

**A model of the travel time of migrating juvenile salmon,
with an application to Snake River spring chinook**

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Abstract

We develop a model of the travel time of juvenile salmonids migrating through a river reach. The model is derived from an advection-diffusion equation with an absorbing boundary at the downstream collection site. The resulting travel time distribution is determined by two biologically meaningful parameters: migration rate and the rate of population spreading. The model is applied to travel time distributions for 46 cohorts of juvenile spring chinook salmon *Oncorhynchus tshawytscha* migrating through the Lower Granite Pool (52 kilometers in length) in the Snake River. Parameters are estimated using maximum likelihood. A Pearson's χ^2 goodness-of-fit test shows that the model is not rejected ($\alpha = 0.05$) for the majority of cohorts.

Introduction

The downstream migration of juvenile salmon is a critical stage of salmon life history, but migratory behavior is not well understood. Some species of salmon migrate hundreds of miles as juveniles and incur heavy mortality due to factors such as predation and disease. In the Columbia River system, downstream migrants pass as many as nine dams during their migration to the ocean. In addition to being a direct source of mortality, dams impede migration by creating large reservoirs which reduce river velocity (Raymond 1968) and disrupt the timing of migration. Also, the reservoirs have higher temperatures and less turbidity compared to free flowing rivers, resulting in greater susceptibility to predation and disease (Park 1969). Accordingly, mitigation efforts have targeted the downstream migration phase as crucial for revitalizing salmon populations in the Columbia River system (NPPC 1992).

This paper focuses on the travel time of outmigrating juvenile salmonids. The length of time juveniles migrate downstream has several implications for salmon populations. During outmigration juvenile salmon undergo a series of physiological and behavioral changes called smoltification, preparing them for saltwater (Hoar 1976). Since arrival to the estuary is coordinated with smoltification (Folmar and Dickhoff 1980), outmigration timing is important to ensure that smolts reach saltwater when they are physiologically ready. From a management standpoint, the ability to predict fish arrival time distributions at dams aids in directing hydrosystem operations to enhance fish survival. The results presented here are currently being used in the Columbia River Salmon Passage (CRiSP) model (Anderson, et al. 1996), a system model that describes smolt passage and survival.

Our approach to the travel time problem is to develop a probabilistic model of the process. The model is based on an advection-diffusion equation, which describes the spatial and temporal

distribution of a migrating population. Travel time through a river reach is expressed by first-passage time to the end of the reach. Diffusion-based models have been applied to many dispersing populations (see (Okubo 1980) for a review). The advection term adds directed movement, allowing the population to move downstream. We expand upon previous applications of advection-diffusion equations to fish migration (Saila and Flowers 1969; DeAngelis and Yeh 1984; Hiramatsu and Ishida 1989; Crittenden 1994) by including a first-passage component and a detailed statistical analysis.

The model is evaluated using data on the migration of yearling chinook salmon *Oncorhynchus tshawytscha* through the Lower Granite Reservoir of the Snake River, the primary tributary of the Columbia River. Active migrants were collected in the river, marked with a PIT (passive interrogative transponder) tag, and released at the head of the reservoir. PIT tags give the exact time of crossing at downstream interrogation sites (Prentice, et al. 1990), so a travel time distribution can be determined for a cohort of fish released at a single time. For each cohort, model parameters are estimated using maximum likelihood, and goodness-of-fit is assessed using Pearson's χ^2 test.

Methods

The Model

The goal of the model is to produce a probability density function, $g(t)$, for the distribution of travel times to a downstream site. The river is considered one-dimensional, with a release point at $X = 0$ and a collection site at $X = L$ (see Figure 1). Travel time experiments involve collecting fish, marking them with a tag and releasing them as a group. The fish are collected at a downstream site giving a travel time distribution for the group. The model is formulated so that the output can be compared directly to these type of data.

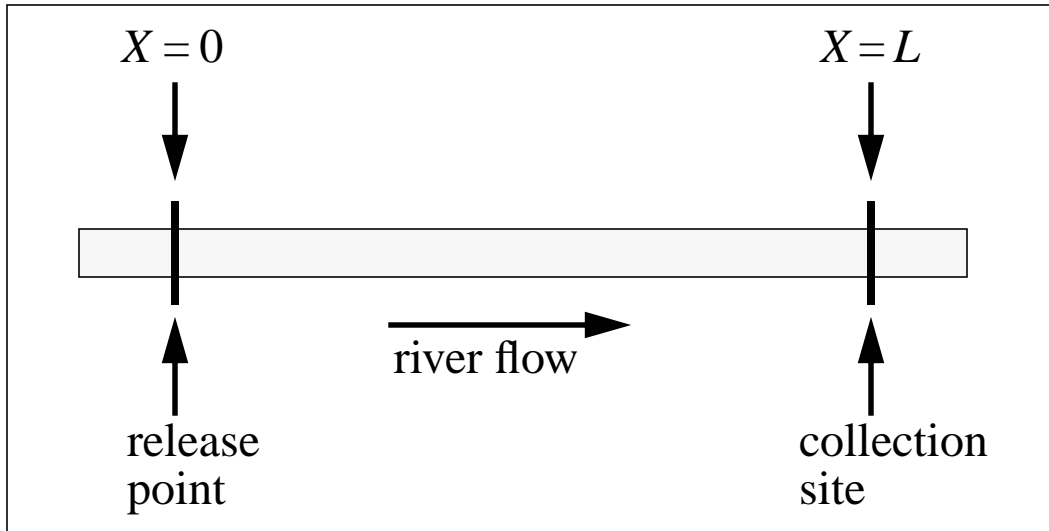


Figure 1. A schematic diagram of the travel time problem. The river is considered one-dimensional, with a group of fish released at $X = 0$ and collected downstream at $X = L$.

overview of migration models

Migration models can express the movements of individuals or populations. Both of these approaches yield similar results in terms of travel times through a river reach.

The migration of individuals is commonly developed in terms of a biased random walk (DeAngelis and Yeh 1984) where the probability of moving downstream is greater than the probability of moving upstream during a time increment. Travel times are determined by recording when an individual first reaches a downstream point. A travel time distribution is generated by conducting many realizations of the process. This procedure is intuitive but cumbersome.

Population level migration models are more complex mathematically but are easier to apply to data because resulting distributions can be stated as an explicit equation instead of simulation results. We have chosen this approach because of its applicability.

modeling travel times in terms of population density

The spatial-temporal distribution of fish along a reach can be expressed as $p(x,t)$. With a population size of N , the population density in the river is $N \cdot p(x, t)$. The travel time model begins with the assumption that $p(x,t)$ is described by an advection-diffusion equation. This equation is derived from a biased random walk by taking the “diffusion limit” (Okubo 1980), which allows the time and space increments to become arbitrarily small. Thus, the advection-diffusion equation is essentially a continuous analog to the discrete random walk process. It is expressed as:

$$\frac{\partial}{\partial t} p(x, t) = -r \frac{\partial p}{\partial x} + \frac{\sigma^2}{2} \frac{\partial^2 p}{\partial x^2}. \quad (1)$$

This equation describes the rate of change of population density with respect to time in terms of an advection (or drift) term (first term right hand side) and diffusion term (second term right hand side). The parameter r determines the average rate of downstream movement, and σ determines the rate of population spreading.

The first step is to solve equation (1) for $p(x,t)$. With unrestricted boundaries and initial conditions of a point release at $X = 0$ and $t = 0$, $p(x,t)$ is a normally distribution (with respect to X for fixed t) with mean rt and variance $\sigma^2 t$. Both the mean and variance increase linearly with time, corresponding to the population moving downstream and spreading with time.

While fish can move upstream or downstream in a reservoir, once they pass a dam, they cannot move upstream from that site. To account for this, an absorbing boundary is imposed at the dam ($X = L$). Once fish reach a dam, they are “absorbed” and passed to the next reservoir. Movement upstream from the release point ($X = 0$) is unrestricted, but the advection term moves fish away from this point. With these boundary conditions and the same initial conditions as above, equation

(1) can still be solved for $p(x,t)$ (Goel and Richter-Dyn 1974) but is more complex than in the previous case.

Since the absorbing boundary corresponds to fish passage at a dam, $p(x,t)$ can be used to derive an arrival time distribution at a dam. The first step is to determine the probability of remaining above the dam at a given point in time (denoted $P(L,t)$). This is achieved by integrating the probability density upstream of the dam:

$$P(L, t) = \int_{-\infty}^L p(x, t) dx . \quad (2)$$

To derive a probability density function for the travel time distribution to $X = L$ for a group of fish released at $X = 0$, equation (2) is differentiated to determine the rate of loss of density from the reach:

$$\begin{aligned} g(t) &= -\frac{d}{dt}P(L, t) , \\ &= \frac{L}{\sqrt{2\pi\sigma^2 t^3}} \exp\left(\frac{-(L - rt)^2}{2\sigma^2 t}\right) \end{aligned} \quad (3)$$

(Cox and Miller 1965). Equation (3) has been called the “inverse Gaussian” distribution (Tweedie 1957a, 1957b; Folks and Chhikara 1978).

Plots of this distribution for various values of r and σ are shown in Figure 2. Note that the distribution is unimodal and right skewed, which is consistent with most observed fish travel time distributions. Decreasing r moves the mode of the distribution to the right and flattens out the distribution. Increasing σ has the effect of moving the mode to the left and flattening the distribution.

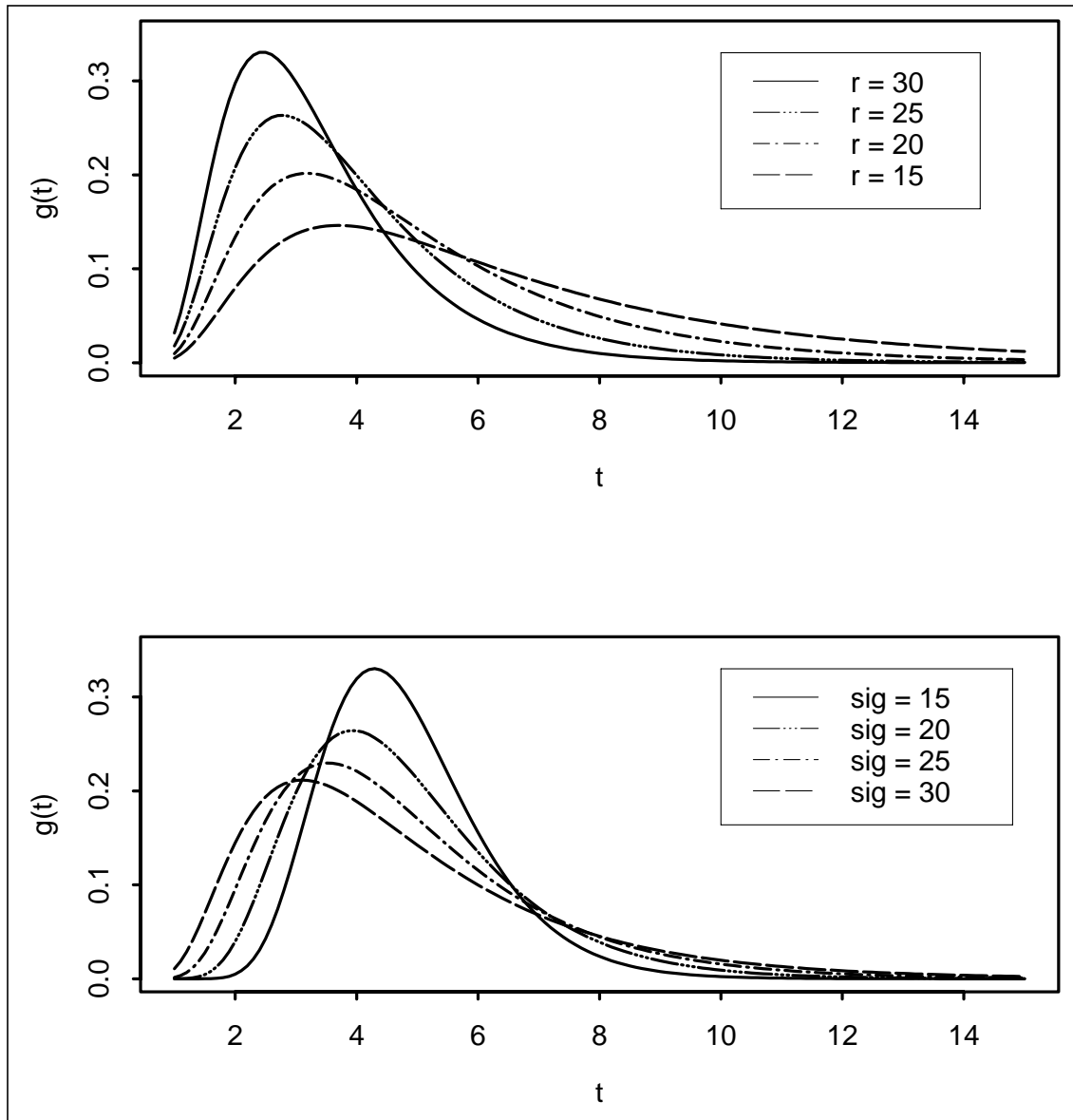


Figure 2. Plots of equation (3), the travel time distribution, with various parameter values. In the top figure, σ is set at 25, and r is varied. In the bottom plot, r is set at 25, and σ is varied. In both plots, $L = 120$.

Statistical methods

assumptions

Several assumptions are made in the travel time model. The first assumption is that individuals in a cohort are independently, identically distributed. Second, the migration process is time

homogeneous – there is no diel or seasonal variation in the migratory behavior. Third, each individual has an equal probability of being sampled at the downstream collection site. This means that survival probabilities are identical among the individuals, and the probability of recapture is also identical. More complexity can be added to the model by relaxing these assumptions.

parameter estimation and confidence intervals

The maximum likelihood estimators (mles) for the two parameters r and σ are:

$$\hat{r} = \frac{L}{\bar{t}} \quad (4)$$

$$\hat{\sigma} = L \sqrt{\frac{1}{N} \sum_{i=1}^N \left(\frac{1}{t_i} - \frac{1}{\bar{t}} \right)^2}, \quad (5)$$

where t_i is the observed arrival time of the i th individual, \bar{t} is the average travel time of the cohort, and N is the number of recaptured individuals in the cohort. Notice that the mle for r is the average migration rate and the mle for σ involves the difference between the harmonic mean and reciprocal of the arithmetic mean of the travel time. The maximum likelihood estimators of these two parameters are independent (Chhikara and Folks 1989), and much of the statistical inference involving the inverse Gaussian distribution parallels that of the normal distribution.

Confidence intervals for the parameters r and σ are available (Tweedie 1957a, 1957b; Folks and Chhikara 1978; Chhikara and Folks 1989). A 100(1- α) percent confidence interval for r is

$$CI_r = \left(\hat{r} \left[1 - \frac{a\hat{\sigma}}{L} \sqrt{\frac{\bar{t}}{N-1}} \right], \hat{r} \left[1 + \frac{a\hat{\sigma}}{L} \sqrt{\frac{\bar{t}}{N-1}} \right] \right) \text{ if } 1 - \frac{a\hat{\sigma}}{L} \sqrt{\frac{\bar{t}}{N-1}} > 0, \text{ and}$$

$$CI_r = \left(0, \hat{r} \left[1 + \frac{a\hat{\sigma}}{L} \sqrt{\frac{\bar{t}}{N-1}} \right] \right) \text{ otherwise.} \quad (6)$$

Here, a is the ($\alpha/2$)th percentile of Student's t distribution with $N - 1$ degrees of freedom. A 100(1-

α) percent confidence interval for σ can be constructed as:

$$CI_{\sigma} = \left(\hat{\sigma} \sqrt{\frac{N}{a}}, \hat{\sigma} \sqrt{\frac{N}{b}} \right), \quad (7)$$

where a is the $(1-\alpha/2)$ th percentile of the χ^2 distribution with $N - 1$ degrees of freedom and b is the $(\alpha/2)$ th percentile of the same distribution.

Notice that the confidence interval for r is determined by the estimates of r and σ , but the confidence interval for σ is determined only by the estimate of σ . Also, the confidence intervals of r and σ are dependent on sample size, with the confidence intervals decreasing as N increases.

goodness-of-fit

Pearson's goodness-of-fit test (Sokal and Rohlf 1981) is used to assess the fit of the model to the data. The cells are constructed such that the expected number of individuals per cell is equal over all cells; this makes the test the most efficient with continuous data (Moore 1986). The expected number of individuals per cell is computed as

$$\hat{n}_i = N \cdot \hat{p}_i = N \cdot \int_{T_{i-1}}^{T_i} g(t) dt, \quad i = 1, 2, \dots, k, \quad (8)$$

where T_i and T_{i+1} delimit the i th time period. The number of cells, k , is determined by Wald's algorithm (Mann and Wald, 1942):

$$k = 4 \left(\frac{2N^2}{c(\alpha)^2} \right), \quad (9)$$

where $c(\alpha)$ is the $(1-\alpha)$ th quantile of the standard normal distribution, with $\alpha = 0.05$. Once the number of cells is set, the limits of integration in equation (8) can be determined with an iterative procedure. The X^2 test statistic is compared to a χ^2 distribution with $(k - 1 - 2)$ degrees of freedom;

the extra two degrees of freedom are subtracted off to account for the two parameters estimated from the data. A p -value is determined for each cohort, with the model being rejected for very low p -values.

Data

To demonstrate the data analysis procedures and to assess the performance of the model, we applied the model to groups of chinook salmon *Oncorhynchus tshawytscha* migrating through the Lower Granite Reservoir in southeastern Washington State. As part of the smolt monitoring program of Idaho Department of Fish and Game (Buettner 1991), fish were captured at the Snake River Trap, fitted with passive integrated transponder (PIT) tags, and sampled at Lower Granite Dam, 52 km downstream from the release site (Figure 3)

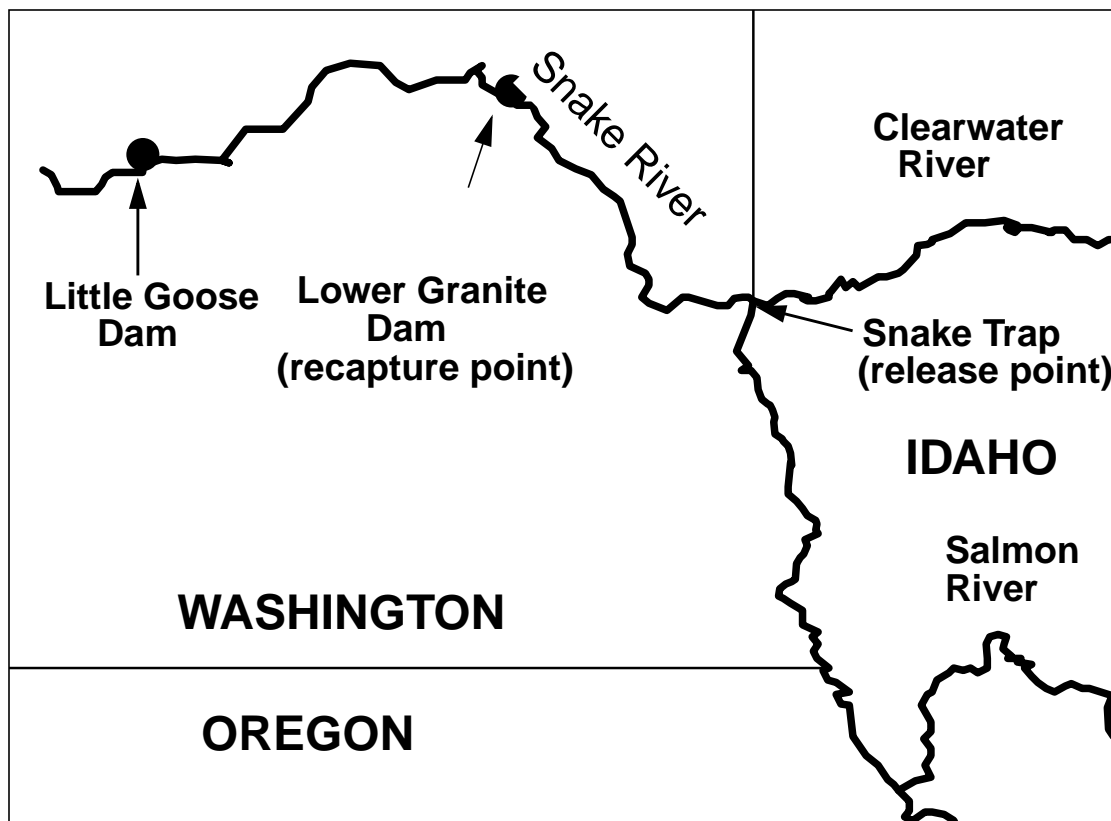


Figure 3. Map showing the release and recapture sites for the Snake River spring chinook salmon.

The chinook salmon in this study were active migrants of unknown origin (hatchery versus wild). Although the run type (spring versus fall) of these fish was not determined at tagging, it is likely that the vast majority of these fish were spring (yearling) chinooks based on their lengths (most fish longer than 110 millimeters) and migration timing (early spring). The migratory season begins in early April, and fish released after May 2 were excluded because after this date average fish length began declining, indicating a possible presence of fall chinook. Treating these fish as spring chinook is consistent with other treatments of this group of fish (e.g., Fish Passage Center 1991). The PIT tag, 12 mm long, is inserted in the fish's body cavity (Prentice, et al. 1990). At monitoring sites the tag emits a unique signal in response to excitation from an interrogation system. The signal is decoded to yield information about instantaneous passage times of individuals. The tags do not adversely affect the fish's survival or swimming performance (Prentice, et al. 1990). Fish were tagged and released as groups on a daily basis throughout the migration season.

Based on the results of simulations and plots of the confidence intervals and bias (Zabel 1994), we used a target cohort sample size of 100 fish observed at the downstream collection site, with a minimum sample size of 80. Release groups were lumped together (if necessary) from up to three consecutive days of release to construct "cohorts" with these sample sizes. If a minimum sample size of 80 could not be obtained from release groups over a three day period, these groups were excluded from the analysis. Also, if a cohort had a sample size of 100 fish or more, no more release groups were lumped into that cohort. 46 cohorts were analyzed, with releases occurring over the six year period 1989-1994.

Results

Table 1 contains results of the data analysis for each of the cohorts, including their sample sizes and release dates. The table provides parameter estimates with 95% confidence intervals and goodness-of-fit p -values.

Migration rate (\hat{r}) ranges from 3.08 km per day to 12.38 km per day. Temporal trends are apparent, with fish generally migrating faster later in the season. The rate of spreading ($\hat{\sigma}$) ranges from 4.58 km/day^{1/2} to 12.43km/day^{1/2}.

Of the 46 cohorts, 24 have goodness-of-fit p -values greater than 0.05, and of these, 17 have p -values greater than or equal to 0.25, indicating that the model performed well for many of the cohorts. Year-to-year variability in model performance is apparent. In 1993, eight out of nine cohorts have p -values greater than or equal to 0.05. On the other hand, in 1991, seven out of ten cohorts have p -values less than 0.05, and in 1994, seven out of eight had p -values less than 0.05.

While the goodness-of-fit tests give statistical measures of the model fit, plots of the model and the data give a qualitative sense of how well the model performs. Figure 4 contains sample plots of the modeled distribution compared to data for a variety of p -values. Even for very low p -values, the model captures the mode and skewness of the distributions.

Discussion

The two parameter travel time model effectively describes the travel time distributions of the Snake River spring chinook. From a statistical standpoint, the model is rejected more times than expected if there was a perfect correspondence between the model and data. Considering the low dimensionality of the model (2 parameters) and homogeneity assumptions, we would not expect

the model to completely describe the data. Given that the X^2 test is conservative (Moore 1986), we are encouraged that for the majority of cohorts the model is not rejected based on the goodness-of-fit tests. Also, for cohorts with low p -values, the plots (Figure 4) show that the model still captures the main features of the arrival distributions.

In addition, the model has other desirable features. The closed form solution (equation (3)) is easy to apply to data, with parameter estimates and confidence intervals easily computed. The parameters are intuitive and are biologically meaningful: r is the average downstream migration rate, and σ is the rate of population spreading. Also, since both the parameters are rates, they can be compared among cohorts even when the river reaches are different lengths. Thus, the model parameters are meaningful descriptors of population behavior.

The underlying model assumptions are simple and intuitive – downstream migration is based on a random and directed movement component, and behavior is constant during the migration period. For other stocks or species, more complexity can be added to incorporate behaviors such as delay in migration, diel migration or population heterogeneity (Zabel 1994).

To predict fish arrival times through a hydrosystem, travel time parameters need to be selected a priori. It is apparent from Table 1 that parameter estimates vary among cohorts. In particular, fish migrating later in the season tend to move faster. Other factors such as river flow and river temperature may also affect migratory behavior. Elsewhere (Zabel 1994) we relate the variability in parameters to these factors and use the model in a predictive manner.

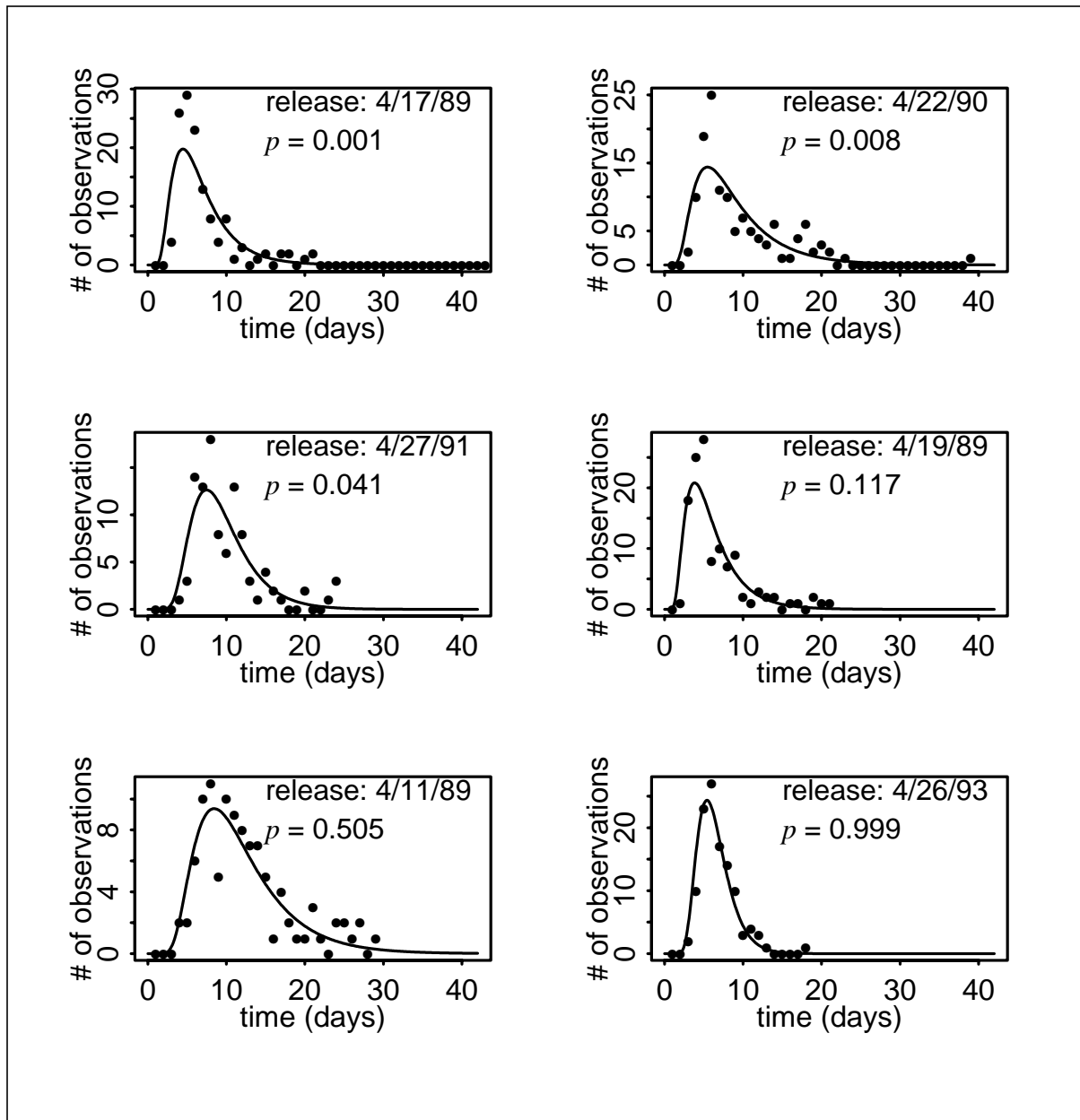


Figure 4. Plots of number of fish observed versus travel time for the model (solid line) and data (points). Cohorts were chosen to represent a variety of p -values from the goodness-of-fit tests.

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References

- Anderson, J. J., J. A. Hayes, R. W. Zabel. 1996. Columbia River Salmon Passage Model theory, calibration and validation manual. Center for Quantitative Studies in Fisheries, Forestry, and Wildlife, University of Washington, Seattle.
- Buettner, E. W. 1992. Smolt monitoring at the head of Lower Granite Reservoir and Lower Granite Dam. Report to the Bonneville Power Administration, Project number 83-323, Portland, Oregon.
- Chhikara, R. S., and J. L. Folks. 1989. The inverse Gaussian distribution. Marcel-Dekker, Inc., New York.
- Cox, D. R., and H. D. Miller. 1965. The theory of stochastic processes. Chapman and Hall, New York.
- Crittenden, R. N. 1994. A diffusion model for the downstream migration of sockeye salmon smolts. *Ecological Modelling* 71:69-84.
- DeAngelis, D. L., and G. T. Yeh. 1984. An introduction to modeling migratory behavior in fishes. Pages 445-469 in J. D. McCleave, G. P. Arnold, J. J. Dodson, and W. H. Neill, editors. *Mechanisms of migration in fishes*. Plenum Press, New York.
- Fish Passage Center. 1991. Annual report. Report to the Bonneville Power Administration, Project number 87-127, Portland, Oregon.
- Folks, J. L., and R. S. Chhikara. 1978. The inverse Gaussian distribution and its statistical applications – a review. *Journal of the Royal Statistical Society, Series B* 40:263-289.
- Folmar, C. F., and W. W. Dickhoff. 1980. The parr-smolt transformation (smoltification) and seawater adaptation in salmonids. *Aquaculture* 21:1-37.

- Goel, N. S., and N. Richter-Dyn. 1974. Stochastic models in biology. Academic Press, New York.
- Groot, C. and L. Margolis. 1991. Pacific Salmon Life Histories. University of British Columbia Press, Vancouver, British Columbia.
- Hiramatsu, K., and Y. Ishida. 1989. Random movement and orientation in pink salmon (*Oncorhynchus gorbuscha*) migrations. Canadian Journal of Fisheries and Aquatic Sciences 46:1062-1066.
- Hoar, W. S. 1976. Smolt transformation: evolution, behavior, and physiology. Journal of the Fisheries Research Board of Canada 33:1234-1252.
- Mann, H. B., and A. Wald. 1942. On the choice of the number of class intervals in the application of the chi-square test. Annals of Mathematical Statistics 13:306-317.
- Moore, D. S. 1986. Tests of the chi-squared type. Pages 63-95 in R. B. D'agostino and M. A. Stephens, editors. Goodness-Of-Fit Techniques. Marcel Dekker, Inc., New York.
- NMFS (National Marine Fisheries Service). 1995. Proposed Recovery Plan for Snake River Salmon. National Marine Fisheries Service and the National Oceanic and Atmospheric Organization.
- NPPC (Northwest Power Planning Council). 1992. Strategy for salmon. NPPC, Portland, Oregon.
- Okubo, A. 1980. Diffusion and ecological problems: mathematical models. Springer-Verlag, New York.
- Park, D. L. 1969. Seasonal changes in downstream migration of age-group 0 chinook salmon in the upper Columbia River. Transactions of the American Fisheries Society 98:315-317.
- Prentice, E. F., T. A. Flagg, and C. S. McCutcheon. 1990. Feasibility of using implantable passive

- integrated transponder (PIT) tags in salmonids. American Fisheries Society Symposium 7:317-322.
- Raymond, H. L. 1968. Migration rates of yearling chinook salmon in relation to flows and impoundments in the Columbia and Snake Rivers. Transactions of the American Fisheries Society 97:356-359.
- Saila, S. B., and J. M. Flowers. 1969. Toward a generalized model of fish migrations. Transactions of the American Fisheries Society. 98:582-588.
- Sokal, R. R., and F. J. Rohlf. 1981. Biometry. W. H. Freeman and Company, New York.
- Tweedie, M. C. K. 1957a. Statistical properties of inverse Gaussian distributions I. Annals of Mathematical Statistics 28:362-377.
- Tweedie, M. C. K. 1957b. Statistical properties of inverse Gaussian distributions II. Annals of Mathematical Statistics 28:696-705.
- Zabel, R. W. 1994. Spatial and temporal models of migrating juvenile salmon with applications. Doctoral dissertation, University of Washington, Seattle.

Table 1. Results of the application of the travel time model to Snake River spring chinook. Each line in the table represents a release cohort. The date of release is the first day of release for the cohort. Parameter estimates with confidence intervals and goodness-of-fit p -values are listed for each cohort. The parameter r represents migration rate (km/day), and the parameter σ represents rate of population spreading (km/day^{1/2}). Increasing p -values indicate better model fit.

# of fish	Release date	\hat{r} (95% C.I.)	$\hat{\sigma}$ (95% C.I.)	p
1989				
97	04/04/89	3.31 (3.00, 3.62)	6.10 (5.38, 7.14)	0.406
110	04/06/89	3.61 (3.30, 3.93)	6.34 (5.62, 7.34)	0.547
97	04/09/89	3.23 (2.89, 3.58)	6.76 (5.95, 7.91)	0.326
103	04/11/89	4.41 (4.00, 4.83)	7.29 (6.44, 8.49)	0.505
119	04/13/89	5.49 (5.03, 5.95)	7.82 (6.97, 9.00)	0.263
119	04/15/89	6.13 (5.53, 6.74)	9.69 (8.63, 11.15)	0.077
130	04/17/89	7.74 (7.02, 8.47)	10.81 (9.68, 12.36)	0.001
122	04/19/89	8.80 (7.91, 9.68)	11.92 (10.63, 13.69)	0.117
122	04/21/89	8.44 (7.65, 9.23)	10.91 (9.73, 12.53)	0.032
130	04/23/89	7.29 (6.59, 7.99)	10.74 (9.61, 12.28)	0.005
136	04/25/89	7.13 (6.61, 7.66)	8.30 (7.44, 9.46)	0.095
103	04/27/89	7.27 (6.56, 7.98)	9.66 (8.54, 11.25)	0.476
1990				
80	04/16/90	8.25 (7.51, 8.98)	8.26 (7.19, 9.85)	0.411

Table 1. Continued.

93	04/18/90	8.56	(7.87, 9.25)	8.24	(7.24, 9.68)	0.039
118	04/20/90	6.31	(5.62, 6.99)	10.73	(9.55, 12.35)	0.005
128	04/22/90	5.87	(5.27, 6.48)	10.18	(9.11, 11.66)	0.008
106	04/24/90	4.65	(4.09, 5.21)	9.67	(8.56, 11.23)	0.728
1991						
97	04/08/91	3.08	(2.85, 3.30)	4.58	(4.04, 5.37)	0.004
89	04/10/91	3.37	(3.12, 3.62)	4.71	(4.13, 5.55)	0.002
94	04/12/91	3.61	(3.35, 3.87)	4.85	(4.26, 5.69)	0.551
143	04/15/91	3.52	(3.26, 3.78)	6.02	(5.42, 6.84)	0.009
102	04/18/91	3.94	(3.62, 4.26)	5.96	(5.26, 6.94)	0.003
127	04/22/91	5.00	(4.55, 5.44)	8.21	(7.34, 9.40)	0.001
90	04/25/91	6.63	(5.70, 7.57)	12.43	(10.90, 14.65)	0.585
84	04/26/91	5.75	(5.14, 6.36)	8.39	(7.33, 9.95)	0.654
101	04/27/91	5.50	(5.06, 5.94)	6.85	(6.05, 7.99)	0.041
99	04/29/91	5.86	(5.37, 6.34)	7.21	(6.36, 8.42)	0.003
1992						
107	04/07/92	3.83	(3.51, 4.15)	6.13	(5.43, 7.12)	0.040
115	04/13/92	4.06	(3.72, 4.40)	6.64	(5.90, 7.66)	0.000
1993						
118	04/09/93	3.71	(3.43, 4.00)	5.76	(5.12, 6.63)	0.575
119	04/11/93	3.52	(3.27, 3.77)	5.26	(4.69, 6.06)	0.462
92	04/19/93	5.37	(4.96, 5.78)	6.14	(5.39, 7.22)	0.400

Table 1. Continued.

82	04/22/93	6.53	(5.97, 7.09)	7.15	(6.24, 8.50)	0.743
94	04/24/93	7.40	(6.88, 7.92)	6.67	(5.86, 7.83)	0.139
115	04/26/93	8.21	(7.69, 8.72)	6.98	(6.21, 8.05)	0.999
101	04/28/93	9.05	(8.38, 9.71)	8.03	(7.09, 9.37)	0.001
113	04/30/93	10.57	(9.93, 11.20)	7.52	(6.68, 8.69)	0.122
113	05/02/93	12.38	(11.65, 13.10)	7.98	(7.09, 9.23)	0.273
1994						
80	04/13/94	4.82	(4.41, 5.23)	5.95	(5.19, 7.10)	0.087
92	04/19/94	6.88	(6.20, 7.56)	8.99	(7.89, 10.57)	0.002
149	04/20/94	6.75	(6.21, 7.30)	9.37	(8.44, 10.61)	0.000
147	04/22/94	5.74	(5.27, 6.21)	8.68	(7.81, 9.84)	0.010
120	04/24/94	5.41	(5.01, 5.82)	6.87	(6.12, 7.90)	0.015
111	04/26/94	5.27	(4.91, 5.63)	5.99	(5.31, 6.93)	0.004
106	04/28/94	5.59	(5.26, 5.93)	5.27	(4.67, 6.12)	0.086
101	04/30/94	6.67	(6.27, 7.07)	5.59	(4.94, 6.52)	0.003