# APPENDIX B6. LIFE STAGE SPECIFIC PASSAGE INFORMATION

# 1. INTRODUCTION

Migratory behavior, fish size, and other factors associated with movement of target fish species will be an important consideration in identifying the design, location, and sizing of various fish passage alternatives. Swimming ability of target species is also an important factor as it relates to the development of fish passage alternatives.

Modes of fish swimming can be classified as one of three categories: sustained, prolonged, or burst swimming (Beamish 1978). Sustained swimming is that which can be maintained indefinitely (i.e., longer than 200 minutes) and is also referred to as cruising speed. Prolonged swimming is a moderate speed that can be maintained for a specific period of time (i.e., up to 200 minutes). Burst swimming is the fastest speed achievable and can only be maintained for short durations (i.e., less than 20 seconds) as it utilizes more anaerobic metabolism than the other swimming modes. Another measurement of fish swimming ability commonly reported in the literature is $U_{crit}$, (or critical swimming speed), which is a standardized calculation of the maximum swimming speed a fish can maintain for a predetermined period of time. As these times are typically between 10 and 200 minutes, $U_{crit}$ falls under the category of prolonged swimming speed. For the purposes of evaluating fish passage alternatives, we focused on burst swimming and prolonged swimming (or $U_{crit}$) as the two most relevant swimming modes. Burst swimming provides an indication of the ability of fish to traverse discrete high velocity areas such as those occurring at fish ladder weirs or at the entrance to a collection facility. Prolonged swimming is an indication of the ability of fish to traverse longer distances within a fish ladder or to avoid impingement or entrainment near turbine intakes.

Species utilize different modes for swimming related to their body shape. Katapodis (1992) describes these modes as follows.

> *Most of the data gathered involve fish swimming in the subcarangiform and anguilliform modes. Subcarangiform is an undulatory mode of swimming characterized by small side-to-side amplitude at the anterior and large amplitude only in the posterior half or one-third of the body. The characteristic body shape is fusiform, the caudal peduncle is fairly deep and the caudal fin has a rather low aspect ratio. In the anguilliform mode most or all of the length of the body participates in propulsion. The body is long and thin, the anterior cylindrical, the posterior compressed and caudal fin is usually small.*

This appendix summarizes the available information related to the behavior, size and swimming ability of target species.

- Although lake trout are an important component of sport fisheries in the Susitna Basin (Jennings et al. 2007, 2011), their importance with regard to the study of fish passage feasibility is thought to be negligible. Should lake trout ultimately inhabit the future Project reservoir, predation by lake trout and entrainment may be considerations. Predation risks associated with Fish Passage are addressed in Appendix B9. The probability of lake trout inhabiting the future Project reservoir and potential entrainment risks will be considered in RSP 9.10 - The Future Watana Reservoir Fish Community and Risk of Entrainment Study.

# 2. ARCTIC GRAYLING

## 2.1. Fish Size

### 2.1.1. Adults

- Maximum length of fish sampled upstream of Devils Canyon during 1982 was 420-mm
- Maturity reached as early as age-4; average length of age-4 grayling in Upper Susitna River was approximately 275 mm (see Appendix B5, Figure B5-1).

### 2.1.2. Juveniles

- Juveniles generally thought to reside in natal tributaries for 1 year.
- Thus, those potentially exhibiting movement range in length from approximately 150-mm (age-1) to 250-mm (age-3) based on average age-specific lengths (see Appendix B5, Figure B5-2).

## 2.2. Migratory and Swimming Behavior

- A preliminary review indicates that information regarding movement patterns in tailrace or forebay areas of hydroelectric facilities is lacking.
- Springtime monitoring of arctic grayling movements at an experimental dam on Poplar Grove Creek, Alaska indicated that peak activity of both upstream and downstream migrants was in late afternoon or early evening, though corresponding increase in water temperature was thought to be an important determinant as well (MacPhee and Watts 1975).
- Spring migration away from overwintering areas is thought to be triggered by a general environmental stimulus such as day length, water temperature, or discharge but can begin prior to break up at temperatures of 1°C or lower (Tack 1980). Pre-spawning migrations intensify during flow increases associated with breakup, with the majority occurring when rivers are at or near flood stage (Tack 1980). Tack (1980) also theorizes that timing upstream migrations with the spring freshet may allow grayling to use channel margins and eddies with slow velocities that only are available during higher flows, as opposed to higher velocities of well defined channels at lower flows.

## 2.3. Swimming Ability

- Exhibit subcarangiform swimming mode (Katapodis 1992).
- Burst swimming ability of 213 to 426 cm/s for fish 20.3 to 30.5 cm FL (Bell 1991 as cited by Furniss 2008).
- Length-specific critical (i.e. prolonged) swimming speeds provided in Figure B6-1 (from Jones et al. 1974).

## 2.4. Other Passage Considerations

- Observations of arctic grayling leaping behavior at experimental dam (MacPhee and Watts 1976).
- Limited information regarding arctic grayling use of passage facilities, though Katapodis (1992) lists adults of this species as showing some use of Denil, vertical slot, weir or culvert fishways.

# 3. BURBOT

## 3.1. Fish Size

### 3.1.1. Adults

- Maximum size of burbot captured downstream of Devils Canyon was 900 mm in 1981; maximum recorded upstream of Devils Canyon was 740 mm in 1981.
- Maturity reached as early as age-6 in interior Alaska (Morrow 1980); average length of age-6 burbot in Upper Susitna River was approximately 425 mm (see Appendix B5, Figure B5-3).

### 3.1.2. Juveniles

- Little is known regarding the movement of juvenile burbot. Aside from spawning and post-spawning migrations, burbot are thought to be relatively sedentary. Thus, the size of juveniles potentially exhibiting migratory behavior is unknown.

## 3.2. Migratory and Swimming Behavior

- A preliminary review indicates that information regarding movement patterns in tailrace or forebay areas of hydroelectric facilities is lacking.
- Burbot movement studies associated with the proposed Dunvegan Hydroelectric Project on the Peace River, Alberta indicated a preference for channel margins as migratory corridors (Mainstream Aquatics 2006).

## 3.3. Swimming Ability

- Exhibit anguilliform swimming mode (Katapodis 1992).
- Burst swimming ability of 36 to 121 cm/s for fish 20 to 70 cm FL (Bell 1991 as cited by Furniss 2008).
- A recent flume study of volitional swimming (Vokoun and Watrous 2009) indicated that Burbot shifted from prolonged to burst swimming at around 4.72 body lengths per second. Swimming performance decreased markedly once flume velocities reached 105 cm/s.

- Length-specific critical (i.e. prolonged) swimming speeds provided in Figure B6-1 (from Jones et al. 1974); however, length was not a significant factor (p=0.1).

## 3.4. Other Passage Considerations

- Burbot are considered benthically oriented, particularly in lakes, inhabiting depths up to 300 m (McPhail and Paragamian 2000).
- Burbot are a large-bodied species with an elongate and cylindrical morphology.
- They are relatively poor swimmers compared to other proposed target species.

# 4. CHINOOK SALMON

## 4.1. Fish Size

### 4.1.1. Adults

- 10 Chinook radio-tagged at Curry that passed the third impediment were 66 to 101 cm FL (mean 83.9 cm).
- 492 Chinook captured at Curry during 2012 were 33 to 123 cm FL (mean 71 cm)

### 4.1.2. Juveniles

- Fry emerge at approximately 32 mm and by late September young of year are typically 50 to 85 mm (weighted average 63.2 mm; Roth and Stratton 1985, Roth et al. 1986).
- Age 1+ were typically 65 to 120 mm at Middle and Lower River outmigrant traps during 1984, weighted average 86.1 mm (Roth et al. 1986).

## 4.2. Migratory and Swimming Behavior

- Upstream adult migration is thought to occur primarily during daylight hours, though some may also migrate upstream at night (Groot and Margolis 1991).
- Downstream movement of fry and subyearling primarily occurs at night, though smaller numbers may move during the day (Groot and Margolis 1991). Yearling smolts appear to be less nocturnal.
- Triggers for downstream movement are poorly understood but increases in flow and density-dependent factors have been suggested (Groot and Margolis 1991).In the Columbia River, yearling smolts tend to migrate at a faster rate exhibiting a more directed outmigration that is independent of river flows compared to subyearling smolts (Groot and Margolis 1991).

## 4.3. Swimming Ability

- For adult Chinook salmon, burst swimming ability ranges from 335 to 671 cm/s and prolonged swimming ability ranges from 91 to 335 cm/s (Bell 1991).

- Sambilay (2005, citing Randall et al. 1987) reports burst swimming ability of juvenile Chinook salmon as 3.019 body lengths per second (SL 19.9 cm) and 2.250 body lengths per second (SL 31.5 cm). This equates to 60.1 cm/s and 70.9 cm/s, respectively
- For juvenile Chinook salmon, several prolonged swimming speeds were reported by Smith and Carpenter (1987, as cited by Furniss et al. 2008): 20.6 cm/s at 10°C (mean FL 4.06 cm), 16.4 cm/s at 7°C (mean FL 3.5 cm), and 14.0 cm/s at 4°C (mean FL 3.95 cm)..

## 4.4. Other Passage Considerations

- Bates and Whiley (2000) summarize various design considerations for Chinook salmon passage:
  - Variable results observed when artificial light provided at fishway entrances; flexibility in the intensity of light should allow for adjustment based on changing conditions.
  - Unlike pink and chum salmon, adult Chinook will exhibit leaping behavior while moving upstream.
  - Within a fish ladder, early-run Chinook tend to use orifices while late-run Chinook prefer weirs.

# 5. DOLLY VARDEN

## 5.1. Fish Size

### 5.1.1. Adults

- Maximum size of Dolly Varden captured during 1981 and 1982 was 205 mm.
- Maturity reached as early as age-4 for the southern form of Dolly Varden (i.e., south of the Alaska Range; Morrow 1980). However, because length-at-age information is unavailable for Dolly Varden in the Upper River, the minimum size at which Dolly Varden would be expected to exhibit any pre-spawning migrations cannot be predicted. However, the length-frequency information is shown in Appendix B5 (Figure B5-4).

### 5.1.2. Juveniles

- Little is known regarding the movement patterns of juvenile Dolly Varden. Likewise, length-at-age information from the Upper River is lacking. Thus, it is difficult to predict the size at which any movements associated with the juvenile life stage would occur. However, the length-frequency information shown in Appendix B5 (Figure B5-4) provides some indication of size distribution in the Upper River.

## 5.2. Migratory and Swimming Behavior

- A preliminary review indicates that information regarding movement patterns in tailrace or forebay areas of hydroelectric facilities is lacking.

## 5.3. Swimming Ability

- While not reported, presumably exhibit subcarangiform swimming mode.
- Although information is unavailable regarding Dolly Varden *(Salvelinus malma)* swimming ability, other studies have examined swimming ability of the closely related bull trout *(Salvelinus confluentus)* and arctic char *(Salvelinus alpinus)*.
- Length-specific critical (i.e. prolonged) swimming speeds provided for bull trout in Figure B6-1 (from Zydlewski et al. 2004).
- Beamish (1980 as cited by Furniss 2008) reports burst swimming speeds ranging from 109 cm/s (at 10°C) to 133 cm/s (at 12°C) for arctic char (mean TL 340 mm).

## 5.4. Other Passage Considerations

- Although examples of Dolly Varden use of passage facilities are limited, several passage facilities designed for or utilized by bull trout have been constructed, with varying degrees of success.

# 6. HUMPBACK WHITEFISH

## 6.1. Fish Size

- Only three humpback whitefish have been captured upstream of Devils Canyon; these ranged in size from 231 to 347 mm.
- The size of juvenile humpback whitefish in the Upper River is unknown.

## 6.2. Migratory and Swimming Behavior

- A preliminary review indicates that information regarding movement patterns in tailrace or forebay areas of hydroelectric facilities is lacking.

## 6.3. Swimming Ability

- Exhibit subcarangiform swimming mode (Katapodis 1992).
- Length-specific critical (i.e. prolonged) swimming speeds for humpback whitefish (reported as *Coregonus clupeaformis*) provided in Figure B6-1 (from Jones et al. 1974).
- Burst swimming ability of 91.4 to 122 cm/s for fish 15.2 to 45.7 cm in length (Bell 1991 as cited by Furniss 2008).

## 6.4. Other Passage Considerations

- There is little information available regarding the behavior of humpback whitefish
- Limited information regarding humpback use of passage facilities, though Katapodis (1992) lists adults of this species as showing some use of Denil, vertical slot, weir or culvert fishways.

# 7. LONGNOSE SUCKER

## 7.1. Fish Size

### 7.1.1. Adults

- Maximum length of fish sampled upstream of Devils Canyon was 495-mm during 1982, 505-mm during 1981, and 404-mm during 2012 (See Appendix B5).
- Maturity may be reached as early as age-5 or age-6 in northern populations (Delaney et al. 1981), which corresponds to a size of approximately 325-mm in the Upper Susitna (see Appendix B5, Figure B5-5).

### 7.1.2. Juveniles

- Some evidence of downstream movement of age-0 juveniles (See Appendix B3) though subsequent movement of juveniles is unknown.
- Thus, the size range of juveniles potentially exhibiting migratory behavior is unknown.

## 7.2. Migratory and Swimming Behavior

- A preliminary review indicates that information regarding movement patterns in tailrace or forebay areas of hydroelectric facilities is lacking.

## 7.3. Swimming Ability

- Exhibit subcarangiform swimming mode (Katapodis 1992).
- Burst swimming ability of 121 to 242 cm/s for fish 10 to 46 cm in length (Bell 1991 as cited by Furniss 2008).
- Length-specific critical (i.e. prolonged) swimming speeds provided in Figure B6-1 (from Jones et al. 1974).

## 7.4. Other Passage Considerations

- Longnose sucker documented passing vertical slot and Denil fishways, though performance was better in vertical slot (Schwalme et al. 1985).
- Afternoon and evening peaks in fishway use (Schwalme et al. 1985, Thiem et al. 2012).

# 8. ROUND WHITEFISH

## 8.1. Fish Size

- Maximum size of round whitefish captured upstream of Devils Canyon was 440 mm during 1981 and 404 mm during 2012 (See Appendix B5).

- Maturity is reached from age-5 to age-7 (Morrow 1980), corresponding to approximately 300 mm (See Appendix B5, Figure B5-6).
- While there is some evidence of juvenile downstream migration, the size distribution, age, and magnitude of movements is unclear.

## 8.2. Migratory and Swimming Behavior

- While round whitefish are thought to exhibit upstream or downstream migrations from summer feeding habitats to spawning areas, they do not exhibit the concentrated migrations exhibited by other whitefish species in Alaska.
- Little is known regarding migratory behavior associated with winter habitat use.
- Preliminary review indicates that information regarding movement patterns in tailrace or forebay areas of hydroelectric facilities is lacking.

## 8.3. Swimming Ability

- While not reported, presumably exhibit subcarangiform swimming mode.
- Information regarding the swimming ability of round whitefish *(Prosopium cylindraceum)* is unavailable. However, information for the congeneric mountain whitefish *(Prosopium williamsoni)* is available.
- Burst swimming ability reported for mountain whitefish of 48.8 to 106.7 cm/s for fish with a mean length of 304 mm (Bell 1991 as cited by Furniss 2008).
- Critical (i.e. prolonged) swimming speed for mountain whitefish of 42.5 cm/s for fish with a mean length of 304 mm (Jones et al. 1974 as cited by Furniss 2008).

## 8.4. Other Passage Considerations

- Preliminary review indicates that information is lacking regarding performance of round whitefish in passage facilities, migratory cues, and behavior associated with passage.

# 9. REFERENCES

Bates, Ken, and Anthony J. Whiley. Fishway Guidelines for Washington State: Draft. Washington Department of Fish and Wildlife, 2000.

Beamish, F.W.H. 1978. Swimming capacity. In Fish Physiology, vol. VII (ed. W. S. Hoar and D.J. Randall), pp. 101–187. New York: Academic Press.

Bell, Milo C. 1991. Fisheries handbook of engineering requirements and biological criteria." (1991).

Delaney, K., D. Crawford, L. Dugan, S. Hale, K. Kuntz, B. Marshall, J. Mauney, J. Quinn, K. Roth, P Suchanek, R. Sundet, and M. Stratton. 1981c. Resident fish investigation on the Upper Susitna River. Phase I Final Draft Report, Alaska Department of Fish and Game Susitna Hydro Aquatic Studies. Prepared for Alaska Power Authority, Anchorage, Alaska. 157 pp. APA Document # 316.

Furniss, M., M. Love, S. Firor, K. Moynan, A. Llanos, J. Guntle, and R. Gubernick. 2008. FishXing, version 3.0. U.S. Forest Service, San Dimas Technology and Development Center, San Dimas, California. Available: www.stream.fs.fed.us/fishxing. (March 2012).

Groot, Cornelis, and Leo Margolis. *Pacific salmon life histories*. UBC press, 1991.

Jones, D.R., Kiceniuk, J.W. and Bamford, O.S. 1974. Evaluation of the swimming performance of several fish species from the Mackenzie River. Journal of the Fisheries Research Board of Canada 31: 1641-1647.

Katopodis, Chris. *Introduction to fishway design*. Freshwater Institute, Central and Arctic Region, Department of Fisheries and Oceans, 1992.

MacPhee, C., & Watts, F. J. (1976). Swimming performance of arctic grayling in highway culverts.

Mainstream Aquatics 2006. Fish Movement Study (2004/2005) Dunvegan Hydroelectric Project. Prepared for Glacier Power Ltd., Calgary, Alberta

McPhail, J. Donald, and Vaughn L. Paragamian. "Burbot biology and life history." Burbot: biology, ecology, and management. American Fisheries Society, Fisheries Management Section, Publication 1 (2000): 11-23.

Morrow, J. E. 1980. The freshwater fishes of Alaska. Alaska Northwest Publishing Co., Anchorage, Alaska. 248 pp.

Roth, K. J. and M. E. Stratton. 1985. The migration and growth of juvenile salmon in Susitna River, 1985. Pages 6-207 in Schmidt, D., S. Hale, and D. Crawford, eds., Resident and juvenile anadromous fish investigations (May - October 1984). Report No. 7, Alaska Department of Fish and Game Susitna Aquatic Studies Program. Prepared for the Alaska Power Authority, Anchorage, Alaska. APA Document # 2836.

Roth, K. J., D. C. Gray, J. W. Anderson, A. C. Blaney, J. P. McDonell. 1986. The migration and growth of juvenile salmon in Susitna River, 1985. Susitna Aquatic Studies Program Report No. 14, Alaska Department of Fish and Game Susitna Hydro Aquatic Studies. Prepared for Alaska Power Authority, Anchorage, Alaska. 130 pp. APA Document # 3413.

Sambilay Jr, V. C. (2005). Interrelationships between swimming speed, caudal fin aspect ratio and body length of fishes. *Fishbyte*, *8*(3), 16-20.

Schwalme, K., W. C. Mackay, and D. Lindner. 1985. Suitability of vertical slot and Denil fishways for passing north-temperate, nonsal9monid fish. Can. I. Fish. Aquat. Sci. 42: 1815-1822.

Tack, S. L. Migrations and distribution of Arctic grayling, Thymallus arcticus (Pallas), in interior and arctic Alaska. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Performance Report, 1979-1980. Project F-9-12, 2 1 (RI), 1980.

Thiem, J. D., Binder, T. R., Dumont, P., Hatin, D., Hatry, C., Katopodis, C., ... & Cooke, S. J. (2012). Multispecies fish passage behaviour in a vertical slot fishway on the Richelieu River, Quebec, Canada. *River Research and Applications*.

Vokoun, J.C. and D.C. Watrous. 2009. Determining swim speed performance characteristics for fish passage of burbot using an experimental flume and nature-like fishway. Completion Report submitted to Connecticut Department of Environmental Protection. University of Connecticut, Storrs. 27 pp.

Zydlewski, G. B. (2004). Critical swimming speeds of wild bull trout. *Northwest Science*, *78*(1), 59.

# 10. FIGURES

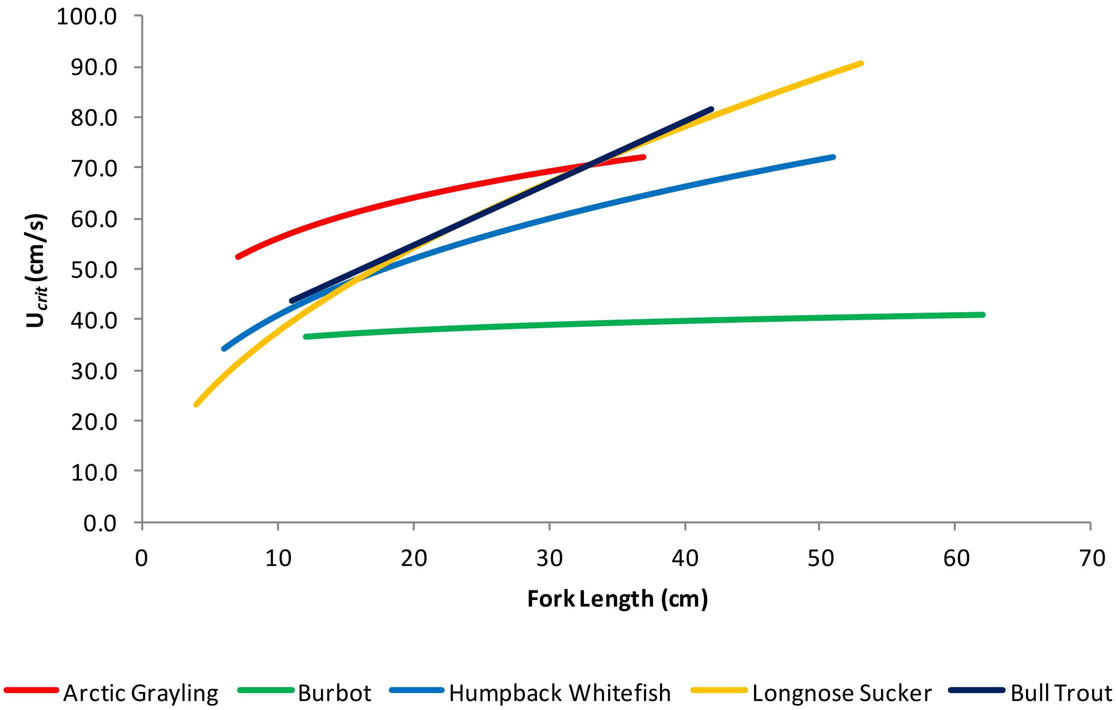


**Figure B6-1. Relationship between fork length and critical swimming speeds ($U_{crit}$) of arctic grayling, burbot, humpback whitefish, and longnose sucker (Jones et al. 1974) and bull trout (Mesa et al. 2004) as a congeneric surrogate for Dolly Varden.**