Precision and Accuracy of Age and Growth Estimates Based on Fin Rays, Scales, and Mark-Recapture Information for Migratory Bull Trout

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relationships are often based on age estimates of annual marks on calcified structures such as fin rays and scales (DeVries and Frie 1996). Ideally, aging methods should be validated for accuracy using known-age fish and verified for precision, or repeatability, of age estimates (Beamish and McFarlane 1983; Campana 2001). In the absence of age validation, two important steps are to review the precision (i.e., repeatability) of methods of age estimation and also evaluate whether non-validated age estimates yield growth rates consistent with growth rates of tagged fish.

Bull trout (*Salvelinus confluentus*), a native char in the northwest United States and western Canada, has multiple life history forms that differ dramatically in growth rates and produce complex age structures (Rieman and McIntyre 1993). They occur as either resident (Chandler et al. 2001,

by assessing differences between predicted and apparent ages.

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Little difference in growth was detected when comparing fin ray data using the age-length model with tag-recovery data using the length-increment model. The differences between the models were

SD = 74.08). The LVB growth model converged on all parameters for scales and was described as $L_t = 561.33(1 - e^{-0.23(t+2.66)})$. Standard errors for all parameter estimates were high (Table 1, Figure 5). In contrast to results for fin rays, differences in growth between scale age-length and length-increment data and models were apparent across all size classes. An age-3 fish from scales had a predicted TL of 408 mm from the age-length model while the length-increment model produced an apparent age of 4.3 for the same sized fish (Figure 6). We observed the least difference between predicted and apparent ages (0.1 years) at age 6 (485 mm). After age 6, however, differences between models began to increase. An age-7 fish from scales (500 mm) had an apparent age of 6.3 from the length-increment model.

Di c- ion

Several lines of evidence suggested that pelvic fin rays were a more reliable structure than scales for estimating ages of migratory bull trout. Fin rays provided higher estimates (mean age = 5.9), higher precision (CV = 5.8), and less between-reader bias (Figure 1) than scales (mean age = 4.7; CV = 12.6). The higher age estimates from pelvic fin rays were associated with age-5 fish and older; much younger estimates were produced from scales. Similar results were reported by Mogen and Kaeding (2005) for migratory bull trout in the St. Mary River drainage, Montana, where validation of annuli formation on scales from recaptured fish found under-aging to occur with age-5 fish and older. Estimates of age-4 fish and younger with fin rays, however, did not tend to be lower than for scales. In our study, only 10 fish (15%) were aged < 5 by pelvic fins (mean age = 3.9) and none under age 3. For these fish, scales produced slightly higher estimates (mean age = 4.2). Although fin ray and scale annuli on younger bull trout (age 4 and under) may present few discrepancies between ages, scale-based age estimates of older chars (Nordeng 1961) and other species should be interpreted with caution (Beamish and Chilton 1977, Beamish 1981).

Higher precision with fin rays has been documented for bull trout populations in northern British Columbia (dorsal fins; Williamson and Macdonald 1997ough

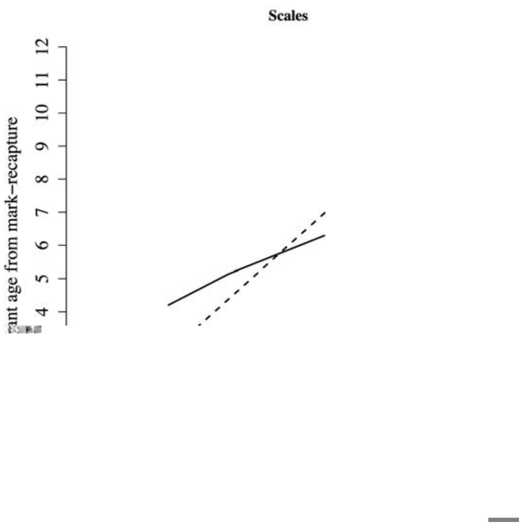

Figure 6. Predicted ages from an age-length LVB versus apparent ages from a mark-recapture Fabens model (solid line). The age-length model was derived from ages estimated from 65 scales of NFC migratory bull trout collected in 2007-2008. The Fs,sus ap-

Montana (pelvic fins; Gust 2001), and the Clark Fork River drainage, Montana and Idaho (pelvic fins; Zymonas and McMahon 2009). Gust (2001) and Zymonas and McMahon (2009), however, used a single-reader multiple-round protocol, which does not incorporate between-reader bias. The CV for ages estimated from fin rays in this study (CV = 5.8) was higher than 3.4 reported for bull trout by Zymonas and McMahon (2009). Campana (2001) conducted a comprehensive review of measuring precision and stated that many aging studies can be carried out with a CV of up to 7.6.

In addition to higher precision, our results indicate that pelvic fin rays are preferable to scales when used to develop estimates of growth of migratory bull trout (274-664 mm TL) within the NFC drainage. The age-length LVB model derived from 189 pelvic fin rays showed only minimal differences (less than one year) in predicted sizes at age compared to the apparent ages from the length-increment model derived from 70 mark-recapture events. This conclusion applies even though annulus formation has not been validated nor were the age or timing of first annulus formation documented in the NFC. The similarities in growth models developed from fin rays (age-length) and mark-recapture data (length-increment) suggest that annuli are being produced on a yearly basis and are identifiable by experienced readers for younger and intermediate aged fish (ages 3-7) and only slight differences may have existed for older individuals (ages > 7).

In contrast, scales appeared to be an unreliable structure on which to base growth estimates of migratory bull trout within the NFC. We observed greater differences in predicted and apparent ages from scale data for fish of most size classes. Comparisons of growth models developed from the scales and mark-recapture data indicated differences below and above age 6. Other studies utilizing scales for age and growth estimation of migratory bull trout produced much lower mean lengths at age for younger fish (< 6, Figure 7) (Bjornn 1961, Fraley and Shepard 1989, Salow 2001). Schiff (2004) used scales of NFC migratory bull trout to back-calculate lengths at previous ages and produced a much lower growth rate overall. In this study, ages estimated for smaller fish were slightly older, indicating that annuli were possibly not discernible. Estimates of age and growth of NFC migratory bull trout with scales should therefore be used with caution.

The observed differences in growth between the fin ray age-length model and the length-increment model may be associated with several factors. First, ages were estimated from fin rays collected in the spring (April-June) while the mark-recapture model was developed from fish captured during the spring and fall (October-November) and included fish at liberty for less than one year. Minor differences between models were expected because of seasonal growth variability associated with the mark-recapture model. A fish aged in the spring may not have developed an annulus for that year's growing season and would therefore be closer in size to the next age group (a fish that recently developed an annulus). Secondly, there were small sample sizes of older individuals in the age-length data

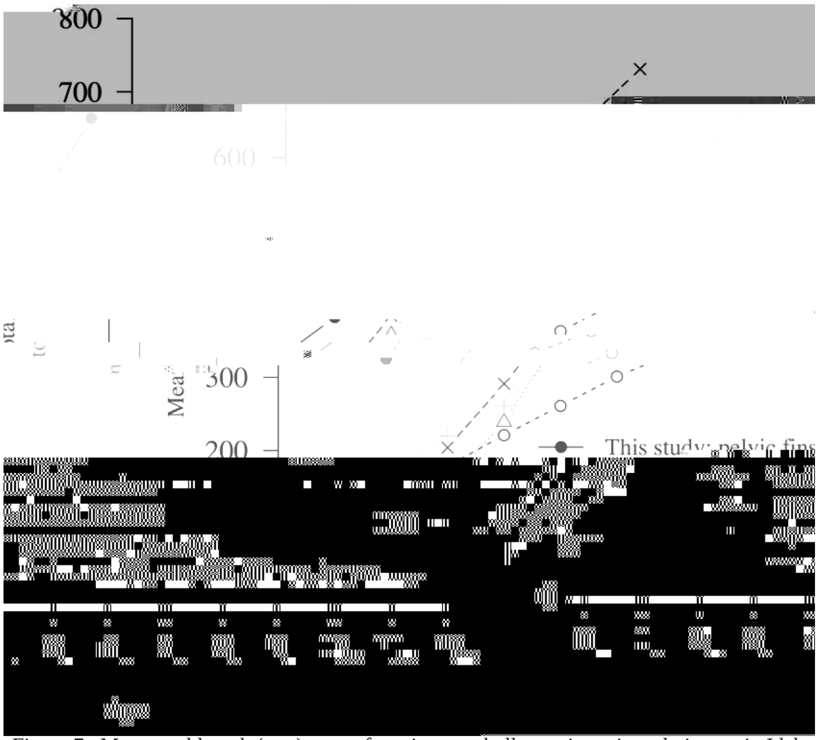

Figure 7. Mean total length (mm) at age for migratory bull trout in various drainages in Idaho and Montana. This study includes estimates from pelvic fin rays from the NFC. Schiff (2004) is based on back-calculation from scales from the NFC. The remaining studies are from scale-based estimates: Bjornn (1961) from Upper Priest Lake, Idaho, Salow (2001) from Boise River, Idaho, and Fraley and Shepard (1989) from Flathead Lake, Montana.

and larger individuals in the mark-recapture data. Haddon (2001) stated that the LVB is inadequate at the curve extremities where sample sizes are often small. Therefore, further research on aging precision of older individuals (> 7) should be attempted. Thirdly, fin ray morphology may have influenced the aging results. For larger individuals, fin ray annuli were often difficult to distinguish near the outer edge of many of the fin ray cross sections because slow growth rates at older ages crowd the annuli. This crowding of annuli was less of a problem for smaller, typically younger, fish. Finally, outliers in the mark-recapture data might explain observed differences between model types. Although, it is unknown whether the outliers were from measurement error, recording error, or just uncommon natural events, when they were removed from the length-increment model the age-length model from fin rays was even closer in age predictions (largest difference < 1 year). The Fabens model has been found to be susceptible to outliers (Francis 1988). These outliers, however, may be indicative of the high growth variability possible in bull trout populations. In addition to the variability of various life history forms (resident and migratory) present in the NFC drainage (Schiff 2004) and the ability for forms to coexist and give rise to one another (Rieman and McIntyre 1993), other factors such as maturation schedules and age/timing of migrations (migratory form) into more productive waters (such as Dworshak Reservoir) could contribute to growth variability at the population level (Rieman and McIntyre 1983). Growth averaging models such as the LVB, therefore, should be used with caution for bull trout.

This is the first study to assess the precision of age estimates from scales and fin rays for modeling growth of adult migratory bull trout. These more accurate age results for fin rays over scales justify their preferential use in growth models. Until actual validation of ages occurs at various localities, it is recommended that our methods be used to evaluate estimates of age and growth for other populations of migratory bull trout.

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