are not likely to be suitable for analyses of factors affecting survival of turbine-passing fish. For example, in one study, 185 of 2,400 yearling Chinook salmon released in the reservoir upstream from McNary Dam (Columbia River kilometer [rkm] 470), were estimated to have passed the 14-unit powerhouse through the turbines (Adams and others, 2010). However, sample sizes increase when a suite of annual studies based on similar methods is considered together, which is the approach we describe in this report.

We had several hypotheses: (1) fish survival would be related to operational covariates, (2) fish survival would be higher during conditions of open geometry (that is, similar [aligned] wicket gate and stay vane angles and higher unit discharges), and (3) tag burden would pose a negative effect on survival. The latter hypothesis was based on results from Brown and others (2009) and Carlson and others (2010), indicating that tag burden was one of several important factors determining mortal injury of tagged fish in controlled laboratory experiments of simulated turbine passage.

Methods

Data from previous studies of dam passage survival were used to determine if several factors of interest affected survival of fish passing through turbines. The original purpose of the studies was to estimate the passage proportions and apparent survival of tagged yearling Chinook salmon (*Oncorhynchus tshawytscha*), subyearling Chinook salmon, and juvenile steelhead (*O. mykiss*) relative to structural or operational changes designed to improve passage survival of juvenile salmonids. Many of the changes in structure or operation were adaptively altered over the years of study.

None of the studies was designed specifically to determine the factors affecting survival of fish passing turbines, but the data needed for doing so were available in most cases. For example, in many of the studies, the date, time, and turbine unit of passage were determined for most fish and the physical, biological, and operational covariates at that time were known. However, there was no experimental operation of the turbines during these studies, such as changing head or turbine discharge on a predetermined schedule. A summary of the dam operations during the years used in analyses is by dam, year, and season (spring or summer) is shown in table 1.

Analyses of data from John Day Dam (rkm 347) were based on studies in 2002 and 2003 (table 1). Data from John Day Dam were selected for analysis due to the wide range of unit discharges for these turbines within the 1 percent rule. Unit discharges within the 1 percent rule at John Day Dam at a typical head of 102 ft range from 12.1 to 21.6 thousand ft^3/s with a peak efficiency at 17.2 thousand ft^3/s (Wittinger and others, 2010). For comparison, unit discharges within the 1 percent rule at McNary Dam at a typical head of 72 ft range from 7.9 to 12.4 thousand ft^3/s with a peak efficiency at 10.0 thousand ft^3/s (Wittinger and others, 2010). Percentage of spill at John Day Dam during spring 2002 and 2003 was varied to evaluate juvenile fish passage and survival during 12- and 24-hour spill. In 2002, the treatments were 24-hour 30 percent spill compared to 0 percent day spill with 60 percent night spill. In 2003, there was no planned spill during the day and the treatments were 45 percent night spill compared to 60 percent night spill. In each year, the treatments were alternated for 3 days each within 6-day blocks following a randomized block design, with changes between day and night operations at 0600 and 1800 hours. The study designs are described in more detail in Hansel and others (2004), Beeman and others (2006), and Counihan and others (2006a, 2006b).

Analyses of data from McNary Dam were based on studies conducted from 2002 to 2009. Data from McNary Dam were selected for analysis due to the many years of data available resulting in attractive sample sizes of fish passing through turbines. Various planned spill operations occurred at McNary Dam during the study years. Percentage of spill during spring at McNary Dam from 2002 through 2004 was dominated by night spill to the gas cap operations (that is, until a regionally approved limit of total dissolved gas supersaturation was reached downstream; “fish passage plan spill”). During 2005 through 2007, fish-passage plan spill compared to 24-hour spill and other spill tests associated with the installation and performance of temporary spillway weirs were investigated. In 2008 and 2009, there were no specific spill treatments. During summer 2005, an involuntary spill was followed by a court-ordered spill, and in 2006–07, a 24-hour 40 percent spill compared to a 24-hour 60 percent spill was evaluated. There were no planned spill treatments during the summers in 2004 and 2009. For more specific information on yearly study designs and spill operations at McNary Dam see Axel and others (2004a, 2004b), Perry and others (2006), Adams and others (2008), Adams and Counihan (2009), and Adams and Liedtke (2009, 2010).

Table 1. Dam operations during studies used in the analysis of factors affecting survival of tagged fish passing turbines.

Dam	Year	Season	Operating conditions	Dates of turbine passage	Reference
John Day	2002	Spring	24-h 30 percent spill vs. 60 percent night spill	Apr. 30–May 31	Counihan and others, 2006a
		Summer	24-h 30 percent spill vs. 60 percent night spill	June 25–July 16	
	2003	Spring	45 percent night spill vs. 60 percent night spill	Apr. 30–June 6	Counihan and others, 2006b
		Summer	24-h 30 percent spill vs. 60 percent night spill	June 23–July 25	
McNary	2002	Spring	Night spill to gas cap	May 8–June 5	Axel and others, 2004a
	2003	Spring	Night spill to gas cap	May 2–June 9	Axel and others, 2004b
	2004	Spring	Night spill to gas cap	Apr. 24–May 25	Perry and others, 2006
		Summer	No treatments	July 1–July 31	
	2005	Spring	12-h vs. 24-h	Apr. 23–June 2	Perry and others, 2007
		Summer	Involuntary spill then Court-ordered spill	June 23–Aug. 1	
	2006	Spring	Fish Passage Plan vs. 2006 test spill	Apr. 27–June 4	Adams and others, 2008
		Summer	24-h 40 percent spill vs. 24-h 60 percent spill	June 20–July 27	
	2007	Spring	2007 test spill vs. Modified 2006 test spill	Apr. 19–June 7	Adams and Counihan, 2009
		Summer	40 percent spill vs. 60 percent spill	June 20–July 28	
	2008	Spring	No treatments	Apr. 20–June 4	Adams and Liedtke, 2009
		Summer	40 percent spill vs. 60 percent spill	June 20–Aug. 2	
	2009	Spring	No treatments	Apr. 18–June 4	Adams and Liedtke, 2010
		Summer	No treatments	June 20–Aug. 9	

The studies were based on fish tagged with radio or acoustic transmitters and incorporated means of detection suitable for determining time spent in the river and forebay upstream from the dam, assigning route-specific passage at the dam, as well as detections downstream from which to estimate dam passage survival. For the purposes of these analyses, the date, time, and turbine unit of passage and at least two detection sites downstream were required. The locations of the sites downstream varied slightly over the years of study at McNary Dam, but were the same during both years at John Day Dam. Studies at McNary Dam used 2–7 detection sites downstream during any 1 year of study, ranging from 11 to 161 km downstream from the dam. Six downstream detection sites ranging from 10 to 74 km downstream from the dam were used in the studies at John Day Dam.

The data from the tagged fish were compiled from databases created during the original studies and added to environmental and operational data. The environmental and operational data were provided by the U.S. Army Corps of Engineers (Jon Renholds, written commun.) either during the original studies, or in some cases, specifically for this analysis. Dam operations data from John Day Dam in 2000 were not available on a turbine-unit-specific basis and few tagged fish passed through turbines during studies that year, so the data from 2000 were omitted from analyses.

The spatial resolution of the fish data was usually sufficient to assign a specific turbine unit of passage, but in some years at McNary Dam passage was assigned to a group of turbine units. At McNary Dam, unit-specific resolution was available only in data from yearling Chinook salmon during 2002–05 and 2009 and in data from juvenile steelhead and subyearling Chinook salmon during 2004, 2005, and 2009. Therefore, analyses of these years was conducted prior to all-year analyses to determine if the potential effects of turbine unit discharge would be affected by the resolution of the passage assignments. If turbine unit discharge was not supported as a factor affecting turbine passage survival in these analyses, the full data set was used for subsequent analyses of all covariates. The most resolute data available were used to assign operations data to the time of passage for analyses of the all-year McNary data, but a south (units 1–7) or north (units 8–14) assignment was used for turbine unit location, as this was the only resolution common to all years. The average of the unit discharges of the operating units to which fish passage was assigned was used as the passage unit discharge when unit-specific passage data were not available. Unit-specific passage data at John Day Dam were available for all years and were used to obtain operating conditions at the time of passage, but the variable of turbine unit location was grouped into south (units 1–8) or north (units 9–16) areas to reduce the number of parameters in the analysis, because relatively few fish were in the data set. The chronological resolution of the operations data was hourly at McNary Dam in 2002 and 2003 and at John Day Dam in 2002 and until noon on May 1, 2003. All other operations data were available at 5-minute intervals. The data from the nearest period available were used as the condition at the time of turbine passage.

Apparent survival was estimated using Cormack-Jolly-Seber capture-recapture methods (Cormack, 1964; Jolly, 1965; Seber, 1965). Apparent survival is the probability that an animal survives and remains available for recapture. In the context of this study, fish that lose their tags leave the study area and do not return, or cease migrating between detection sites are assumed to be mortalities. All references to survival in this report refer to apparent survival.

The probability of detection at a site is the product of the probability of survival to the site and the probability of recapture at the site, so these parameters must be separately estimated. Thus, models contain parameters to estimate recapture probability and to estimate survival, although only those used to estimate survival are typically of interest.

Capture histories were created from the data for use in models of recapture and survival probabilities. A capture history is a series of values representing if tagged animals were alive when released and if they were detected passing each detection site or recapture occasion. In most studies used in these analyses, treatment fish were released upstream from the dam and control fish were released downstream from the dam, because relative survival was estimated in the original studies using methods such as the route-specific survival model (Skalski and others, 2002b). The only exception was the studies at McNary Dam in 2002 and 2003, which did not include a control group. We used data from the control group to represent riverine conditions present during the studies apart from powerhouse operations by assessing the effects of total river discharge on the survival of this group. All estimates of survival were based on single-release models and represented the survival from turbine passage to the first downstream detection site. In analyses of data from McNary Dam, the distance between these points was used as a model covariate to account for differences in site placements among years and the same values were used for control and turbine fish. The site locations were identical in each year of study at John Day Dam.

The goal of this study was to determine effects of the factors of interest on in-river survival between turbine passage and the nearest downstream detection site, so data from subsequent downstream detection sites were combined. For example, at John Day Dam in 2002, there were detection sites at rkms 337, 324, 309, 287, and 273, but data from sites downstream from rkm 337 were pooled into a single occasion. This resulted in a three-occasion data structure for analysis, including release, the first site downstream from the dam, and all sites downstream from the first.

The variables used in the analyses included group and individual covariates and were selected based on results of a meeting of biologists and engineers from U.S. Geological Survey (USGS), National Oceanic and Atmospheric Administration (NOAA), and the U.S. Army Corps of Engineers (USACE) held at the USACE Portland District office on April 13, 2010. The meeting resulted in a list of biological, physical, and operational covariates to use as covariates in a priori models of the survival of tagged fish passing turbines.

The variables can be classified into group and individual covariates describing operational or biological factors (table 2). Group covariates included treatment, year, photoperiod (day or night based on civil twilight at the time of turbine passage or release of the control group), and river reach. Operational variables included head (forebay elevation minus tailwater elevation, in feet), spill percentage, turbine discharge, total dam discharge, and turbine location (the unit number, or bivariate division by north or south). Discharge variables were in units of thousand cubic feet per second (thousand ft^3/s). Biological variables included tag burden percentage (tag weight in air * 100/fish weight in air) and water temperature at the regional tailrace water-quality measurement site. Several interactions between variables also were included. The turbine location and photoperiod interaction was used to account for potential differences in predation in the tailrace, assuming that the location of turbine of passage may affect predation downstream and be influenced by the ambient light. Total discharge was applied to data from fish in the control group as a potential measure of overall effects of discharge, but was not applied to data from fish in the turbine group because it was highly correlated with hydraulic head and the latter variable was thought to be more pertinent for fish passing turbines. Bivariate and multivariate collinearity was assessed using Pearson's r and variance inflation factor prior to survival analyses to avoid using highly correlated variables in models together. Using correlated or collinear variables together in models makes it difficult to separate their separate influence on the response variable, which in our analyses was survival of fish passing through turbines. This is indicated when Pearson's r is greater than an absolute value of about 0.8 ($|0.8|$), and generally as variance inflation factors increase (Belsley and others, 1980).

The effects of the covariates on fish survival were evaluated using an information-theoretic approach. In this approach, mathematical models representing hypotheses are compared based on the principle of parsimony. Parsimony is the balance between bias and variance of prediction. The square of bias is reduced as parameters are added to a model, but this increases the variance (Burnham and Anderson, 2002). Thus, the principle of parsimony attempts to find a balance between the fit of the model and the number of parameters required. Several measures of parsimony can be used for this assessment. We selected the commonly used Akaike Information Criterion with an adjustment to reflect the effects of sample size (AICc). Models are compared based on the differences in the AICc values. Unlike in the null hypothesis testing statistical framework, there is no strict cutoff representing "significance" between models, and in fact, the method does not determine significance at all. Alternatively, support for differences between hypotheses, based on the data and the models, increases with difference in AICc between competing models. Burnham and Anderson (2002) suggest that when AICc values differ by less than 2 units the support for one hypothesis over another is not meaningfully different based on the data and models considered. They also suggest that differences of 4–7 indicate considerably less support for the model with the greater AICc and those greater than 10 indicate essentially no support for the model with the greater AICc. We will use the terms "no" or "weak" support, "moderate" support, and "strong" support for models differing by no more than 2 units, more than 2, and as much as 7 units, or more than 7 units, respectively.

Table 2. Variables used in analyses of the survival of fish passing turbines.

[The Application column indicates which of the treatment groups the variables were applied to. Fish weight was used as a secondary variable instead of tag burden after all other variables were evaluated, due to their close association. The first model evaluated (global model) included all possible interactions among group covariates plus the other variables and interactions listed. A linear function between survival and each variable was used except for head and turbine discharge, for which linear and quadratic functions were used. km, kilometer; yyyy 4-digit year format; Trt, treatment; Turq, turbine discharge; Persp, percentage spill; Turbloc, turbine unit location]

Type	Name	Definition	Application	Note
Group	Photo	Day (0) or night (1)	Both	
Group	Gated	Distance to first detection site (km)	Both	
Group	Year	yyyy	Both	
Group	Trt	Control (0) or turbine (1)	Both	
Group	Reach	River reach	Both	
Operational	Totq	Total discharge	Control	
Operational	Head (linear)	Forebay elevation minus tailwater elevation	Turbine	Linear
Operational	Head (quadratic)	Forebay elevation minus tailwater elevation	Turbine	Quadratic
Operational	Turq (linear)	Unit discharge	Turbine	Linear
Operational	Turq (quadratic)	Unit discharge	Turbine	Quadratic
Operational	Turbloc	Unit number, or south (0) & north (1)	Turbine	
Operational	Persp	(Spill discharge / total discharge) * 100	Both	
Biological	Tagb	Tag burden percent	Both	Primary
Biological	Weight	Fish weight	Both	Secondary
Biological	Temp	Tailrace water temp	Both	
Interaction	Turbloc*photo	Turbloc*photo	Turbine	Predation
Interaction	Trt*photo	Trt*photo	Both	
Interaction	Persp*trt	Persp*trt	Both	
Interaction	Tagb*year	Tagb*year	Both	
Interaction	Tagb*trt	Tagb*trt	Both	
Interaction	Temp*trt	Temp*trt	Both	
Interaction	Temp*yr	Temp*yr	Both	
Interaction	Other	All possible group interactions	Both	Only in global model

One must cautiously evaluate models when AICc differences are within about 0–2 units per unit difference in parameter number, because the larger-parameter model may seem to have support from the data only because it is similar to the supported reduced-parameter model. As indicated in equation 1, in the absence of a change in the deviance ($-2\log L(\hat{\Theta})$), which represents the fit of the model to the data, AICc increases by 2 for each added parameter. In these cases, the additional variable is sometimes called a "pretender" variable. The analyses in this report contain many comparisons of models differing by one parameter, which are simple to evaluate in this context. The AICc is calculated as

$$AICc = -2\log L(\hat{\Theta}) + 2K + \frac{2K(K+1)}{n-K-1} \tag{1}$$

where $L(\hat{\Theta})$ is the maximized likelihood for the model, K is the number of estimable parameters in the model, and n is the sample size.

The analyses were done using Program MARK (White and Burnham, 1999). A recaptures-only data type with a logit link was used in each analysis. Each analysis began with a "full model" consisting of all group covariates and interactions among them, plus the full suite of individual covariates and interactions listed in table 2. Survival and recapture probabilities are inseparable in the last reach, although in the MARK software their joint probability (λ) is divided between estimates of survival and recapture. We fixed the value of the survival estimate in the last reach to 1.0 so that an estimate of λ was reflected in the estimate of recapture probability. We also fixed survival or recapture probabilities to 1.0 and reduced the number of estimated parameters accordingly in cases where the data indicated all fish in the sample survived or were detected.

The full model was used as a basis for modifications of parameters describing recapture probabilities to determine the most parsimonious model of recapture probabilities for use in all other comparisons. Five models of recapture probabilities were evaluated including models with group, reach, multiplicative and additive combinations of group and reach, and the intercept only. In the event that more than one model of recapture probability was supported by the data, we selected the most parameterized model for use in subsequent analyses.

The analyses were conducted following an a priori order of variable removal and evaluation (table 3). This strategy is consistent with the principles of information theoretic analyses and parsimony. The premise behind the order was to evaluate for removal the interaction effects and as many group and biological covariates as possible prior to evaluating the operational covariates, so that the effects of the operational covariates would not be affected by evaluation within a series of potentially over-fitted models. The exception to this convention was the covariate of tag burden and the treatment*tag burden interaction, which we purposely left in the models to control for any effects until after the operational covariates were evaluated. This decision was based on laboratory results of Brown and others (2009) indicating tag burden was an important factor in survival and injury of tagged fish after simulated turbine passage.

Table 3. A priori order of covariate evaluations.

[Group covariates included treatment, photoperiod, and year. Individual covariates included tag burden, spill percentage, turbine passage location, turbine discharge, head, and total discharge. Interactions between treatment and tag burden and spill percentage were used to examine the potential differential effects of tag burden and spill percentage on turbine and control fish. The effect of total discharge was applied only to control fish (treatment = 0) and the effects of turbine location, head, and turbine unit discharge were applied only to turbine fish (treatment = 1). A tag burden and year interaction was included to address the potential effect of different tag types on the tag burden effect. A turbine passage location and photoperiod interaction was included to determine potential effects of photoperiod on the effect of passage location that might be related to predation. Each covariate or interaction was evaluated in the order listed]

Group covariates and all possible interactions, plus individual covariates and selected interactions.
Tag burden and year interaction.
Temperature and year interaction.
Year effect.
Turbine passage location and photo period interaction.
Photoperiod and treatment interaction.
Temperature and treatment interaction.
Photoperiod effect.
Temperature effect.
Spill percentage and treatment interaction.
Total discharge effect.
Main spill percentage effect.
Main turbine passage location effect.
Linear head effect.
Quadratic head effect.
Linear turbine unit discharge effect.
Quadratic turbine unit discharge effect.
Tag burden and treatment interaction.
Distance to first gate effect (McNary only).
Tag burden effect.

Results of Analyses from Studies at John Day Dam

Yearling Chinook Salmon

Environmental Conditions

The ranges of the individual covariates at the times of fish passage were similar between years. The turbines were usually operated within 1 percent of the peak turbine operating efficiency during the studies. The turbine unit discharge ranged from 11.4 to 22.2 thousand ft^3/s (fig. 1). A summary of covariate values at the times of fish passage is shown in appendix A and covariate daily averages are presented in figure 2. Total discharge ranged from 138.9 to 372.4 thousand ft^3/s, with a median of 227.7 thousand ft^3/s. The hydraulic head ranged from 97.0 to 104.5 ft, with a median of 101.6 ft. Spill percentages were generally according to the designed operation tests in each year, but were as high as 73.7 percent. Tag burden ranged from 1.23 to 8.92 percent, with a median of 4.53 percent. Water temperature ranged from 9.70 to 15.44 °C, with a median of 12.17 °C.

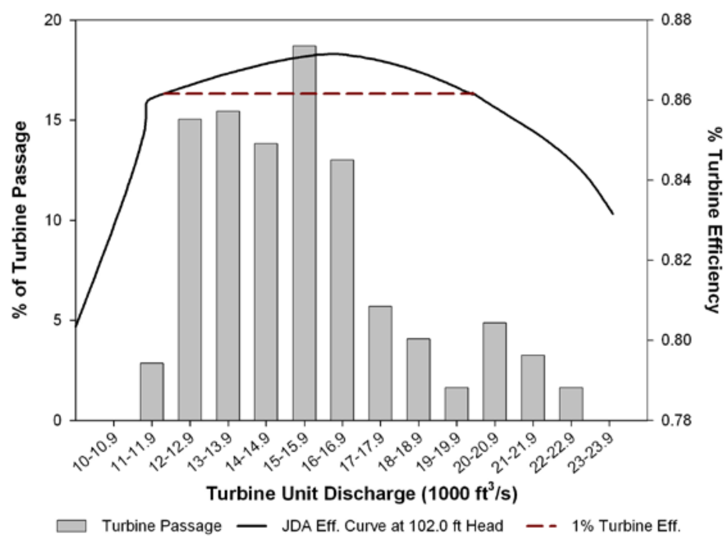

Figure 1. Graph showing turbine unit discharges during yearling Chinook salmon passage (bars) and turbine efficiency (solid line) from data used in studies at John Day Dam in 2002 and 2003. The discharges bounded by the dashed line are within 1 percent of the peak turbine efficiency at a head of 102 feet.

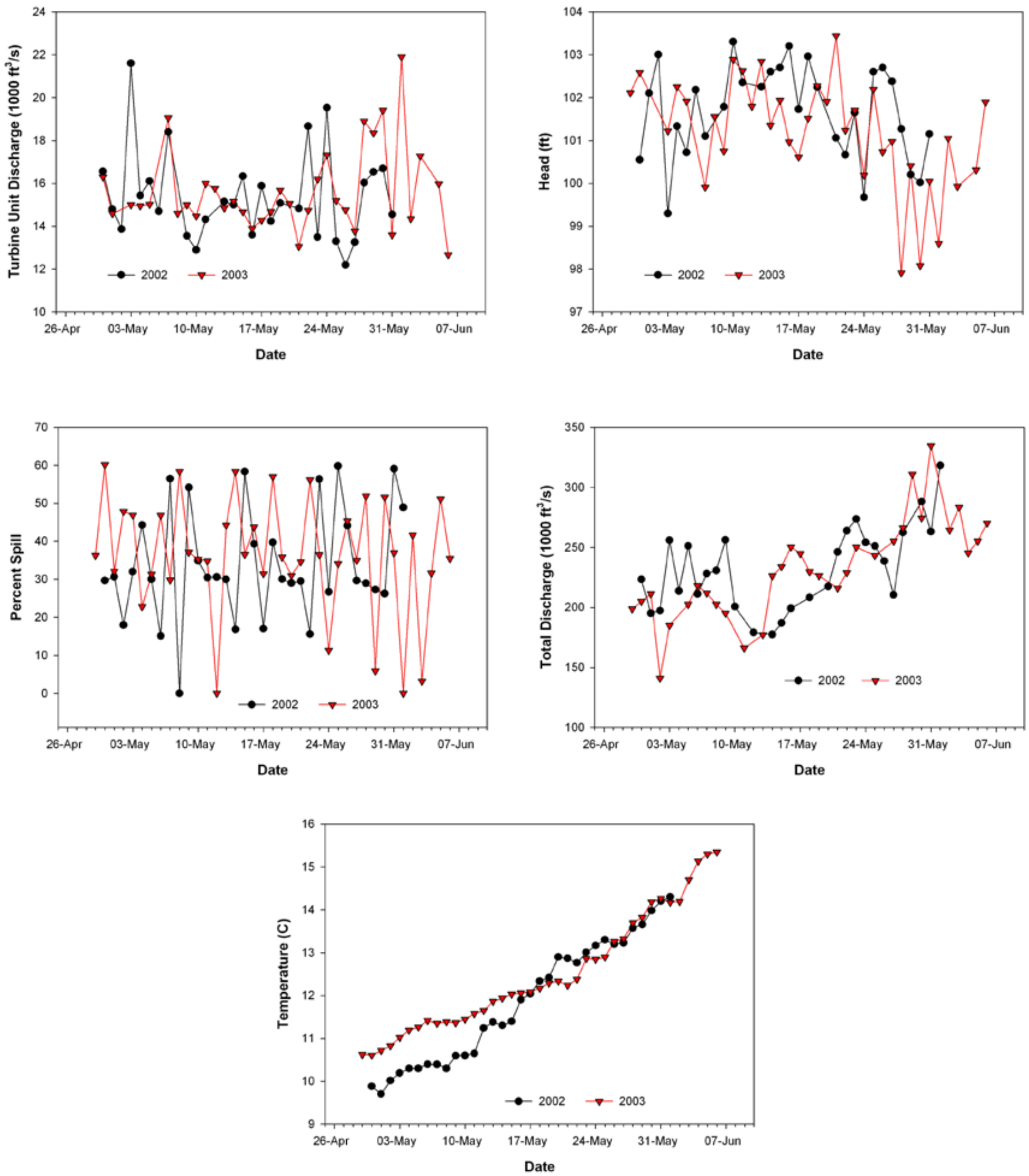

Figure 2. Graph showing daily-averaged covariate values for yearling Chinook salmon from data used in studies at John Day Dam in 2002 and 2003.

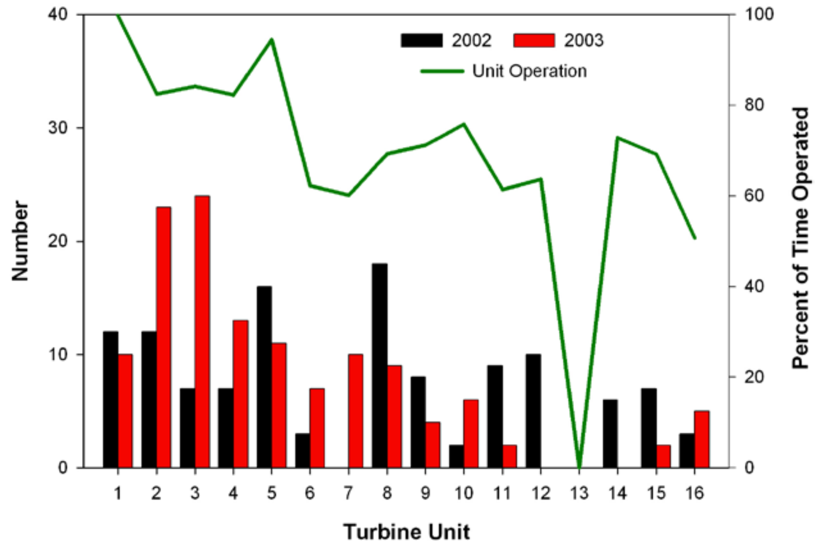

Figure 3. Graph showing number of yearling Chinook salmon passing through each turbine by year (bars) and the percentage of time each turbine was operated (line) from data used in studies at John Day Dam in 2002 and 2003.

Fish passage was present at most turbine units in at least 1 year except for unit 13 (fig. 3). Fewer fish passed through higher-numbered units (northern) than lower numbered units (southern), particularly in 2003, indicating that passage was generally higher in units near the Oregon shoreline. Fish passage location generally coincided with unit operation. Similar numbers of fish passed turbines in 2002 ($N = 120$) and 2003 ($N = 126$).

Survival

The analyses of factors affecting survival were based on 246 fish in the turbine group and 2,973 fish in the control group. Nearly three times as many fish were in the control group at night in 2003 ($N = 1,562$) than in the other groups of year, treatment, and photoperiod (appendix B).

Correlation analyses indicated that several variables were highly related. Pearson correlation coefficients greater than an absolute value of 0.8 (|0.8|) indicated that the separate influences of several pairs of variables could be difficult to determine if they were used together (tables 4 and 5; Belsley and others, 1980). These include the pairs head and total discharge, head and turbine discharge, tag burden and fish weight, percentage of spill and powerhouse discharge, and percentage of spill and photoperiod. The last pair was expected to be correlated because the dam operations were being tested during the original studies. Analyses of multicollinearity indicated that few dependencies among the variables would result from these correlations, although there would be some inflation of parameter variances if total discharge and head were used together. However, we had planned to apply only total discharge to the control group and head to the turbine group, so no difficulties were expected from these correlations. Fish weight and tag burden were not examined for multicollinearity because they likely would not be used together due to their high bivariate correlation coefficient (>|0.9|). Based on these results, tag burden and fish weight were not used in models together. If the data and models supported an effect of tag burden, it was replaced with fish weight during post-hoc analyses to determine which factor was better supported.

A single model of recapture probabilities was supported by the data. The multiplicative model of group and reach (model 1 in appendix C) received more than 99 percent of the AICc weight, indicating that it was the only model supported by the data. This model of recapture probabilities was used in all comparisons of effects on survival. Visual examination of the capture histories (appendix B) indicated all fish in the turbine group passing the dam during the night in 2002 and 2003 were detected at the first downstream site, so these parameters were fixed to 1.0 in the analyses. In subsequent analyses (model 17 from table 6), the recapture probabilities at the first downstream site ranged from 0.666 (SE 0.020) to 0.870 (SE 0.009), and averaged 0.761. The λ term ranged from 0.708 (SE 0.056) to 1.0 (manually fixed for analysis), and averaged 0.980.

Few of the covariates examined were supported as determinants of survival in these data. Only water temperature and tag burden were supported by the data and models (table 6). The operational covariates contributed little to the fit of the models, as indicated by the similarities in deviances between competing models (for example, model 12 with total discharge compared to model 11 without it). Additionally, most models differed by a single parameter and in every case the difference in AICc values between models with and without each operational covariate changed by 0–2 units for each unit difference in the number of parameters, indicating that the covariates added little to the model fit. Linear effects require one parameter to describe and two parameters for those with a quadratic effect (the linear term and the squared term); therefore, for a factor with even a small effect one would expect a delta AICc of at least 2 for a linear effect (2 times the number of parameters to describe the effect) and at least 4 for a factor with a quadratic effect. For example, the AICc of the model with a linear effect of head (model 14) was 1.6 greater than the model without a linear effect of head (model 15) and the model with the quadratic effect of head (model 14a) was 3.7 greater than the model without that parameter. The AICc of the model with a linear effect of turbine discharge (model 15) was 1.6 greater than the model without that effect (model 16) and the AICc of the model with a quadratic effect of turbine unit discharge (model 15a) was 3.5 greater than the model without turbine unit discharge. These results indicated that effects of the operational covariates were not supported. The only model of survival supported by the data included the group covariates of treatment and year plus the individual covariates of water temperature and tag burden (model 17 in table 6).

A positive effect of water temperature on survival was supported. When water temperature was removed, the delta AICc increased by 10 units (model 9 compared to model 10 in table 6), indicating that it was strongly supported. The model slopes indicate a greater temperature effect on turbine fish than control fish (table 7, fig. 4). The estimated survival of the control group was higher than the turbine group, as expected.

Table 4. Correlation indices of data from yearling Chinook salmon from the turbine group from data used in studies at John Day Dam in 2002 and 2003.

[Pearson correlation coefficients are listed above the probabilities of obtaining a greater value under the hypothesis that Rho = 0. Sample size is 246; <, less than; see table 2 for variable name definitions]

	TOTQ	PER_SPI	HEAD	TURQ	UNITLOC	PHOTO	TEMP	WEIGHT	TAG BURDEN
TOTQ	1.0000	-0.0831	-0.8584	0.5075	-0.0374	0.1081	0.4566	-0.0089	0.0234
		0.1938	<0.0001	<0.0001	0.5593	0.0907	<0.0001	0.8901	0.7147
PER_SPI		1.0000	0.4017	-0.6509	-0.0157	-0.8185	0.1107	0.1678	-0.1389
			<0.0001	<0.0001	0.8070	<0.0001	0.0831	0.0083	0.0294
HEAD			1.0000	-0.6930	0.1055	-0.4002	-0.3908	0.0619	-0.0670
				<0.0001	0.0987	<0.0001	<0.0001	0.3336	0.2949
TURQ				1.0000	-0.0328	0.5749	0.1515	-0.1399	0.1033
					0.6089	<0.0001	0.0175	0.0283	0.1062
UNITLOC					1.0000	-0.0791	-0.1024	0.0749	-0.1032
						0.2166	0.1091	0.2417	0.1063
PHOTO						1.0000	-0.0502	-0.1790	0.1648
							0.4333	0.0049	0.0096
TEMP							1.0000	0.0206	0.0055
								0.7476	0.9316
WEIGHT								1.0000	-0.9225
									<0.0001

A negative effect of tag burden was also strongly supported. The a priori order of variable assessment would have resulted in model 16 being the best-supported model, but close inspection indicated it was over parameterized. The tag burden and tag burden*treatment interaction in model 16 were of similar size, but of opposite sign, indicating the net effect may have been only on the control group. Model 17 includes a tag burden effect only on the control fish, is more supported than model 16 by a difference of 2 AICc units, and differs by a single parameter. This indicates the treatment*tag burden interaction term in model 16 is not contributing to the fit of the model, and model 17 is better supported. Model 17 represents the hypothesis that tag burden is a factor only for the control group. Removing this effect results in an increase in AICc of more than 20 units (model 17compared with model 18), indicating it is a strongly supported effect. It also indicates that the effect of tag burden on survival of the control group is negative (table 7, fig. 4).

As a final comparison, model 17 was altered by replacing the tag burden covariate with fish weight. This model (19) differed from model 17 by an increase of nearly 9 AICc units, has the same number of parameters, and is not supported. Thus, despite the high correlation between tag burden and fish weight (r = -0.9225), the data and models strongly support the effect on survival being due to tag burden.

Table 5. Correlation indices of data from yearling Chinook salmon from the control group from data used in studies at John Day Dam in 2002 and 2003.

[Pearson correlation coefficients are listed above the probabilities of obtaining a greater value under the hypothesis that Rho = 0. Sample size is 2,973; <, less than; see table 2 for variable name definitions]

	TOTQ	PER_SPI	PHOTO	TEMP	WEIGHT	TAG BURDEN
TOTQ	1.0000	-0.0538	0.0095	0.5916	-0.0165	0.0408
		0.0034	0.6046	<0.0001	0.3697	0.0261
PER_SPI		1.0000	-0.8768	0.0442	-0.0295	0.0301
			<0.0001	0.0159	0.1077	0.1007
PHOTO			1.0000	-0.0272	0.0036	0.0026
				0.1380	0.8461	0.8858
TEMP				1.0000	-0.0449	0.0852
					0.0144	<0.0001
WEIGHT					1.0000	-0.9190
						<0.0001

Table 6. Model-selection results of data from radio-tagged yearling Chinook salmon used in studies at John Day Dam in 2002 and 2003.

[Presence of a factor in a model is indicated by an 'x' in the column for that factor. Model 1 was a global model including all group covariates and their interactions (g) as well as all individual covariates and interactions listed. All models shared a common g*reach model of recapture probability. K indicates the number of parameters. The tag burden covariate was applied only to the control group in model 17. An asterisk after the model number indicates the best-supported model of the suite. See table 2 for variable name definitions]

	Group covariates									Individual covariates																Model selection results		
										Biological							Operational											
Model No.	g*reach	trt	yr	photo	trt*yr	trt*photo	yr*photo	trt*yr*photo	reach	wt	tagb	trt*tagb	yr*tagb	temp	trt*temp	yr*temp	persp	trt*persp	linear turq	quadratic turq	linear head	quadratic head	turloc	turloc*photo	totq	AICc	K	Deviance
1	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x		x		x	x	x	4505.9	35	4435.4
2		x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x		x		x	x	x	4491.7	28	4435.4
3		x	x	x	x	x	x	x	x		x	x		x	x	x	x	x	x		x		x	x	x	4490.6	27	4436.6
4		x	x	x	x	x	x	x	x		x	x		x	x		x	x	x		x		x	x	x	4488.5	26	4436.3
5		x		x		x			x		x	x		x	x		x	x	x		x		x	x	x	4484.7	22	4440.6
6		x		x		x			x		x	x		x	x		x	x	x		x		x		x	4483.6	21	4441.4
7		x		x					x		x	x		x	x		x	x	x		x		x		x	4482.5	20	4442.4
8		x		x					x		x	x		x			x	x	x		x		x		x	4482.8	19	4444.6
9		x							x		x	x		x			x	x	x		x		x		x	4481.2	18	4445.1
10		x							x		x	x					x	x	x		x		x		x	4491.2	17	4457.1
11		x							x		x	x		x			x		x		x		x		x	4479.3	17	4445.2
12		x							x		x	x		x			x		x		x		x			4477.8	16	4445.8
13		x							x		x	x		x					x		x		x			4476.3	15	4446.2
14		x							x		x	x		x					x		x					4474.9	14	4446.9
14a		x							x		x	x		x					x			x				4477.0	15	4446.9
15		x							x		x	x		x					x							4473.3	13	4447.3
15a		x							x		x	x		x						x						4475.2	14	4447.2
16		x							x		x	x		x												4471.7	12	4447.7
17*		x							x		x			x												4469.7	11	4447.7
18		x							x					x												4490.0	10	4470.0
19		x							x	x				x												4478.5	11	4456.5

Table 7. Beta (slope) coefficients of estimable survival parameters of yearling Chinook salmon from data used in studies at John Day Dam in 2002 and 2003.

[The data are from model 17 in table 6; Beta, slope coefficient]

Parameter	Beta	Standard error	95 percent confidence Lower	95 percent confidence Upper
Intercept	1.959324	1.180059	-0.353590	4.272239
Treatment group	-3.862740	0.603389	-5.045380	-2.680100
Tag burden for control group	-0.480580	0.103616	-0.683670	-0.277490
Temperature	0.333017	0.090592	0.155456	0.510577

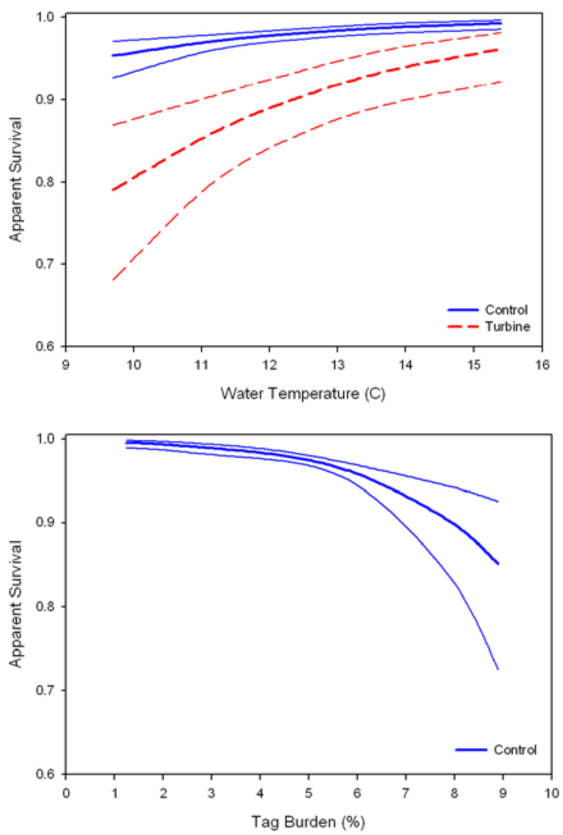

Figure 4. Graph showing estimated effects of water temperature (upper plate) and tag burden (lower plate) on apparent survival of yearling Chinook salmon from data used in studies at John Day Dam in 2002 and 2003. Predictions (thick lines) and 95 percent confidence intervals (thin lines) from model 17 in table 6 are plotted. Note that the effect of tag burden was only supported for fish in the control group.

Key Findings in Data from Yearling Chinook Salmon at John Day Dam

- The data set included 246 fish in the turbine group and 2,973 fish in the control group.
- Most data were collected at turbine discharges within 1 percent of peak unit efficiency.
- Operational covariates were not supported as factors affecting turbine passage survival.
- A positive effect of water temperature on survival was strongly supported.
- A negative effect of tag burden on survival was strongly supported for the control group. There was strong support that this effect was due to tag burden rather than fish weight. An effect of tag burden was not supported for the turbine group.

Subyearling Chinook Salmon

Environmental Conditions

The environmental conditions occurring during passage of subyearling Chinook salmon at John Day Dam differed between years. The differences between years were related to discharge and water temperature. As in the spring, the turbines were generally operated within 1 percent of peak efficiency during fish passage (fig. 5). Overall turbine unit discharge ranged from 9.7 to 22.7 thousand ft^3/s with a median of 14.7 thousand ft^3/s and was higher in 2003 than in 2002. The turbine unit discharge ranged from 11.9 to 22.7 thousand ft^3/s in 2002 and 9.7 to 20.9 thousand ft^3/s in 2003. Covariate values at the time of passage are summarized in appendix D and daily averages are shown in fig. 6. The median head was 102.70 ft (range 97.00 to 105.65 ft) and was similar between years. The median total discharge was 194.70 thousand ft^3/s (range 89.90 to 396.20 thousand ft^3/s), but differed between years. In 2002, the median total discharge was 253.90 thousand ft^3/s (range 157.70 to 396.20 thousand ft^3/s) and in 2003 it was 152.20 (range 89.90 to 237.40 thousand ft^3/s). Additionally, total discharge was 7 percent greater during the day than at night in 2002 and 6 percent greater during the day than at night in 2003. The percentage of spill also differed between years per the planned studies in 2002 and 2003. The median tag burden was 5.35 percent (range 1.67 to 7.33 percent) and was similar between years and day/night periods. The water temperature was higher in 2003 than in 2002, particularly in July. The medians were 17.60 °C (range 15.90 to 20.30 °C) in 2002 and 18.44 °C (range 16.33 to 21.61 °C) in 2003. The data included fish passing through all 16 units (fig. 7). In 2002, the passage was similar among units, but in 2003, most passage was through units 1–5. Location of passage coincided with unit operation. There were 249 fish in the turbine group in 2002 and 547 in 2003, so most fish passage in the overall data set was through units 1–5.

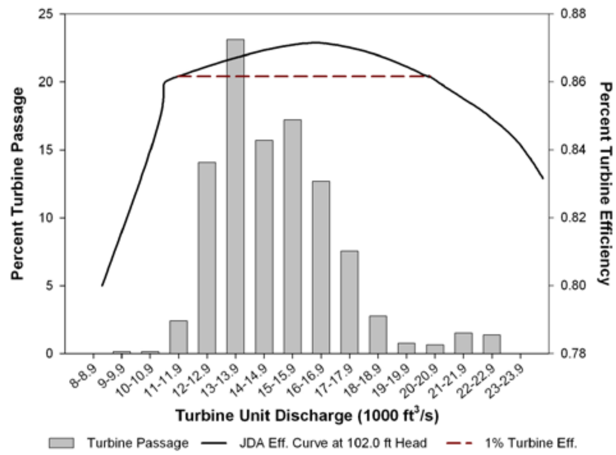

Figure 5. Graph showing turbine unit discharges during subyearling Chinook salmon passage (bars) and turbine efficiency (solid line) from data used in studies at John Day Dam in 2002 and 2003. The discharges bounded by the dashed line are within 1 percent of the peak turbine efficiency at a head of 102 feet.

Survival

Analyses of survival were based on 796 fish in the turbine group and 5,463 fish in the control group. Sample sizes among groups of treatment, year, and photoperiod were generally similar within treatment groups, with 115–318 treatment fish and 1,150–1,499 control fish per group (appendix E). Results of bivariate correlation and multicollinearity analyses were similar to those from yearling Chinook salmon (tables 8 and 9). Total discharge was applied only to the control group, head was applied only to the treatment group, and tag burden and fish weight were not used in models together.

Two of the five models of recapture probabilities were supported by the data and the more general of the two was selected for use in subsequent analyses (appendix F). The full model, which allows recapture probabilities to vary among all combinations of group and reach, and the additive model of group and reach in which recapture probabilities vary among groups and reach in a similar manner, were the only models supported by the data. Their AICc values were identical and were at least 909 units smaller than those of the other models evaluated. The recapture probabilities at the first downstream site estimated from the more general model (model 18 in table 10) ranged from 0.466 (SE 0.015) to 0.957 (SE 0.015) and averaged 0.757. The λ term ranged from 0.948 (SE 0.006) to 0.993 (SE 0.002), and averaged 0.972.

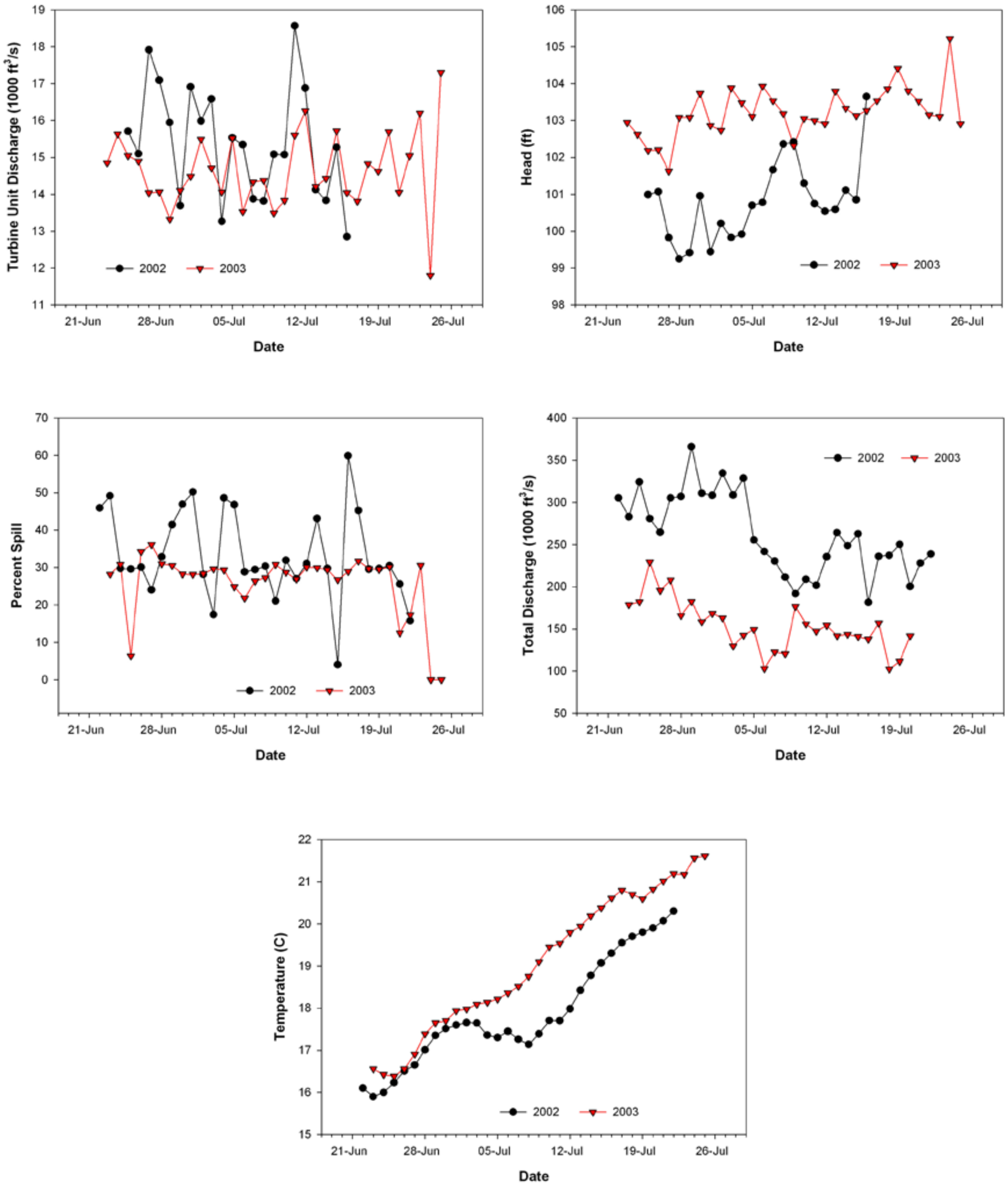

Figure 6. Graph showing daily-averaged covariate values for subyearling Chinook salmon used in analyses of survival from data used in studies at John Day Dam in 2002 and 2003.

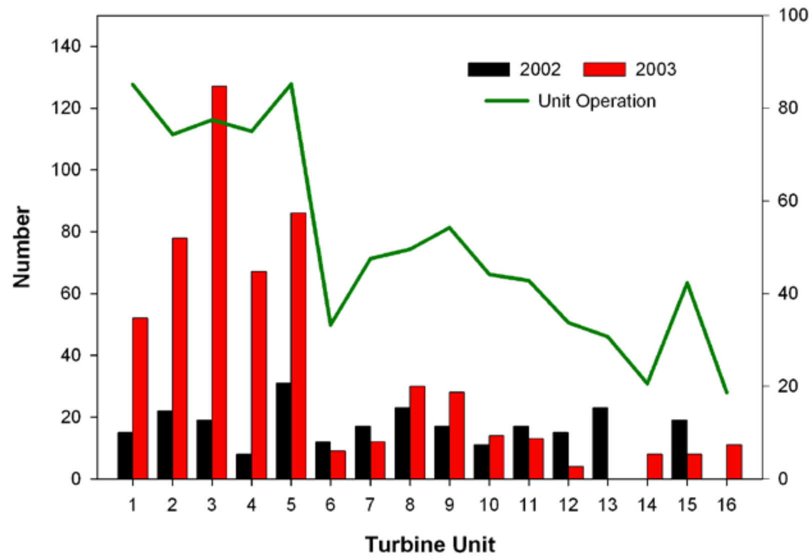

Figure 7. Graph showing number of subyearling Chinook salmon passing through each turbine by year (bars) and the percentage of time each turbine was operated (line) from data used in studies at John Day Dam in 2002 and 2003.

Survival effects of several group covariates and one individual covariate were supported by the data and the models. Effects of treatment, year, photoperiod, reach, temperature, several interactions between these variables, and a quadratic effect of turbine unit discharge were supported (table 10). Models 5–5d evaluated several hypotheses about the effects of year. The models with linear and quadratic effects of head had AICc values 1.3 and 1.4 units greater than models without head, indicating the effects were not supported (models 14 and 14a compared to model 15). The model with a linear effect of turbine unit discharge (model 15) had an AICc value 2.0 greater than the model without turbine unit discharge (model 16), indicating that it was not a supported effect.

An effect of water temperature was supported. The model with the year*temperature interaction term (model 3 in table 10) had an AICc value about 22 units smaller than the AICc value of the model without this term (model 4) indicating that this effect was strongly supported by the data. The treatment* temperature interaction term was weakly supported by the data, as indicated by the 1-unit AICc reduction when the term was in the model (model 7 compared to model 8). Model 9, with the temperature main effect, had an AICc value about 4 units lower than model 10 without the effect, indicating moderate support for the factor. The most parsimonious model, model 18 in table 10, indicates that the effects of temperature were positive for control and turbine fish in 2002, had little effect on control fish in 2003, and were negative for turbine fish in 2003. Figure 8 depicts the effects of temperature on survival of subyearling Chinook salmon based on the coefficients in table 11. The different effects between the years may be due to the lower discharge and higher temperatures during 2003 compared to 2002. Additionally, the study season ended later in 2003 than in 2002.

Table 8. Correlation indices of data from subyearling Chinook salmon from the turbine group from data used in studies at John Day Dam in 2002 and 2003.

[Pearson correlation coefficients are listed above the probabilities of obtaining a greater value under the hypothesis that Rho = 0. Sample size is 796; <, less than; see table 2 for variable name definitions]

	TOTQ	PER_SPI	HEAD	TURQ	TURLOC	PHOTO	TEMP	WEIGHT	TAG BURDEN
TOTQ	1.0000	0.1668	-0.9308	0.4006	0.3314	-0.0218	-0.5238	0.0002	-0.0064
		<0.0001	<0.0001	<0.0001	<0.0001	0.5388	<0.0001	0.9946	0.8562
PER_SPI		1.0000	0.0289	-0.3981	-0.0555	-0.5664	-0.1202	-0.0407	0.0208
			0.4156	<0.0001	0.1180	<0.0001	0.0007	0.2520	0.5572
HEAD			1.0000	-0.5006	-0.3198	-0.0998	0.4721	-0.0263	0.0206
				<0.0001	<0.0001	0.0048	<0.0001	0.4594	0.5620
TURQ				1.0000	0.0610	0.3598	-0.1304	0.0578	-0.0329
					0.0855	<0.0001	0.0002	0.1032	0.3542
TURLOC					1.0000	-0.0499	-0.1759	-0.0057	-0.0051
						0.1592	<0.0001	0.8725	0.8849
PHOTO						1.0000	0.0697	0.0183	0.0017
							0.0495	0.6071	0.9610
TEMP							1.0000	0.2641	-0.2849
								<0.0001	<0.0001
WEIGHT								1.0000	-0.9600
									<0.0001

A quadratic model of turbine unit discharge was weakly supported by the data. The model with the quadratic effect of turbine unit discharge (model 15a in table 10) had an AICc value 1.3 units smaller than the model without the effect (model 16), despite having two additional parameters. The model coefficients indicate an intermediate maximum survival at 15.9 thousand ft^3/s, with a 95 percent confidence interval (95 percent CI) of -1.7–33.7 thousand ft^3/s (fig. 8). The confidence interval spans more than the entire operating range of the turbines at John Day Dam. The range of discharges within 1 percent of peak turbine operating efficiency at John Day Dam is 12.0 to 21.6 thousand ft^3/s and the peak operating efficiency is at 17.2 thousand ft^3/s (at a head of 102 ft near the median in the data we examined).

Table 9. Correlation indices of data from subyearling Chinook salmon from the control group from data used in studies at John Day Dam in 2002 and 2003.

[Pearson correlation coefficients are listed above the probabilities of obtaining a greater value under the hypothesis that Rho = 0. Sample size is 5,463]

	TOTQ	PER_SPI	PHOTO	TEMP	WEIGHT	TAG BURDEN
TOTQ	1.0000	0.0428	0.0855	-0.5063	-0.0692	0.0759
		0.0015	<0.0001	<0.0001	<0.0001	<0.0001
PER_SPI		1.0000	-0.6701	-0.0487	-0.0070	0.0156
			<0.0001	0.0003	0.6045	0.2480
PHOTO			1.0000	0.0462	-0.0016	0.0030
				0.0006	0.9080	0.8275
TEMP				1.0000	0.2791	-0.3140
					<0.0001	<0.0001
WEIGHT					1.0000	-0.9636
						<0.0001

Key Findings in Data from Subyearling Chinook Salmon at John Day Dam

- The data set included 796 fish in the turbine group and 5,463 fish in the control group.
- Most data were collected primarily at turbine discharges within 1 percent of peak unit efficiency.
- Turbine discharge was the only operational covariate supported as a factor affecting turbine passage survival. A curvilinear fit to the data indicated maximum turbine passage survival was at 15.9 thousand ft^3/s, but the estimate was imprecise and had a 95 percent confidence interval of -1.7–33.7 thousand ft^3/s.
- Water temperature was supported as a factor affecting survival. A difference in the effect of water temperature between the 2 years was strongly supported. The data and models indicated moderate support for a positive effect for control and turbine groups in 2002 and a negative effect for the turbine group in 2003.
- An effect of tag burden on survival was not supported.

Table 10. Model-selection results of data from radio-tagged subyearling Chinook salmon used in studies at John Day Dam in 2002 and 2003.

[Presence of a factor in a model is indicated by an 'x' in the column for that factor. Model 1 was a global model including all group covariates and their interactions (g) as well as all individual covariates and interactions listed. All models shared a common g*reach model of recapture probability. K indicates the number of parameters. An asterisk after the model number indicates the best-supported model of the suite. See table 2 for variable name definitions]

										Individual covariates																		
	Group covariates									Biological						Operational									Model selection results		
Model No.	g	trt	yr	photo	trt*yr	trt*photo	yr*photo	trt*yr*photo	reach	tagb	trt*tagb	yr*tagb	temp	trt*temp	yr*temp	persp	trt*persp	linear turq	quadratic turq	linear head	quadratic head	turloc	turloc*photo	totq	AICc	K	Deviance
1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x		x	x	x	9175.0	37	9100.7
2		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x		x	x	x	9160.9	30	9100.7
3		x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x		x		x	x	x	9159.0	29	9100.9
4		x	x	x	x	x	x	x	x	x	x		x	x		x	x	x		x		x	x	x	9181.4	28	9125.3
5		x		x		x			x	x	x		x	x	x	x	x	x		x		x	x	x	9194.3	25	9144.2
5a		x	x	x	x	x	x		x	x	x		x	x	x	x	x	x		x		x	x	x	9157.0	28	9100.9
5b		x	x	x	x	x			x	x	x		x	x	x	x	x	x		x		x	x	x	9157.0	27	9102.8
5c		x	x	x		x	x		x	x	x		x	x	x	x	x	x		x		x	x	x	9181.1	26	9128.9
5d		x		x	x	x			x	x	x		x	x	x	x	x	x		x		x	x	x	9183.9	26	9131.8
6		x	x	x	x	x			x	x	x		x	x	x	x	x	x		x		x		x	9155.0	26	9102.8
7		x	x	x	x				x	x	x		x	x	x	x	x	x		x		x		x	9154.4	25	9104.3
8		x	x	x	x				x	x	x		x		x	x	x	x		x		x		x	9155.5	24	9107.4
9		x	x		x				x	x	x		x	x	x	x	x	x		x		x		x	9152.7	24	9104.6
10		x	x		x				x	x	x			x	x	x	x	x		x		x		x	9156.9	23	9110.8
11		x	x		x				x	x	x		x	x	x	x		x		x		x		x	9152.1	23	9106.0
12		x	x		x				x	x	x		x	x	x	x		x		x		x			9151.5	22	9107.4
13		x	x		x				x	x	x		x	x	x			x		x		x			9150.4	21	9108.3
14		x	x		x				x	x	x		x	x	x			x		x					9148.9	20	9108.9
14a		x	x		x				x	x	x		x	x	x			x			x				9149.0	21	9106.9
15		x	x		x				x	x	x		x	x	x			x							9147.6	19	9109.5
15a		x	x		x				x	x	x		x	x	x				x						9144.3	20	9104.3
16		x	x		x				x	x	x		x	x	x										9145.6	18	9109.5
17		x	x		x				x	x			x	x	x				x						9142.8	19	9104.7
18*		x	x		x				x				x	x	x				x						9141.3	18	9105.2

Table 11. Beta (slope) coefficients of estimable survival parameters of subyearling Chinook salmon from data used in studies at John Day Dam in 2002 and 2003.

[The data are from model 18 in table 10; Beta, slope coefficient]

Parameter	Beta	Standard error	95 percent confidence	
			Lower	Upper
Intercept	-1.9540	1.4886	-4.8715	0.9636
treatment	-13.6919	4.7556	-23.0128	-4.3710
year	16.1561	3.3910	9.5097	22.8026
treatment*year	-3.0346	0.5684	-4.1488	-1.9205
temperature	0.2752	0.0851	0.1084	0.4420
temperature*year	-0.7767	0.1755	-1.1206	-0.4328
temperature*treatment	0.2842	0.1769	-0.0626	0.6309
turbine unit discharge	1.0694	0.4497	0.1880	1.9509
turbine unit discharge ^2	-0.0334	0.0139	-0.0607	-0.0062

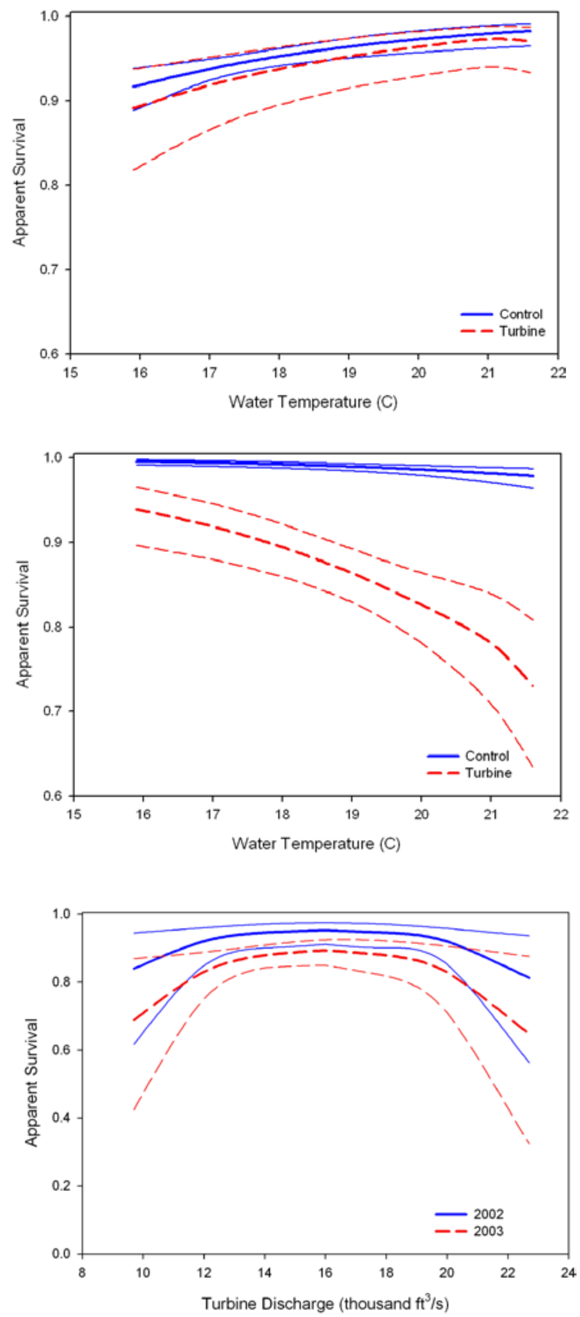

Figure 8. Graph showing the estimated effects of water temperature in 2002 (upper plate) and 2003 (middle plate) and turbine discharge (lower plate) on apparent survival of subyearling Chinook salmon from data used in studies at John Day Dam in 2002 and 2003. Predictions (thick lines) and 95 percent confidence intervals (thin lines) from model 18 in table 10 are plotted.

Results of Analyses from Studies at McNary Dam

Yearling Chinook Salmon

Environmental Conditions

The environmental conditions occurring during fish passage differed among years available for analysis (2002–2009). The turbines were primarily operated within 1 percent of peak efficiency during fish passage (fig. 9). Covariate values at the time of fish passage are summarized in appendix G and daily averages are plotted in fig. 10. Overall turbine unit discharge ranged from 7.80 to 17.27 thousand ft^3/s with a median of 11.90 thousand ft^3/s. The maximum turbine unit discharges were higher in 2002–2005 (16.30–17.27 thousand ft^3/s) than in 2006–2009 (12.42–13.11 thousand ft^3/s). The median head was 72.13 ft (range 67.47 to 75.91 ft) and was slightly lower in 2006 (median 69.92 ft) than in the other years (medians ranging from 71.63 to 73.12 ft). The total project discharge, which was applied only to fish in the control group, ranged from 90.30 to 421.09 thousand ft^3/s and had a median of 255.60 thousand ft^3/s. Percentage of spill varied among years and photoperiod according to annual study designs and environmental conditions (see table 1). Spill percentage spill ranged from 0.00 to 78.84 over the years of studies. The median tag burden was 4.35 percent (range 0.86 to 9.78 percent) and was similar in all years except 2003. In 2003, the tag burden was higher than in the other years, with a median of 7.06 percent and range of 3.47 to 9.78 percent. In 2003, a larger size transmitter was used to reduce regurgitation after gastric implantation. The median water temperature ranged from 10.72 °C in 2009 to 12.83 °C in 2004. Water temperature ranged from 8.11 to 15.78 °C among years with a median of 12.33 °C.

The data included fish passing through all turbine units (fig. 11). The distribution of the unit of passage was similar among years and overall was slightly greater in lower-numbered units (closer to the Oregon shore). This distribution generally reflects the percentage of time individual turbines were operating (fig. 11). Sample sizes for the turbine group were smaller in 2002 ($N = 33$) and 2003 ($N = 95$) than in the other years ($N =$ 162–287).

Survival

Two separate analyses were completed using data from McNary Dam due to the inconsistent resolution of the turbine unit of passage among years. An analysis of a data set restricted to 2002, 2003, 2004, 2005 and 2009, years with unit-specific passage assignments, was conducted first followed by analyses based on the complete data set from 2002–2009.

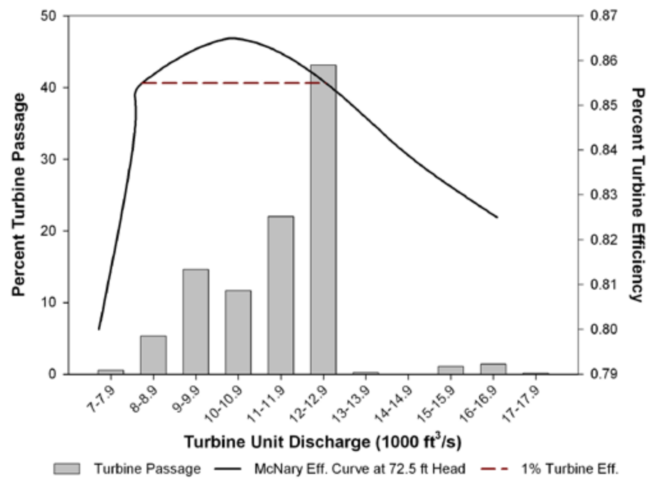

Figure 9. Graph showing turbine unit discharges during yearling Chinook salmon passage (bars) and turbine efficiency (solid line) from data used in studies at McNary Dam in 2002–2005 and 2009. The discharges bounded by the dashed line are within 1 percent peak turbine efficiency at a head of 72.5 feet.

The restricted analyses of survival at McNary Dam were based on 770 fish in the turbine group and 3,286 fish in the control group. Sample sizes varied among groups of treatment, year, and photoperiod and ranged from 114 to 1,219 per group for control fish and 12 to 189 per group for turbine fish (appendix H). There were no control fish in the studies during 2002 or 2003.

Correlation analyses indicated several variables were moderately related. Pearson correlation coefficients for fish weight and tag burden and total discharge and head were about |0.80| indicating that the separate influence of these variables might not be reliably determined if used together (appendix I). Analyses of multicollinearity indicated no dependencies among the variables would result from these correlations. The correlations between head and total discharge would not be problematic in the analysis, because head was only applied to the turbine group and total discharge was only applied to the control group. As in analyses of data from John Day Dam, tag burden and fish weight were not used in models together. Rather, tag burden was used as a covariate and, if supported as a factor affecting survival, it was replaced with fish weight during post-hoc analyses to determine which was more supported as the causal factor.

A model of recapture probabilities based on a multiplicative effect of group and reach was best supported by the data and used for all survival models for the reduced data set. The AICc of this model was 67 units less than the next best-supported model (model 1 compared to model 2, appendix J) and received greater than 99.9 percent of the model weight. Thus, there was little evidence to support the other models of recapture probability evaluated.

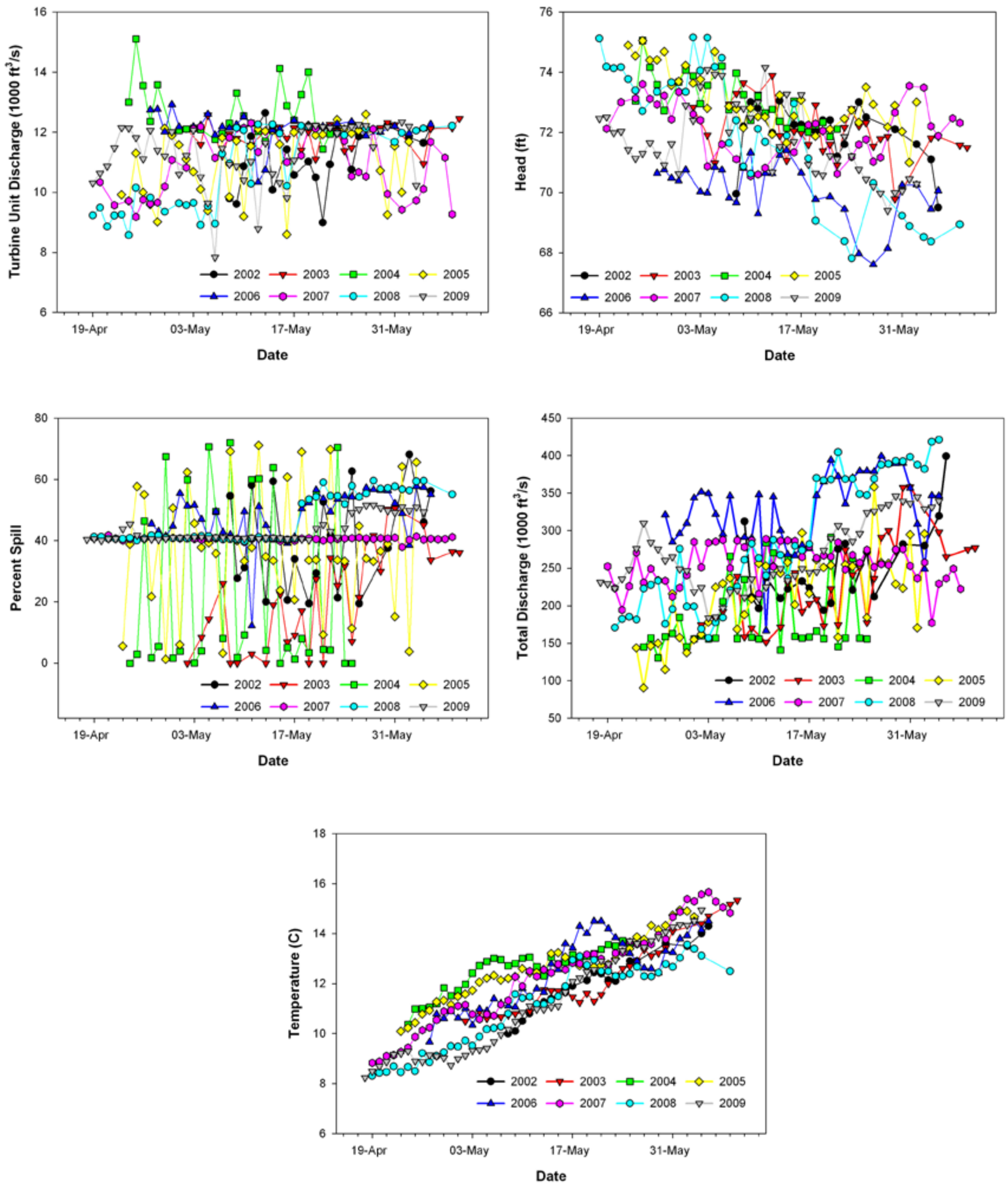

Figure 10. Graph showing daily-averaged covariate values for yearling Chinook salmon from data used in studies at McNary Dam in 2002–2009.

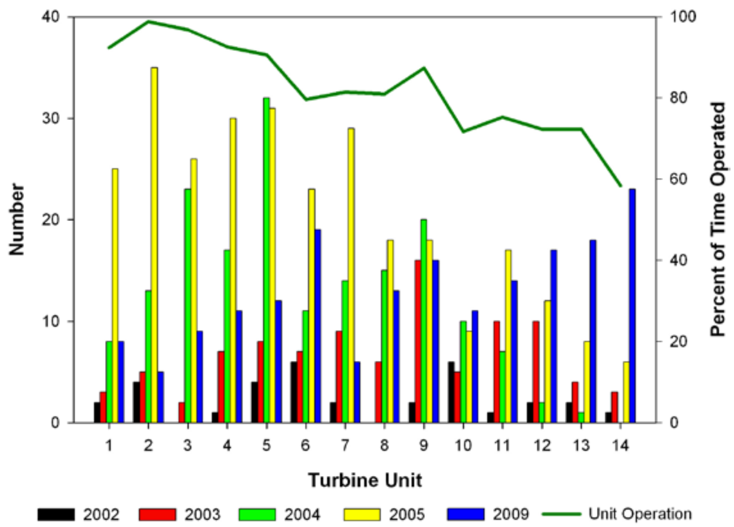

Figure 11. Graph showing number of yearling Chinook salmon passing through each turbine by year (bars) and overall percentage of time each turbine was operating (line) from data used in studies at McNary Dam in 2002–2005 and 2009. Unit-specific passage assignments were not made as part of the studies in 2002–2005 and 2009.

Effects on survival of five of the covariates examined were supported by the data and models from the reduced data set (appendixes K and L). These included tag burden, head, percentage spill, water temperature, and total discharge. The linear model of head received only weak support with an AICc value 0.7 less than the model without head (model 13 compared to 14a), whereas the quadratic model had an AICc 0.3 greater than the model with no head effect and was not supported (model 14b compared to 14a). Both linear and quadratic models of turbine unit discharge had AICc values about 3 units greater than the model without turbine unit discharge and therefore were not supported (model 14b and 15b compared to 15). The model containing water temperature, percentage spill, and total project discharge (model 9) had AICc values 2.8 to 12 units less than the alternative models without these covariates (models 10, 11, and 12) indicating that they were moderately to strongly supported. Tag burden also received moderate support relative to the model without tag burden (model 16 compared to model 17). Because there was no evidence of an effect of turbine unit discharge, further analyses were conducted based on all the years of data (2002–2009).

The analyses of factors affecting survival of yearling Chinook salmon at McNary Dam using all the data were based on 1,419 fish in the turbine group and 6,737 fish in the control group (appendix M). Numbers of fish in the turbine and control groups were similar among years except in 2002 and 2003. In these years, there were no control groups and there were fewer fish in the turbine groups ($N = 33$ in 2002 and $N = 95$ in 2003) than in other years ($N = 163$–287).

Correlation analyses indicated that several variables in the full data set were related. As in the analysis of the smaller data set, Pearson correlation coefficients for fish weight and tag burden and total discharge and head were greater than or equal to |0.79| indicating that the separate influence of these variables might not be separable when used together (tables 12 and 13). Analyses of multicollinearity indicated that only minor dependencies among the variables would result from these correlations and variance inflation factors were less than 5. As in the previous analysis, the correlation between head and total discharge would not be problematic in the analysis, because head was applied only to the turbine group and total discharge was applied only to the control group. Tag burden and fish weight also were treated as in the previous analysis. The unit-specific turbine of passage variable (turbloc) was replaced by a north or south passage location (unitloc) in the analyses of all years, because it was the only resolution common to all years.

A multiplicative recapture probability model of group and reach was supported by the data and used in all comparisons among survival models. This model received most of the AICc weight. The AICc value was 23 units less than the next best-supported model, indicating that it was the only model supported relative to the others evaluated (appendix N). Visual examination of the capture histories (appendix M) indicated that all fish in the sample from the turbine night group in 2009 were detected, so the capture probability was fixed to 1.0 for the first downriver reach. Similarly, the λ for the turbine night group in 2003 in the second downriver reach was also fixed to 1.0. Capture histories also indicated that no mortality occurred in the sample from the turbine night group in 2002, so it was fixed to 1.0 for analysis. Recapture probabilities at the first downriver site ranged from 0.309 (SE 0.0.062) to 1.0 (manually fixed for analysis) and averaged 0.717. The λ parameter ranged from 0.461 (SE 0.050) to 1.0 (manually fixed for analysis), and averaged 0.849.

Few of the individual covariates examined were supported as determinants of survival for the turbine group. Only tag burden, water temperature, total discharge, and head were supported by the data and models (table 14). The total discharge covariate, which was applied only to control fish, had a slightly positive effect on survival, and was included in models to account for environmental conditions apart from those related to powerhouse operation.

The operational covariates contributed little to the fit of the survival models examined with the exception of head. The model with a linear effect of head had an AICc value 1.4 units greater than the model without head and was not supported (model 13 compared to 14a). The quadratic model of head received moderate support compared to the model with no head effect as evidenced by an AICc that was 3.6 units lower (model 14a compared to 14b). That model simulates an intermediate maximum survival at a head of 71.2 ft, with a 95 percent confidence interval of 70.7–71.8 ft (fig. 12, table 15). Models with a linear or quadratic effect of turbine unit discharge had AICc values 1.8 and 2.1 greater than the model without turbine unit discharge and were not supported by the data (models 14b and 15b compared to model 15a). Similarly, models with percentage spill and a percentage spill by treatment interaction were not supported compared to the model without percentage spill (models 8 and 10 compared to model 12). The interaction effect of water temperature and year was strongly supported (model 1) with an AICc value about 8 units less than the model without this interaction (model 2). The effect of tag burden was also strongly supported with an AICc value nearly 11 units less than the alternative model without it (model 17 compared to model 16). Following the systematic evaluation of the individual and group covariates the best supported model contained only treatment, photoperiod, year, their interactions, and the individual covariates of tag burden, water temperature, total discharge, and a quadratic effect of head (model 16 in table 14). The post-hoc evaluation using fish weight in place of tag burden in the best-supported model indicated that weight was the better supported of the two correlated variables with an AICc value 3.4 units less than the model with tag burden (model 18 vs. model 16).

Table 12. Table of correlation indices of data from yearling Chinook salmon from the turbine group from data used in studies at McNary Dam in 2002–2009.

[Pearson correlation coefficients are listed above the probabilities of obtaining a greater value under the hypothesis that Rho = 0. Sample size is 1,419; <, less than; see table 2 for variable name definitions]

	TOTQ	PER_SPI	HEAD	TURQ	UNITLOC	PHOTO	TEMP	WEIGHT	TAG BURDEN
TOTQ	1.0000	0.6082	-0.8693	0.2371	-0.1919	0.1939	0.3038	-0.0892	0.1022
		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0008	0.0001
PER_SPI		1.0000	-0.3156	-0.2626	-0.1579	0.4278	-0.0121	0.0425	-0.1181
			<0.0001	<0.0001	<0.0001	<0.0001	0.6502	0.1098	<0.0001
HEAD			1.0000	-0.3915	0.1523	-0.0870	-0.3601	0.0754	-0.1496
				<0.0001	<0.0001	0.0010	<0.0001	0.0045	<0.0001
TURQ				1.0000	0.1253	-0.0816	0.3595	-0.0778	0.1902
					<0.0001	0.0021	<0.0001	0.0034	<0.0001
UNITLOC					1.0000	0.0167	0.1332	-0.0061	-0.0460
						0.5293	<0.0001	0.8188	0.0832
PHOTO						1.0000	-0.0227	-0.0080	-0.0425
							0.3936	0.7625	0.1097
TEMP							1.0000	-0.2044	0.1692
								<0.0001	<0.0001
WEIGHT								1.0000	-0.7917
									<0.0001

Low and high values of head and high values of water temperature and tag burden had negative effects on survival in most years. Values of head that were in the mid-range near 71 ft had higher rates of survival than those that were in the lower or higher part of the range of observed values (fig. 12). The model slopes generally indicate a greater temperature effect on turbine fish during the day than on turbine fish at night or control groups during day or night (table 15). A negative effect of water temperature on survival was supported for all years except for 2006 in which the effect was positive (fig. 13). Post-hoc analyses indicated this anomaly was caused by a treatment, year, temperature interaction, which did not affect the interpretation of the important factors. Survival estimates of the control groups generally were higher than for the turbine groups, as expected. Tag burden had a negative effect on survival in all years, but it was more pronounced for the turbine group than the control group (fig. 14). A positive effect of total discharge was also supported.

Table 13. Table of correlation indices of data from yearling Chinook salmon from the control group from data used in studies at McNary Dam in 2002–2009.

[Pearson correlation coefficients are listed above the probabilities of obtaining a greater value under the hypothesis that Rho = 0. Sample size is 6,737; <, less than; see table 2 for variable name definitions]

	TOTQ	PER_SPI	PHOTO	TEMP	WEIGHT	TAG BURDEN
TOTQ	1.0000	0.5873	-0.1071	0.2913	-0.1141	0.1996
		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
PER_SPI		1.0000	0.2342	0.0597	-0.0321	0.0219
			<0.0001	<0.0001	0.0085	0.0721
PHOTO			1.0000	-0.1809	0.0858	-0.1292
				<0.0001	<0.0001	<0.0001
TEMP				1.0000	-0.1742	0.1617
					<0.0001	<0.0001
WEIGHT					1.0000	-0.8487
						<0.0001

Key Findings in Data from Yearling Chinook Salmon at McNary Dam

- Initial analyses were based on a subset of the data because turbine unit-specific passage location was not available in all years. Unit-specific discharge was not supported as a factor on survival in these data (from 2002 to 2008 and 2009), so inferences were based on the full 2002–2009 data set and a "north-south" assignment for unit passage location.
- The full data set included 1,419 fish in the turbine group and 6,737 fish in the control group.
- Most data were collected at turbine discharges within 1 percent of peak unit efficiency.
- A positive effect of total discharge on survival was moderately supported (this covariate was applied only to the control group).
- Head was moderately supported as a factor affecting turbine passage survival. A curvilinear fit to the data indicated maximum turbine passage survival at a head of 71.2 ft with lower survival at greater or lesser values.
- Water temperature was supported as a factor affecting turbine passage survival. A difference in the effect of water temperature among years was strongly supported: the effect of water temperature was positive in 2006 and negative in all other years.
- A negative effect of tag burden was strongly supported. There was moderate support for the alternative hypothesis that this was due to fish weight rather than tag burden.

Table 14. Model-selection results from radio- and acoustic-tagged yearling Chinook salmon from data used in studies at McNary Dam in 2002–2009.

[Presence of a factor in a model is indicated by an 'x' in the column for that factor. Model 1 was a global model including all group covariates and their interactions (g) as well as all individual covariates and interactions listed. All models shared a common g*reach model of recapture probability. K indicates the number of parameters. An asterisk after the model number indicates the best-supported model of the suite]

	Group covariates								Individual covariates																	Model selection results		
									Biological								Operational											
Model No.	**g**	**trt**	**yr**	**photo**	**trt*yr**	**trt*photo**	**yr*photo**	**trt*yr*photo**	**gated**	**wt**	**tagb**	**trt*tagb**	**yr*tagb**	**temp**	**trt*temp**	**yr*temp**	**persp**	**trt*persp**	**head linear**	**head quadratic**	**turq linear**	**turq quadratic**	**turloc**	**turloc*photo**	**totq**	**AICc**	**K**	**Deviance**
1	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	x	x		x		x	x	x	14694.8	89	14515.6
2	x	x	x	x	x	x	x	x			x	x	x	x	x		x	x	x		x		x	x	x	14702.9	82	14537.9
3	x	x	x	x	x	x	x	x			x	x		x	x	x	x	x	x		x		x	x	x	14687.1	82	14522.1
4a		x		x		x			x		x	x		x	x	x	x	x	x		x		x	x	x	14694.7	65	14564.1
4b		x	x	x	x	x					x	x		x	x	x	x	x	x		x		x	x	x	14691.4	75	14540.6
4c		x	x	x		x	x				x	x		x	x	x	x	x	x		x		x	x	x	14690.4	76	14537.5
4d		x	x	x		x					x	x		x	x	x	x	x	x		x		x	x	x	14690.2	70	14549.4
5		x	x	x	x	x	x	x			x	x		x	x	x	x	x	x		x		x		x	14685.6	81	14522.6
6		x	x	x	x		x	x			x	x		x	x	x	x	x	x		x		x		x	14687.0	80	14526.0
7		x	x		x						x	x		x	x	x	x	x	x		x		x		x	14702.0	72	14557.2
8		x	x	x	x	x	x	x			x	x		x		x	x	x	x		x		x		x	14684.0	80	14523.0
9		x	x	x	x	x	x	x			x	x				x	x	x	x		x		x		x	14684.4	79	14525.5
10		x	x	x	x	x	x	x			x	x		x		x	x		x		x		x		x	14682.4	79	14523.4
11		x	x	x	x	x	x	x			x	x		x		x	x		x		x		x			14684.5	78	14527.6
12		x	x	x	x	x	x	x			x	x		x		x			x		x		x		x	14680.8	78	14523.9
13		x	x	x	x	x	x	x			x	x		x		x			x		x				x	14679.9	77	14525.0
14a		x	x	x	x	x	x	x			x	x		x		x					x				x	14678.5	76	14525.6
14b		x	x	x	x	x	x	x			x	x		x		x				x	x				x	14674.9	78	14518.0
15a		x	x	x	x	x	x	x			x	x		x		x				x					x	14673.1	77	14518.2
15b		x	x	x	x	x	x	x			x	x		x		x				x		x			x	14675.2	79	14516.2
16*		x	x	x	x	x	x	x			x			x		x				x					x	14671.8	76	14519.0
17		x	x	x	x	x	x	x						x		x				x					x	14682.7	75	14531.8
18		x	x	x	x	x	x	x		x				x		x				x					x	14668.4	76	14520.8

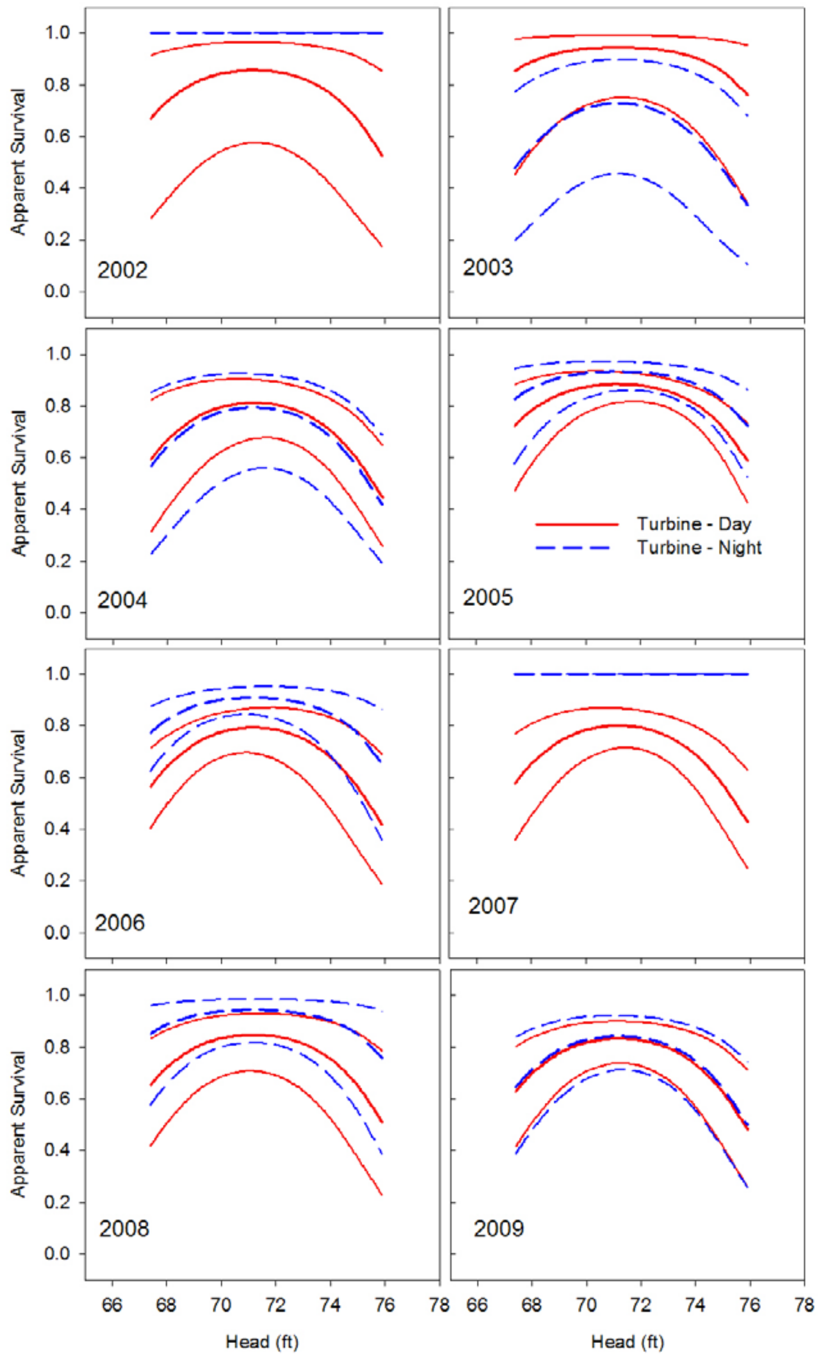

Figure 12. Graph showing estimated effects of head on apparent survival of yearling Chinook salmon at McNary Dam in 2002–2009. Predictions (thick lines) and 95 percent confidence intervals (thin lines) from model 16 in table 14 are plotted.

Table 15. data used in studies at McNary Dam in 2002–2009.

[The data are from model 16 in table 14]

Parameter	Beta	Standard error	95 percent confidence Lower	95 percent confidence Upper
intercept	6.7960	2.7932	1.3214	12.2705
treatment	-384.8641	2.1281	-389.0352	-380.6930
photo	1.0985	0.9047	-0.6747	2.8717
2005	1.4746	3.0765	-4.5553	7.5045
2006	-7.9079	3.0029	-13.7936	-2.0223
2007	-0.9634	2.9527	-6.7508	4.8240
2008	-0.4017	3.3019	-6.8734	6.0700
2009	-2.4378	2.8305	-7.9857	3.1100
2002	-1.9472	7.6035	-16.8501	12.9558
2003	2.5164	5.1175	-7.5139	12.5466
treatment*photo	-1.2107	0.6779	-2.5395	0.1181
treatment*2005	-0.5280	0.5670	-1.6392	0.5833
treatment*2006	-0.5468	0.6364	-1.7942	0.7006
treatment*2007	-0.9346	0.6615	-2.2311	0.3619
treatment*2008	-0.7543	0.7552	-2.2345	0.7259
treatment*2009	0.6700	0.5831	-0.4730	1.8129
photo*2005	-1.3721	1.0370	-3.4046	0.6604
photo*2006	1.0762	0.7204	-0.3358	2.4881
photo*2007	484.2001	0.0000	484.2001	484.2001
photo*2008	1.2204	0.9388	-0.6197	3.0605
photo*2009	0.1860	0.7605	-1.3046	1.6765
photo*2003	-1.7392	1.1979	-4.0871	0.6088
treatment*photo*2005	2.0918	0.9478	0.2341	3.9494
tag burden	-0.2462	0.0704	-0.3841	-0.1082
head	10.8140	0.0000	10.8140	10.8140
head^2	-0.0759	0.0003	-0.0766	-0.0753
totq	0.0058	0.0020	0.0018	0.0098
temp	-0.3519	0.2134	-0.7701	0.0664
temp*2005	-0.0304	0.2381	-0.4970	0.4362
temp*2006	0.6758	0.2373	0.2107	1.1410
temp*2007	0.1479	0.2287	-0.3003	0.5961
temp*2008	0.1143	0.2659	-0.4069	0.6354
temp*2009	0.1547	0.2232	-0.2827	0.5921
temp*2002	0.1837	0.6169	-1.0254	1.3929
temp*2003	-0.0925	0.4110	-0.8981	0.7130

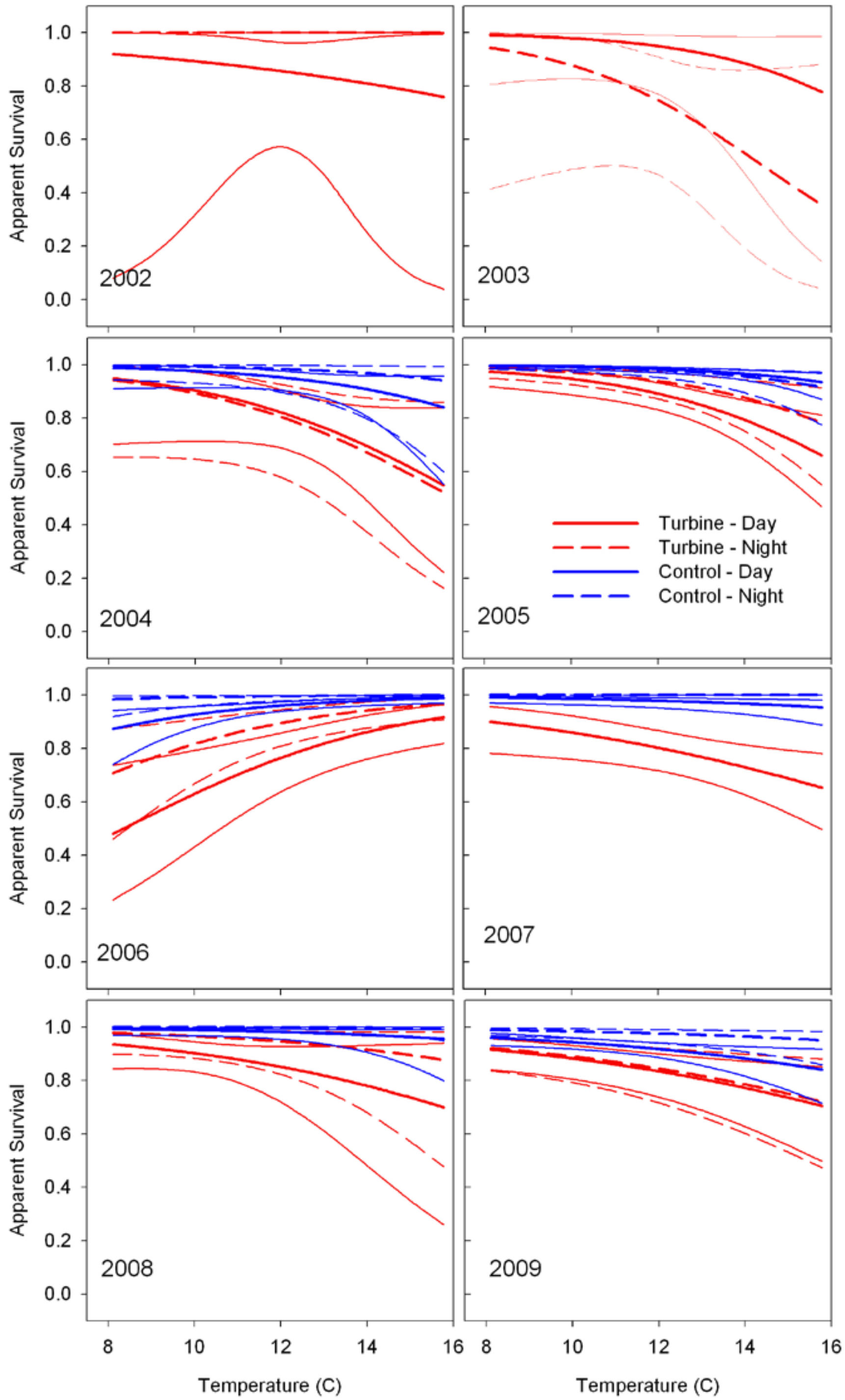

Figure 13. Graph showing estimated effects of water temperature on apparent survival of yearling Chinook salmon from data used in studies at McNary Dam in 2002–2009. Predictions (thick lines) and 95 percent confidence intervals (thin lines) from model 16 in table 14 are plotted.

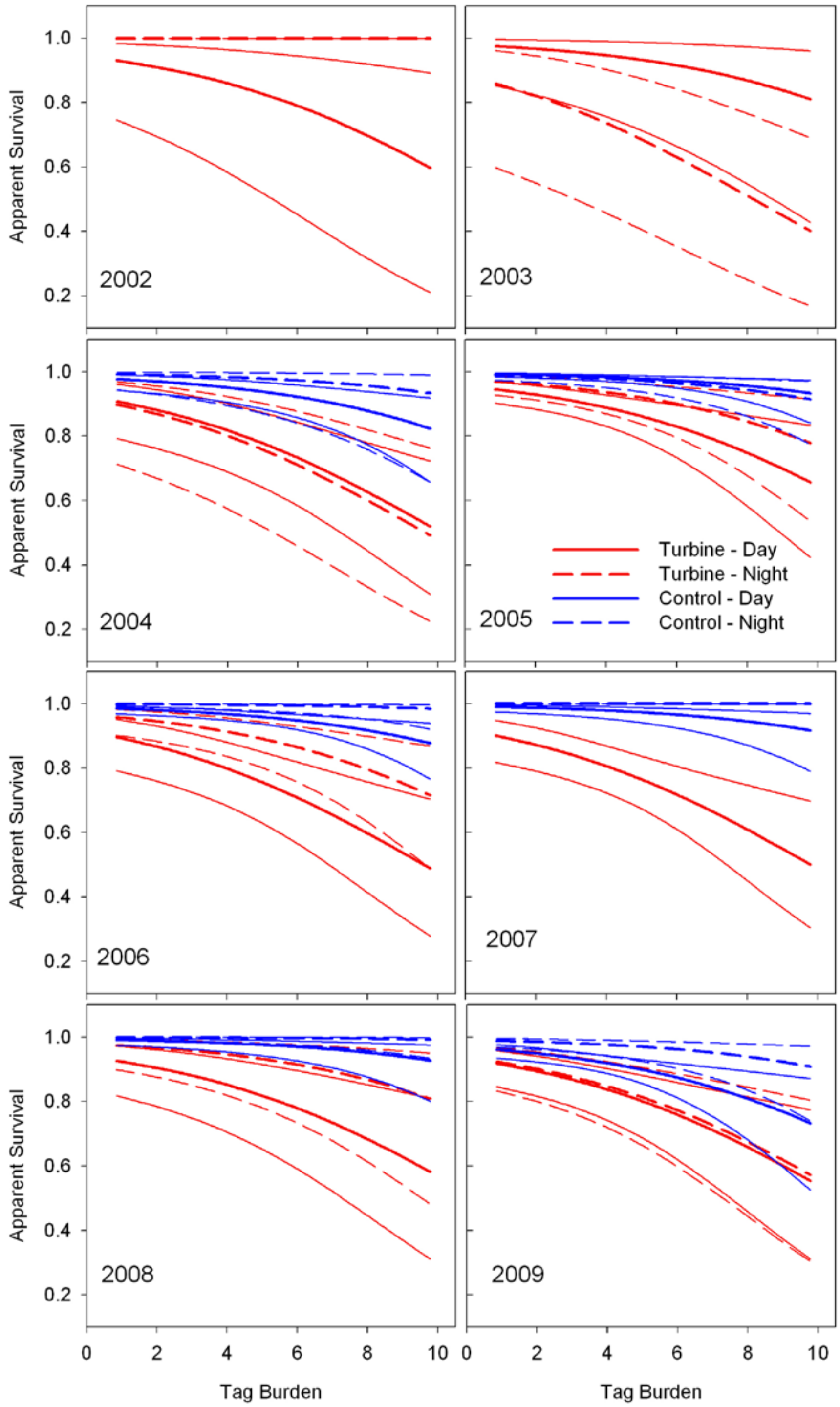

Figure 14. Graph showing estimated effects of tag burden on apparent survival of yearling Chinook salmon from data used in studies at McNary Dam in 2002–2009. Predictions (thick lines) and 95 percent confidence intervals (thin lines) from model 16 in table 14 are plotted.

Juvenile Steelhead

Environmental Conditions

The environmental conditions during passage of juvenile steelhead differed among the years analyzed (2004–2009). The turbines were operated primarily within 1 percent of peak efficiency during fish passage (fig. 15). Covariate values at the time of fish passage are summarized in appendix P and daily averages are plotted in fig. 16. Overall turbine unit discharge ranged from 7.90 to 16.60 thousand ft^3/s with a median of 11.90 thousand ft^3/s. The maximum turbine unit discharges were higher in 2004 and 2005 (16.30–16.60 thousand ft^3/s) than in 2006–2009 (12.28–12.94 thousand ft^3/s). The median head was 71.98 ft (range 67.36 to 75.64 ft) and it was lower in 2006 (70.11 ft) than during the other years (range in medians 71.32 to 73.76 ft). The total project discharge, which was applied as a covariate only to the control group, ranged from 90.90 to 418.52 thousand ft^3/s and had a median of 235.92 thousand ft^3/s. Spill percentage varied among years and photoperiod according to annual study designs and environmental conditions (see table 1). Spill percentage ranged from 0.00 to 78.49 for the years analyzed. The median tag burden was 1.89 percent (range 0.60 to 6.41 percent) and was similar for all years (range of medians 1.49 to 2.12 percent). The median water temperature ranged from 10.72 °C in 2008 and 2009 to 13.03 °C in 2007. Daily water temperature ranged from 8.11 to 15.67 °C among years with a median of 11.72 °C.

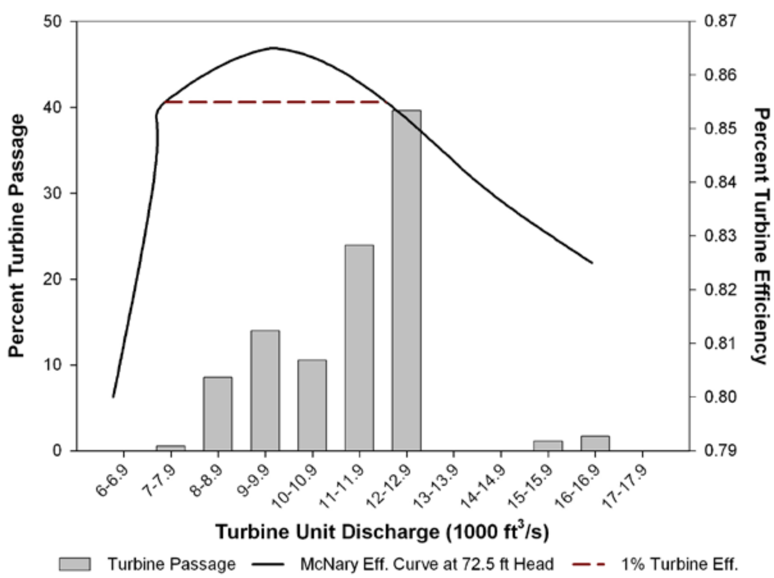

Figure 15. Graph showing turbine unit discharges during juvenile steelhead passage (bars) and turbine efficiency (solid line) from data used in studies at McNary Dam in 2004–2009. The discharges bounded by the dashed line are within 1 percent of the peak turbine efficiency at a head of 72.5 feet.

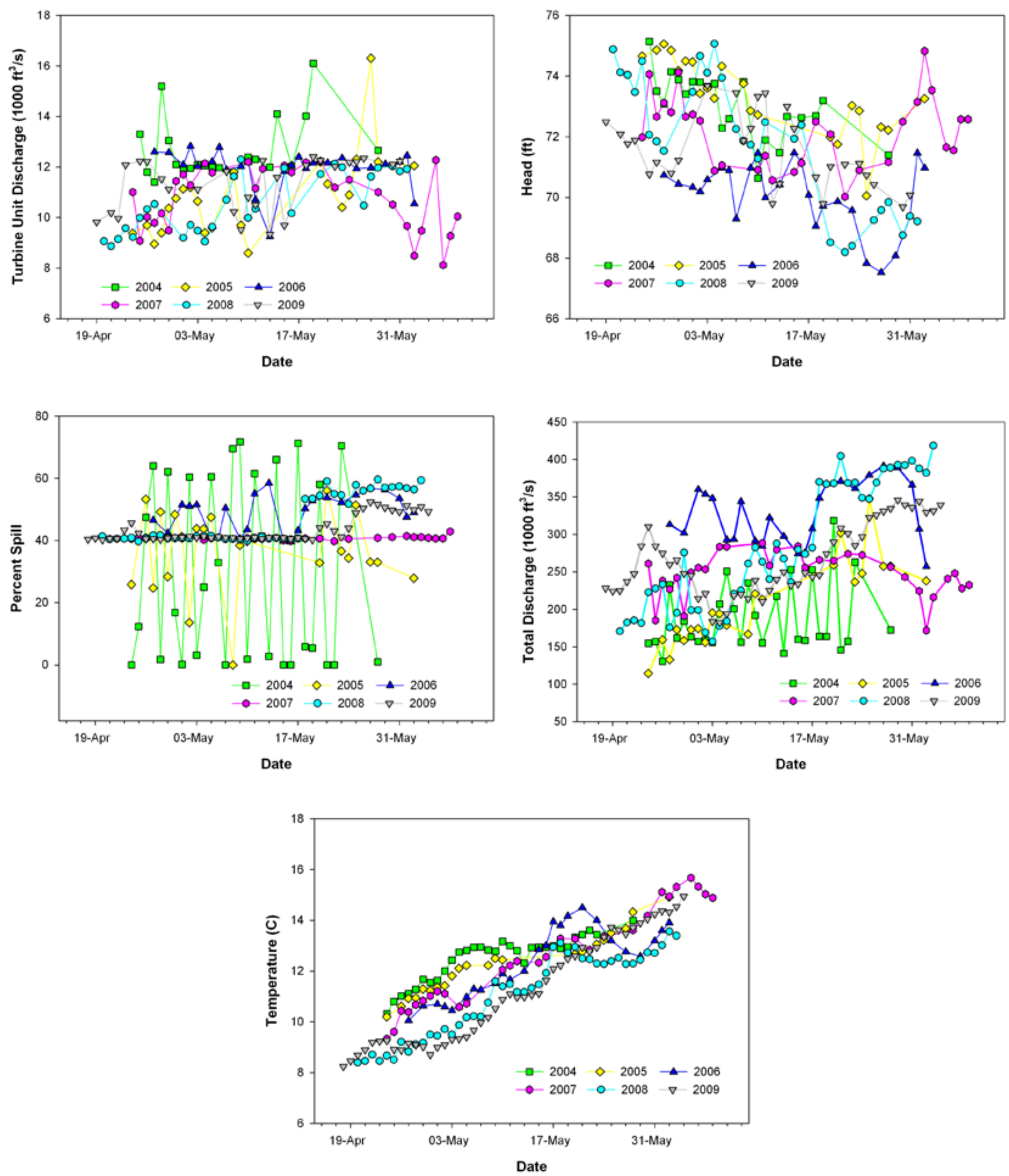

Figure 16. Graph showing daily-averaged covariate values for juvenile steelhead from data used in studies at McNary Dam in 2004–2009.

The passage data included fish passing through all turbine units (fig. 17). In 2004 and 2005, most fish passed through turbine units 1–7 (closer to the Oregon shore) where the turbines were operating a higher percentage of the time. In 2009, the median total discharge was higher than the other 2 years and passage tended to be more evenly distributed across the powerhouse.

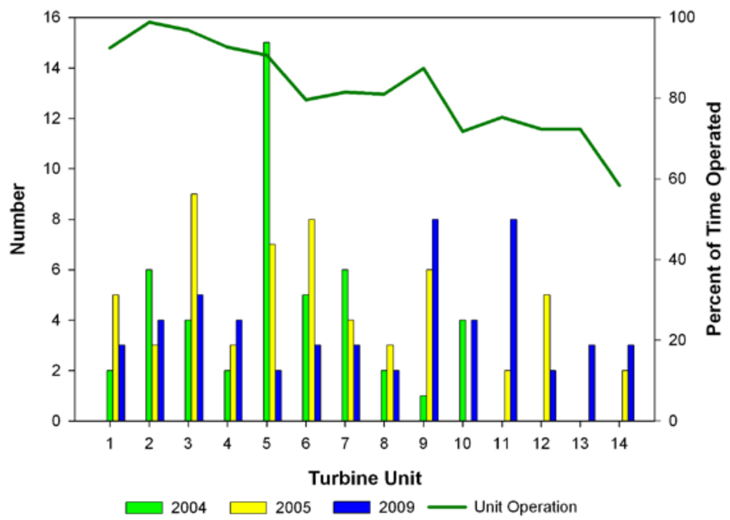

Figure 17. Graph showing number of juvenile steelhead passing through each turbine by year (bars) and overall percentage of time individual turbine units were operating (line) from data used in studies at McNary Dam in 2004, 2005, and 2009. Unit-specific passage assignments were not made as part of the studies in 2006–2008.

Survival

As in analyses of Chinook salmon at McNary Dam, two separate analyses of data from juvenile steelhead were conducted due to differences in turbine unit specificity when assigning turbine passage among years. First an analysis restricted to years having unit-specific passage locations (2004, 2005, and 2009) was performed, followed by an analysis of all years, 2004–2009.

The restricted analysis was based on 158 fish in the turbine group and 1,531 fish in the control group. Turbine and control groups contained similar numbers of fish among years, except 2005 when there were no control fish (appendix P). Pearson correlation coefficients ranged from |0.75| to |0.84| for the covariate pairs of fish weight and tag burden and total discharge and head (appendix Q). Analyses of multicollinearity indicated moderate dependencies associated with total discharge and head for the turbine group (variance inflation factor: total discharge = 9.2, head = 7.5), but no other serious dependencies were indicated for the turbine or control groups. As in previous analyses, we applied head only to the turbine group and total discharge to the control group and we used tag burden for all analyses, with post-hoc replacement with fish weight if a tag burden effect was supported by the data.

In the restricted analysis, a multiplicative model of recapture probabilities by group and reach was supported by the data and used in all comparisons among survival models (appendix R). The AICc for this model was about 54 units lower than the next best model indicating a much better fit to the data than the other models of recapture probability. Of the individual covariates examined, tag burden was weakly supported and spill percentage was moderately supported by the data and models as determinants of survival for the turbine group. In addition to these variables, total discharge was weakly supported for the control group (appendixes S and T). Models with linear and quadratic effects of head (models 13 and 14b) had AICc values 1.6 and 3.3 greater than the model without head (model 14a). Similarly, models with linear and quadratic effects of turbine unit discharge (models 14a and 15b) had AICc values 2.0 and 3.7 greater than the model with no turbine discharge effect (model 15a). These results indicate weak or no support for head or turbine unit discharge on turbine survival. Because an effect of turbine unit discharge on survival was not supported by these data, further analyses were based on the full 2004–2009 data set.

The analyses of factors affecting survival based on data from all years were based on 351 fish in the turbine group and 2,316 fish in the control group (appendix U). Numbers of fish in the turbine group ranged from 47 to 79 fish among years, whereas control fish numbers ranged from 746 to 785 for years in which control releases were made. No juvenile steelhead control releases were made during 2005–2007.

Correlation analyses indicated that the relation between two pairs of the individual covariates was moderately high in the data from all years. Pearson correlation coefficients for fish weight and tag burden were |0.82| for turbine and control groups and the coefficient for head and total discharge for the turbine group was |0.9262| (tables 16 and 17). The variance inflation factors for total discharge and head were 14.4 and 10.8 for the turbine group also indicating moderately high dependencies between the two covariates; total discharge and head therefore were used in the manner described previously. The location of the turbine unit of passage used in the restricted data set was replaced by a north or south passage location for all years, because that resolution was common to all years.

A multiplicative recapture probability model of group and reach was supported by the data for all years and was used in all comparisons among survival models. Examination of data in appendix U indicated all fish from several control and turbine groups were detected at one or more of the downstream sites, so their recapture or λ parameters were fixed to 1.0 in the analyses. The AICc for this model was 116 units smaller than the next best model indicating a better fit to the data than the other models of recapture probability (model 1 in appendix table V). Recapture probabilities at the first downriver site ranged from 0.250 (SE 0.108) to 1.000 (fixed for analysis) and averaged 0.739. The λ parameters ranged from 0.774 (SE 0.079) to 1.000 (fixed for analysis) and averaged 0.908.

Table 16. Table of correlation indices of data from juvenile steelhead from the turbine group from data used in studies at McNary Dam in 2004–2009.

[Pearson correlation coefficients are listed above the probabilities of obtaining a greater value under the hypothesis that Rho = 0. Sample size is 351; <, less than; see table 2 for variable name definitions]

	PER_SPI	HEAD	TURQ	UNITLOC	PHOTO	TEMP	WEIGHT	TAG BURDEN
TOTQ	0.5179	-0.9262	0.3740	-0.2733	-0.0678	0.3287	-0.1260	0.1567
	<0.0001	<0.0001	<0.0001	<0.0001	0.2051	<0.0001	0.0182	0.0033
PER_SPI	1.0000	-0.2959	-0.0231	-0.1321	0.3337	0.0753	-0.1340	0.0566
		<0.0001	0.6664	0.6664	<0.0001	0.1591	0.0120	0.2899
HEAD		1.0000	-0.4112	0.2532	0.1455	-0.3065	0.1053	-0.1847
			<0.0001	<0.0001	0.0063	<0.0001	0.0487	0.0005
TURQ			1.0000	0.0074	-0.1057	0.2747	-0.0328	0.2044
				0.8908	0.0478	<0.0001	0.5407	0.0001
UNITLOC				1.0000	0.0961	0.0534	0.0333	0.0094
					0.0721	0.3188	0.5341	0.8608
PHOTO					1.0000	-0.1413	-0.0044	-0.0871
						0.0080	0.9348	0.1033
TEMP						1.0000	0.0010	0.1346
							0.9856	0.0116
WEIGHT							1.0000	-0.8252
								<0.0001

Head and spill percentage were the only individual covariates that were supported by the data and models for all years as having an effect on turbine passage survival (table 18). The final model after all group and individual covariates had been systematically evaluated included the effects of treatment, total discharge for the control group, photoperiod for the turbine group, unique spill percentage effects for the turbine and control groups, and a quadratic effect of head (model 18 in table 18). The model with a

Table 17. Table of correlation indices of data from juvenile steelhead from the control group from data used in studies at McNary Dam in 2004–2009.

[Pearson correlation coefficients are listed above the probabilities of obtaining a greater value under the hypothesis that Rho = 0. Sample size is 2,316; <, less than; see table 2 for variable name definitions]

	PER_SPI	PHOTO	TEMP	WEIGHT	TAG BURDEN
TOTQ	0.5872	-0.0296	0.2583	-0.1312	-0.0228
	<0.0001	0.1539	<0.0001	<0.0001	0.2736
PER_SPI	1.0000	0.2614	-0.0659	-0.0886	-0.0601
		<0.0001	0.0015	<0.0001	0.0038
PHOTO		1.0000	-0.1096	0.0426	-0.0627
			<0.0001	0.0402	0.0025
TEMP			1.0000	0.0427	0.2171
				0.0398	<0.0001
WEIGHT				1.0000	- 0.8160
					<0.0001

linear effect of head (model 13) was only weakly supported with an AICc 1.2 less than the model without head. The quadratic model of head (model 14b) received moderate support, with an AICc value 5.7 less than the model without head (model 14a). That this effect for the turbine group. Survival of the control group was higher than survival of the turbine group and survival of the turbine group was higher at night than during the day. An effect of photoperiod (day/night) on survival of the control group was not supported.

Key Findings in Data from Juvenile Steelhead at McNary Dam

- Initial analyses were based on a subset of the data because turbine unit-specific passage location was not available in all years. Unit-specific discharge was not supported as a factor on survival in these data (from 2004, 2005, and 2009), so inferences were based on the full 2004–2009 data set and a "north-south" assignment for unit passage location.
- The full data set included 351 fish in the turbine group and 2,316 fish in the control group.
- Most data were collected at turbine discharges within 1 percent of peak unit efficiency.
- Head was moderately supported as a factor affecting turbine passage survival. A curvilinear fit to the data indicated minimum turbine passage survival at a head of 73.1 ft with higher survival at greater or lesser values. This effect is in the opposite direction as the effect supported by data from yearling Chinook salmon at McNary Dam.
- Spill percentage was supported as a factor affecting survival. A negative effect of spill percentage was moderately supported as a factor affecting passage survival and a different effect of fish in turbine and controls groups was weakly supported. The final model described a smaller negative effect of spill percentage on control fish than on turbine fish.
- An effect of photoperiod was supported on survival of fish in the turbine group, but not those of the control group. The data and models indicated greater turbine passage survival at night than during the day.
- An effect of tag burden on survival was not supported from the full (2004–2009) data set, but a negative effect was weakly supported in the restricted data set (2004, 2005, and 2009).

Table 18. Model-selection results from radio- and acoustic-tagged juvenile steelhead from data used in studies at McNary Dam in 2004–2009.

[Presence of a factor in a model is indicated by an 'x' in the column for that factor. Model 1 was a global model including all group covariates and their interactions (g) as well as all individual covariates and interactions listed. All models shared a common g*reach model of recapture probability. K indicates the number of parameters. An asterisk after the model number indicates the best-supported model of the suite]

	Group covariates								Individual covariates																Model selection results		
									Biological							Operational											
Model No.	g	trt	yr	photo	trt*yr	trt*photo	yr*photo	trt*yr*photo	gated	tagb	trt*tagb	yr*tagb	temp	trt*temp	yr*temp	persp	trt*persp	head linear	head quadratic	turq linear	turq quadratic	turloc	turloc*photo	totq	AICc	K	Deviance
1	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x		x		x	x	x	4806.9	62	4681.2
2	x	x	x	x	x	x	x	x		x	x		x	x	x	x	x	x		x		x	x	x	4799.5	57	4684.0
3	x	x	x	x	x	x	x	x		x	x		x	x		x	x	x		x		x	x	x	4793.5	52	4688.2
4		x		x		x			x	x	x		x	x		x	x	x		x		x	x	x	4787.6	39	4709.0
5		x		x		x			x	x	x		x	x		x	x	x		x		x		x	4785.9	38	4709.3
6		x		x					x	x	x		x	x		x	x	x		x		x		x	4791.4	37	4716.7
7		x		x		x			x	x	x		x			x	x	x		x		x		x	4784.1	37	4709.5
8		x				x			x	x	x		x			x	x	x		x		x		x	4783.5	36	4711.0
9		x				x			x	x	x					x	x	x		x		x		x	4783.1	35	4712.5
10		x				x			x	x	x					x		x		x		x		x	4783.5	34	4715.0
11		x				x			x	x	x					x	x	x		x		x			4790.7	34	4722.2
12		x				x			x	x	x						x	x		x		x		x	4787.9	34	4719.4
13		x				x			x	x	x					x	x	x		x				x	4781.1	34	4712.6
14a		x				x			x	x	x					x	x			x				x	4782.3	33	4715.8
14b		x				x			x	x	x					x	x		x	x				x	4776.7	35	4706.1
15a		x				x			x	x	x					x	x		x					x	4776.6	34	4708.1
15b		x				x			x	x	x					x	x		x		x			x	4778.6	36	4706.0
16		x				x			x	x						x	x		x					x	4774.7	33	4708.2
17		x				x				x						x	x		x					x	4772.9	32	4708.4
18*		x				x										x	x		x					x	4770.8	31	4708.9

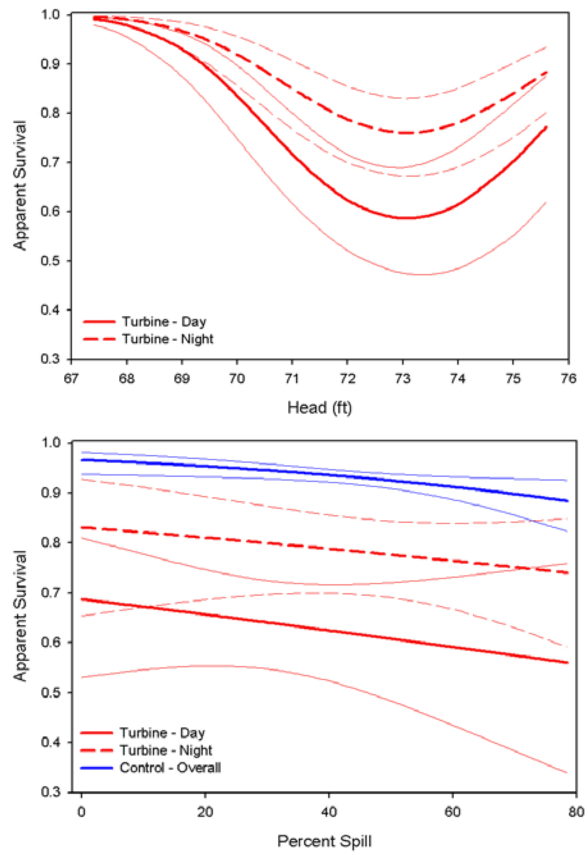

Figure 18. Graph showing estimated effects of head (upper plate) and spill percentage (lower plate) on apparent survival of juvenile steelhead at McNary Dam 2004–2009.

Table 19. Beta (slope) coefficients of estimable survival parameters of juvenile steelhead from data used in studies at McNary Dam in 2004–2009.

[The data are from model 18 in table 18]

Parameter	Beta	Standard error	95 percent confidence Lower	95 percent confidence Upper
intercept	2.14319	0.44930	1.26255	3.02382
treatment	725.04850	3.69852	717.79939	732.29761
treatment*photo	0.80499	0.33321	0.15189	1.45809
totq	0.00516	0.00173	0.00177	0.00855
persp	-0.01687	0.00695	-0.03049	-0.00326
persp*trt	0.00992	0.01124	-0.01210	0.03194
head	-19.88829	0.05170	-19.98962	-19.78695
head^2	0.13610	0.00068	0.13477	0.13744

Subyearling Chinook Salmon

Environmental Conditions

The environmental conditions occurring during passage of subyearling Chinook salmon varied among years due to the natural hydrograph and annual evaluations at McNary Dam. The turbines usually were operated within 1 percent of peak efficiency and the data primarily were collected during turbine unit discharge from 8 to 13 thousand ft^3/s (fig. 19). Covariate values at the times of fish passage are summarized in appendix Y and daily averaged values are plotted in fig. 20. Turbine unit discharge was slightly lower during 2006, 2007, and 2009 than in 2004, 2005, and 2008. Head ranged from 69.04 to 76.60 ft, with a median of 73.53 ft. Total project discharge ranged from 55.41 to 355.44 thousand ft^3/s with a median of 192.58 thousand ft^3/s, and decreased over the study periods of most years. Spill percentage varied among years based on annual study objectives and the natural runoff, and ranged from 0.00 to 77.82 percent. Tag burden was generally similar among years, ranging from 0.68 to 7.01 percent with a median of 4.57 percent. The median tag burden was lowest in 2005 (3.82 percent) and highest in 2004 (5.12 percent). Water temperature increased throughout the study period in each year, ranging from 14.56 to 22.39 °C over the years, with a median of 18.81 °C. Water temperature was slightly lower in 2008 than in the other years.

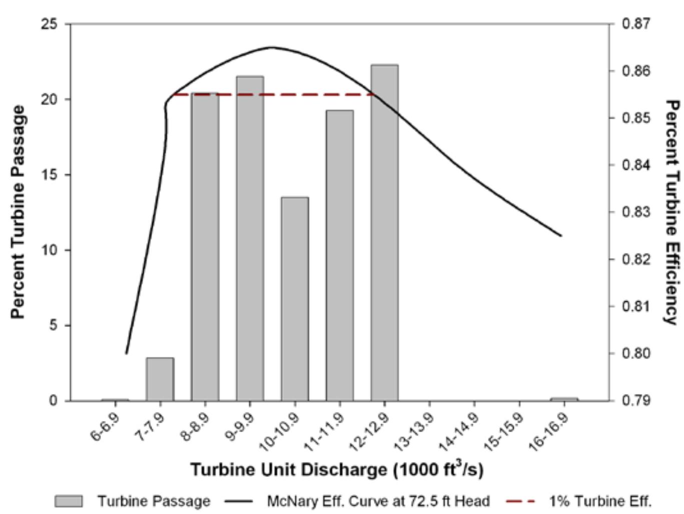

Figure 19. Graph showing turbine unit discharges during subyearling Chinook salmon passage (bars) and turbine efficiency (solid line) from data used in studies at McNary Dam in 2004–2009. The discharges bounded by the dashed line are within 1 percent of the peak turbine efficiency at a head of 72.5 feet.

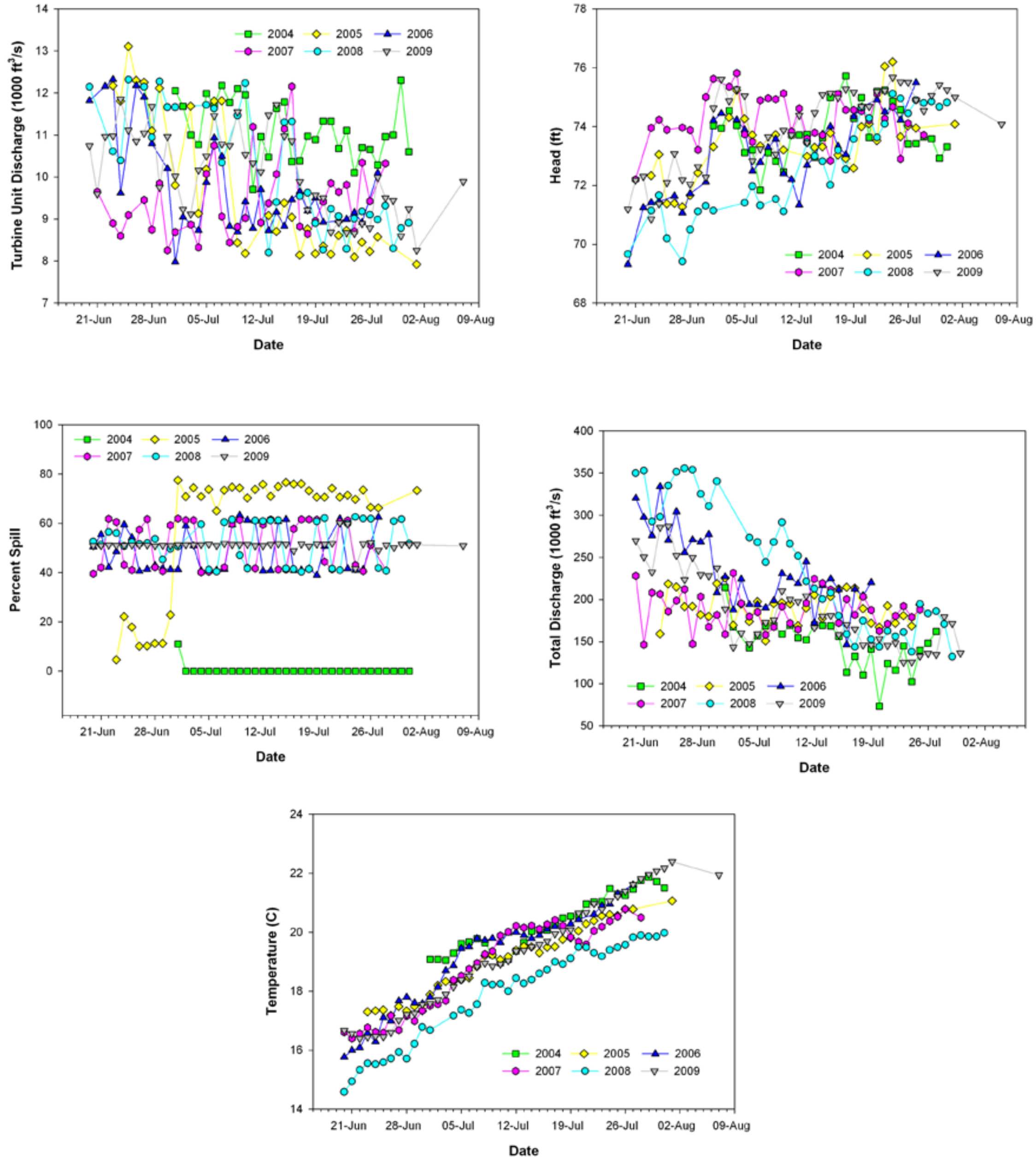

Figure 20. Graph showing daily-averaged covariate values for subyearling Chinook salmon from data used in studies at McNary Dam in 2004–2009.

Overall fish passage was similar among most turbine units, but annual differences existed. In 2004, one of the years with the largest sample sizes, most passage was through units 2–10 (fig. 21). In 2009, the pattern was nearly the opposite, with most passage occurring through units 9–14. Passage in 2005 followed a pattern similar to 2004, but the sample size was smaller. Unit-specific passage assignments were not made during the studies from 2006–2008.

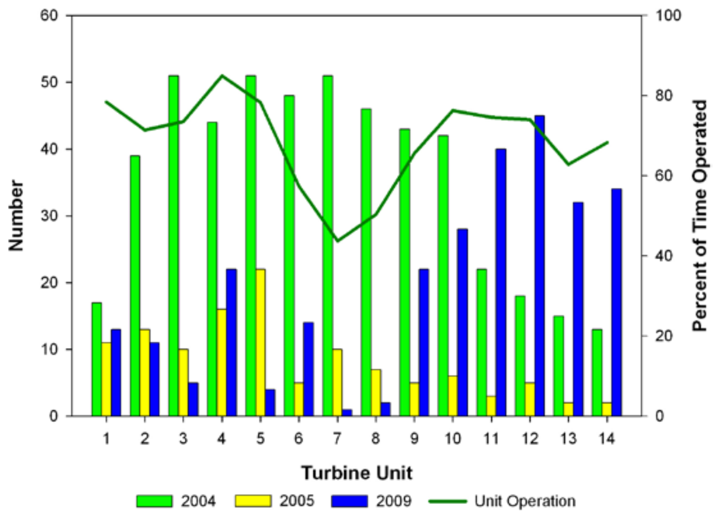

Figure 21. Graph showing number of subyearling Chinook salmon passing through each turbine by year (bars) and overall (line) from data used in studies at McNary Dam in 2004, 2005, and 2009. Unit-specific passage assignments were not made as part of the studies in 2006–2008.

Survival

As in analyses of yearling Chinook salmon and juvenile steelhead at McNary **Dam, two separate analyses of data from subyearling Chinook salmon were performed** due to the inconsistent resolution of the turbine unit of passage. Data from 2004, 2005, and 2009, years with unit-specific passage assignments, were analyzed first followed by analyses based on the complete data set from 2004–2009.

The analyses using years with unit-specific passage assignments were based on 890 fish in the turbine group and 2,998 fish in the control group. The turbine group in 2004 contained 2–4 times as many fish as the turbine groups in 2005 and 2009, and the control group in 2004 contained fewer fish than the other years (appendix W). Pearson correlation coefficients for fish weight and tag burden and total discharge and head ranged from |0.47| to |0.71| (appendix Y). Analyses of multicollinearity did not indicate any serious dependencies. As in previous analyses, we applied head only to the turbine group and total discharge to the control group. Tag burden was also treated in a similar to the other analyses, with post-hoc replacement with fish weight if an effect of tag burden was supported by the data.

A multiplicative recapture probability model of group and reach was supported by the data and used in all comparisons among survival models. This model received essentially 100 percent of the AICc weight, indicating it was the only model supported among those considered (model 1 in appendix Z).

Four of the covariates examined were supported by the data and models as determinants of survival for the turbine group. These included tag burden, spill percentage, turbine passage location, and water temperature (appendixes AA and AB). Models with a linear or quadratic effect of head (models 13 and 14b) had AICc values 5 and 6 units greater than the model having no head effect (model 14a) indicating no support for these models. Similarly, models with linear or quadratic effects of turbine unit discharge (models 14a and 15b) had AICc values 2 and 3 units greater than the model without turbine unit discharge (model 15a). Because an effect of turbine unit discharge on survival was not supported, further analyses were based on the complete 2004–2009 data set.

The analyses of factors affecting survival for all years (2004–2009) were based on 1,912 fish in the turbine group and 6,547 in the control group (appendix AC). Numbers of fish in the turbine groups ranged from 117 to 500 fish among years, whereas annual control fish numbers ranged from 763 to 1,191. No control fish were released at night in 2006 or 2008.

Correlation analyses indicate that several variables were moderately related. Pearson correlation coefficients ranged from |0.63| to |0.72| for fish weight and tag burden and was |0.69| for total discharge and head (tables 20 and 21). The correlation coefficient for total discharge and water temperature was |0.69|. We applied the head covariate only to the turbine group and total discharge only to the control group. Tag burden was applied to turbine and control groups. As in analyses of yearling Chinook salmon at McNary Dam, specific turbine unit passage location used in the reduced data set was replaced by a north or south passage location for all years, because that was the only resolution common to all years.

A multiplicative recapture probability model of group and reach was supported by the data and used in all comparisons among survival models. This model received greater than 99.9 percent of the AICc weight, indicating that it was the only model supported among those considered (model 1 in appendix AD). Recapture probabilities at the first downriver site ranged from 0.345 (SE 0.095) to 0.996 (SE 0.004) and averaged 0.779. The λ parameter ranged from 0.573 (SE 0.043) to 0.953 (SE 0.045) and averaged 0.796. Survival effects of spill percentage and water temperature were the only individual covariates supported by the data and models (table 22). Operational covariates other than spill percentage contributed little to the fit of the survival models. The linear and quadratic models of head (model 13 and 14b) had AICc values 1.8 and 3.8 greater than the model with no head effect (model 14a) indicating no support for this covariate. Turbine unit discharge was also not supported; with linear and quadratic models having AICc values 2 and 4 units greater than the model without turbine unit discharge (models 14a and 15b compared to model 15a). Among the models examined, the model containing treatment, photoperiod, year, 2-way interactions, and the individual covariates of water temperature and spill percentage were supported (model 17 in table 22).

Table 20. Table of correlation indices of data from subyearling Chinook salmon from the turbine group from data used in studies at McNary Dam in 2004–2009.

[Pearson correlation coefficients are listed above the probabilities of obtaining a greater value under the hypothesis that Rho = 0. Sample size is 1,912; <, less than; see table 2 for variable name definitions]

	TOTQ	PER_SPI	HEAD	TUQ	UNITLOC	PHOTO	TEMP	WEIGHT	TAG BURDEN
TOTQ	1.0000	0.4719	-0.6881	0.3034	-0.1285	-0.3848	-0.6972	-0.2939	0.0607
		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0079
PER_SPI		1.0000	-0.0623	-0.3898	-0.1087	-0.0955	-0.3069	-0.2425	-0.2020
			0.0065	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
HEAD			1.0000	-0.3611	0.0391	0.3604	0.5204	0.2378	-0.0674
				<0.0001	0.0877	<0.0001	<0.0001	<0.0001	0.0032
TUQ				1.0000	0.0573	-0.2433	-0.2106	0.0336	0.0740
					0.0122	<0.0001	<0.0001	0.1421	0.0012
UNITLOC					1.0000	0.0050	0.0441	0.0029	0.0129
						0.8275	0.0540	0.8979	0.5718
PHOTO						1.0000	0.2242	0.1092	-0.0255
							<0.0001	<0.0001	0.2654
TEMP							1.0000	0.3102	-0.0909
								<0.0001	<0.0001
WEIGHT								1.0000	-0.7196
									<0.0001

Table 21. Table of correlation indices of data from subyearling Chinook salmon from the control group from data used in studies at McNary Dam in 2004–2009.

[Pearson correlation coefficients are listed above the probabilities of obtaining a greater value under the hypothesis that Rho = 0. Sample size is 6,547; <, less than; see table 2 for variable name definitions]

	TOTQ	PER_SPI	PHOTO	TEMP	WEIGHT	TAG BURDEN
TOTQ	1.0000	0.2798	-0.2329	-0.6861	-0.2086	0.1625
		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
PER_SPI		1.0000	-0.0436	-0.1374	-0.2374	-0.2019
			0.0004	<0.0001	<0.0001	<0.0001
PHOTO			1.0000	0.1202	0.0094	-0.1284
				<0.0001	0.4493	<0.0001
TEMP				1.0000	0.2608	-0.2156
					<0.0001	<0.0001
WEIGHT					1.0000	-0.6296
						<0.0001

A negative effect of water temperature was moderately supported for fish in turbine and control groups and a negative effect of spill percentage was weakly supported for fish in the turbine group. A negative effect of water temperature on survival was supported for all years except for 2005 in which the effect was positive (table 23, fig. 22). The model slopes generally indicate a greater temperature effect on the turbine group than the control group. Survival estimates of the control group were higher than for the turbine group, as expected. Spill percentage had a negative effect on survival of the turbine group in all years (fig. 23). The effect of photoperiod varied among years, with some years having higher survival during the day than at night, and other years with the opposite trend.

Key Findings in Data from Subyearling Chinook Salmon at McNary Dam

- Initial analyses were based on a subset of the data because turbine unit-specific passage location was not available in all years. Unit-specific discharge was not supported as a factor on survival in these data (from 2004, 2005, and 2009), so inferences were based on the full 2004–2009 data set and a “north-south” assignment for unit passage location.
- The full data set included 1,912 fish in the turbine group and 6,547 fish in the control group.
- Most data were collected at turbine discharges within 1 percent of peak unit efficiency.
- A negative effect of spill percentage was weakly supported as a factor affecting turbine passage survival.
- An effect of water temperature on survival was moderately supported. The effect was positive in 2005 and negative in all other years.
- An effect of tag burden on survival was not supported.

Table 22. Model-selection results from radio- and acoustic-tagged subyearling Chinook salmon from data used in studies at McNary Dam in 2004–2009.

[Presence of a factor in a model is indicated by an 'x' in the column for that factor. Model 1 was a global model including all group covariates and their interactions (g) as well as all individual covariates and interactions listed. All models shared a common g*reach model of recapture probability. K indicates the number of parameters. An asterisk after the model number indicates the best-supported model of the suite]

									Individual covariates																					
	Group covariates								Biological							Operational									Model selection results		
Model No.	g	trt	yr	photo	trt*yr	trt*photo	yr*photo	trt*yr*photo	gated	tagb	trt*tagb	yr*tagb	temp	trt*temp	yr*temp	persp	trt*persp	head linear	head quadratic	turq linear	turq quadratic	turloc	turloc*photo	totq	AICc	K	Deviance
1	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x		x		x	x	x	17789.84	85	17618.8
2	x	x	x	x	x	x	x	x		x	x		x	x	x	x	x	x		x		x	x	x	17765.37	80	17604.4
3	x	x	x	x	x	x	x	x		x	x		x	x		x	x	x		x		x	x	x	17789.25	75	17638.4
4a		x		x		x			x	x	x		x	x	x	x	x	x		x		x	x	x	17803.94	65	17673.3
4b		x	x	x	x	x	x			x	x		x	x	x	x	x	x		x		x	x	x	17763.18	77	17608.3
4c		x	x	x	x	x				x	x		x	x	x	x	x	x		x		x	x	x	17777.38	72	17632.6
4d		x	x	x		x	x			x	x		x	x	x	x	x	x		x		x	x	x	17760.67	72	17615.9
5		x	x	x		x	x			x	x		x	x	x	x	x	x		x		x		x	17759.29	71	17616.6
6		x	x	x			x			x	x		x	x	x	x	x	x		x		x		x	17758.88	70	17618.2
7		x	x	x			x			x	x		x		x	x	x	x		x		x		x	17757.15	69	17618.5
8		x	x				x			x	x		x		x	x	x	x		x		x		x	17761.43	68	17624.8
9		x	x	x			x			x	x				x	x	x	x		x		x		x	17759.84	68	17623.2
10		x	x	x			x			x	x		x		x	x		x		x		x		x	17757.46	68	17620.8
11		x	x	x			x			x	x		x		x	x	x	x		x		x			17755.38	68	17618.7
12		x	x	x			x			x	x		x		x		x	x		x		x			17753.49	67	17618.8
13		x	x	x			x			x	x		x		x		x	x		x					17751.55	66	17618.9
14a		x	x	x			x			x	x		x		x		x			x					17749.70	65	17619.1
14b		x	x	x			x			x	x		x		x		x		x	x					17753.57	67	17618.9
15a		x	x	x			x			x	x		x		x		x								17747.73	64	17619.1
15b		x	x	x			x			x	x		x		x		x				x				17751.71	66	17619.1
16		x	x	x			x			x			x		x		x								17747.29	63	17620.7
17*		x	x	x			x						x		x		x								17746.75	62	17622.2

Table 23. Beta (slope) coefficients of estimable survival parameters of subyearling Chinook salmon from data used in studies at McNary Dam in 2004–2009.

[The data are from model 17 in table 22]

Parameter	Beta	Standard error	95 percent confidence	
			Lower	Upper
intercept	6.46134	1.91771	2.70263	10.22004
treatment	-0.92842	0.15768	-1.23748	-0.61937
photo	-0.51201	0.18596	-0.87649	-0.14753
2005	-7.14920	2.69855	-12.43835	-1.86005
2006	4.65938	2.39320	-0.03129	9.35005
2007	1.45289	2.74781	-3.93282	6.83860
2008	3.43575	2.41183	-1.29143	8.16293
2009	6.13040	2.23710	1.74567	10.51512
photo*2005	0.68992	0.31715	0.06831	1.31153
photo*2006	0.67572	0.31164	0.06490	1.28654
photo*2007	-0.41557	0.33937	-1.08073	0.24960
photo*2008	1.30430	0.39638	0.52739	2.08120
photo*2009	0.28627	0.25838	-0.22015	0.79269
persp*treatment	-0.00756	0.00353	-0.01448	-0.00063
temp	-0.22686	0.09441	-0.41191	-0.04181
temp*2005	0.37577	0.13996	0.10145	0.65008
temp*2006	-0.23237	0.12016	-0.46789	0.00315
temp*2007	-0.05709	0.13775	-0.32707	0.21289
temp*2008	-0.19011	0.12272	-0.43064	0.05043
temp*2009	-0.29683	0.11036	-0.51313	-0.08053

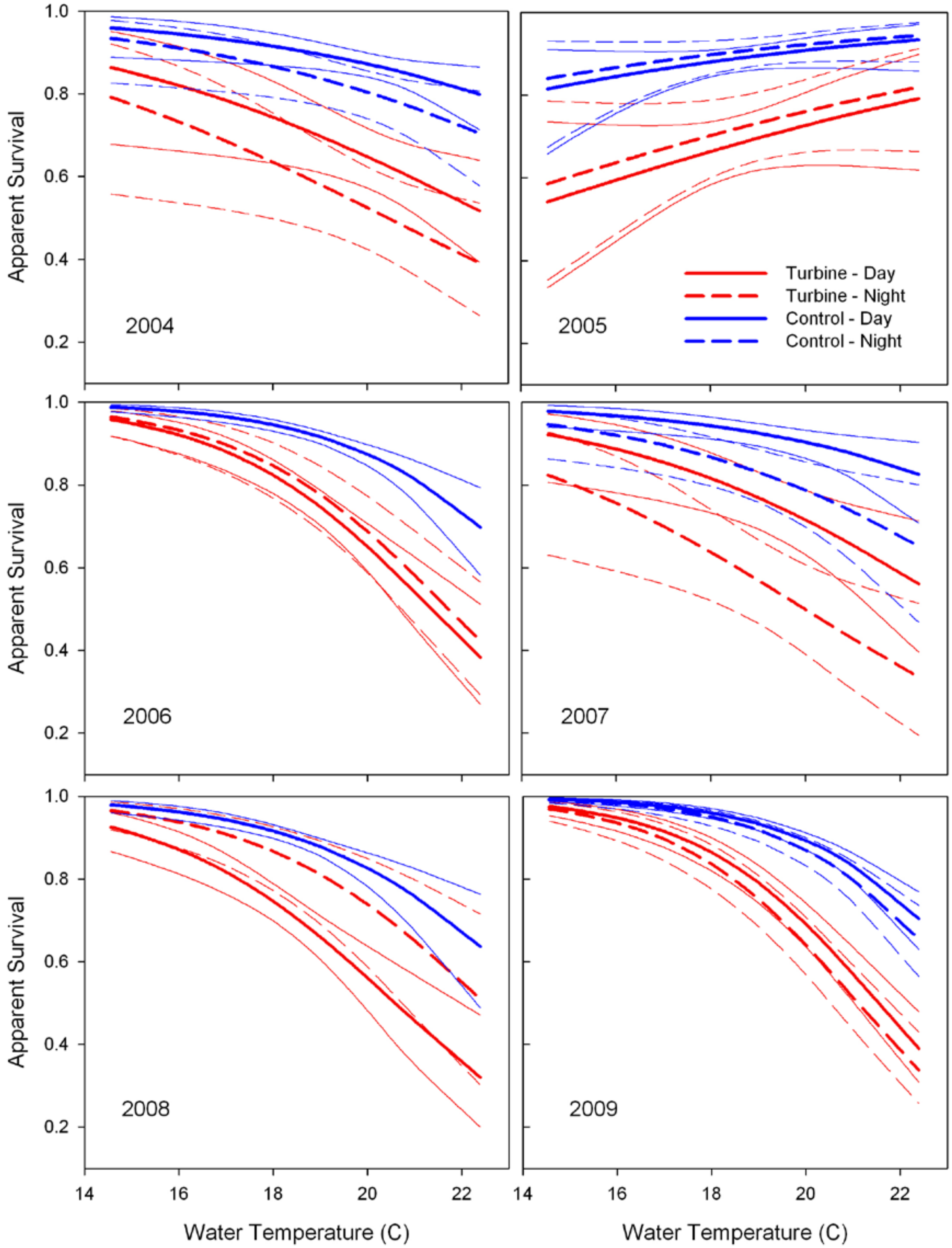

Figure 22. Graph showing estimated effects of water temperature on apparent survival of subyearling Chinook salmon from data used in studies at McNary Dam in 2004–2009. Predictions (thick lines) and 95 percent confidence intervals (thin lines) from model 17 in table 22 are plotted.

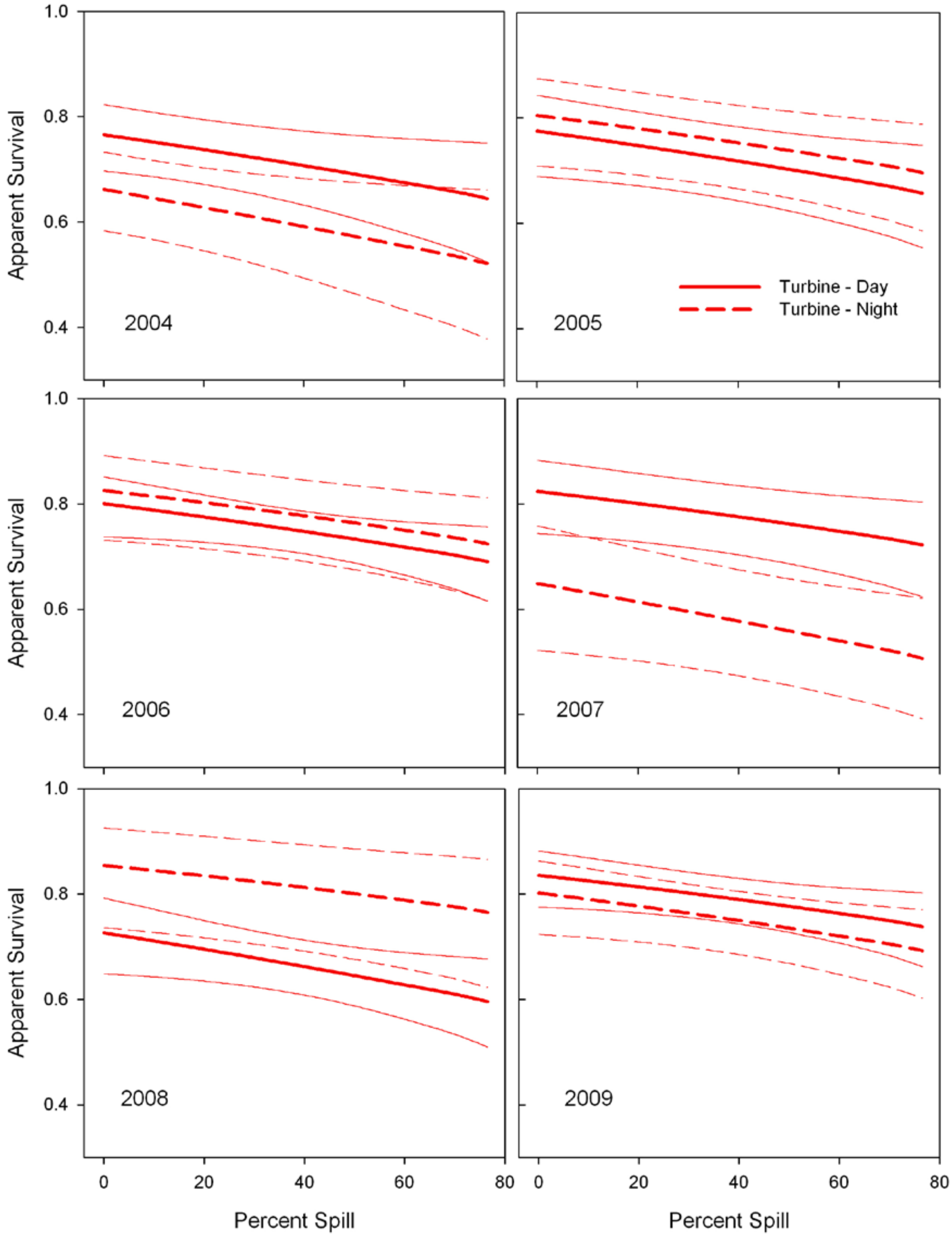

Figure 23. Graph showing estimated effects of spill percentage on apparent survival of subyearling Chinook salmon from data used in studies at McNary Dam in 2004–2009. Predictions (thick lines) and 95 percent confidence intervals (thin lines) from model 17 in table 22 are plotted.

Discussion

Results of our analyses indicate the survival of tagged fish passing turbines was primarily affected by factors unrelated to turbine operation. Effects of water temperature were supported in four of the five data sets and were strongly supported in all but one. Tag burden was strongly supported in data from yearling Chinook salmon, but not in data from subyearling Chinook salmon or juvenile steelhead. Spill percentage, head, and turbine unit discharge received weak or moderate support in some cases. These findings are similar to results from several other studies of juvenile salmonids passing through turbines in the Columbia River Basin. Studies of turbine passage in the Columbia River Basin have most commonly been controlled field experiments based on fish fitted with balloon tags (Heisey and others, 1992). These studies generally find small and often statistically insignificant differences among fish survival at different turbine unit discharges, yet some show small, but statistically significant differences.

Our results are similar to those of Ferguson and others (2006), who reported estimates of survival of turbine-passed fish from concurrent studies of controlled turbine unit discharges based on radio telemetry and balloon tags at McNary Dam. They reported that both methods found small, statistically insignificant, differences between survival of juvenile salmonids passing turbine unit 9 operated at discharges of 11.2 thousand ft^3/s and 16.4 thousand ft^3/s. Results based on balloon tags, which incorporate primarily direct mortality sources, were 0.930 (SE 0.021) at the lower discharge and 0.946 (SE 0.019) at the higher discharge. Examples of direct mortality sources from turbine passage include strike, shear, and barotrauma (Cada, 2001). Estimates of survival based on the radio-telemetry method, incorporating direct and indirect mortality sources from turbine passage to the release point of a control group of fish 2 km downstream, were 0.871 (SE 0.016) and 0.856 (SE 0.011) at the lower and higher discharge levels, respectively. Examples of indirect, or delayed, mortality include predation on dead, moribund, or healthy fish (Mesa and others, 1994). Predaceous fish pose a significant source of mortality of juvenile salmonids in the Columbia River Basin (Rieman and others, 1991; Ward and others 1995). Faler and others (1988) determined that northern pikeminnow (*Ptychocheilus oregonensis*) were opportunistic predators in the tailrace of McNary Dam, moving quickly into near-dam areas as dam operations changed. Avian predators are also important predators (Ryan and others, 2001). Ferguson and others (2006) suggested that delayed mortality comprised 46–70 percent of the total estimated juvenile salmon mortality from turbine passage at McNary Dam. Our methods are similar to those of Ferguson and others (2006) in that we used data from studies incorporating direct and indirect sources of mortality, but differ from their methods by not controlling turbine discharges. The methods also differ analytically: we examined what may be considered observational data for specific trends, such as linear or quadratic fits, and Ferguson and others (2006) estimated survival at specific operating points from a controlled experiment.

Our finding of infrequent support for the turbine operation factors on survival is consistent with results of most controlled experiments. Evaluations of specific turbine discharges often find a numerical optimum in terms of fish survival, but the ranges in survival across test discharges are small and generally not statistically different. For example, Normandeau Associates and others (2003) estimated direct survival of balloon-tagged fish released into turbine intakes at McNary Dam and found no significant differences among estimates of survival of fish when the turbine was operated at four discrete levels from 8.0 to 16.4 thousand ft^3/s, with survival estimates ranging from 0.930 to 0.983. Similar results were found at other Columbia and Snake River dams (Mathur and others, 2000; Skalski and others, 2002a; Normandeau Associates and others, 2008a, 2008b). Additionally, the ranges of survival in these controlled studies are small. In four studies at Columbia or Snake River dams, Skalski and others (2002a) determined that estimates of fish survival generally differed by less than 5 percent over the range of unit discharges tested. In our analyses, a quadratic model of turbine unit discharge was weakly supported for subyearling Chinook salmon passing turbines at John Day Dam, but linear or quadratic effects were not supported for any other group. The effect size from lowest to highest survival from the relation at John Day Dam over the range of turbine discharges we examined was 11.2 to 13.9 percent (that is, a difference in survival probabilities of 0.112–0.139) for fish passing during the day and 20.5–24.5 percent for those passing at night. We estimated the peak survival of subyearling Chinook salmon at John Day Dam occurred at a turbine discharge of 15.9 thousand ft^3/s, but the 95 percent confidence interval ranged from -1.7 to 33.7 thousand ft^3/s, indicating the estimate was imprecise. This may be due to the broad range of turbine discharges within 1 percent of peak unit efficiency at John Day Dam.

Results from this study likely will be compared to the studies of turbine survival based on balloon tags, but the methods used in studies we examined differ from balloon tag studies in five primary ways. First, the fish used in this work were released into the Columbia River about 10–20 km upstream from the dams and are assumed to be depth-acclimated by the time they reach the dam. That depth, assumed to be the depth of neutral buoyancy, is not known, but Beeman and Maule (2006) estimated mean in-situ migration depths of radio-tagged juvenile Chinook salmon to be 3.2 m and juvenile steelhead to be 2.3 m in McNary Reservoir slightly upstream from McNary Dam. The fish used in studies based on balloon tags are acclimated to near-surface depths, because they are removed directly from a shallow tank, fitted with the balloon and other tags, and released into a hose leading to the turbine intake or runner. Brown and others (2009) and Carlson and others (2010) determined that in controlled laboratory conditions simulating pressure changes that may occur during turbine passage that the depth of acclimation (that is, neutral buoyancy) was an important factor in subsequent signs of mortal injury. They determined that signs of mortal injury increased with acclimation depth, suggesting that data from studies using balloon-tags will underestimate passage mortality and the data we examined would be more representative of run-of-river fish.

Second, the data we examined were based on fish volitionally entering turbine intakes and data from balloon tag studies were based on fish passed into turbine intakes or runners through hoses. This is an important distinction, because the elevation of entry into a turbine intake may affect area of turbine passage and fish survival. Normandeau Associates and others (1996) as reported in Skalski and others (2002a) detected significantly different survival of fish from releases made at different depths within the turbine intakes at Wanapum Dam on the Columbia River. Conversely, Mathur and others (1996, 2000) detected no statistically significant difference in survivals when releasing fish into turbine intakes at different elevations at other dams. Thus, interpretations of results from studies based on fish released through hoses may be affected by potential differences between fish release locations and location of passage of the untagged population. The vertical distribution of fish volitionally entering turbines is not known, but is likely different from the distribution of fish released from a hose. The availability of data from fish volitionally entering turbine intakes was one of the reasons our analyses were conducted.

Third, mortality in studies based on balloon tags only address direct effects and our analyses included direct and indirect effects. By recapturing fish floated to the surface shortly after turbine passage, studies using balloon tags do not generally incorporate indirect effects of turbine passage, such as predation by fishes or birds. The estimates of survival in our analyses therefore are expected to be lower than those of studies based on balloon tags, which is consistent with our results. Ferguson and others (2006) also detected lower survival in groups incorporating direct and indirect sources of mortality compared to those from a balloon tag study at McNary Dam. The inclusion of indirect effects may dilute the effects of turbine discharge sometimes found in controlled studies of direct survival.

Fourth, studies based on balloon tags are carefully designed and controlled studies of turbine unit discharge, whereas turbine unit discharges were not controlled during collection of the data we used. The data we used were collected during studies controlling structures or operations at the spillway rather than at the powerhouse and were collected primarily during operation within one percent of the peak turbine efficiency (the "1 percent" rule). The ramifications of reliance on data collected predominantly within the 1 percent rule vary depending on the efficiency curve of the turbines being studied. For example, at John Day Dam the generator limit (21.3 thousand ft^3/s at a head of 102 ft) is near the upper end of the 1 percent rule (21.6 thousand ft^3/s at a head of 102 ft), but at McNary Dam considerable operational range exists between the upper end of the 1 percent rule (12.4 thousand ft^3/s at a head of 73 ft) and the generator limit (16.2 thousand ft^3/s at ahead of 73 ft). The uncontrolled nature of the turbine discharges represents an important difference between the studies, and was one reason we selected the information-theoretic method of analysis.

Fifth, our results are based on fish carrying transmitters internally and the balloon-tag studies are based on fish carrying balloon tags and transmitters externally. There is evidence from this study and others that the method of tag attachment (internal or external) is likely to affect the effect of tag burden on survival of fish passing turbines due to the mechanism of injury from barotrauma. A common cause of injury in juvenile salmonids exposed to rapid decompression, such as that during turbine passage, is from the expansion of the swim bladder and gas-laden tissues causing trauma to the swim bladder and internal organs (Brown and others, 2009). This is exacerbated as the volume of the swim bladder prior to exposure increases and as the space it can expand into decreases. Swim bladder volume increases with acclimation depth and tag burden, regardless of tag attachment method, so this effect is similar in both study types with similar tag burdens. However, the space the swim bladder can expand into is reduced by the use of internal placement of transmitters and is different in studies of balloon tags (external attachment) and the data we examined (internal attachment). Brown and others (2009) found this to be true for transmitters placed internally with either gastric or surgical methods, both of which are present in the data we examined. This suggests that the turbine-passage survival of fish with internal transmitters will be lower than fish with external transmitters, which is consistent with empirical data (for example Ferguson and others, 2006). These results support the commonly-held hypothesis that one of the differences between results of balloon tag studies and active-tag studies of dam-passage survival is the inclusion of indirect sources of mortality in results from active-tag studies, but indicates that some part of what has been called "indirect mortality" actually may be direct plus indirect mortality caused by the method of tag attachment. Our analyses support this premise for yearling Chinook salmon at McNary Dam and potentially at John Day Dam.

We used information-theoretic methods to determine which factors produced effects supported by the data rather than statistical null-hypothesis testing with strict "significance" cutoffs. We created models representing a priori hypotheses and used information-theoretic methods to determine the strength of evidence from the data, given the models, to determine which factors were supported as affecting survival of tagged fish passing turbines. Our analyses were not based on controlled experiments manipulating the operational factors while controlling for others and thus frequentist statistics were not appropriate (Burnham and Anderson, 2002). There is no strict cutoff of importance in information-theoretic methods, which is one of the reasons we selected the method. Rather, differences in AICc (or other measures of parsimony) represent a continuous scale of the support of models (hypotheses) by the data. Our use of this method was more dichotomous than in some applications, and might be considered akin to a series of stepwise comparisons. However, the factors considered and the order of model comparisons were determined a priori through consultation of experts in turbine design and operation, fishery management, and fishery research, and thus our use was consistent with the information-theoretic approach. Our goal in this study was to determine if the selected factors were supported as having effects on survival, which is not logically a "yes" or "no" question.

We did not estimate overdispersion, but varying the overdispersion parameter ($\hat{c}$) did not appreciably alter the primary conclusions from the analyses. Mark-recapture data are based on theoretical models assuming subjects behave as individuals rather than as groups. An estimate of $\hat{c}$ is 1 if individuals behave independently, 2 if they behave as pairs (for example, breeding pairs of Canada geese), 3 if they behave as triplets, and so on. A $\hat{c}$ of 3 would be considered high (Burnham and Anderson, 2002). Estimates of $\hat{c}$ are generally based on some form of deviance divided by the degrees of freedom and a chi-square goodness of fit test based on groups of individuals with like capture histories. However, in the presence of individual covariates, the typical analyses are not possible, because all individuals can be uniquely identified, and thus there are no groups. Pollock (2002) and White (2002) discuss this problem and suggest the estimation of $\hat{c}$ in the presence of individual covariates as a topic requiring further research. We selected the approach used by Devries and others (2003), and examined the effects on the study conclusions over hypothetical $\hat{c}$ values of 1 and 3. An adjustment to the AICc and parameter variances favoring models with fewer parameters is made when $\hat{c}$ is greater than 1. This adjustment can affect interpretation of the support for modeled hypotheses, so is usually of primary importance. The primary conclusions from analyses of data from John Day Dam remained similar at $\hat{c}$ values of 1 and 3, although the level of support was reduced at the higher value. For example, the change in AICc when removing the strongly supported tag burden effect in the yearling Chinook salmon analyses was -18.3 when $\hat{c}$ was 1 and -14.9 when it was 3. However, the delta AICc of the weakly supported quadratic effect of turbine unit discharge in the subyearling Chinook salmon analyses was -1.3 when $\hat{c}$ was set to 1 and +2.2 when it was 3, changing the conclusion from weakly supported to not supported (recall the quadratic effect requires two parameters, so a delta AICc of 2–4 would be required to indicate no support). The primary conclusions from McNary Dam were also changed only slightly at a $\hat{c}$ value of 3. The most supported conclusion, that tag burden affected survival of yearling Chinook salmon, was unchanged. Increasing $\hat{c}$ to 3 reduced or removed support for factors that were weakly or moderately supported in the original analyses, such as year, photoperiod, spill percentage, and head.

Our results suggest tag burden is an important factor affecting survival of yearling Chinook salmon at John Day and McNary dams. Data from John Day Dam strongly supported an effect of tag burden on control fish and data from McNary Dam strongly supported an effect on control and turbine fish. The lack of support for an effect on yearling Chinook salmon turbine fish at John Day Dam may be from the sparseness of the data: there were 246 turbine fish and 2,973 control fish in the data set from John Day Dam and 1,419 turbine fish and 6,737 control fish at McNary Dam. The simulated effect on control fish was similar between dams and was much less than the simulated effect on turbine fish at McNary Dam.

We detected little evidence to suggest tag burden affects survival of turbine passing juvenile steelhead or subyearling Chinook salmon. Effects of tag burden on turbine passage survival of juvenile steelhead and subyearling Chinook salmon at McNary Dam received weak to moderate support in analyses of the restricted set of years from McNary Dam (2004, 2005, and 2009), indicating some evidence for an effect, but when the entire 2004–2009 data set was examined an effect of tag burden was not supported in these groups. The effect may be initially expected to be greatest in subyearling Chinook salmon, because they are physically smaller than the other fish studied, but the tag burden was similar in yearling and subyearling Chinook salmon due to different tags sizes used in each group. Therefore, there is no basis for a greater effect in subyearling Chinook salmon based on differences in tag burden. However, Brown and others (2009) reported more frequent mortality and signs of injury in radio-tagged subyearling Chinook salmon than in yearling Chinook salmon after simulated turbine passage and suggested the difference was due to the differences in fish sizes. Perhaps the lower turbine-passage survival of subyearling Chinook is primarily due to factors apart from tag burden, such as the effects of fish size and barotrauma described by Brown and others (2009) or other environmental factors. As in data we examined, tag burdens in the yearling and subyearling Chinook salmon groups studied by Brown and others (2009) were similar because different size tags were used in the two groups. A lack of support for the tag burden effect in juvenile steelhead might be expected, because their large size relative to the Chinook salmon resulted in a lower tag burden (median 1.89 percent) than the other groups (median 4.35 percent or greater). Turbine passage survival could also vary due to differences in the pressures along the paths different species or races of fish take as they pass through turbines.

The negative effects of tag burden supported in our analyses are generally consistent with those of the laboratory experiments of Brown and others (2009) and Carlson and others (2010). However, Carlson and others (2010) likely overestimated the effect of tag burden when using data from field-based studies to illustrate the potential effect of tag burden on survival. The source of mortality in their laboratory study of simulated turbine passage was barotrauma. However, the mortality of turbine-passing fish in field studies includes mortality from barotrauma, strike, shear, and other direct effects of turbine passage as well as indirect effects of turbine passage affecting predation after passage. Thus, one cannot use survival estimates from field studies of turbine-passing fish to correctly back-calculate the likely pressure history during turbine passage using results of Carlson and others (2010) without separating the mortality from barotrauma and mortality from other causes. Failing to do so overestimates the log ratio of pressure change during turbine passage described by Carlson and others (2010), which will then overestimate the mortality of tagged fish relative to untagged fish. The bias in using data from field studies of turbine passage to illustrate the effects of tag burden from the laboratory experiments of Carlson and others (2010) increases with tag burden. The proportion of turbine-passage mortality that may be attributed to sources other than barotrauma following passage is likely to be an important component of the total mortality. Petersen (1994) and Ward and others (1995) found that much of the reservoir-wide predation of juvenile salmonids by predaceous fishes occurs in the relatively small spatial area near hydro dams, and predation by avian predators is also high in these areas.

We were not able to separate effects of tag burden and fish weight using the data available. Tag burden and fish weight were inextricably confounded in our analyses, preventing us from determining their independent effects. Replacing tag burden with fish weight in models of yearling Chinook salmon at John Day and McNary dams resulted in ambiguous results, suggesting weight was the more supported factor in one case and tag burden was the more supported factor in the other. However, results from the controlled laboratory experiments of Carlson and others (2010), indicated fish weight was not an important contributor to the fit of models describing an index of mortal injury, lending support to tag burden as the causative factor in our analyses.

Additional controlled field experiments of factors affecting juvenile salmonid are needed to assess turbine survival. We feel most studies have been too narrowly focused to add substantially to the knowledge base on the subject. For example, most studies have examined turbine passage survival relative to the 1 percent rule and thus often only have three turbine discharge levels in their design (see Skalski and others [2002a] for a description of four studies). These studies aid the quest for information about survival relative to the 1 percent rule, but do little to answer what we see as the larger question, which is whether there is a reproducible pattern between turbine discharge and survival. We suggest future studies be designed with at least four discharge levels spanning the entire operating range of turbine discharge and that the results be examined relative to a priori hypotheses such as linear or curvilinear patterns, rather than tests of statistical significance among operating points. The study conducted by Normandeau and Associates and others (2008a) exemplifies this approach. They estimated survival at each of five turbine discharge levels at Ice Harbor Dam on the Snake River. They concluded no statistical difference existed in survival among the five levels (although the data from the peak discharge was not used in the analysis due to a single test condition), but there was a clear curvilinear relation with a maximum at the intermediate discharge level. Their effect sizes were insufficient to result in statistically significant differences in survival, but a quadratic model provided a good fit to the relation between survival and discharge. Further studies of this type, despite being conducted using surface acclimated fish released through hoses, could be used to determine if there is a consistent relation between survival and turbine operation within turbine families (turbines of similar design) or at different dams. This level of information is needed if turbines are to be operated to achieve the greatest fish survival, as Skalski and others (2002a) recommend.

In summary, our results indicate that few operational covariates were supported as factors affecting turbine passage survival of juvenile salmonids at McNary or John Day dams. Support for linear or quadratic effects of head or turbine unit discharge was not common. Potential reasons the operational factors were generally not supported include the uncontrolled nature of the experiments and the small effect sizes common to even carefully controlled experiments of turbine discharge. Tag burden and water temperature were well-supported factors affecting the survival of juvenile salmonids passing turbines at these dams, and generally corroborate results of other field and laboratory studies. The results suggest tag burden should be minimized in studies of turbine passage, or that factor should be included as an explanatory variable in analyses. Additionally, effects of water temperature on survival were supported in several analyses suggesting it should be considered in designs or analyses of studies. The design of existing turbines at McNary Dam is unique to the Columbia River Basin, but those at John Day are similar to turbines at three of the four lower Snake River dams (Wittinger and others, 2010). This study identified several factors affecting the survival of fish passing turbines, but it is the only study we know of that examined data from tagged fish volitionally passing through turbines for this purpose. It may be prudent to examine similar data from past studies at other FCRPS dams to corroborate these results.

Acknowledgments

This work was made possible by a suite of people and organizations responsible for the design, conduct, reporting, and funding of the studies that collected the data we used in analyses. These include staff at the U.S. Geological Survey (USGS), Western Fisheries Research Center office in Cook, Washington, National Oceanic and Atmospheric Administration (NOAA), Northwest Fisheries Science Center office in Pasco, Washington, and the U.S. Army Corps of Engineers, Portland District located in Portland, Oregon, and Walla Walla District located in Walla Walla, Washington. The contracts for this study were overseen by Michael Langeslay, George Medina, and Dennis Schwartz of the Portland District U.S. Army Corps of Engineers. Gordon Axel of NOAA Fisheries and Amy Braatz, Scott Brewer, Scott Evans, Gabriel Hansen of USGS, and Christopher Walker, formerly of USGS, assisted with the compilation of the data sets. Jon Renholds with the Walla Walla District Corps of Engineers provided much of the operations data. Reviews by Paul Heisey, Toby Kock, and staff of the U.S. Army Corps of Engineers improved the document. This work was completed under contract numbers W66QKZ00712046 and W66QKZ00712056.

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Appendix A. Summaries of Covariate Values from Data used in Studies of Yearling Chinook Salmon at John Day Dam in 2002 and 2003.

Table A1 — Summary statistics of turbine unit discharge (thousand ft3/s) during yearling Chinook salmon passage from data used in studies at John Day Dam in 2002 and 2003.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2002	120	11.90	22.10	15.33	15.00	2.33	0.21
	2003	126	11.40	22.20	15.48	15.10	2.86	0.25
	Overall	246	11.40	22.20	15.41	15.05	2.61	0.17
Day	2002	46	12.30	22.10	16.66	15.85	2.73	0.40
	2003	59	11.50	22.20	17.52	17.00	2.70	0.35
Night	2002	74	11.90	18.30	14.51	14.60	1.57	0.18
	2003	67	11.40	17.30	13.69	13.30	1.44	0.18

Table A2 — Summary statistics of head (feet) at John Day Dam during yearling Chinook salmon passage from data used in studies at John Day Dam in 2002 and 2003.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2002	120	98.00	104.10	101.61	101.60	1.19	0.11
	2003	126	97.00	104.49	101.27	101.53	1.64	0.15
	Overall	246	97.00	104.49	101.44	101.57	1.44	0.09
Day	2002	46	98.00	103.50	101.32	101.50	1.31	0.19
	2003	59	97.00	102.61	100.34	100.50	1.53	0.20
Night	2002	74	99.50	104.10	101.79	101.80	1.08	0.13
	2003	67	99.11	104.49	102.09	102.12	1.26	0.15

Table A3 — Summary statistics of total project discharge (thousand ft^3/s) during yearling Chinook salmon passage from data used in studies at John Day Dam in 2002 and 2003.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2002	871	150.30	318.20	226.96	228.00	38.94	1.32
	2003	2102	138.90	372.40	230.75	226.50	50.24	1.10
	Overall	2973	138.90	372.40	229.64	227.70	47.24	0.87
Day	2002	301	160.10	316.50	215.81	217.50	43.02	2.48
	2003	540	166.20	372.40	238.46	221.20	52.50	2.26
Night	2002	570	150.30	318.20	232.85	234.00	35.24	1.48
	2003	1562	138.90	344.30	228.08	226.90	49.18	1.24

Table A4 — Summary statistics of spill percentage during yearling Chinook salmon passage from data used in studies at John Day Dam in 2002 and 2003.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2002	991	0.00	61.67	33.08	30.13	19.03	0.60
	2003	2228	0.00	73.69	39.15	46.13	23.98	0.51
	Overall	3219	0.00	73.69	37.28	45.54	22.74	0.40
Day	2002	347	0.00	43.12	15.83	18.89	14.47	0.78
	2003	599	0.00	48.25	1.13	0.00	4.56	0.19
Night	2002	644	26.12	61.67	42.37	31.34	14.06	0.55
	2003	1629	43.88	73.69	53.13	54.17	7.19	0.18

Table A5 — Summary statistics of tag burden (percent) of yearling Chinook salmon from data used in studies at John Day Dam in 2002 and 2003.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

		N	Min	Max	Mean	Median	SD	SE
Overall	2002	991	1.30	8.92	4.66	4.67	1.33	0.04
	2003	2228	1.23	7.78	4.42	4.46	1.28	0.03
	Overall	3219	1.23	8.92	4.49	4.53	1.30	0.02
Day	2002	347	2.03	8.24	4.83	4.86	1.35	0.07
	2003	599	1.23	7.69	4.34	4.36	1.26	0.05
Night	2002	644	1.30	8.92	4.56	4.59	1.30	0.05
	2003	1629	1.35	7.78	4.44	4.49	1.28	0.03

Table A6 — Summary statistics of temperature during yearling Chinook salmon passage from data used in studies at John Day Dam in 2002 and 2003.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2002	991	9.70	14.30	11.88	11.80	1.38	0.04
	2003	2228	10.56	15.44	12.56	12.17	1.40	0.03
	Overall	3219	9.70	15.44	12.35	12.17	1.43	0.03
Day	2002	347	9.90	14.10	11.76	11.80	1.36	0.07
	2003	599	10.56	15.22	12.59	12.17	1.41	0.06
Night	2002	644	9.70	14.30	11.94	12.20	1.40	0.06
	2003	1629	10.61	15.44	12.55	12.17	1.40	0.03

Appendix B. Capture History Summary of Yearling Chinook Salmon from data used in studies at John Day Dam in 2002 and 2003.

[Occ. represents the Occasion number after release. R(i) represents numbers released and j=2 and 3 indicate the released number detected at each downstream site]

Group 1 control day 2002				
Occ.	R(i)	j=2	j=3	Total
1	301	208	79	287
2	208		203	203

Group 2 control day 2003				
Occ.	R(i)	j=2	j=3	Total
1	540	401	127	528
2	401		398	398

Group 3 control night 2002				
Occ.	R(i)	j=2	j=3	Total
1	570	366	174	540
2	366		349	349

Group 4 control night 2003				
Occ.	R(i)	j=2	j=3	Total
1	1562	1332	195	1527
2	1332		1304	1304

Group 5 turbine day 2002				
Occ.	R(i)	j=2	j=3	Total
1	46	31	9	40
2	31		30	30

Group 6 turbine day 2003				
Occ.	R(i)	j=2	j=3	Total
1	59	38	12	50
2	38		38	38

Group 7 turbine night 2002				
Occ.	R(i)	j=2	j=3	Total
1	74	47	19	66
2	47		46	46

Group 8 turbine night 2003				
Occ.	R(i)	j=2	j=3	Total
1	67	53	10	63
2	53		53	53

Appendix C. Model Summary from Analyses of Recapture Probabilities (p) of Yearling Chinook Salmon from data used in studies at John Day Dam in 2002 and 2003.

[Models of p include those in which values can vary in various combinations of detection site (t) and group (treatment, year, and photoperiod). A '*' indicated a multiplicative effect, a '+' indicates an additive effect, and a '.' indicates a common value fitted to all groups and reaches. A multiplicative model (g*t) of apparent survival (phi) was used in all models. K indicates the number of estimable parameters]

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	K	Deviance
{01 phi(g*t), p(g*t)}	4521.89	0.00	1.00	1.00	24	4473.67
{02 phi(g*t), p(g+t)}	4536.05	14.17	0.00	0.00	24	4487.84
{03 phi(g*t), p(g}	5069.96	548.07	0.00	0.00	24	5021.75
{04 phi(g*t), p (t)}	4639.80	117.92	0.00	0.00	17	4605.69
{05 phi(g*t), p (.)}	5178.08	656.20	0.00	0.00	17	5143.97

Appendix D. Summaries of Covariate Values of Subyearling Chinook Salmon from data used in studies at John Day Dam in 2002 and 2003.

Table D1 — Summary statistics of turbine unit discharge (thousand ft^3/s) during subyearling Chinook salmon passage from data used in studies at John Day Dam in 2002 and 2003.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2002	249	11.90	22.70	15.64	15.20	2.75	0.17
	2003	547	9.70	20.90	14.58	14.40	1.72	0.07
	Overall	796	9.70	22.70	14.91	14.70	2.15	0.08
Day	2002	115	12.00	22.70	17.13	16.50	3.04	0.28
	2003	318	9.70	20.90	15.07	15.00	1.63	0.09
Night	2002	134	11.90	18.70	14.36	13.70	1.62	0.14
	2003	229	10.70	19.80	13.89	13.50	1.59	0.11

Table D2 — Summary statistics of head (feet) during subyearling Chinook salmon passage from data used in studies at John Day Dam in 2002 and 2003.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2002	249	97.00	104.00	100.61	100.40	1.33	0.08
	2003	547	99.50	105.65	103.12	103.18	0.91	0.04
	Overall	796	97.00	105.65	102.34	102.70	1.57	0.06
Day	2002	115	97.00	103.80	100.26	100.30	1.47	0.14
	2003	318	99.50	105.31	102.89	102.91	0.93	0.05
Night	2002	134	98.30	104.00	100.92	100.90	1.13	0.10
	2003	229	100.58	105.65	103.43	103.41	0.79	0.05

Table D3 — Summary statistics of total project discharge (thousand ft^3/s) during subyearling Chinook salmon passage from data used in studies at John Day Dam in 2002 and 2003.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2002	2649	157.70	396.20	264.62	253.90	54.19	1.05
	2003	2814	89.90	237.40	153.77	152.20	33.12	0.62
	Overall	5463	89.90	396.20	207.52	194.70	71.12	0.96
Day	2002	1150	182.90	396.20	282.45	269.40	51.44	1.52
	2003	1392	89.90	230.60	157.52	156.00	36.69	0.98
Night	2002	1499	157.70	369.40	250.93	252.10	52.24	1.35
	2003	1422	90.80	237.40	150.11	146.80	28.77	0.76

Table D4 — Summary statistics of spill percentage during subyearling Chinook salmon passage from data used in studies at John Day Dam in 2002 and 2003.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2002	2898	0.00	67.93	33.18	30.36	17.51	0.33
	2003	3361	0.00	64.87	28.66	29.80	21.04	0.36
	Overall	6259	0.00	67.93	30.76	29.93	19.61	0.25
Day	2002	1265	0.00	61.21	21.13	28.54	14.54	0.41
	2003	1710	0.00	61.03	14.28	0.00	14.92	0.36
Night	2002	1633	27.28	67.93	42.52	33.08	13.45	0.33
	2003	1651	0.00	64.87	43.56	31.74	15.30	0.38

Table D5 — Summary statistics of tag burden (percent) of subyearling Chinook salmon from data used in studies at John Day Dam in 2002 and 2003.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2002	2898	1.67	7.33	5.13	5.28	0.81	0.01
	2003	3361	2.24	7.20	5.31	5.45	0.78	0.01
	Overall	6259	1.67	7.33	5.22	5.35	0.80	0.01
Day	2002	1265	1.95	7.33	5.13	5.28	0.82	0.02
	2003	1710	2.24	6.54	5.30	5.45	0.78	0.02
Night	2002	1633	1.67	6.75	5.13	5.28	0.79	0.02
	2003	1651	2.28	7.20	5.31	5.41	0.78	0.02

Table D6 — Summary statistics of temperature during subyearling Chinook salmon passage from data used in studies at John Day Dam in 2002 and 2003.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2002	2898	15.90	20.30	17.82	17.60	1.18	0.02
	2003	3361	16.33	21.61	18.74	18.44	1.43	0.02
	Overall	6259	15.90	21.61	18.31	18.00	1.40	0.02
Day	2002	1265	16.20	20.30	17.97	17.60	1.13	0.03
	2003	1710	16.33	20.89	18.69	18.44	1.40	0.03
Night	2002	1633	15.90	20.30	17.69	17.40	1.21	0.03
	2003	1651	16.33	21.61	18.79	18.61	1.45	0.04

Appendix E. Capture History Summary of Subyearling Chinook Salmon from data used in studies at John Day Dam in 2002 and 2003.

[Occ. represents the Occasion number after release. R(i) represents numbers released and j=2 and 3 indicate the released number detected at each downstream site]

Group 1 control day 2002				
Occ.	R(i)	j=2	j=3	Total
1	1150	504	565	1069
2	504		496	496

Group 2 control day 2003				
Occ.	R(i)	j=2	j=3	Total
1	1392	1122	255	1377
2	1122		1114	1114

Group 3 control night 2002				
Occ.	R(i)	j=2	j=3	Total
1	1499	919	499	1418
2	919		890	890

Group 4 control night 2003				
Occ.	R(i)	j=2	j=3	Total
1	1422	1328	75	1403
2	1328		1259	1259

Group 5 turbine day 2002				
Occ.	R(i)	j=2	j=3	Total
1	115	66	36	102
2	66		64	64

Group 6 turbine day 2003				
Occ.	R(i)	j=2	j=3	Total
1	318	223	49	272
2	223		217	217

Group 7 turbine night 2002				
Occ.	R(i)	j=2	j=3	Total
1	134	96	26	122
2	96		93	93

Group 8 turbine night 2003				
Occ.	R(i)	j=2	j=3	Total
1	229	183	8	191
2	183		179	179

Appendix F. Model Summary from Analyses of Recapture Probabilities (p) of Subyearling Chinook Salmon from data used in studies at John Day Dam in 2002 and 2003.

[Models of p include those in which values can vary in various combinations of detection site (t) and group (treatment, year, and photoperiod). A '*' indicated a multiplicative effect, a '+' indicates an additive effect, and a '.' indicates a common value fitted to all groups and reaches. A multiplicative model (g*t) of apparent survival (phi) was used in all models. K indicates the number of estimable parameters]

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	K	Deviance
{1 phi(g*t), p(g*t)}	9182.65	0.00	0.50	1.00	24	9134.54
{2 phi(g*t), p(g+t)}	9182.65	0.00	0.50	1.00	24	9134.54
{3 phi(g*t), p (t)}	10092.45	909.80	0.00	0.00	17	10058.39
{4 phi(g*t), p(g}	10828.06	1645.41	0.00	0.00	24	10779.94
{5 phi(g*t), p (.)}	11560.39	2377.74	0.00	0.00	17	11526.34

Appendix G. Summaries of Covariate Values from Yearling Chinook Salmon from data used in studies at McNary Dam from 2002–2009.

Table G1 — Summary statistics of turbine unit discharge (thousand ft^3/s) during yearling Chinook salmon passage from data used in studies at McNary Dam in 2002–2009.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2002	33	7.93	16.40	11.12	11.48	1.46	0.25
	2003	95	8.14	17.27	11.85	12.07	1.01	0.10
	2004	173	7.90	17.10	12.54	12.10	1.65	0.13
	2005	287	7.80	16.30	11.15	11.80	1.51	0.09
	2006	213	7.99	13.11	12.13	12.15	0.56	0.04
	2007	273	8.41	12.46	10.77	10.82	1.14	0.07
	2008	163	8.12	12.42	10.37	10.21	1.34	0.10
	2009	182	7.83	12.43	11.34	12.01	1.14	0.08
	Overall	1419	7.80	17.27	11.38	11.90	1.43	0.04
Day	2002	12	8.67	11.86	10.73	11.51	1.21	0.35
	2003	14	8.71	12.34	11.33	12.06	1.23	0.33
	2004	32	7.90	16.60	12.56	12.05	1.96	0.35
	2005	98	7.90	16.30	10.48	10.05	1.77	0.18
	2006	107	8.71	12.94	12.19	12.21	0.59	0.06
	2007	55	8.41	12.31	10.39	10.09	1.10	0.15
	2008	56	8.12	12.42	10.57	10.31	1.41	0.19
	2009	67	7.83	12.36	11.30	12.04	1.26	0.15
Night	2002	21	7.93	16.40	11.35	11.37	1.57	0.34
	2003	81	8.14	17.27	11.94	12.07	0.95	0.11
	2004	141	10.00	17.10	12.54	12.10	1.58	0.13
	2005	189	7.80	16.20	11.50	12.00	1.22	0.09
	2006	106	7.99	13.11	12.06	12.14	0.53	0.05
	2007	218	8.50	12.46	10.87	10.88	1.13	0.08
	2008	107	8.33	12.33	10.27	10.16	1.29	0.12
	2009	115	7.92	12.43	11.37	11.95	1.06	0.10

Table G2 — Summary statistics of head (feet) during yearling Chinook salmon passage from data used in studies at McNary Dam in 2002–2009.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2002	33	69.50	74.20	71.98	72.10	1.01	0.18
	2003	95	69.78	73.97	72.06	72.01	1.07	0.11
	2004	173	69.06	75.91	72.98	72.99	0.99	0.08
	2005	287	69.85	75.31	73.15	73.02	1.19	0.07
	2006	213	67.47	72.69	69.98	69.92	0.99	0.07
	2007	273	69.93	74.28	72.19	72.10	0.98	0.06
	2008	163	67.81	75.41	72.53	73.12	1.97	0.15
	2009	182	69.40	75.43	71.75	71.63	1.23	0.09
	Overall	1419	67.47	75.91	72.12	72.13	1.58	0.04
Day	2002	12	70.30	74.20	71.99	71.75	1.05	0.30
	2003	14	69.93	72.27	70.95	70.86	0.84	0.23
	2004	32	69.06	75.91	73.18	73.35	1.53	0.27
	2005	98	69.85	75.31	73.18	72.93	1.59	0.16
	2006	107	67.47	71.47	69.97	69.93	0.98	0.09
	2007	55	70.08	74.28	72.38	72.43	1.04	0.14
	2008	56	68.30	75.16	72.45	73.02	2.24	0.30
	2009	67	70.07	75.43	71.91	71.67	1.26	0.15
Night	2002	21	69.50	73.40	71.97	72.20	1.01	0.22
	2003	81	69.78	73.97	72.25	72.17	0.99	0.11
	2004	141	70.21	75.04	72.93	72.96	0.82	0.07
	2005	189	70.92	75.08	73.14	73.15	0.92	0.07
	2006	106	67.57	72.69	69.98	69.92	1.00	0.10
	2007	218	69.93	74.18	72.14	72.07	0.96	0.06
	2008	107	67.81	75.41	72.57	73.16	1.81	0.18
	2009	115	69.40	74.43	71.65	71.49	1.21	0.11

Table G3 — Summary statistics of total project discharge (thousand ft^3/s) during yearling Chinook salmon passage from data used in studies at McNary Dam in 2002–2009.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error.
* This variable was only applied to fish of the control group, but there was no control group in 2002 or 2003. Data summaries for 2002 and 2003 are based on fish of the turbine group, but are not included in the Overall row]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	*2002	33	163.40	399.10	239.30	238.20	56.70	9.87
	*2003	95	148.32	358.34	222.56	175.64	62.68	6.43
	2004	755	130.20	291.50	183.84	158.10	48.18	1.75
	2005	1575	90.30	358.40	215.62	228.90	52.26	1.32
	2006	1213	166.68	399.28	327.24	343.69	48.58	1.39
	2007	1310	177.02	289.06	255.44	257.24	26.89	0.74
	2008	949	157.03	421.09	285.46	275.62	83.74	2.72
	2009	935	141.43	356.09	262.79	261.27	51.01	1.67
	Overall	6737	90.30	421.09	256.28	255.60	69.41	0.85
Day	*2002	12	203.90	312.10	256.12	255.60	30.48	8.80
	*2003	14	230.36	326.54	293.97	302.15	26.34	7.04
	2004	114	130.20	291.50	231.35	234.90	55.47	5.19
	2005	356	90.30	358.40	199.64	188.20	65.93	3.49
	2006	139	285.08	378.74	344.77	351.64	34.50	2.93
	2007	92	194.39	283.84	238.53	233.32	31.30	3.26
	2008	116	170.77	369.03	230.57	220.67	65.91	6.12
	2009	244	141.43	350.88	244.34	236.17	59.59	3.82
Night	*2002	21	163.40	399.10	229.70	211.90	66.08	14.42
	*2003	81	148.32	358.34	210.22	173.88	58.80	6.53
	2004	641	140.90	283.90	175.39	157.30	41.45	1.64
	2005	1219	92.30	297.80	220.28	229.70	46.54	1.33
	2006	1074	166.68	399.28	324.97	335.88	49.67	1.52
	2007	1218	177.02	289.06	256.72	257.45	26.11	0.75
	2008	833	157.03	421.09	293.10	279.78	83.13	2.88
	2009	691	177.02	356.09	269.31	266.63	45.92	1.75

Table G4 — Summary statistics of spill percentage during yearling Chinook salmon passage from data used in studies at McNary Dam in 2002–2009.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2002	33	0.00	68.09	35.67	49.60	25.11	4.37
	2003	95	0.00	62.64	19.00	0.02	21.71	2.23
	2004	928	0.00	78.52	21.30	0.00	30.66	1.01
	2005	1862	0.00	78.84	36.30	35.82	21.96	0.51
	2006	1426	0.00	63.66	47.72	50.27	9.67	0.26
	2007	1583	36.80	42.41	40.58	40.70	0.61	0.02
	2008	1112	38.92	59.56	46.15	41.18	7.46	0.22
	2009	1117	38.77	59.13	42.97	40.85	4.01	0.12
	Overall	8156	0.00	78.84	39.47	40.77	17.77	0.20
Day	2002	12	41.19	68.09	55.32	54.80	7.33	2.12
	2003	14	36.30	62.64	46.65	45.59	6.21	1.66
	2004	146	49.44	78.52	65.06	63.79	5.90	0.49
	2005	454	32.79	78.84	53.16	56.37	14.29	0.67
	2006	246	39.94	63.66	49.79	51.20	4.85	0.31
	2007	147	36.80	42.41	40.87	40.78	0.58	0.05
	2008	172	39.65	59.49	43.48	41.19	5.19	0.40
	2009	311	39.98	54.30	42.54	40.93	3.33	0.19
Night	2002	21	0.00	62.61	24.44	19.44	24.81	5.41
	2003	81	0.00	56.92	14.22	0.00	19.76	2.20
	2004	782	0.00	71.29	13.14	0.00	26.16	0.94
	2005	1408	0.00	73.56	30.86	33.80	21.23	0.57
	2006	1180	0.00	61.65	47.29	50.06	10.34	0.30
	2007	1436	37.39	41.83	40.55	40.68	0.61	0.02
	2008	940	38.92	59.56	46.64	41.18	7.70	0.25
	2009	806	38.77	59.13	43.13	40.85	4.23	0.15

Table G5 — Summary statistics of tag burden (percent) of yearling Chinook salmon from data used in studies at McNary Dam in 2002–2009.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2002	33	2.12	4.35	3.35	3.28	0.54	0.09
	2003	95	3.47	9.78	6.96	7.06	1.17	0.12
	2004	928	1.42	6.96	4.86	4.97	1.24	0.04
	2005	1862	1.33	5.69	3.78	3.80	0.84	0.02
	2006	1426	2.52	6.64	4.93	4.95	0.84	0.02
	2007	1583	1.90	6.52	4.66	4.69	0.91	0.02
	2008	1112	1.96	6.52	4.39	4.36	0.96	0.03
	2009	1117	0.86	5.17	3.60	3.69	0.84	0.03
	Overall	8156	0.86	9.78	4.37	4.35	1.10	0.01
Day	2002	12	2.65	4.35	3.44	3.22	0.61	0.18
	2003	14	3.92	8.57	6.83	7.13	1.31	0.35
	2004	146	1.85	6.87	4.76	4.93	1.31	0.11
	2005	454	1.33	5.53	3.85	3.94	0.88	0.04
	2006	246	3.02	6.49	4.78	4.77	0.83	0.05
	2007	147	1.97	6.05	4.25	4.29	0.85	0.07
	2008	172	1.96	6.33	4.03	3.95	0.86	0.07
	2009	311	0.86	5.08	3.64	3.75	0.83	0.05
Night	2002	21	2.12	4.04	3.29	3.33	0.51	0.11
	2003	81	3.47	9.78	6.98	7.06	1.15	0.13
	2004	782	1.42	6.96	4.88	4.98	1.23	0.04
	2005	1408	1.54	5.69	3.76	3.77	0.83	0.02
	2006	1180	2.52	6.64	4.96	4.98	0.84	0.02
	2007	1436	1.90	6.52	4.70	4.75	0.90	0.02
	2008	940	2.18	6.52	4.46	4.44	0.96	0.03
	2009	806	1.26	5.17	3.59	3.68	0.85	0.03

Table G6 — Summary statistics of temperature during yearling Chinook salmon passage from data used in studies at McNary Dam in 2002–2009.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2002	33	10.00	14.30	11.80	11.80	1.12	0.20
	2003	95	10.50	15.33	12.04	11.78	1.14	0.12
	2004	928	10.22	13.72	12.51	12.83	0.84	0.03
	2005	1862	9.89	15.00	12.48	12.56	1.21	0.03
	2006	1426	9.50	14.60	12.49	12.60	1.39	0.04
	2007	1583	8.83	15.78	12.24	12.50	1.97	0.05
	2008	1112	8.28	13.56	10.96	11.33	1.66	0.05
	2009	1117	8.11	15.00	10.96	10.72	1.94	0.06
	Overall	8156	8.11	15.78	12.01	12.33	1.69	0.02
Day	2002	12	10.00	13.50	11.55	11.50	0.89	0.26
	2003	14	10.83	15.17	12.39	11.78	1.34	0.36
	2004	146	10.83	13.56	12.56	12.72	0.71	0.06
	2005	454	9.89	14.94	12.04	12.22	1.08	0.05
	2006	246	10.10	14.60	12.07	11.80	1.23	0.08
	2007	147	9.06	15.50	10.63	10.22	1.52	0.13
	2008	172	8.33	13.33	10.03	9.50	1.56	0.12
	2009	311	8.33	14.94	10.81	10.00	1.95	0.11
Night	2002	21	10.00	14.30	11.95	12.10	1.23	0.27
	2003	81	10.50	15.33	11.97	11.72	1.10	0.12
	2004	782	10.22	13.72	12.50	12.83	0.86	0.03
	2005	1408	10.06	15.00	12.62	12.56	1.22	0.03
	2006	1180	9.50	14.60	12.58	12.80	1.41	0.04
	2007	1436	8.83	15.78	12.40	12.56	1.94	0.05
	2008	940	8.28	13.56	11.13	11.44	1.62	0.05
	2009	806	8.11	15.00	11.02	10.89	1.94	0.07

Appendix H. Capture History Summary of Yearling Chinook Salmon from Data Used in Studies at McNary Dam in 2002–2005, and 2009.

[Occ. represents the Occasion number after release. R(i) represents numbers released and j=2 and 3 indicate the released number detected at each downstream site]

Group 1 control day 2004					Group 9 turbine day 2004				
Occ.	R(i)	j=2	j=3	Total	Occ.	R(i)	j=2	j=3	Total
1	641	299	162	461	1	141	56	28	84
2	299		163	163	2	56		33	33
Group 2 control day 2005					**Group 10 turbine day 2005**				
Occ.	R(i)	j=2	j=3	Total	Occ.	R(i)	j=2	j=3	Total
1	1219	1015	156	1171	1	189	132	28	160
2	1015		913	913	2	132		124	124
Group 3 control day 2009					**Group 11 turbine day 2009**				
Occ.	R(i)	j=2	j=3	Total	Occ.	R(i)	j=2	j=3	Total
1	691	641	10	651	1	115	97	3	100
2	641		598	598	2	97		92	92
Group 4 control night 2004					**Group 12 turbine night 2002**				
Occ.	R(i)	j=2	j=3	Total	Occ.	R(i)	j=2	j=3	Total
1	114	59	22	81	1	12	10	2	12
2	59		29	29	2	10		8	8
Group 5 control night 2005					**Group 13 turbine night 2003**				
Occ.	R(i)	j=2	j=3	Total	Occ.	R(i)	j=2	j=3	Total
1	356	295	47	342	1	14	4	4	8
2	295		269	269	2	4		4	4
Group 6 control night 2009					**Group 14 turbine night 2004**				
Occ.	R(i)	j=2	j=3	Total	Occ.	R(i)	j=2	j=3	Total
1	244	233	6	239	1	32	14	4	18
2	233		220	220	2	14		9	9
Group 7 turbine day 2002					**Group 15 turbine night 2005**				
Occ.	R(i)	j=2	j=3	Total	Occ.	R(i)	j=2	j=3	Total
1	21	15	3	18	1	98	77	11	88
2	15		14	14	2	77		71	71
Group 8 turbine day 2003					**Group 16 turbine night 2009**				
Occ.	R(i)	j=2	j=3	Total	Occ.	R(i)	j=2	j=3	Total
1	81	38	18	56	1	67	59	0	59
2	38		17	17	2	59		54	54

Appendix I. Correlation Analyses of Yearling Chinook Salmon from Data Used in Studies at McNary Dam in 2002–2005, and 2009.

Table I1. Table of correlation indices of data from yearling Chinook salmon from the turbine group at McNary Dam in 2002–2005 and 2009.

[Pearson correlation coefficients are listed above the probabilities of obtaining a greater value under the hypothesis that Rho = 0. Sample size is 770; <, less than; see table 2 for variable name definitions]

	TOTQ	PER_SPI	HEAD	TURQ	TURLOC	PHOTO	TEMP	WEIGHT	TAG BURDEN
TOTQ	1.0000	0.5980	-0.7568	0.0105	0.1995	0.2288	0.1362	0.1116	-0.0791
		<0.0001	<0.0001	0.7714	<0.0001	<0.0001	0.0001	0.0019	0.0282
PER_SPI		1.0000	-0.1566	-0.3468	0.0338	0.5888	-0.0901	0.1169	-0.2090
			<0.0001	<0.0001	0.3487	<0.0001	0.0124	0.0012	<0.0001
HEAD			1.0000	-0.2068	-0.2034	-0.0005	-0.1870	-0.1325	-0.0170
				<0.0001	<0.0001	0.9893	<0.0001	0.0002	0.6377
TURQ				1.0000	-0.0145	-0.2136	0.1912	0.0193	0.1448
					0.6878	<0.0001	<0.0001	0.5933	<0.0001
TURLOC					1.0000	-0.0616	-0.2044	0.0422	0.0397
						0.0875	<0.0001	0.2426	0.2708
PHOTO						1.0000	-0.0912	0.0223	-0.1044
							0.0114	0.5371	0.0037
TEMP							1.0000	-0.1309	0.0780
								0.0003	0.0305
WEIGHT								1.0000	-0.7305
									<0.0001

Table I2. Table of correlation indices of data from yearling Chinook salmon from the control group at McNary Dam in 2002–2005 and 2009.

[Pearson correlation coefficients are listed above the probabilities of obtaining a greater value under the hypothesis that Rho = 0. Sample size is 3,265; <, less than; see table 2 for variable name definitions]

	TOTQ	PER_SPI	PHOTO	TEMP	WEIGHT	TAG BURDEN
TOTQ	1.0000	0.5410	-0.0163	0.2874	0.1694	-0.1926
		<0.0001	0.3529	<0.0001	<0.0001	<0.0001
PER_SPI		1.0000	0.3768	0.0059	0.0549	-0.1419
			<0.0001	0.7353	0.0017	<0.0001
PHOTO			1.0000	-0.1241	0.0118	-0.0311
				<0.0001	0.4997	0.0759
TEMP				1.0000	-0.1200	0.0812
					<0.0001	<0.0001
WEIGHT					1.0000	-0.7973
						<0.0001

Appendix J. Model Summary from Analyses of Recapture Probabilities (p) of Yearling Chinook Salmon from Data Used in Studies at McNary Dam in 2002–2005, and 2009.

[Models of p include those in which values can vary in various combinations of detection site (t) and group (treatment, year, and photoperiod). A '*' indicated a multiplicative effect, a '+' indicates an additive effect, and a '.' indicates a common value fitted to all groups and reaches. A multiplicative model (g*t) of apparent survival (phi) was used in all models. K indicates the number of estimable parameters]

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	K	Deviance
{1 Phi(g*t), p(g*t)}	7216.47	0.00	1.00	1.00	48	7119.80
{2 Phi(g*t), p(g+t)}	7283.83	67.36	0.00	0.00	48	7187.16
{3 Phi(g*t), p(g)}	7298.73	82.27	0.00	0.00	48	7202.07
{4 Phi(g*t), p(t)}	8004.71	788.24	0.00	0.00	33	7938.39
{5 Phi(g*t), p(.)}	8037.00	820.53	0.00	0.00	33	7970.68

Appendix K. Model-selection Results from Radio- and Acoustic-tagged Yearling Chinook Salmon from Data Used in Studies at McNary Dam in 2002–2005, and 2009.

[Presence of a factor in a model is indicated by an 'x' in the column for that factor. Model 1 was a global model including all group covariates and their interactions (g) as well as all individual covariates and interactions listed. Distance to the first downriver gate (gated) was only used when year was present in the model. All models shared a common year*reach model of recapture probability. K indicates the number of parameters.]

	Group Covariates								Individual Covariates																	Model Selection Results		
									Biological								Operational											
Model Number	g	trt	yr	photo	trt*yr	trt*photo	yr*photo	trt*yr*photo	gated	wt	tagb	trt*tagb	yr*tagb	temp	trt*temp	yr*temp	persp	trt*persp	head linear	head quadratic	turq linear	turq quadratic	turloc	turloc*photo	totq	AICc	K	Deviance
1	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	x	x		x		x	x	x	7216.4	64	7087.2
2	x	x	x	x	x	x	x	x			x	x		x	x	x	x	x	x	x	x		x	x	x	7212.9	60	7091.8
3	x	x	x	x	x	x	x	x			x	x		x	x		x	x	x		x		x	x	x	7206.0	56	7093.0
4a		x		x		x			x		x	x		x	x		x	x	x		x		x	x	x	7215.7	45	7125.2
4b		x	x	x	x	x	x				x	x		x	x		x	x	x		x		x	x	x	7205.6	54	7096.8
4c		x	x	x		x	x				x	x		x	x		x	x	x		x		x	x	x	7203.2	52	7098.4
4d		x	x	x		x					x	x		x	x		x	x	x		x		x	x	x	7204.0	48	7107.3
5		x	x	x		x	x				x	x		x	x		x	x	x		x		x		x	7201.8	51	7099.0
6		x	x	x			x				x	x		x	x		x	x	x		x		x		x	7200.4	50	7099.6
7		x	x				x				x	x		x	x		x	x	x		x		x		x	7198.7	49	7100.0
8		x	x				x				x	x		x			x	x	x		x		x		x	7197.3	48	7100.6
9		x	x				x				x	x		x			x		x		x		x		x	7195.3	47	7100.7
10		x	x				x				x	x					x		x		x		x		x	7207.3	46	7114.7
11		x	x				x				x	x		x			x		x		x		x			7198.1	46	7105.5
12		x	x				x				x	x		x					x		x		x		x	7201.0	46	7108.3
13		x	x				x				x	x		x			x		x		x				x	7194.9	46	7102.3
14a		x	x				x				x	x		x			x				x				x	7195.6	45	7105.0
14b		x	x				x				x	x		x			x			x	x				x	7195.9	47	7101.2
15a		x	x				x				x	x		x			x		x						x	7192.9	45	7102.3
15b		x	x				x				x	x		x			x		x			x			x	7195.9	47	7101.3
16*		x	x				x				x			x			x		x						x	7191.3	44	7102.8
17		x	x				x							x			x		x						x	7196.1	43	7109.6
18										x																7196.5	44	7102.9

Appendix L. Beta (Slope) Coefficients of Estimable Survival Parameters of Yearling Chinook Salmon from Data Used in Studies at McNary Dam in 2002–2005, and 2009.

[The data are from model 16 in appendix L]

Parameter	Beta	Standard Error	95% Confidence Lower	95% Confidence Upper
intercept	5.403126	0.880395	3.677551	7.128701
treatment	14.439400	8.404396	-2.033210	30.912020
2005	0.836723	0.290310	0.267715	1.405731
2009	-0.443710	0.367891	-1.164770	0.277360
2002	0.259362	0.743256	-1.197420	1.716145
2003	1.709109	1.345273	-0.927630	4.345844
photo*2005	0.040509	0.361362	-0.667760	0.748779
photo*2009	0.743644	0.331634	0.093642	1.393646
photo*2003	-2.505620	1.473538	-5.393760	0.382511
tag burden	-0.214470	0.084410	-0.379920	-0.049030
persp	0.005215	0.004853	-0.004300	0.014726
head	-0.201670	0.112947	-0.423040	0.019711
totq	0.005538	0.002532	0.000577	0.010500
temp	-0.259040	0.066728	-0.389820	-0.128250

Appendix M. Capture History Summary of Yearling Chinook Salmon from Data Used in Studies at McNary Dam in 2002–2005, and 2009.

[Occ. represents the Occasion number after release. R(i) represents numbers released and j=2 and 3 indicate the released number detected at each downstream site]

Group 1 control day 2004

Occ.	R(i)	j=2	j=3	Total
1	641	299	162	461
2	299		163	163

Group 2 control day 2005

Occ.	R(i)	j=2	j=3	Total
1	1219	1015	156	1171
2	1015		913	913

Group 3 control day 2006

Occ.	R(i)	j=2	j=3	Total
1	1074	923	107	1030
2	923		840	840

Group 4 control day 2007

Occ.	R(i)	j=2	j=3	Total
1	1218	386	715	1101
2	386		334	334

Group 5 control day 2008

Occ.	R(i)	j=2	j=3	Total
1	833	623	187	810
2	623		589	589

Group 6 control day 2009

Occ.	R(i)	j=2	j=3	Total
1	691	641	10	651
2	641		598	598

Group 7control night 2004

Occ.	R(i)	j=2	j=3	Total
1	114	59	22	81
2	59		29	29

Group 8 control night 2005

Occ.	R(i)	j=2	j=3	Total
1	356	295	47	342
2	295		269	269

Group 9 control night 2006

Occ.	R(i)	j=2	j=3	Total
1	139	91	45	136
2	91		76	76

Group 10 control night 2007

Occ.	R(i)	j=2	j=3	Total
1	92	39	42	81
2	39		35	35

Group 11 control night 2008

Occ.	R(i)	j=2	j=3	Total
1	116	98	17	115
2	98		92	92

Group 12 control night 2009

Occ.	R(i)	j=2	j=3	Total
1	244	233	6	239
2	233		220	220

Group 13 turbine day 2002

Occ.	R(i)	j=2	j=3	Total
1	21	15	3	18
2	15		14	14

Group 14 turbine day 2003

Occ.	R(i)	j=2	j=3	Total
1	81	38	18	56
2	38		17	17

Group 15 turbine day 2004

Occ.	R(i)	j=2	j=3	Total
1	141	56	28	84
2	56		33	33

Group 16 turbine day 2005

Occ.	R(i)	j=2	j=3	Total
1	189	132	28	160
2	132		124	124

Group 17 turbine day 2006

Occ.	R(i)	j=2	j=3	Total
1	106	70	11	81
2	70		65	65

Group 18 turbine day 2007

Occ.	R(i)	j=2	j=3	Total
1	218	70	89	159
2	70		63	63

Group 19 turbine day 2008

Occ.	R(i)	j=2	j=3	Total
1	107	80	12	92
2	80		73	73

Group 20 turbine day 2009

Occ.	R(i)	j=2	j=3	Total
1	115	97	3	100
2	97		92	92

Group 21 turbine night 2002

Occ.	R(i)	j=2	j=3	Total
1	12	10	2	12
2	10		8	8

Group 22 turbine night 2003

Occ.	R(i)	j=2	j=3	Total
1	14	4	4	8
2	4		4	4

Group 23 turbine night 2004

Occ.	R(i)	j=2	j=3	Total
1	32	14	4	18
2	14		9	9

Group 24 turbine night 2005

Occ.	R(i)	j=2	j=3	Total
1	98	77	11	88
2	77		71	71

Group 25 turbine night 2006

Occ.	R(i)	j=2	j=3	Total
1	107	80	13	93
2	80		78	78

Group 26 turbine night 2007

Occ.	R(i)	j=2	j=3	Total
1	55	17	32	49
2	17		15	15

Group 27 turbine night 2008

Occ.	R(i)	j=2	j=3	Total
1	56	31	21	52
2	31		30	30

Group 28 turbine night 2009

Occ.	R(i)	j=2	j=3	Total
1	67	59	0	59
2	59		54	54

Appendix N. Model Summary from Analyses of Recapture Probabilities (p) of Yearling Chinook Salmon from Data Used in Studies at McNary Dam in 2002–2005, and 2009.

[Models of p include those in which values can vary in various combinations of detection site (t) and group (treatment, year, and photoperiod). A '*' indicated a multiplicative effect, a '+' indicates an additive effect, and a '.' indicates a common value fitted to all groups and reaches. A multiplicative model (g*t) of apparent survival (phi) was used in all models. K indicates the number of estimable parameters]

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	K	Deviance
{1 Phi(g*t) p(g*t)}	14736.09	0.00	1.00	1.00	84	14567.04
{2 Phi(g*t) p(g+t)}	14759.35	23.26	0.00	0.00	84	14590.31
{3 Phi(g*t) p(g)}	15908.43	1172.34	0.00	0.00	84	15739.38
{4 Phi(g*t) p(t)}	16562.16	1826.07	0.00	0.00	57	16447.68
{5 Phi(g*t) p(.)}	17414.50	2678.41	0.00	0.00	57	17300.02

Appendix O. Summaries of Covariate Values of Juvenile Steelhead from Data Used in Studies at McNary Dam in 2004–2009.

Table O1 — Summary statistics of turbine unit discharge (thousand ft^3/s) during juvenile steelhead passage from data used in studies at McNary Dam in 2004–2009.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2004	47	10.50	16.60	12.69	12.00	1.66	0.24
	2005	57	7.90	16.30	10.69	10.70	1.54	0.20
	2006	79	8.33	12.94	11.97	12.12	0.89	0.10
	2007	48	8.13	12.28	10.72	11.17	1.40	0.20
	2008	66	8.31	12.30	10.40	10.18	1.25	0.15
	2009	54	8.65	12.56	11.32	11.97	1.12	0.15
	Overall	351	7.90	16.60	11.29	11.90	1.51	0.08
Day	2004	19	11.40	16.60	13.22	12.20	1.88	0.43
	2005	32	7.90	12.20	10.13	9.90	1.21	0.21
	2006	39	8.33	12.94	12.12	12.19	0.83	0.13
	2007	23	8.49	12.24	10.82	11.16	1.30	0.27
	2008	31	8.37	12.30	9.92	9.48	1.15	0.21
	2009	27	8.65	12.39	11.05	11.59	1.20	0.23
Night	2004	28	10.50	16.40	12.33	12.00	1.41	0.27
	2005	25	7.90	16.30	11.40	12.00	1.66	0.33
	2006	40	8.80	12.94	11.82	12.06	0.92	0.15
	2007	25	8.13	12.28	10.62	11.23	1.51	0.30
	2008	35	8.31	12.18	10.83	11.29	1.19	0.20
	2009	27	9.34	12.56	11.59	12.05	0.98	0.19

Table O2 — Summary statistics of head (ft) during juvenile steelhead passage from data used in studies at McNary Dam in 2004–2009.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2004	47	69.22	75.35	72.86	72.80	1.15	0.17
	2005	57	70.05	75.64	73.72	73.76	1.18	0.16
	2006	79	67.36	71.89	70.00	70.11	1.11	0.12
	2007	48	70.02	74.82	72.23	72.46	1.11	0.16
	2008	66	68.12	75.19	71.94	72.08	2.30	0.28
	2009	54	69.42	74.06	71.58	71.32	1.25	0.17
	Overall	351	67.36	75.64	71.90	71.98	1.89	0.10
Day	2004	19	70.81	75.35	73.12	72.74	1.25	0.29
	2005	32	71.62	75.64	74.03	74.24	1.20	0.21
	2006	39	67.47	71.47	69.86	69.86	1.01	0.16
	2007	23	70.02	74.82	72.08	71.86	1.29	0.27
	2008	31	68.27	75.19	73.01	73.18	1.86	0.33
	2009	27	69.64	74.01	71.83	71.67	1.19	0.23
Night	2004	28	69.22	74.04	72.68	72.83	1.06	0.20
	2005	25	70.05	75.09	73.34	73.64	1.06	0.21
	2006	40	67.36	71.89	70.13	70.54	1.19	0.19
	2007	25	70.63	74.15	72.37	72.51	0.92	0.18
	2008	35	68.12	74.91	71.00	69.89	2.26	0.38
	2009	27	69.42	74.06	71.33	71.02	1.28	0.25

Table O3 — Summary statistics of total project discharge (thousand ft^3/s) during juvenile steelhead passage from data used in studies at McNary Dam in 2004–2009.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2004	746	130.40	318.60	190.74	172.10	44.24	1.62
	2005	57	90.90	347.90	189.69	172.70	54.88	7.27
	2006	79	248.99	396.37	329.67	342.01	40.98	4.61
	2007	48	171.95	288.34	245.99	253.14	29.87	4.31
	2008	785	157.03	418.52	267.59	260.99	79.21	2.83
	2009	785	141.43	356.09	263.88	262.87	50.68	1.81
	Overall	2500	90.90	418.52	243.26	235.92	70.28	1.41
Day	2004	123	184.40	253.50	237.21	250.10	23.25	2.10
	2005	32	90.90	301.10	193.01	182.90	46.53	8.22
	2006	39	271.28	389.22	334.02	346.50	34.66	5.55
	2007	23	171.95	288.34	248.00	255.59	33.15	6.91
	2008	104	170.77	369.03	223.95	220.67	49.41	4.85
	2009	200	141.43	350.88	244.15	242.40	60.41	4.27
Night	2004	623	130.40	318.60	181.57	163.50	41.55	1.66
	2005	25	92.80	347.90	185.43	158.00	64.80	12.96
	2006	40	248.99	396.37	325.43	310.03	46.39	7.33
	2007	25	177.23	283.38	244.14	248.09	27.08	5.42
	2008	681	157.03	418.52	274.25	267.49	80.79	3.10
	2009	585	177.02	356.09	270.62	268.91	45.01	1.86

Table O4 — Summary statistics of spill percentage during juvenile steelhead passage from data used in studies at McNary Dam in 2004–2009.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2004	793	0.00	78.49	28.23	0.32	31.74	1.13
	2005	57	0.00	75.09	36.65	45.43	24.08	3.19
	2006	79	36.09	64.43	48.79	50.65	6.77	0.76
	2007	48	39.81	46.67	40.82	40.72	0.94	0.14
	2008	851	39.42	60.52	45.17	40.82	7.09	0.24
	2009	839	38.77	59.13	43.03	40.89	4.01	0.14
	Overall	2667	0.00	78.49	39.31	40.82	19.71	0.38
Day	2004	142	48.88	78.49	67.47	68.43	4.20	0.35
	2005	32	32.83	75.09	51.21	48.39	11.59	2.05
	2006	39	40.10	64.43	49.23	50.68	5.80	0.93
	2007	23	39.81	41.46	40.71	40.77	0.41	0.08
	2008	135	40.02	59.80	42.37	40.89	4.15	0.36
	2009	227	40.11	54.30	42.61	41.00	3.39	0.22
Night	2004	651	0.00	75.48	19.67	0.00	28.53	1.12
	2005	25	0.00	55.71	18.02	0.00	23.13	4.63
	2006	40	36.09	61.91	48.36	50.60	7.65	1.21
	2007	25	39.87	46.67	40.93	40.69	1.24	0.25
	2008	716	39.42	60.52	45.69	40.79	7.40	0.28
	2009	612	38.77	59.13	43.18	40.85	4.20	0.17

Table O5 — Summary statistics of tag burden (percent) during juvenile steelhead passage from data used in studies at McNary Dam in 2004–2009.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2004	793	0.76	6.41	2.19	2.08	0.73	0.03
	2005	57	0.85	4.96	1.62	1.49	0.63	0.08
	2006	79	0.66	4.84	2.22	2.12	0.82	0.09
	2007	48	0.94	4.00	2.04	1.95	0.73	0.10
	2008	851	0.60	5.60	2.01	1.95	0.64	0.02
	2009	839	0.69	4.63	1.73	1.67	0.53	0.02
	Overall	2667	0.60	6.41	1.98	1.89	0.67	0.01
Day	2004	142	0.95	4.71	2.15	2.05	0.65	0.05
	2005	32	1.01	2.90	1.62	1.51	0.46	0.08
	2006	39	0.66	4.66	2.03	1.93	0.70	0.11
	2007	23	0.94	3.39	2.02	1.87	0.74	0.15
	2008	135	0.95	4.90	1.91	1.84	0.56	0.05
	2009	227	0.72	4.63	1.74	1.68	0.56	0.04
Night	2004	651	0.76	6.41	2.20	2.09	0.74	0.03
	2005	25	0.85	4.96	1.63	1.41	0.81	0.16
	2006	40	1.04	4.84	2.40	2.34	0.89	0.14
	2007	25	1.17	4.00	2.07	1.97	0.73	0.15
	2008	716	0.60	5.60	2.03	1.98	0.65	0.02
	2009	612	0.69	4.20	1.73	1.66	0.53	0.02

Table O6 — Summary statistics of water temperature during juvenile steelhead passage from data used in studies at McNary Dam in 2004–2009.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2004	793	10.33	14.00	12.64	12.83	0.80	0.03
	2005	57	10.06	14.94	11.83	11.39	1.08	0.14
	2006	79	10.00	14.50	12.39	12.40	1.41	0.16
	2007	48	9.33	15.67	12.77	13.03	1.98	0.29
	2008	851	8.28	13.56	10.74	10.72	1.59	0.05
	2009	839	8.11	15.00	10.98	10.72	1.92	0.07
	Overall	2667	8.11	15.67	11.49	11.72	1.74	0.03
Day	2004	142	10.67	13.00	12.30	12.83	0.76	0.06
	2005	32	10.06	14.33	11.78	11.61	0.90	0.16
	2006	39	10.10	14.50	12.53	12.40	1.41	0.23
	2007	23	10.44	15.28	12.74	12.39	1.80	0.38
	2008	135	8.44	12.67	9.73	9.50	1.18	0.10
	2009	227	8.33	14.94	10.85	10.33	1.94	0.13
Night	2004	651	10.33	14.00	12.71	12.89	0.79	0.03
	2005	25	10.11	14.94	11.89	11.39	1.30	0.26
	2006	40	10.00	14.50	12.26	12.40	1.41	0.22
	2007	25	9.33	15.67	12.80	13.28	2.17	0.43
	2008	716	8.28	13.56	10.93	11.33	1.59	0.06
	2009	612	8.11	15.00	11.02	10.89	1.91	0.08

Appendix P. Capture History Summary of Juvenile Steelhead from Data Used in Studies at McNary Dam in 2004–2005 and 2009.

[Occ. represents the Occasion number after release. R(i) represents numbers released and j=2 and 3 indicate the released number detected at each downstream site]

Group 1 control day 2004				
Occ.	R(i)	j=2	j=3	Total
1	623	397	142	539
2	397		334	334

Group 2 control day 2009				
Occ.	R(i)	j=2	j=3	Total
1	585	548	2	550
2	548		517	517

Group 3 control night 2004				
Occ.	R(i)	j=2	j=3	Total
1	123	91	14	105
2	91		84	84

Group 4 control night 2009				
Occ.	R(i)	j=2	j=3	Total
1	200	185	0	185
2	185		168	168

Group 5 turbine day 2004				
Occ.	R(i)	j=2	j=3	Total
1	28	14	5	19
2	14		13	13

Group 6 turbine day 2005				
Occ.	R(i)	j=2	j=3	Total
1	25	14	4	18
2	14		12	12

Group 7 turbine day 2009				
Occ.	R(i)	j=2	j=3	Total
1	27	19	0	19
2	19		19	19

Group 8 turbine night 2004				
Occ.	R(i)	j=2	j=3	Total
1	19	14	2	16
2	14		11	11

Group 9 turbine night 2005				
Occ.	R(i)	j=2	j=3	Total
1	32	21	3	24
2	21		21	21

Group 10 turbine night 2009				
Occ.	R(i)	j=2	j=3	Total
1	27	23	0	23
2	23		23	23

Appendix Q. Results of Correlation Analyses of Juvenile Steelhead from Data Used in Studies at McNary Dam in 2004–2005 and 2009.

Table Q1. Table of correlation indices of data from juvenile steelhead from the turbine group from data used in studies at McNary Dam in 2004, 2005, and 2009 .

[Pearson correlation coefficients are listed above the probabilities of obtaining a greater value under the hypothesis that Rho = 0. Sample size is 158; <, less than; see table 2 for variable name definitions]

	TOTQ	PER_SPI	HEAD	TURQ	TURBLOC	PHOTO	TEMP	WEIGHT	TAG BURDEN
TOTQ	1.0000	0.4610	-0.8358	0.2063	0.0956	0.0662	0.1317	0.0836	-0.0137
		<0.0001	<0.0001	0.0093	0.2322	0.4088	0.0991	0.2961	0.8645
PER_SPI		1.0000	-0.0449	-0.0582	-0.0929	0.6055	-0.0355	-0.0871	-0.0293
			0.5755	0.4675	0.2455	<0.0001	0.6576	0.2763	0.7147
HEAD			1.0000	-0.2839	-0.1596	0.2075	-0.0850	-0.1414	-0.0441
				0.0003	0.0451	0.0089	0.2882	0.0764	0.5825
TURQ				1.0000	-0.0618	-0.1779	0.3206	-0.0164	0.2995
					0.4407	0.0253	<0.0001	0.8381	0.0001
TURBLOC					1.0000	-0.0439	-0.2326	-0.0956	0.0646
						0.5838	0.0033	0.2324	0.4197
PHOTO						1.0000	-0.2778	-0.0658	-0.0832
							0.0004	0.4117	0.0298
TEMP							1.0000	0.0474	0.1779
								0.5546	0.0254
WEIGHT								1.0000	-0.7478
									<0.0001

Table Q2. Table of correlation indices of data from juvenile steelhead from the control group from data used in studies at McNary Dam in 2004, 2005, and 2009.

[Pearson correlation coefficients are listed above the probabilities of obtaining a greater value under the hypothesis that Rho = 0. Sample size is 1,531; <, less than; see table 2 for variable name definitions]

	TOTQ	PER_SPI	PHOTO	TEMP	WEIGHT	TAG BURDEN
TOTQ	1.0000	0.6132	0.1143	0.0466	-0.0667	-0.1793
		<0.0001	<0.0001	0.0683	0.0090	<0.0001
PER_SPI		1.0000	0.3654	-0.1099	-0.0412	-0.1102
			<0.0001	<0.0001	0.1070	<0.0001
PHOTO			1.0000	-0.0917	0.0011	-0.0453
				0.0003	0.9651	0.0767
TEMP				1.0000	0.0512	0.2124
					0.0451	<0.0001
WEIGHT					1.0000	-0.8071
						<0.0001

Appendix R. Model Summary from Analyses of Recapture Probabilities (p) of Juvenile Steelhead from Data Used in Studies at McNary Dam in 2004–2005 and 2009.

[Models of p include those in which values can vary in various combinations of detection site (t) and group (treatment, year, and photoperiod). A '*' indicated a multiplicative effect, a '+' indicates an additive effect, and a '.' indicates a common value fitted to all groups and reaches. A multiplicative model (g*t) of apparent survival (phi) was used in all models. K indicates the number of estimable parameters]

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	K	Deviance
{1 Phi(g*t), p(g*t}	2773.45	0.00	1.00	1.00	25	2723.02
{2 Phi(g*t), p(g+t}	2830.40	56.95	0.00	0.00	25	2779.97
{3 Phi(g*t), p(g)}	2865.30	91.85	0.00	0.00	25	2814.87
{4 Phi(g*t), p(t)}	2994.67	221.22	0.00	0.00	16	2962.49
{5 Phi(g*t), p(.)}	3011.59	238.14	0.00	0.00	16	2979.41

Appendix S. Model-selection Results from Radio- and Acoustic-tagged Juvenile Steelhead from Data Used in Studies at McNary Dam in 2004–2005 and 2009.

[Presence of a factor in a model is indicated by an 'x' in the column for that factor. Model 1 was a global model including all group covariates and their interactions (g) as well as all individual covariates and interactions listed. Distance to the first downriver gate (gated) was only used when year was present in the model. All models shared a common year*reach model of recapture probability. K indicates the number of parameters.]

									Individual Covariates																			
	Group Covariates								Biological								Operational									Model Selection Results		
Model Number	g	trt	yr	photo	trt*yr	trt*photo	yr*photo	trt*yr*photo	gated	wt	tagb	trt*tagb	yr*tagb	temp	trt*temp	yr*temp	persp	trt*persp	head linear	head quadratic	turq linear	turq quadratic	turloc	turloc*photo	totq	AICc	K	Deviance
1	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	x	x		x		x	x	x	2790.	38	2713.0
2	x	x	x	x	x	x	x	x			x	x		x	x	x	x	x	x		x		x	x	x	2792.	36	2719.5
3	x	x	x	x	x	x	x	x			x	x	x	x	x		x	x	x		x		x	x	x	2800.	36	2728.0
4		x		x		x			x		x	x	x	x	x	x	x	x	x		x		x	x	x	2781.	33	2715.2
5		x		x		x			x		x	x	x	x	x	x	x	x	x		x		x		x	2779.	32	2715.2
6		x		x					x		x	x	x	x	x	x	x	x	x		x		x		x	2779.	31	2716.7
7		x		x					x		x	x	x	x		x	x	x	x		x		x		x	2778.	30	2717.7
8		x							x		x	x	x	x		x	x	x	x		x		x		x	2776.	29	2717.7
9		x							x		x	x	x			x	x	x	x		x		x		x	2774.	28	2717.7
10		x							x		x	x	x			x	x		x		x		x		x	2776.	27	2722.2
11		x							x		x	x	x			x	x	x	x		x		x			2774.	27	2720.0
12		x							x		x	x	x			x		x	x		x		x		x	2778.	27	2724.1
13		x							x		x	x	x			x	x	x	x		x				x	2773.	27	2719.3
14a		x							x		x	x	x			x	x	x			x				x	2772.	26	2719.7
14b		x							x		x	x	x			x	x	x		x	x				x	2775.	28	2718.9
15a		x							x		x	x	x			x	x	x							x	2770.	25	2719.7
15b		x							x		x	x	x			x	x	x				x			x	2773.	27	2719.4
16		x							x		x		x			x	x	x							x	2768.	24	2720.4
17*		x									x		x			x	x	x							x	2766.	23	2720.4
18		x											x			x	x	x							x	2767.	22	2722.6
19		x								x			x			x	x	x							x	2765.	23	2719.5

Appendix T. Beta (Slope) Coefficients of Estimable Survival Parameters of Juvenile Steelhead from Data Used in Studies at McNary Dam in 2004–2005 and 2009.

[The data are from model 17 in appendix S]

Parameter	Beta	Standard Error	95% Confidence Lower	95% Confidence Upper
intercept	2.38540	0.56300	1.28191	3.48889
treatment	-1.09401	0.64970	-2.36741	0.17940
tag burden	-0.23449	0.15202	-0.53246	0.06348
totq	0.00427	0.00273	-0.00108	0.00962
persp	-0.01389	0.00563	-0.02492	-0.00286
persp*trt	0.02231	0.01025	0.00222	0.04240
temp*2009	-0.01401	0.05052	-0.11303	0.08500
temp*2005	-0.06593	0.08709	-0.23662	0.10476
tag burden*2009	0.18442	0.25036	-0.30629	0.67512
tag burden*2005	0.40273	0.56854	-0.71161	1.51706

Appendix U. Capture History Summary of Juvenile Steelhead from Data Used in Studies at McNary Dam in 2004–2005 and 2009.

[Occ. represents the Occasion number after release. R(i) represents numbers released and j=2 and 3 indicate the released number detected at each downstream site]

Group 1 control day 2004

Occ.	R(i)	j=2	j=3	Total
1	623	397	142	539
2	397		334	334

Group 7 turbine day 2004

Occ.	R(i)	j=2	j=3	Total
1	28	14	5	19
2	14		13	13

Group 13 turbine night 2004

Occ.	R(i)	j=2	j=3	Total
1	19	14	2	16
2	14		11	11

Group 2 control day 2008

Occ.	R(i)	j=2	j=3	Total
1	681	428	215	643
2	428		399	399

Group 8 turbine day 2005

Occ.	R(i)	j=2	j=3	Total
1	25	14	4	18
2	14		12	12

Group 14 turbine night 2005

Occ.	R(i)	j=2	j=3	Total
1	32	21	3	24
2	21		21	21

Group 3 control day 2009

Occ.	R(i)	j=2	j=3	Total
1	585	548	2	550
2	548		517	517

Group 9 turbine day 2006

Occ.	R(i)	j=2	j=3	Total
1	40	23	8	31
2	23		17	17

Group 15 turbine night 2006

Occ.	R(i)	j=2	j=3	Total
1	39	27	7	34
2	27		23	23

Group 4 control night 2004

Occ.	R(i)	j=2	j=3	Total
1	123	91	14	105
2	91		84	84

Group 10 turbine day 2007

Occ.	R(i)	j=2	j=3	Total
1	25	6	9	15
2	6		5	5

Group 16 turbine night 2007

Occ.	R(i)	j=2	j=3	Total
1	23	4	12	16
2	4		4	4

Group 5 control night 2008

Occ.	R(i)	j=2	j=3	Total
1	104	67	28	95
2	67		62	62

Group 11 turbine day 2008

Occ.	R(i)	j=2	j=3	Total
1	35	15	6	21
2	15		14	14

Group 17 turbine night 2008

Occ.	R(i)	j=2	j=3	Total
1	31	13	14	27
2	13		12	12

Group 6 control night 2009

Occ.	R(i)	j=2	j=3	Total
1	200	185	0	185
2	185		168	168

Group 12 turbine day 2009

Occ.	R(i)	j=2	j=3	Total
1	27	19	0	19
2	19		19	19

Group 18 turbine night 2009

Occ.	R(i)	j=2	j=3	Total
1	27	23	0	23
2	23		23	23

Appendix V. Model Summary from Analyses of Recapture Probabilities (p) of Juvenile Steelhead from Data Used in Studies at McNary Dam in 2004–2005 and 2009.

[Models of p include those in which values can vary in various combinations of detection site (t) and group (treatment, year, and photoperiod). A '*' indicated a multiplicative effect, a '+' indicates an additive effect, and a '.' indicates a common value fitted to all groups and reaches. A multiplicative model (g*t) of apparent survival (phi) was used in all models. K indicates the number of estimable parameters]

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	K	Deviance
{1 Phi (g*t), p(g*t)}	4799.74	0.00	1.00	1.00	47	4704.74
{2 Phi (g*t), p(g+t)}	4915.38	115.64	0.00	0.00	47	4820.38
{3 Phi (g*t), p(g)}	5071.73	271.99	0.00	0.00	47	4976.74
{4 Phi (g*t), p(t)}	5159.27	359.53	0.00	0.00	30	5098.86
{5 Phi (g*t), p(.)}	5330.28	530.54	0.00	0.00	30	5269.87

Appendix W. Summaries of Covariate Values of Subyearling Chinook Salmon from Data Used in Studies at McNary Dam in 2004–2009.

Table W1 — Summary statistics of turbine unit discharge (thousand ft^3/s) during subyearling Chinook salmon passage from data used in studies at McNary Dam in 2004–2009.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2004	500	7.80	12.50	11.07	11.70	1.33	0.06
	2005	117	7.92	16.60	10.95	12.00	1.96	0.18
	2006	435	6.20	12.95	9.94	9.61	1.30	0.06
	2007	276	7.85	12.24	9.78	9.48	1.24	0.07
	2008	308	5.05	12.43	10.57	10.65	1.58	0.09
	2009	273	7.87	12.35	10.02	9.87	1.26	0.08
	Overall	1909	5.05	16.60	10.39	10.32	1.48	0.03
Day	2004	245	7.80	12.50	10.63	11.10	1.50	0.10
	2005	41	7.92	12.30	9.75	8.74	1.77	0.28
	2006	114	7.96	12.53	9.15	9.10	0.76	0.07
	2007	94	7.88	12.24	9.54	9.20	1.29	0.13
	2008	79	5.05	12.43	9.97	9.57	1.72	0.19
	2009	113	7.87	11.86	9.44	9.24	1.12	0.11
Night	2004	255	7.80	12.40	11.50	11.90	0.97	0.06
	2005	76	8.10	16.60	11.61	12.10	1.74	0.20
	2006	321	6.20	12.95	10.22	9.94	1.33	0.07
	2007	182	7.85	12.20	9.91	9.65	1.20	0.09
	2008	229	7.08	12.39	10.77	11.02	1.48	0.10
	2009	160	8.17	12.35	10.42	10.38	1.19	0.09

Table W2 — Summary statistics of head (feet) during subyearling Chinook salmon passage from data used in studies at McNary Dam in 2004–2009.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2004	500	71.60	76.19	74.01	73.98	1.01	0.04
	2005	117	70.72	76.47	72.67	72.78	1.24	0.11
	2006	435	69.09	75.74	72.77	72.58	1.41	0.07
	2007	276	71.26	75.90	73.96	73.90	0.90	0.05
	2008	308	69.04	75.59	72.35	71.99	1.51	0.09
	2009	273	70.59	76.60	74.28	74.73	1.31	0.08
	Overall	1909	69.04	76.60	73.41	73.53	1.45	0.03
Day	2004	245	71.71	76.12	74.28	74.33	0.97	0.06
	2005	41	71.22	76.47	73.44	73.52	1.23	0.19
	2006	114	69.49	75.51	73.92	74.30	1.32	0.12
	2007	94	71.73	75.77	74.31	74.49	0.87	0.09
	2008	79	69.39	75.59	72.87	72.82	1.32	0.15
	2009	113	70.80	76.60	74.82	75.03	0.99	0.09
Night	2004	255	71.60	76.19	73.76	73.56	0.97	0.06
	2005	76	70.72	74.91	72.25	71.82	1.03	0.12
	2006	321	69.09	75.74	72.36	72.09	1.20	0.07
	2007	182	71.26	75.90	73.77	73.74	0.86	0.06
	2008	229	69.04	75.38	72.17	71.85	1.54	0.10
	2009	160	70.59	76.32	73.90	74.13	1.37	0.11

Table W3 — Summary statistics of total project discharge (thousand ft^3/s) during subyearling Chinook salmon passage from data used in studies at McNary Dam in 2004–2009.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2004	763	73.40	214.40	146.51	154.30	25.33	0.92
	2005	1048	150.69	225.69	190.98	192.20	18.25	0.56
	2006	1191	146.33	333.97	236.52	224.55	46.50	1.35
	2007	1182	146.45	231.21	188.59	187.44	22.29	0.65
	2008	1176	132.12	355.44	238.43	221.37	74.59	2.17
	2009	1187	55.41	298.39	182.54	175.53	49.08	1.42
	Overall	6547	55.41	355.44	200.64	192.58	54.58	0.67
Day	2004	173	73.40	169.70	138.88	160.10	36.83	2.80
	2005	314	166.99	218.90	191.38	191.00	18.59	1.05
	2006	NA	NA	NA	NA	NA	NA	NA
	2007	30	157.86	157.86	157.86	157.86	0.00	0.00
	2008	NA	NA	NA	NA	NA	NA	NA
	2009	299	104.24	278.15	158.50	142.12	43.35	2.51
Night	2004	590	110.40	214.40	148.74	152.20	20.29	0.84
	2005	734	150.69	225.69	190.81	192.55	18.11	0.67
	2006	1191	146.33	333.97	236.52	224.55	46.50	1.35
	2007	1152	146.45	231.21	189.39	187.88	22.02	0.65
	2008	1176	132.12	355.44	238.43	221.37	74.59	2.17
	2009	888	55.41	298.39	190.64	188.25	48.26	1.62

Table W4 — Summary statistics of spill percentage during subyearling Chinook salmon passage from data used in studies at McNary Dam in 2004–2009.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2004	1263	0.00	22.24	0.23	0.00	2.23	0.06
	2005	1165	0.00	77.82	56.08	70.95	27.39	0.80
	2006	1626	0.72	63.71	47.71	41.64	8.81	0.22
	2007	1458	37.15	62.66	51.18	42.68	10.12	0.27
	2008	1484	0.19	62.61	51.12	51.59	8.73	0.23
	2009	1460	0.00	67.85	51.18	51.25	5.22	0.14
	Overall	8456	0.00	77.82	43.57	50.79	22.14	0.24
Day	2004	418	0.00	0.00	0.00	0.00	0.00	0.00
	2005	355	10.09	77.82	59.27	70.89	24.30	1.29
	2006	114	39.76	63.47	46.99	41.71	8.94	0.84
	2007	124	37.15	62.66	46.49	41.18	9.28	0.83
	2008	79	37.76	62.45	50.64	44.50	9.47	1.07
	2009	412	49.52	67.13	51.79	51.57	1.92	0.09
Night	2004	845	0.00	22.24	0.34	0.00	2.72	0.09
	2005	810	0.00	77.53	54.68	71.07	28.54	1.00
	2006	1512	0.72	63.71	47.77	41.64	8.80	0.23
	2007	1334	39.58	62.22	51.62	57.43	10.09	0.28
	2008	1405	0.19	62.61	51.15	51.59	8.69	0.23
	2009	1048	0.00	67.85	50.94	51.17	6.03	0.19

Table W5 — Summary statistics of tag burden (percent) of subyearling Chinook salmon from data used in studies at McNary Dam in 2004–2009.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2004	1263	1.32	7.01	5.03	5.12	1.19	0.03
	2005	1165	1.66	5.00	3.75	3.82	0.68	0.02
	2006	1626	1.78	5.93	4.75	4.88	0.76	0.02
	2007	1458	1.34	6.25	4.73	4.88	0.83	0.02
	2008	1484	0.68	6.67	4.86	4.94	0.85	0.02
	2009	1460	1.38	5.93	4.18	4.32	0.91	0.02
	Overall	8456	0.68	7.01	4.57	4.65	0.97	0.01
Day	2004	418	1.86	7.01	5.00	4.98	1.19	0.06
	2005	355	2.06	5.00	3.76	3.82	0.68	0.04
	2006	114	2.45	5.80	4.59	4.69	0.72	0.07
	2007	124	1.81	5.93	4.71	4.86	0.87	0.08
	2008	79	2.95	6.67	5.00	5.10	0.85	0.10
	2009	412	1.58	5.93	4.18	4.32	0.91	0.04
Night	2004	845	1.32	7.01	5.05	5.18	1.19	0.04
	2005	810	1.66	5.00	3.75	3.82	0.69	0.02
	2006	1512	1.78	5.93	4.76	4.91	0.77	0.02
	2007	1334	1.34	6.25	4.73	4.88	0.83	0.02
	2008	1405	0.68	6.67	4.85	4.94	0.84	0.02
	2009	1048	1.38	5.93	4.18	4.32	0.90	0.03

Table W6 — Summary statistics of temperature during subyearling Chinook salmon passage from data used in studies at McNary Dam in 2004–2009.

[*N*, number of observations; Min, minimum; Max, maximum; SD, standard deviation; SE, standard error]

	Year	*N*	Min	Max	Mean	Median	SD	SE
Overall	2004	1263	18.83	21.94	20.12	20.06	0.82	0.02
	2005	1165	17.11	21.06	18.76	19.06	1.08	0.03
	2006	1626	15.70	21.60	18.54	18.80	1.45	0.04
	2007	1458	16.28	20.78	18.70	19.28	1.47	0.04
	2008	1484	14.56	20.06	17.84	18.28	1.55	0.04
	2009	1460	16.22	22.39	19.10	19.06	1.71	0.04
	Overall	8456	14.56	22.39	18.81	19.17	1.55	0.02
Day	2004	418	18.83	21.78	20.10	19.89	0.84	0.04
	2005	355	17.17	21.06	18.92	19.22	1.08	0.06
	2006	114	16.30	21.30	19.58	19.80	1.03	0.10
	2007	124	16.50	20.78	19.08	19.39	1.06	0.10
	2008	79	15.33	20.00	18.22	18.33	1.19	0.13
	2009	412	16.33	22.22	19.28	19.33	1.72	0.08
Night	2004	845	18.89	21.94	20.13	20.11	0.81	0.03
	2005	810	17.11	20.78	18.69	18.83	1.08	0.04
	2006	1512	15.70	21.60	18.47	18.70	1.45	0.04
	2007	1334	16.28	20.78	18.66	19.28	1.50	0.04
	2008	1405	14.56	20.06	17.82	18.28	1.56	0.04
	2009	1048	16.22	22.39	19.03	19.00	1.70	0.05

Appendix X. Capture History Summary of Subyearling Chinook Salmon from Data Used in Studies at McNary Dam in 2004–2009.

[Occ. represents the occasion number after release. R(i) represents numbers released and j=2 and 3 indicate the released number detected at each downstream site]

Group 1 control day 2004					Group 7 turbine day 2004				
Occ.	R(i)	j=2	j=3	Total	Occ.	R(i)	j=2	j=3	Total
1	590	466	30	496	1	255	157	14	171
2	466		283	283	2	157		95	95

Group 2 control day 2005					Group 8 turbine day 2005				
Occ.	R(i)	j=2	j=3	Total	Occ.	R(i)	j=2	j=3	Total
1	734	462	149	611	1	76	37	16	53
2	462		370	370	2	37		29	29

Group 3 control day 2009					Group 9 turbine day 2009				
Occ.	R(i)	j=2	j=3	Total	Occ.	R(i)	j=2	j=3	Total
1	888	789	19	808	1	160	116	1	117
2	789		658	658	2	116		92	92

Group 4 control night 2004					Group 10 turbine night 2004				
Occ.	R(i)	j=2	j=3	Total	Occ.	R(i)	j=2	j=3	Total
1	173	105	14	119	1	245	125	19	144
2	105		65	65	2	125		70	70

Group 5 control night 2005					Group 11 turbine night 2005				
Occ.	R(i)	j=2	j=3	Total	Occ.	R(i)	j=2	j=3	Total
1	314	230	44	274	1	41	19	12	31
2	230		192	192	2	19		18	18

Group 6 control night 2009					Group 12 turbine night 2009				
Occ.	R(i)	j=2	j=3	Total	Occ.	R(i)	j=2	j=3	Total
1	299	265	1	266	1	113	69	2	71
2	265		216	216	2	69		48	48

Appendix Y. Results of Correlation Analyses Subyearling Chinook Salmon from Data Used in Studies at McNary Dam in 2004–2005 and 2009.

Table Y1. Table of correlation indices of data from subyearling Chinook salmon from the turbine group from data used in studies at McNary Dam in 2004, 2005, and 2009.

[Pearson correlation coefficients are listed above the probabilities of obtaining a greater value under the hypothesis that Rho = 0. Sample size is 890; <, less than; see table 2 for variable name definitions]

	TOTQ	PER_SPI	HEAD	TURQ	TURLOC	PHOTO	TEMP	WEIGHT	TAG BURDEN
TOTQ	1.0000	0.4428	-0.7172	0.2668	0.0977	-0.3370	-0.6506	-0.2352	-0.1389
		<0.0001	<0.0001	<0.0001	0.0035	<0.0001	<0.0001	<0.0001	<0.0001
PER_SPI		1.0000	0.0987	-0.4328	0.1989	-0.0186	-0.2085	-0.1835	-0.3585
			0.0032	<0.0001	<0.0001	0.5794	<0.0001	<0.0001	<0.0001
HEAD			1.0000	-0.4883	0.0585	0.3116	0.5662	0.1904	0.0287
				<0.0001	0.0811	<0.0001	<0.0001	<0.0001	0.3925
TURQ				1.0000	-0.1302	-0.3232	-0.2785	0.0185	0.0931
					<0.0001	<0.0001	<0.0001	0.5807	0.0054
TURLOC					1.0000	0.0343	0.0364	0.0186	-0.0295
						0.3066	0.2786	0.5805	0.3793
PHOTO						1.0000	0.1445	0.0682	0.0238
							<0.0001	0.0421	0.4781
TEMP							1.0000	0.2297	0.1108
								<0.0001	0.0009
WEIGHT								1.0000	-0.6328
									<0.0001

Table Y2. Table of correlation indices of data from subyearling Chinook salmon from the control group from data used in studies at McNary Dam in 2004–2005 and 2009.

[Pearson correlation coefficients are listed above the probabilities of obtaining a greater value under the hypothesis that Rho = 0. Sample size is 2,998; <, less than; see table 2 for variable name definitions]

	TOTQ	PER_SPI	PHOTO	TEMP	WEIGHT	TAG BURDEN
TOTQ	1.0000	0.3941	-0.1364	-0.6318	-0.2725	-0.0937
		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
PER_SPI		1.0000	0.0631	-0.1137	-0.2930	-0.4022
			0.0005	<0.0001	<0.0001	<0.0001
PHOTO			1.0000	0.0036	-0.0380	-0.0373
				0.8421	0.0374	0.0412
TEMP				1.0000	0.2450	0.0250
					<0.0001	0.1720
WEIGHT					1.0000	-0.4751
						<0.0001

Appendix Z. Model Summary from Analyses of Recapture Probabilities (p) of Subyearling Chinook Salmon from Data used in Studies at McNary Dam in 2004–2005 and 2009.

[Models of p include those in which values can vary in various combinations of detection site (t) and group (treatment, year, and photoperiod). A '*' indicated a multiplicative effect, a '+' indicates an additive effect, and a '.' indicates a common value fitted to all groups and reaches. A multiplicative model (g*t) of apparent survival (phi) was used in all models. K indicates the number of estimable parameters]

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	K	Deviance
{1 Phi(g*t), p(g*t)}	8445.31	0.00	1.00	1.00	36	8307.72
{2 Phi(g*t), p(g+t)}	8645.42	200.10	0.00	0.00	36	8573.02
{3 Phi(g*t), p(g)}	8792.06	346.75	0.00	0.00	36	8719.66
{4 Phi(g*t), p(t)}	8817.73	372.41	0.00	0.00	25	8767.53
{5 Phi(g*t), p(.)}	8964.37	519.05	0.00	0.00	25	8914.17

Appendix AA. Model-selection Results from Radio- and Acoustic-tagged Subyearling Chinook Salmon from Data used in Studies at McNary Dam in 2004–2005 and 2009.

[Presence of a factor in a model is indicated by an 'x' in the column for that factor. Model 1 was a global model including all group covariates and their interactions (g) as well as all individual covariates and interactions listed. Distance to the first downriver gate (gated) was only used when year was present in the model. All models shared a common g*reach model of recapture probability. K indicates the number of parameters. Unlike other analyses in this report, a treatment and weight interaction (trt*wt) was tested post hoc here instead of the weight main effect because the treatment and tag burden interaction (trt*tagb) was supported rather than the tag burden main effect in this data set]

									Individual Covariates																			
	Group Covariates								Biological								Operational									Model Selection Results		
Model Number	g	trt	yr	photo	trt*yr	trt*photo	yr*photo	trt*yr*photo	gated	trt*Wt	tagb	trt*tagb	yr*tagb	temp	trt*temp	yr*temp	persp	trt*persp	head linear	head quadratic	turloc	turq linear	turq quadratic	turloc*photo	totq	AICc	K	Deviance
1	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	x	x		x	x		x	x	8986.	4	8888.0
2	x	x	x	x	x	x	x	x			x	x		x	x	x	x	x	x		x	x		x	x	8283.	4	8188.6
3	x	x	x	x	x	x	x	x			x	x		x	x		x	x	x		x	x		x	x	8303.	4	8212.4
4a		x		x		x			x		x	x		x	x	x	x	x	x		x	x		x	x	8306.	3	8227.5
4b		x	x	x	x	x	x				x	x		x	x	x	x	x	x		x	x		x	x	8282.	4	8191.8
4c		x	x	x		x	x				x	x		x	x	x	x	x	x		x	x		x	x	8279.	4	8193.0
4d		x	x	x		x					x	x		x	x	x	x	x	x		x	x		x	x	8281.	4	8198.8
5		x	x	x			x				x	x		x	x	x	x	x	x		x	x		x	x	8277.	4	8193.1
6		x	x				x				x	x		x	x	x	x	x	x		x	x		x	x	8285.	4	8203.0
7		x	x	x			x				x	x		x		x	x	x	x		x	x		x	x	8276.	4	8193.7
8		x	x	x			x				x	x		x		x	x	x	x		x	x			x	8277.	4	8196.7
9		x	x	x			x				x	x		x		x	x		x		x	x		x	x	8277.	4	8197.0
10		x	x	x			x				x	x				x	x	x	x		x	x		x	x	8278.	4	8197.6
11		x	x	x			x				x	x		x		x	x	x	x		x	x		x		8274.	4	8194.0
12		x	x	x			x				x	x		x		x		x	x		x	x		x		8272.	3	8194.0
13		x	x	x			x				x	x		x		x		x	x			x		x		8273.	3	8196.9
14a		x	x	x			x				x	x		x		x		x			x	x		x		8268.	3	8194.0
14b		x	x	x			x				x	x		x		x		x		x	x	x		x		8274.	3	8196.1
15a		x	x	x			x				x	x		x		x		x			x			x		8266.	3	8194.1
15b		x	x	x			x				x	x		x		x		x			x		x	x		8269.	3	8193.3
16		x	x	x			x				x			x		x		x			x			x		8267.	3	8197.5
17*		x	x	x			x					x		x		x		x			x			x		8264.	3	8194.1
18		x	x	x			x			x				x		x		x			x			x		8267.	3	8196.7

Appendix AB. Beta (Slope) Coefficients of Estimable Survival Parameters of Subyearling Chinook Salmon from Data used in Studies at McNary Dam in 2004–2005 and 2009.

[The data are from model 17 in appendix AA]

Parameter	Beta	Standard Error	95% Confidence Lower	95% Confidence Upper
Intercept	6.064139	1.900079	2.339984	9.788295
treatment	0.376022	0.462350	-0.530190	1.282228
photo	-0.738320	0.206600	-1.143260	-0.333390
2005	-6.999290	2.680197	-12.252500	-1.746100
2009	6.903824	2.236789	2.519718	11.287930
photo*2005	0.847542	0.316948	0.226325	1.468760
photo*2009	0.351506	0.253333	-0.145030	0.848038
tag burden*treatment	-0.201000	0.079477	-0.356770	-0.045220
spill percentage*treatment	-0.010710	0.004455	-0.019440	-0.001980
turbine location	-0.044660	0.026510	-0.096620	0.007298
turbine location*photo	0.045399	0.025110	-0.003820	0.094615
temp	-0.206850	0.093677	-0.390460	-0.023240
temp*2005	0.367133	0.139097	0.094503	0.639763
temp*2009	-0.333630	0.110448	-0.550100	-0.117150

Appendix AC. Capture History Summary of Subyearling Chinook Salmon from Data Used in Studies at McNary Dam in 2004–2009.

[Occ. represents the Occasion number after release. R(i) represents numbers released and j=2 and 3 indicate the released number detected at each downstream site]

Group 1 control day 2004

Occ.	R(i)	j=2	j=3	Total
1	590	466	30	496
2	466		283	283

Group 2 control day 2005

Occ.	R(i)	j=2	j=3	Total
1	734	462	149	611
2	462		370	370

Group 3 control day 2006

Occ.	R(i)	j=2	j=3	Total
114	1191	936	150	1086
74	936		801	801

Group 4 control day 2007

Occ.	R(i)	j=2	j=3	Total
1	1152	382	567	949
2	382		317	317

Group 5 control day 2008

Occ.	R(i)	j=2	j=3	Total
1	1176	961	95	1056
2	961		851	851

Group 6 control day 2009

Occ.	R(i)	j=2	j=3	Total
1	888	789	19	808
2	789		658	658

Group 7 control night 2004

Occ.	R(i)	j=2	j=3	Total
1	173	105	14	119
2	105		65	65

Group 8 control night 2005

Occ.	R(i)	j=2	j=3	Total
1	314	230	44	274
2	230		192	192

Group 9 control night 2007

Occ.	R(i)	j=2	j=3	Total
1	30	9	16	25
2	9		8	8

Group 10 control night 2009

Occ.	R(i)	j=2	j=3	Total
1	299	265	1	266
2	265		216	216

Group 11 turbine day 2004

Occ.	R(i)	j=2	j=3	Total
1	255	157	14	171
2	157		95	95

Group 12 turbine day 2005

Occ.	R(i)	j=2	j=3	Total
1	76	37	16	53
2	37		29	29

Group 13 turbine day 2006

Occ.	R(i)	j=2	j=3	Total
1	321	202	32	234
2	202		172	172

Group 14 turbine day 2007

Occ.	R(i)	j=2	j=3	Total
1	182	64	64	128
2	64		50	50

Group 15 turbine day 2008

Occ.	R(i)	j=2	j=3	Total
1	232	156	13	169
2	156		137	137

Group 16 turbine day 2009

Occ.	R(i)	j=2	j=3	Total
1	160	116	1	117
2	116		92	92

Group 17 turbine night 2004

Occ.	R(i)	j=2	j=3	Total
1	245	125	19	144
2	125		70	70

Group 18 turbine night 2005

Occ.	R(i)	j=2	j=3	Total
1	41	19	12	31
2	19		18	18

Group 19 turbine night 2006

Occ.	R(i)	j=2	j=3	Total
1		74	7	81
2			63	63

Group 20 turbine night 2007

Occ.	R(i)	j=2	j=3	Total
1	94	31	19	50
2	31		29	29

Group 21 turbine night 2008

Occ.	R(i)	j=2	j=3	Total
1	79	61	5	66
2	61		50	50

Group 22 turbine night 2009

Occ.	R(i)	j=2	j=3	Total
1	113	69	2	71
2	69		48	48

Appendix AD. Model Summary from Analyses of Recapture Probabilities (p) of Subyearling Chinook Salmon from Data used in Studies at McNary Dam in 2004–2009.

[Models of p include those in which values can vary in various combinations of detection site (t) and group (treatment, year, and photoperiod). A '*' indicated a multiplicative effect, a '+' indicates an additive effect, and a '.' indicates a common value fitted to all groups and reaches. A multiplicative model (g*t) of apparent survival (phi) was used in all models. K indicates the number of estimable parameters]

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	K	Deviance
{1 Phi(g*t), p(g*t)}	17951.17	0.00	1.00	1.00	66	17818.54
{2 Phi(g*t), p(g)}	18907.49	956.33	0.00	0.00	66	18774.86
{3 Phi(g*t), p(g+t)}	18921.35	970.19	0.00	0.00	66	18788.73
{4 Phi(g*t), p(t)}	19677.74	1726.57	0.00	0.00	45	19587.44
{5 Phi(g*t), p(.)}	19692.38	1741.21	0.00	0.00	45	19602.08

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Publishing support provided by the U.S. Geological Survey
Publishing Network, Tacoma Publishing Service Center

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Beeman and others—**Analyses of Potential Factors Affecting Survival of Juvenile Salmonids Volitionally Passing Through Turbines at McNary and John Day Dams, Columbia River**—Open-File Report 2011-1227