1   Identifying optimal translocation policies given factors associated with adult spring-run Chinook

2   Salmon translocation mortality

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23 **Abstract**

24 Translocation is a common management tactic used to conserve animal populations by

25 circumventing high mortality locations or events and enhance population abundance, reintroduce

26 fish to historical habitats, or mitigate for fish passage limitations. The conservation of spring-run

27 Chinook Salmon *Oncorhynchus tshawytscha* populations in the Willamette River typifies the

28 challenges associated with large-scale translocation programs. The objectives of this study were

29 to 1) evaluate factors associated with translocation mortality events and 2) identify optimal

30 translocation policies that minimize mortality risk and effort. We used an information-theoretic

31 approach evaluating factors hypothesized to influence translocation mortality.   Factors found to

32 influence survival in this analysis varied between the two dams evaluated but were related to

33 operations and annual or in-river conditions. Specifically, the amount of time it took to load fish

34 and the density of fish in tank trucks were positively associated with translocation mortality.

35 Instream flows and thermal exposure also were identified as factors associated with translocation

36 mortality; however, outplant location was not. We further used the results of model selection to

37 predict mortality risk in an effort to identify optimal translocation policies for varying numbers

38 of fish to translocate and transport truck volume. Lastly, we discuss how this analysis can be

39 incorporated into an adaptive management approach providing managers a way to integrate

40 research, monitoring, and management to improve understanding of factors associated with

41 translocation mortality and refine optimal translocation policies.

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Introduction

The process of moving organisms from one location to another (hereafter translocation) is a

common management tactic used to conserve animal populations. Managers use translocations

to enhance survival by circumventing high mortality locations or events and enhance population

abundance (e.g., stocking). For example, managers collect and translocate adult Pacific salmon

Oncorhynchus spp. upstream when in-stream conditions limit migration or pose a mortality risk

in the Central Valley of California (Mosser et al. 2013) and basins like the Willamette River in

Oregon (Beidler and Knapp 2005; Keefer et al. 2010; NMFS 1999). Natural resource agencies

also collect juvenile salmon smolts and translocate them downstream with barges and trucks in

the Columbia River Basin to minimize cumulative mortality associated with multiple dam

passage (Muir et al. 2006; Naughton et al. 2004; Schreck et al. 2006). Conservation hatchery

operations rear at-risk species such as Brook Trout *Salvelinus fontinalis* and Pallid Sturgeon

Scaphirhynchus albus and translocate individuals to natural systems within their native range to

augment populations (Humston et al. 2012; Steffensen et al. 2010). Colorado River Cutthroat

Trout *O. clarki pleuriticus* collected from donor populations were translocated to streams where

models predicted reintroduction efforts would likely be successful (Harig and Fausch 2002).

Translocation has obvious and immediate conservation benefits, but the handling and transport

of these fish during translocation is an additional source of stress and mortality. This additional

mortality source can be problematic when translocating threatened or endangered species, and

significant mortality occurs.

The conservation of spring-run Chinook Salmon (hereafter Chinook Salmon) populations

in the Willamette River typifies the challenges associated with large-scale translocation

programs. A variety of reasons including habitat loss due to the construction of 13 dams on five

66 tributaries without fish passage facilities resulted in Upper Willamette River (UWR) Chinook

67 Salmon listing as threatened under the U.S. Endangered Species Act in 1999 (NMFS 1999). An

68 adult translocation program using trucks with tanks to transport fish began in the 1990's as a

69 conservation strategy initially to provide an additional prey base for listed Bull Trout *Salvelinus*

70 *confluentus*. The program changed into an effort to increase natural production of Chinook

71 Salmon *Oncorhynchus tshawytscha* and Steelhead Trout *O. mykiss* in their historic habitats once

72 natural production from these outplanted fish was detected (Beidler and Knapp 2005; Keefer et

73 al. 2010; NMFS 1999). Mortality of translocated individuals has varied among years since the

74 initiation of the adult translocation program. Mortalities of adult fish during translocation limits

75 natural production and wastes scarce management resources. Thus, understanding the factors

76 associated with mortality during translocation is important to develop translocation policies that

77 minimize mortalities in translocation programs. In this study, we investigated the mortality of

78 UWR Chinook Salmon transported in tank trucks as part of the translocation program with the

79 objectives to 1) evaluate factors associated with translocation mortality and 2) identify optimal

80 translocation policies that minimize mortality risk and effort.

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83 **Methods**

84 *Study area*

85   The Willamette River is a 7th order tributary draining 29,728 km^2 to the Columbia River

86 (Hulse et al. 2002). A waterfall located in the lower part of the watershed, Willamette Falls,

87 demarks the lower and upper Willamette River (Figure 1). Fish ladders at the falls provide

88 upstream passage for anadromous fish returning from the Pacific Ocean to spawn in natal

89   Willamette River tributary reaches. Anadromous fishes of the UWR include Chinook Salmon,

90   Coho Salmon *O. kisutch*, Steelhead Trout *O. mykiss*, and Pacific Lamprey *Entosphenus*

91   *tridentatus*. Once fish ascend the Willamette Falls fish ladder, they migrate upstream until they

92   encounter impassable dams located on the major UWR tributaries (Figure 1). Oregon

93   Department of Fish and Wildlife (ODFW) and U.S Army Corps of Engineers (USACE) hatchery

94   operations capture returning adult Chinook Salmon in traps located at impassible dams (Figure

95   1) (Beidler and Knapp 2005; Keefer et al. 2010).

96   Our study evaluated translocation mortality of spring-run Chinook Salmon trapped and

97   translocated from Foster and Dexter dams located on the South Fork of the Santiam River and

98   the Middle Fork of the Willamette River, respectively (Figure 1). The fish traps located at these

99   two dams capture fish that volitionally enter and ascend a fish ladder to a trap located near the

100   base of the dams. The Foster Dam fish trap operates year round. The trap located at Dexter

101   Dam opens to intercept arriving Chinook Salmon by June. Fates of trapped Chinook Salmon

102   include: 1) use as broodstock in hatchery operations; 2) outplanting downstream to provide

103   additional recreational fishing opportunities (hatchery origin only); or 3) translocation using

104   trucks to stream reaches upstream of impassible dams to repopulate those reaches (mostly natural

105   origin fish from Foster; mostly hatchery origin fish from Dexter) (Figure 1).

106   *Translocation operations.*—Fish traps located at Foster and Dexter dam are physically

107   unique for each location but operate similarly. The trap at Foster Dam is on the south bank and

108   the trap at Dexter Dam is on the north bank (USACE 2014). An older, less efficient trapping

109   system at Foster Dam was used in years prior to 2014 when a new trap came on line; these

110   differences did not affect our results. The facilities at Dexter Dam were unchanged over the

111   course of this study. Basic descriptions of the traps and trapping protocols can be found in

112   hatchery specific management plans (ODFW 2016a; ODFW 2016b; USACE 2014). The traps

113   consist of a concrete fish ladder that leads to a raceway with the downstream exit blocked by a

114   weir. A mechanical crowder forces the fish into a much smaller upstream chamber confining the

115   fish where they can be anesthetized and netted for stocking into a tank truck. Once a desired

116   number of fish have been collected the crowder is removed; this means that fish to be loaded for

117   subsequent trips may experience several crowding and un-crowding events. How long the fish

118   have been holding below the fish ladder before entry or in some cases how long the fish have

119   been holding in the raceway are not known. Fish that volitionally enter the trap at both locations

120   remain in the trap until processing. Processing at both locations followed 4 steps: crowding of

121   fish in trap, removal of a portion of the crowded fish and exposure to CO_2 (Foster Dam began

122   using AQUI-S 20E in 2014) at sedation or nearly anesthetic levels, handling of sedated fish to

123   determine sex, origin (natural or hatchery), checking for tags (passive integrated transponder,

124   coded wire, floy), and assigment to one of the 3 fates previously described. Hatchery staff then

125   loaded fish into transport truck tanks containing local source, oxygenated water. Fish captured in

126   the trap were regularly processed (i.e., weekly) and more frequently (i.e., daily) if fish numbers

127   in the trap were high—at the discretion of the ODFW hatchery personnel. Drivers recorded the

128   number of fish transported and the number dead on arrival at liberation site, including moribund,

129   for each translocation occasion.

130   *Data analysis*

131   We identified factors hypothesized to affect translocation mortality and organized those

132   factors into 3 levels. The levels represented included factors acting annually to set the stage for

133   elevated translocation mortality within a year, daily weather and trap conditions influencing

134   mortalities occurring that day, and occasion specific factors influencing mortalities during

135   translocations (Table 1). Additionally, each hypothesis was represented by numerical values

136   used to predict translocation mortalities and an information theoretic approach used to evaluate

137   the relative evidence for each hypothesis.

138   *Annual conditions.*—Annual conditions such as run size, water temperature, and flows

139   were hypothesized to influence translocation mortality (Table 1). We characterized run size and

140   timing as the total number of fish counted at the Willamette Falls passage facilities and the day

141   of the year that 50% of the total run passed the facilities, respectively. Stream flows and thermal

142   exposure during migration were characterized for two different time periods defined as 1) the

143   period from the first fish passing the Willamette Falls facility to the time of outplanting, and 2)

144   the day that 50% of the total run passed the facilities to the time of outplanting. For each of

145   these time periods, we calculated discharge at the respective dams using data from USGS gages

146   on the South Santiam River (USGS: 14187200) and Middle Fork Willamette River (USGS:

147   14150000) for Foster and Dexter dams, respectively. Finally, we calculated cumulative water

148   temperatures for each period as total degree days using water temperatures measured at the

149   respective USGS gages, listed above.

150   *Daily weather and trap conditions.*—We hypothesized that weather and trap conditions

151   influenced translocation mortality (Table 1). The amount of cloud cover and air temperature

152   were included as potential covariates based on previous experience handling and transporting

153   salmonids and associated mortalities (C.B. Schreck personal observation). Maximum air

154   temperature during transport and cloud cover were estimated using data from nearby airports

155   (Corvallis Municipal Airport, Eugene Airport) because they were the nearest locations where

156   daily records of temperature and cloud cover were available for the study period. We quantified

157   trap and holding conditions that were potentially stressful by including the number of fish

158   trapped and held before outplanting and the number of days between trap tending events.

159   *Truck and translocation occasion data.*—Several values were measured and recorded for each

160   truck and translocation occasion that were hypothesized to influence mortality. Personnel

161   recorded trip-specific truck-level data including truck number, outplant location, the number of

162   fish transported and water temperatures at the collection facility holding tanks and transport

163   tanks to the nearest $0.5^{\circ}C$. Post trip tank water temperature was also measured to quantify

164   change in water temperature during the trip.   We calculated the difference in temperature

165   between the collection facility and the transport truck and the start and end of the trip. Also, the

166   amount of time that it took to load fish on the transport truck (loading time), and drive the fish to

167   the outplant locations (hauling time) was recorded. Loading time was calculated as the

168   difference of the loading end time and start time.   If multiple transportation events were required

169   in a day, fish were uncrowded during idle times between events and start time assigned when

170   fish processing resumed. Hauling time was calculated as hauling end time – hauling start time.

171   We calculated total handling time as the sum of loading time and hauling time. We estimated

172   potential crowding during transport as the volume of the truck tank divided by the number of fish

173   transported. The number of outplant trips per day was recorded. The water temperature at the

174   release site was recorded but not used in this analysis because mortalities were counted in the

175   truck tank prior to release.

176   *Model fitting.*—We fit location-specific generalized linear mixed-effects models

177   (GLMM) to identify and quantify factors associated with the translocation mortality (Agresti et

178   al. 2000; Venables and Dichmont 2004). The model related the proportion of dead and

179   moribund fish at the time of outplanting to annual conditions, daily weather and trap conditions,

180   and truck and translocation occasion conditions for each location. We fit each candidate model

181   to the repsonse variable assuming the number of mortalites were binomially distributed with a

182   logit link. We used separate analyses for each facility to describe mortality differences between

183   locations and to provide the foundation for an adaptive management program (see discussion).

184   Continuous predictor variables were standardized to a mean of zero and standard deviation of 1

185   to facilitate model fitting and allow comparison of the relative effect of variables that were on

186   different scales. Repeated observations and measurements within a year, at a trapping facility, or

187   outplanting location were potentially dependent, which would violate independence assumptions

188   and preclude the use of traditional regression models as discussed by Royle and Dorazio (2008).

189   Therefore, we initially fit a model with all the candidate predictors to the translocation mortality

190   data. An examination of the model residuals ordered by date and outplant location indicated

191   temporal and spatial autocorrelation.

192   There were several potential sources of statistical dependence leading to the non-random

193   structure of the residuals. Therefore, we evaluated the relative fit of alternative variance

194   structures for the GLMM using a model including all predictors and all possible combinations of

195   random effects that included transport truck and truck driver, outplant location, year, and

196   outplant occasion (i.e., each outplanting event). The best approximating variance structure was

197   selected as the model with the smallest Akaike's Information Criteria with the small-sample bias

198   adjustment (AICc) (Hurvich and Tsai 1989). That variance structure was used during the

199   evaluation of the relative plausibility of the candidate models, detailed below. Plots of predicted

200   and observed mortality rates were used to assess the fit of candidate models. All models were fit

201   using the glmer function in the R package lme4 (Bates et al. 2012).

202   We developed models representing 21 hypotheses to explain variation in translocation

203   mortality (Table 1) and used an information-theoretic approach evaluating the relative support

204   for the candidate hypotheses (Burnham and Anderson 2002). We fit a single model representing

205   each hypothesis in Table 1, as well as an intercept only model, and calculated AICc and Akaike

206   weights following Burnham and Anderson (2002) rather than combining all possible

207   combinations of the 21 predictors. We then retained models with AIC values lower than the

208   intercept only model as a confidence model set and assessed the precision of the parameter

209   estimates by calculating 95% confidence intervals of estimated parameters. Statistical inference

210   was restricted to models retained in the confidence model set and parameter estimates where the

211   95% confidence intervals did not contain 0. Model weights for models retained in the

212   confidence model set were calculated as described in Burnham and Anderson (2002) and then

213   used to weight model predictions used to identify optimal translocation policies detailed below.

214   *Visualizing predicted mortality and uncertainty.*—We predicted the expected mortality

215   for each model and plotted the expected values along with 95% prediction intervals to visually

216   assess the relationships and associated uncertainty. Prediction intervals represent the

217   unexplained variation around the estimate of fixed and random effects. The predicted mortality

218   rates for each location (Foster and Dexter Dam) were estimated for each model retained in the

219   confidence model set and estimates combined by weighting each prediction by the model-

220   specific Aikake weight to account for model selection uncertainty. Weighted predictions were

221   then summed to provide a singular mortality rate estimate given model selection uncertainty. In

222   the case when a single model was retained in the confidence model set, the predicted values were

223   multiplied by 1. We then used these predicted mortality rates to evaluate optimal translocation

224   practices detailed below.

225 *Identifying optimal translocation policies*

226   From a management perspective, several hypothesized factors affecting translocation

227 mortality are controllable during translocation operations. Specifically, the confidence model

228 sets contained loading time for Foster Dam and density for Dexter Dam as factors associated

229 with translocation mortality. However determining optimal location-specific loading times or

230 density is a management challenge because hatchery locations will minimize loading time or

231 density potentially causing confusion if personnel work at multiple hatcheries. Therefore, we

232 identified optimal translocation policies for fish originating from Foster and Dexter Dam by

233 calculating the number of hauls needed for a truck volume and the number of fish to be

234 translocated. Number of hauls was selected because it provided uniformity between hatcheries

235 and it integrates loading time and fish density. Lastly, the daily translocation effort in hours

236 depends on the number of hauls, and therefore daily effort can be considered when identifying

237 optimal translocation policies.

238   We identified the optimal translocation policy (number of hauls given truck volume and

239 number of fish to translocate for this example) as one that maximizes survival and minimizes

240 effort for this study. However, this requires a tradeoff. In an extreme situation, translocating one

241 fish per haul will likely result in high survival, but the amount of effort to translocate individuals

242 is unreasonable given personnel constraints. Translocating all outplant fish in a single haul

243 minimizes effort but may result in elevated mortalities associated with high densities. To

244 quantify this tradeoff we calculated a utility that combined risk of mortality and effort into a

245 single value and used that value to identify optimal translocation policies at Foster and Dexter

246 Dam.

247   We identified the optimal number of a hauls for varying numbers of fish to be outplanted

248   and truck volumes by generating all possible combinations of number of fish outplanted (1 to

249   400, increments of 10), number of truck hauls (1 to 20, increments of 1), and truck volumes (1 to

250   11 m^3, increments of 0.5). There were 16.8K possible combinations (hereafter referred to as

251   policy combinations). For each policy combination, we calculated the number of fish in each

252   haul assuming the numbers of fish to be translocated were evenly distributed among the number

253   of hauls. The density of fish was calculated as the number of fish divided by the truck volume.

254   The loading time for each haul was calculated as the number of fish hauled times the average

255   location-specific loading time (0.25 and 4.6 minutes per fish for Dexter and Foster dam

256   respectively). The mortality rate was then predicted from density for Dexter Dam because this

257   was the only factor retained in the confidence model set. The confidence model set was used to

258   calculate model weighted predictions of the mortality rate for Foster Dam. In this example,

259   loading time varied depending on the policy combination while the remaining factors were

260   evaluated using mean values. Mortality rate and loading time were then used to calculate

261   mortality risk and total daily effort values. These values were then used to select the optimal

262   number of hauls, described below.

263   *Mortality risk.*—The biological consequences of the predicted mortality rates can be

264   difficult to ascertain, especially when rates are low. For example, is a mortality rate of 0.005

265   versus 0.01 meaningful within a manager's decision-making process? Additionally, while

266   mortality rate will be the same given similar conditions, the expected number of mortalities will

267   depend on the number of fish translocated. For example, the expected number of mortalities

268   from translocating 100 fish will be higher than translocating 10 under the same conditions,

269   further complicating evaluation of varying translocation conditions and number of fish

270   translocated. Because multiple hauls may be needed to translocate all fish and the mortality rate

271   was predicted for each haul we estimated mortality risk as the probability of observing 1 or more

272   mortalities over the entire daily effort. Mortality risk was calculated as 1 minus the product of

273   probability of observing 0 mortalities in each haul calculated from a binomial distribution given

274   the predicted mortality rate and number of fish translocated as:

275

276    $$Mortality\ risk_j = 1 - \prod_{i=1}^{Hauls_j} \frac{n_{ij}!}{0! \cdot (n_{i,j} - 0)!} \cdot p_i^0 \cdot (1 - p_{i,j})^{n_{i,j} - 0} \qquad (1)$$

277

278   where j indexed each policy combination, *hauls* was the number of hauls used to translocate

279   fish, n is the number of Chinook Salmon translocated, p is the predicted mortality rate, and i

280   indexes daily hauls. Policy combinations with mortality risk values approaching 1 are more

281   likely to observe 1 or more mortalities over the translocation effort.

282   *Daily effort.*—The amount of time in hours required to complete translocation of a given

283   number of fish and number of hauls is an important consideration to constrain translocation

284   policies to reasonable efforts. We calculated total daily effort for each policy combination as:

285

286    $$Effort_j = \sum_{i=1}^{Hauls_j} (Loading\ time_{i,j} + 2 \cdot Hauling\ time_{i,j}) / 60 \qquad (2)$$

287

288   where, j indexed each policy combination, *Effort* was the total effort in hours required to

289   translocate fish, *Loading time* was the amount of time required to load all fish, and

290   *Hauling time* was the amount of time in minutes to reach an outplant location multiplied by 2 to

291   account for the return trip. For this study *Hauling time* was assumed to be the mean hauling

292   time for each location, 37.4 and 77.3 minutes for Foster and Dexter dam respectively.

293   *Identifying optimal translocation policies*

294   *Overall utility.*—We calculated a utility combining the mortality risk and daily effort to

295   identify optimal translocation policy at Foster and Dexter Dams. Because mortality risk and

296   daily effort are on different scales, we scaled these values to a minimum of 0 and a maximum of

297   1 using a proportional scoring equation (Conroy and Peterson 2013). Mortality risk was scaled,

298   so low mortality risk values approached 1, and high mortality risk values approached 0 as:

299

300    $$U_{mortality\,risk,j} = \frac{Mortality\,risk_j - \max(Mortality\,risk_j)}{\min(Mortality\,risk_j) - \max(Mortality\,risk_j)},$$ (3)

301

302   where j indexed each policy combination, and *Mortality risk* was calculated from equation 1.

303   Effort values were scaled so low daily efforts approached 1 and daily efforts equal to 12 hours

304   was 0 as:

305

306    $$U_{effort,j} = \frac{Daily\,effort_j - 12}{12 - \min(Daily\,effort_j)},$$ (4)

307

308   where j indexed each policy combination, *Effort* was calculated from equation 2, and 12 was

309   the maximum amount of effort reasonable for a given day. We excluded policy combinations

310   with efforts exceeding 12 hours from analysis.

311   The utility value used to identify the optimal number of hauls required given the number

312   of fish to translocate and truck volume was calculated as $U_j = w_1 \cdot U_{mortality\ risk,j} + w_2 \cdot U_{effort,j}$ where

313   U_i was the overall utility, w_1 is the weight given to the morality risk, w_2 is the weight given to

314   the effort utility, and $U_{mortality\ risk}$ and U_{effort} are described. For this analysis, w_1 and w_2 were set to

315   0.5 to give equal weight to mortality risk and effort for this study. It should be recognized that

316   weights can be changed to reflect agency objectives. For example, if minimizing mortality was

317   more important relative to effort then w_1 can be set at a level greater than 0.5 and then

318    $w_2 = 1 - w_1$. We determined the optimal translocation policy as the number of hauls for a given

319   truck volume and number of fish to translocate that maximized the utility value. Policy plots

320   were generated to illustrate the optimal number of hauls depending on the number of fish to

321   outplant and the tank volume. Lastly, the optimal policy analysis was repeated with policy

322   combinations where fish densities that exceeded 10.56 fish per m^3 were excluded from potential

323   combinations to reflect the current density constraint policy (USACE 2014). and compared to the

324   optimal policies identified using mortality risk and effort.

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326

327   **Results**

328   Translocation of adult spring-run Chinook Salmon during 2006 to 2013 occurred each

329   year starting in early May and ceasing in late September. The number of fish outplanted from

330   Foster and Dexter dams varied between locations and among years. Overall, fewer fish were

331   captured at Foster Dam and translocated upstream varying from 259 to 1176, relative to Dexter

332   Dam where 451 to 4183 fish were translocated annually. Additionally, fewer fish were

333   translocated per haul at Foster Dam (16-32 fish median) relative to Dexter Dam with median

334   number of fish translocated annually varying from 78 to 154. Within year, mortalities at each

335   location varied from 0 to 28 and 0 to 75 fish for Foster and Dexter Dam, respectively. During

336   the study period, these translocated fish were exposed to varying thermal and flow conditions.

337   Degree days and average discharge from the time that the first fish passed Willamette Falls until

338   outplanting varying from 317 to 1168 C and 64 to 189 m^3/s, respectively (Table 2). Thus, our

339   study was conducted over a wide range of migration conditions.

340   A random effect of outplant occasion was identified as the best approximating variance

341   structure in models for Foster and Dexter Dam which accounts for overdispersion in the binomial

342   model. Confidence model sets of variables hypothesized to influence mortality varied between

343   Foster and Dexter dams (Table 3). Hypotheses relating total handling time and density were

344   retained in the confidence model set for Foster and Dexter Dam respectively. Confidence

345   intervals for estimated parameters in each of these models did not include 0, indicating that

346   mortality rate increased as loading time and density increased (Table 4; Figures 2 and 3).

347   Additionally, total time, mean daily discharge and degree days accumulated since the first

348   Chinook Salmon passed Willamette Falls were retained in the confidence model set for Foster

349   Dam (Table 3). A positive relationship was estimated for total time and degree days while a

350   negative relationship was estimated for flow conditions (Figure 2). Confidence intervals for all

351   three of these effects did not include 0 indicating that the effects are meaningful. There was a

352   substantial uncertainty around the predicted mortality rates due to the random effect of outplant

353   occasion for fish originating from Foster and Dexter Dam (Figure 2 and 3); that would have

354   otherwise been unaccounted for if this extra variation was not included as a random effect in this

355   analysis.

356   Patterns in optimal translocation policies varied between Foster and Dexter dams

357   reflecting the results of model selection. The optimal number of hauls did not vary with truck

358   volume for Foster Dam when there was not a density constraint imposed (Figure 3). There were

359   instances where the number of hauls decreased with increasing number of fish to translocate

360   resulting from the exclusion of policy combinations where daily effort exceeded 12 hours, and

361   these policies should be used with caution because they result in elevated fish densities to satisfy

362   the effort constraint. More hauls were needed for situations where trucks with smaller volumes

363   were available and policies exceeding a density of 10.56 fish/m^3 [i.e., the NOAA density

364   constraint (USACE 2014)] were excluded from consideration. There also were several

365   combinations of number of fish to translocate and truck volume where there was no policy that

366   met density or effort constraints at Foster Dam. The optimal number of hauls varied with the

367   number of fish to translocate and truck volume at Dexter Dam (Figure 4). For the same number

368   of fish to outplant, fewer hauls were needed with increasing truck volume illustrating the effect

369   of density on the optimal policy. Further constraining the optimal policy to existing maximum

370   densities increased the number of hauls required to translocate a given amount of fish and

371   constrained the number of optimal policies meeting effort and density constraints.

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373

374   **Discussion**

375   We identified factors associated with translocation mortality and then used this

376   understanding to identify simple translocation policies minimizing the number of trips per truck

377   per day and using trucks of sufficient size to accommodate the number of fish to be moved.

378   These translocation policies that relate fish density in the trucks and the time it takes to load fish

379   onto the trucks could be employed as a framework to improve survival of translocated Chinook

380   Salmon. Translocation mortality was related to factors like loading time and density that are

381   controllable by management and, in the case of Foster Dam, several uncontrollable factors

382   associated with exposure to instream conditions (e.g., degree days, flow).   The uncontrollable

383   factors do not preclude using the optimal translocation policies identified in this study because

384   optimal translocation policies can be updated given instream conditions and run timing as that

385   information becomes available to managers. While we used average values to identify optimal

386   translocation policies in this study, the methods we used can provide a flexible management

387   framework that identifies translocation policies given factors such as the number of degree days

388   and mean flow since the first Chinook Salmon passed Willamette Falls. For example, policy

389   plots can be created for situations with similar streamflow and temperature conditions, such as

390   water year type. Data collected from existing USGS temperature and flow gages and ODFW

391   monitoring of fish passage at Willamette Falls can be integrated to inform translocation policies

392   in real time and provides additional importance to these monitoring programs.

393   The objective of using trucks or other methods to translocate anadromous salmonids is to

394   minimize mortality due to environmental stressors and to circumvent anthropogenic and

395   environmental barriers. Mortality occurring during translocation events limits the efficacy of

396   this conservation tool. Translocation of migratory fish to mitigate for migration barriers is likely

397   to remain a conservation tool for environmental and anthropogenic conditions in the Willamette

398   River system. For example, Chinook Salmon in the Willamette basin will continue to be

399   translocated upstream of barrier dams (Beamesderfer et al. 2011). Also, drought conditions in

400   the Central Valley of California have necessitated the movement of adult salmon above thermal

401   barriers (Mosser et al. 2013) and the proposal of new translocation programs (USDOI BLM

402   2015; YCWA 2015). Similarly, environmental conditions in the Central Valley of California

403   required juvenile Chinook Salmon to be translocated directly from hatcheries to the estuary,

404   bypassing potentially lethal instream conditions in the same system (Chea 2014). While

405   technological approaches, such as a salmon cannon (Solomon 2014), can mechanically move fish

406   around migration barriers, these technologies cannot bypass distances comparable to truck-based

407   translocation. However, they may provide short-term fixes to fish passage issues, such as when a

408   crack in the Wanapum Dam on the Columbia River forced fish ladders to be shut down while the

409   reservoir was drawn down for repairs. In this instance, adult salmon were captured and

410   translocated by truck above the dam.

411   In this study, we found mortality occurring during translocation events was associated

412   with trip specific variables at Foster and Dexter dams. The most important were the amount of

413   time it took to load and density in the truck tank. These results are similar to findings in previous

414   studies where the amount of time fish were transported in truck tanks was positively associated

415   with mortality (Harmon 2009; Hasan and Bart 2007). Mortality associated with high density

416   may be mediated by the use of salts or water conditioners to mitigate for stress and minimize

417   potential pathogen infection or anesthetics to minimize stress in commercial operations (Harmon

418   2009; Harnish et al. 2011; Swanson et al. 1996; Wedemeyer et al. 1985). High salmon densities

419   can potentially lead to horizontal transmission of diseases which may influence the health status

420   of individual fish and also increase stress responses which may increase mortality (Ogut et al.

421   2005; Zuray et al. 2012). Mortality associated with *Aeromonas salmonicida*, a horizontally

422   transferred pathogen causing furunculosis, was positively associated with Chinook Salmon

423   densities in controlled experiments (Ogut et al. 2005; Ogut et al. 2004). In a natural setting,

424   Traxler et al. (1998) found Sockeye Salmon mortality due to *Ichthyophthirius multlfiliis* was

425   enhanced by fish density on the spawning grounds. Aeromonas salmonicida, a horizontally

426   transferred pathogen causing furunculosis, was positively associated with Chinook Salmon

427   densities in controlled experiments (Ogut et al. 2005; Ogut et al. 2004). This bacterial pathogen

428   is common in adult Chinook Salmon from the Willamette River, and in our pathogen

429   examinations of these fish in 2010 and 2011 we found 67% and 43% prevalence of infection in

430   dead and apparently healthy fish, respectively (Kent et al. 2013).

431   There are several plausible explanations as to why trip number is positively correlated

432   with mortality. Fish transported after earlier groups in a day may have experienced more stress

433   because of the total duration of the stressor events or the cumulative effects of having been

434   exposed to more stressors and sequential stressor. For example, multiple crowding and un-

435   crowding events likely increases stress levels, and in combination with CO_2 , also known to be

436   quite stressful to fish (Schreck 1972), the effects of crowding and handling are likely

437   exacerbated. It is well know that both duration and number of discrete stressful events could

438   negatively affect fish fitness (see Schreck and Tort 2016 for a review of this topic).

439   We hypothesized that metrics indexing mainstem Willamette River migration conditions

440   (flow, temperature) would influence translocation mortality rates. Annual and within year

441   factors quantifying flow and temperature were hypothesized to set the stage for elevated

442   translocation mortality. For example, Chinook Salmon were hypothesized to expend additional

443   energy migrating through elevated stream flows and water temperatures, similar to mortality

444   hypotheses posited by Cooke et al. (2006) for anadromous Sockeye Salmon. Counter to our

445   expectation, mortality rates were negatively associated with mean daily discharge. It is unclear

446   why this is the case but exposure to high flows may not result in severe depletion of energetic

447   stores as to cause immediate mortality during truck transportation if energetic stores are

448   sufficient. Prespawning mortality of Chinook Salmon has been positively associated with

449   temperature in a previous study (Keefer et al. 2010). Our analysis is inconclusive but flows and

450   thermal exposure at Foster Dam were associated with translocation mortality rates and further

451   research is needed to provide evidence for this hypothesized effect.

452   We expected factors associated with run timing and size to influence the rate of

453   translocation mortality. Abnormal run timing was associated with en route mortality of Sockeye

454   Salmon migrating from the Pacific Ocean to natal freshwater streams (Cooke et al. 2004). Early

455   returns of Chinook Salmon to freshwater may result in variable energetic stores for fish

456   migrating through the system to natal stream reaches to mature sexually during summer months

457   before spawning in the fall. This life history requires that fish return to freshwater with

458   sufficient energetic reserves to reach their natal stream because they do not feed as adults in

459   freshwater. Studies of Sockeye Salmon indicate that amount of energetic reserves in salmon are

460   locally adapted to provide sufficient energy to migrate, become sexually mature, and spawn

461   (Crossin et al. 2004b). Given the long freshwater period experienced by UWR Chinook Salmon,

462   energetic reserves are typically high, and energetic depletion may not influence translocation

463   mortality because this event occurs early in the run when fish likely have sufficient energetic

464   reserves. However, among year variation in ocean conditions can influence the initial energetic

465   status of salmon migrating to freshwater (Cooke et al. 2004; Crossin et al. 2004a), which in turn

466   may increase prespawning mortalities rates after outplanting above barriers (Keefer et al. 2010).

467   It was not surprising that air temperature and cloud cover were not associated with

468   translocation mortality. The original premise for these hypotheses was previous experiences

469   handling and transporting salmonid species that were closer to sexual maturation, and the

470   mechanism remains uncertain. These variables were quantified using the closest airport because

471   these were the only locations where cloud cover was recorded which may have influenced results

472   due to differences between local conditions and conditions recorded at airports. Both fish

473   processing facilities at Foster and Dexter Dam provide shade while handling fish and air

474   exposure is minimized, and therefore, factors such as sun and air exposure may not influence

475   translocation mortality as severely as other factors like density or loading time.

476   Random effects associated with outplant occasion were contained in the final dam-

477   specific models used for statistical inference. These random effects were estimates of the

478   amount variation in transport mortality that was not accounted for by the fixed effects included

479   in the models. Although random effects are not helpful for interpreting associations between

480   factors, like a fixed effect, they provide insight into where additional variability may be targeted

481   for future experimental study. In this analysis, the random effects were fairly large indicating

482   that predicted probabilities of translocation mortality varied substantially among translocation

483   occasions. This suggests that there are unknown trip-specific factors not included in this study

484   that could potentially explain variation in translocation mortality. This contention is supported

485   by the findings of Benda et al. (2004) that prespawning mortality is lower in adult Chinook

486   Salmon allowed to mature in captivity in cool pathogen free water than in the wild.

487   The mechanistic cause of translocation mortality is uncertain. The mechanisms causing

488   en route mortality of Sockeye Salmon proposed by Cooke et al. (2006) (i.e., energetic,

489   reproductive, stress, and osmoregulatory status) may influence the likelihood of transportation

490   mortality. We expected one of those factors in particular to be associated with cumulative

491   handling that likely lead to stress such as repeated crowding and human presence during sorting

492   operation to have a positive effect on transportation mortality.   Trip number was used in the

493   analysis to account for cumulative stress effects however this factor was associated with

494   mortality. This result should be interpreted cautiously and not preclude the possibility of an

495   adverse effect of stress on fish (Schreck and Tort 2016). It is likely that daily trip number may

496   not have indexed cumulative stress as we believed or there just was not enough days where

497   multiple trips were made as days with 2 trips accounted for 37% of observations and 3 or more

498   trips was 13% . Pathogen status also applies when horizontal transmission of pathogens may be

499   exacerbated by interactions of fish in tanks. Necropsies of transport mortalities were not

500   conducted, but may provide additional insight into the potential cause of mortality. Indeed,

501   transportation mortality of Chinook Salmon limits the efficacy of conservation translocation

502   operations, and this study identifies several factors that can be controlled or modified to

503   minimize transport morality. For example, a study by Benda et al. (2015) provided guidelines

504   for potential Chinook Salmon holding strategies in cool, pathogen-free water to minimize

505   pathogen loads.

506   While this study identified factors associated with translocation mortalities, these factors

507   did not predict translocation mortality rate with absolute certainty. This result indicates that

508   there is the potential to reduce predictive uncertainty and subsequently improve optimal hauling

509   policies identified in this study. Specifically, the competing hypotheses evaluated in this study

510   represent our understanding of the system and the varying support for each hypothesis quantifies

511   uncertainty in this understanding. This analysis can provide the foundation for an adaptive

512   management program where management actions, translocating fish, in this case, can be used

513   iteratively to update the weights (or probabilities) for each hypothesis (Conroy and Peterson

514   2013). These updated weights can then be used to estimate the amount of effort and mortality

515   risk and update the optimal hauling policies. This iterative process of learning and updating

516   optimal translocation policies is important because it is likely that other factors unrelated to

517   operational factors like loading time and density will become more important as optimal

518   translocation policies that minimize mortality risk are used. For example, this study identified

519   density as the dominant hypotheses influencing translocation mortality at Dexter Dam (Figure 3).

520   It is likely that if translocation policies are implemented that minimize mortality risk at locations

521   like Dexter Dam, other biotic or abiotic factors associated with translocation events will become

522   important. While this process may appear complicated, it requires little change regarding data

523   collection by managers. The most significant change needed is that data collected for each haul

524   needs to be entered in a timely fashion, such that analyses can be run again and optimal

525   translocation policies updated in time for the next translocation effort. Timely data entry can

526   either be accomplished by prioritizing data entry post hauling or with technological fixes such as

527   tablet computers and data entry forms that sync to an online database. Once data is available, the

528   weights for each hypothesis retained in the confidence model set can be updated given the

529   number of mortalities observed and optimal translocation policies revised given this new

530   information. While this initial analysis evaluated several hypotheses, the process does not

531   preclude the addition of hypotheses over time, such as those that might be identified as part of

532   annual coordinating meetings. The analysis, policy evaluation, and potential adaptive

533   management framework resulting from this study can provide managers a way to integrate

534   research, management, and monitoring with minimal modifications to existing operations and

535   monitoring.

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668   **Figures**
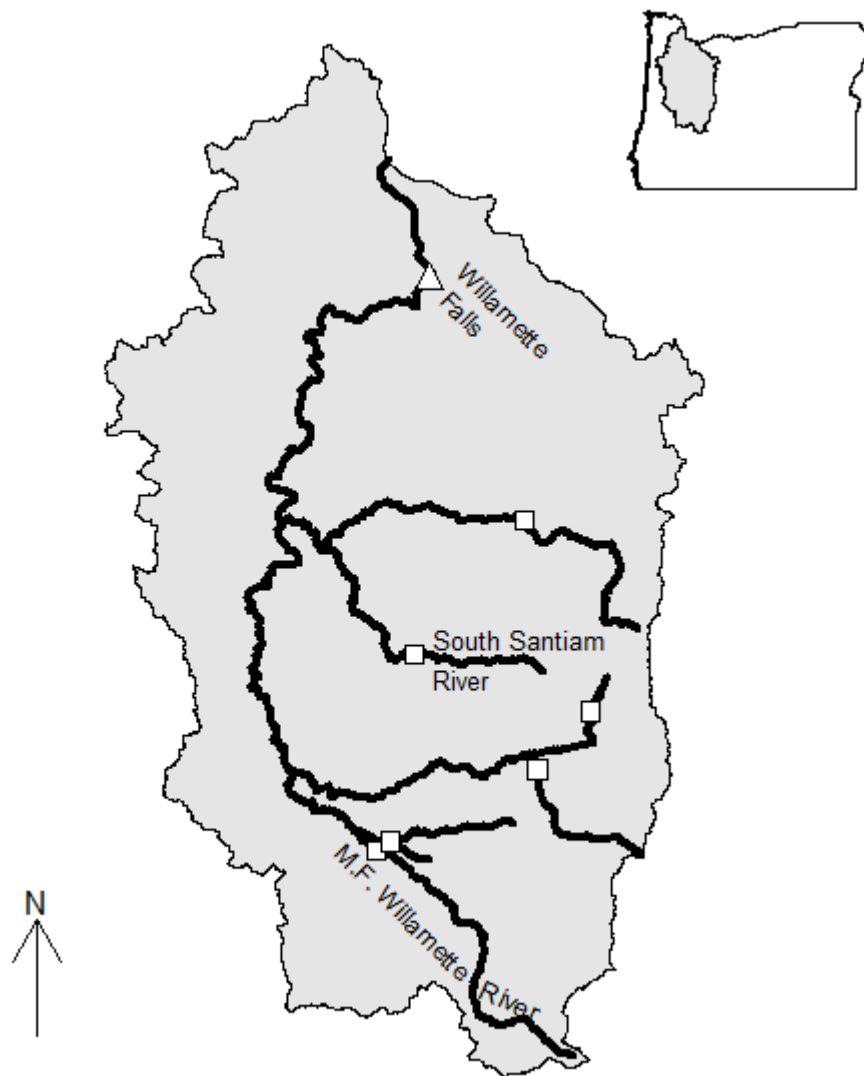
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670   Figure 1. Study area and location of tributary populations of interest within the Willamette River
671   basin, Oregon. Open squares denote the first impassible major tributary dams. The open triangle
672   denotes the location of Willamette Falls. Arrow denotes north and direction of river flow. Spring
673   Chinook in this study were outplanted above the dams on the South Santiam and M.F.
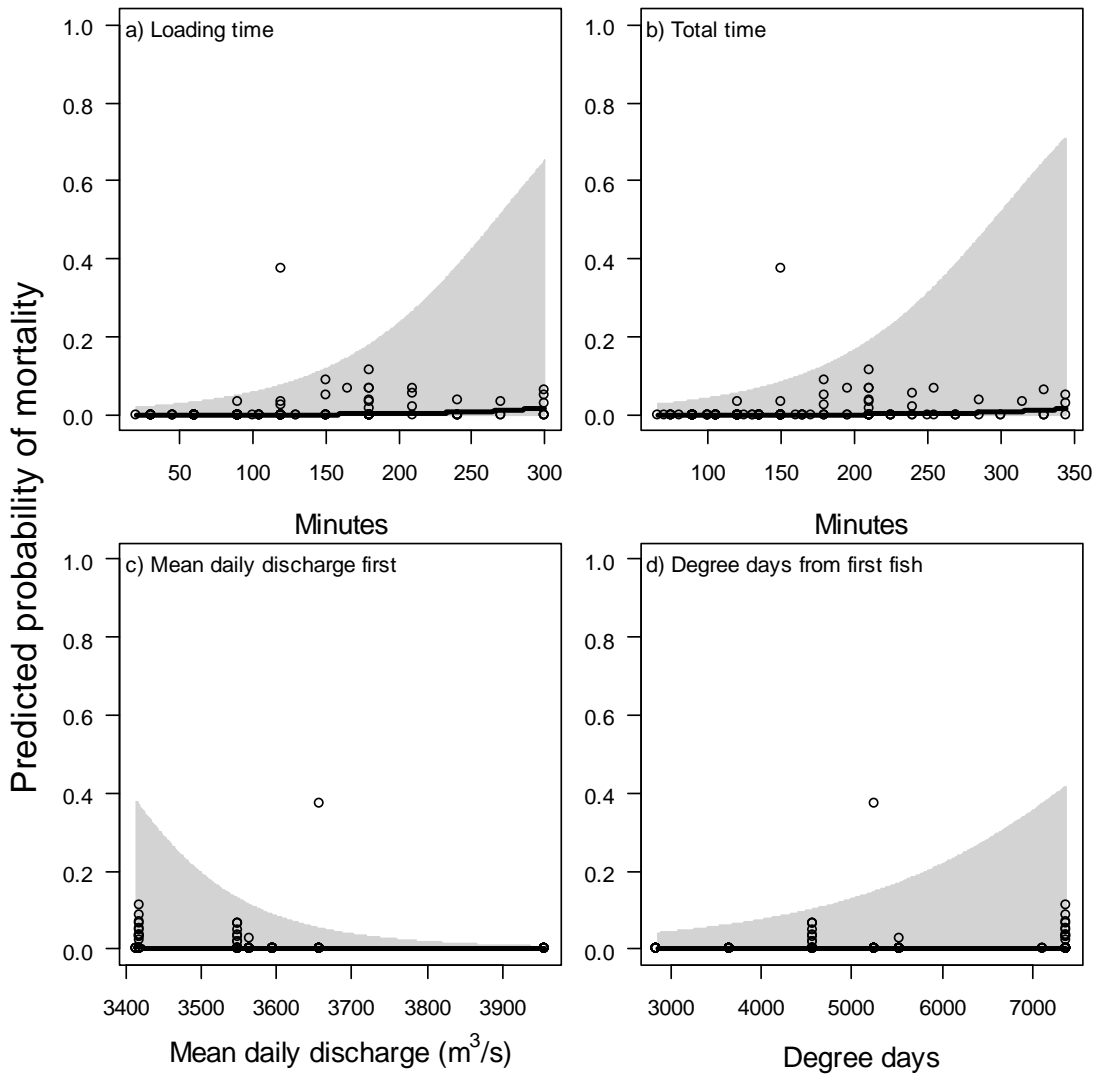674   Willamette River.

675

Figure 2. Predictions (solid black line) and 95% prediction interval (gray area) for models
representing hypotheses predicting the mortality rate of Chinook Salmon transported. Panels
represent prediction for models retained in the confidence model set for Foster Dam located
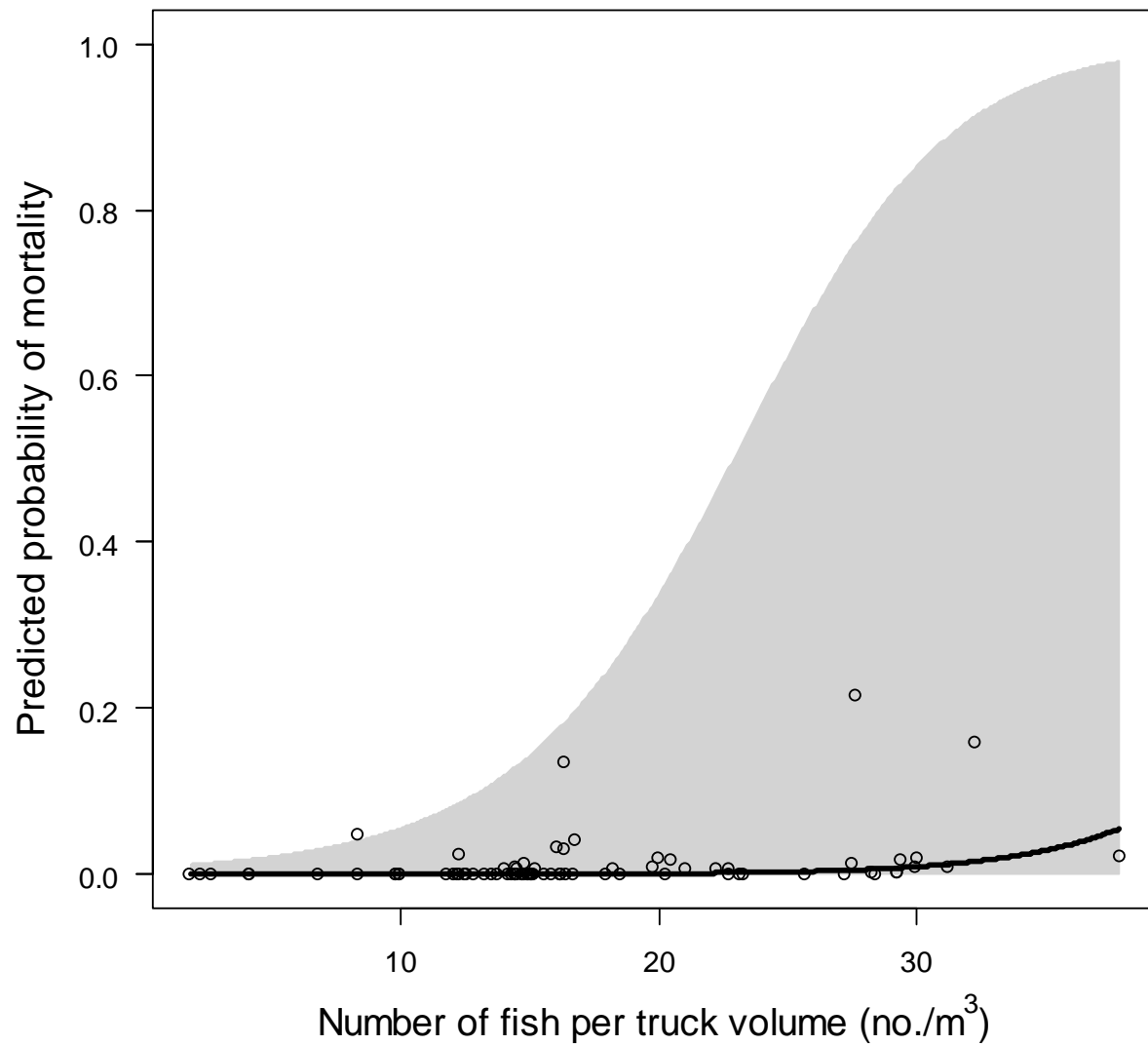within the Willamette River basin, Oregon.

680

681

682   Figure 3. Predictions (solid black line) and 95% prediction interval (gray area) for models
683   representing hypotheses predicting the mortality rate of Chinook Salmon transported. Panel
684   represents prediction for the model retained in the confidence model set for Dexter Dam located
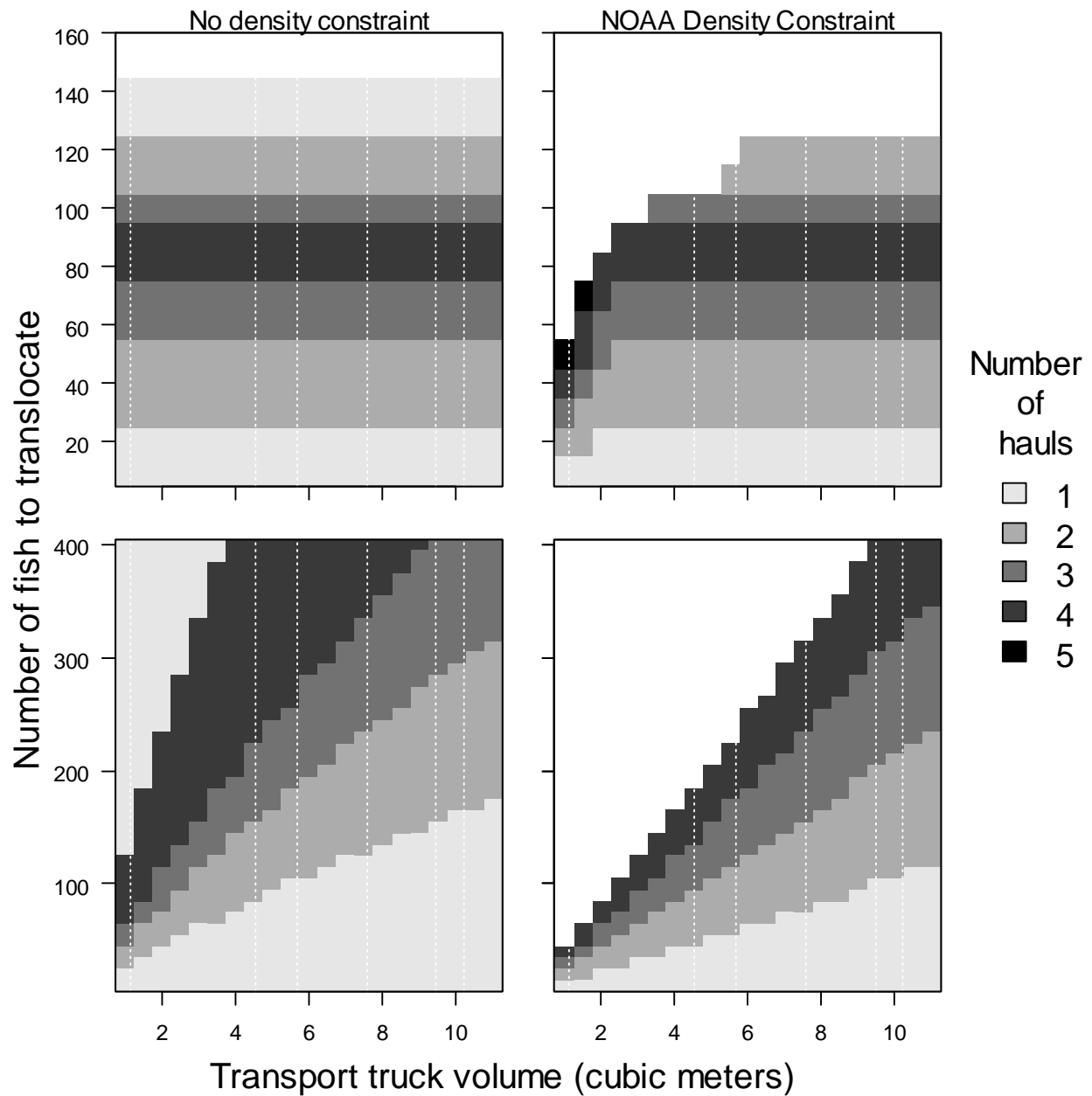685   within the Willamette River basin, Oregon.

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Figure 4. Optimal translocation policies for adult spring-run Chinook Salmon trapped at Foster Dam (Top panels) and Dexter Dam (Bottom panels). Shading represents the optimal number of hauls that minimize both mortality and effort for combinations of transport truck volume and total number of fish to translocate. The right panels illustrate the optimal number of hauls with no density constraint but effort limited to 12 hours per day. The right panels illustrate the optimal number of hauls with a 10.56 fish/m^3 density and effort limited to 12 hours per day. The dotted white lines denote commonly used trucks tank volumes in Upper Willamette River spring-run Chinook Salmon translocation. White areas denote combinations where no optimal policy exists.

697

Tables

699 Table 1. Candidate explanatory variables, descriptions, and hypotheses used to explain mortality
700 occurring during translocation of Spring-run Chinook Salmon from dams to upstream
701 outplanting locations in the Willamette River basin, Oregon.

Predictor	Description and hypothesis
Truck and translocation occasion conditions	
Loading time (min)	How long it took to load fish. **Hypothesis**: longer loading durations increase the probability of mortality events.
Hauling Time (min)	How long it took to transport fish to outplant location. **Hypothesis**: longer travel durations increase the probability of mortality events.
Total time handling (min)	How long it took to load and transport fish. **Hypothesis**: longer trip durations increase the probability of mortality events.
Trip number for the day	Number of trips conducted in a day. **Hypothesis**: this metric integrates the number of fish trapped and a rate of trapping (sort of). Probability of mortality events increase with the number of daily hauls, later hauls may have a higher probability of mortality
Truck volume (m³)	The volume of the transport tank. **Hypothesis**: Trucks with larger volumetric capacity decreases probability of mortality events.
Number of fish transported	The number of fish transported in a single trip. **Hypothesis**: higher numbers of fish transported increases the probability of mortality events.
Number of fish per truck volume (fish/m³)	The density of fish in the truck (fish/truck volume). **Hypothesis**: higher densities increase the probability of mortality events
Difference in temperature between collection facility and tank (C)	Difference between collection facility water temperature and transport tank water temperature. **Hypothesis**: fish are more likely to experience mortality events if stressful water temperature differences are experienced.
Difference in tank water temperature over trip (C)	Difference between transport tank water temperature at the start and end of transport event. **Hypothesis**: fish are more likely to experience mortality events if stressful water temperature differences are experienced.
Day of the year transported	Day of year of hauling event. **Hypothesis**: Fish from the middle of the run will experience higher mortality due to environmental conditions (e.g., temperatures below dam, water quality) conditions that may peak mid-run.
Daily weather and trap conditions	
Number of fish in trap	Cumulative number of fish captured in the trap. **Hypothesis**: high numbers of fish in the trap may increase stress, which may increase the probability of mortality events.
Water temperature	Temperature at collection facility at time of hauling. **Hypothesis**: fish

at collection facility (C)	collected from higher water temperature are more likely to experience mortality events
Maximum daily air temperature (C)	Maximum air temperature when loading and transporting. **Hypothesis**: Exposure to elevated air temperatures increase the probability of mortality.
Average number of days since last trap tending	Average number of days between trap tending occasions (cumulative). **Hypothesis**: increased time in the trap increases stress, which may increase the probability of mortality events.
Cloud cover index	Daily cloud cover when loading and transport. **Hypothesis**: Exposure to sunlight increases the probability of mortality

Annual conditions

Run size	Number of fish escaping Willamette Falls. **Hypothesis**: density dependent factors (e.g., horizontal disease transmission) increase probability and magnitude of a mortality event
Day of the year 50% of run passed Willamette Falls	Day of 50% passage of immigrating spring Chinook at Willamette Falls. This variable is intended to characterize the potential effects of run timing. **Hypothesis**: as transport mortalities increase in years where the run timing is earlier and therefore fish are likely to have higher exposure in the migratory corridor.
Degree days from first fish (C)	Number of accumulated degree days from the first fish ascending Willamette Falls to the first fish captured at Dexter dam. **Hypothesis**: the probability of mortality increases with the accumulated degree days
Degree days 50% fish (C)	Number of accumulated degree days from 50% passage of immigrating spring Chinook at Willamette Falls to the 50% passage of fish at Dexter Dam. **Hypothesis**: the probability of mortality events increases with increasing degree days.
Mean daily discharge first (m³/s)	Average discharge at dam from the first fish ascending Willamette Falls plus travel time to the first fish captured at each dam. **Hypothesis**: the probability of mortality decreases with increased flows
Mean daily discharge 50% fish (m³/s)	Average discharge at dam from 50% passage of immigrating spring Chinook at Willamette Falls plus travel time to the 50% passage of fish at each dam. **Hypothesis**: the probability of mortality decreases with increased flows.

Response variable

Mortality	The proportion of dead and moribund fish (i.e., mortalities) for each outplanting event estimated assuming a binomial distribution of the number of mortalities to total number of fish translocated by individual truck.

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703

704 Table 2. Summary of responses and candidate predictor variables used to evaluate the factors
705 related to Chinook Salmon transport mortality in the Upper Willamette Basin.

Variable	Foster Dam			Dexter Dam		
	Mean (SD)	Minimum	Maximum	Mean (SD)	Minimum	Maximum
Response variable						
Moralities	0.28 (0.81)	0	4	2.98(15.2)	0	147
Proportion mortality	0.008 (0.03)	0	0.375	0.01 (0.03)	0	0.21
Predictors						
Loading time (min)	122.78 (68.39)	20.00	300.00	43.53 (27.77)	10.00	135.00
Hauling Time (min)	37.37 (17.98)	0.00	120.00	77.28 (20.86)	45.00	130.00
Total time handling (min)	160.16 (66.99)	65.00	345.00	120.82 (37.55)	65.00	235.00
Trip number for the day	1.35 (0.62)	1.00	4.00	2.13 (1.46)	1.00	8.00
Truck volume (m^3)	2.8 (2.1)	1.14	5.68	9.27 (1.72)	5.68	10.22
Number of fish transported	33.4 (24.22)	1.00	144.00	149.81 (72.34)	18.00	387.00
Number of fish per truck volume (fish/m^3)	12.31 (8.59)	0.18	57.24	17.01 (7.34)	1.76	37.86
Difference in temperature between collection facility and tank (C)	0.84 (1.19)	-1.11	3.89	-0.18 (1.18)	-3.89	2.22
Day of the year transported	199.2 (36.28)	128.00	276.00	206.27 (19.83)	177.00	255.00
Number of fish in trap	250.39 (191.64)	0.00	715.00	569.91 (287.43)	26.00	1108.00
Water temperature at collection facility (C)	10.55 (1.06)	6.67	12.22	14.07 (1.71)	10.56	16.11
Difference in tank water temperature over trip (C)	0.2 (0.42)	0.00	2.78	-0.01 (0.91)	-3.68	2.22
Maximum daily air temperature (C)	25.37 (4.77)	12.78	37.78	27.32 (3.73)	19.44	33.89
Average number of days since last trap tending	4.59 (2.99)	1.00	14.00	4 (3.85)	0.00	20.00

Cloud cover index	0.34 (0.37)	0.00	1.00	0.37 (0.29)	0.00	1.00
Run size	40995.92 (15660.29)	14149.00	65293.00	40262.18 (14851.96)	14149.00	65293.00
Day of the year 50% of run passed Willamette Falls	144.61 (10.02)	134.00	164.00	143.41 (9.9)	132.00	164.00
Degree days from first fish (C)	5163.48 (1395.19)	2836.70	7381.40	7874.73 (624.45)	6946.65	8573.05
Degree days 50% fish (C)	4810.05 (656.22)	3839.14	5724.34	4937.75 (1189.98)	3134.40	6830.88
Mean daily discharge first (m^3/s)	3580.31 (135.07)	3413.34	3956.36	3041.61 (186.12)	2791.83	3603.25
Mean daily discharge 50% fish (m^3/s)	1884.99 (259.96)	1281.62	2193.30	3465.55 (425.01)	2667.08	3966.73

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707 Table 3. Candidate models and model selection criteria for the confidence model set for adult
708 spring-run Chinook Salmon translocation mortality. All models contained an intercept and a
709 random effect of sample in addition to the variable being evaluated.

Model	AICc	ΔAICc	Model likelihood	Model weight
Dexter Dam				
Number of fish per truck volume (no./m^3)	801.9	0.000	1.000	1
Foster Dam				
Loading time (min)	312.3	0.000	1.000	0.638
Total time handling (min)	314.7	2.387	0.303	0.193
Mean daily discharge first (m^3/s)	316.3	3.996	0.136	0.086
Degree days from first fish (C)	318.5	6.255	0.044	0.028

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711 Table 4. Parameter estimates and 95% confidence limits of fixed and random effects for best
712 approximating model of adult Chinook Salmon translocation mortality. Random effects are
713 variance components.

Model	Parameter	Estimate	95% Confidence limits	
			Lower	Upper
Dexter Dam				
Number of fish per truck volume (no./m^3)	Intercept	-7.002	-9.215	-6.645
	Random effect of outplant occasion	3.113	2.264	4.571
	Effect of umber of fish per truck volume (no./m^3)	1.707	0.819	2.845
Foster Dam				
Loading time (min)	Intercept	-7.002	-8.958	-5.864
	Random effect of outplant occasion	2.162	1.292	3.964
	Effect of loading time (min)	1.173	0.593	1.947
Total time handling (min)	Intercept	-7.175	-9.320	-5.954
	Random effect of outplant occasion	2.342	1.393	4.404
	Total time handling (min)	1.117	0.505	1.918
Mean daily discharge first (m^3/s)	Intercept	-7.164	-9.526	-5.878
	Random effect of outplant occasion	2.329	1.344	4.598
	Mean daily discharge first (m^3/s)	-1.428	-2.740	-0.508
Degree days from first fish (C)	Intercept	-7.107	-9.623	-5.801
	Random effect of outplant occasion	2.487	1.390	5.186
	Degree days from first fish (C)	0.934	0.284	1.725

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