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**Synthesis of biological and harvest information used to assess populations of northern form Dolly Varden (*Salvelinus malma malma*) in Canada. Part II: Big Fish River**

**Synthèse des données biologiques et sur la récolte utilisées pour évaluer les populations de la forme nordique du Dolly Varden (*Salvelinus malma malma*) au Canada. Partie II : rivière Big Fish**

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**ABSTRACT**

Biological information of anadromous northern form Dolly Varden (*Salvelinus malma malma*) collected from the Big Fish River, Northwest Territories, between 1972 and 2000 along with harvest statistics are synthesized in order to assess the population and examine for any trends over time. Data include abundance, length, age, growth, sex, maturity, mortality, and estimated and reported subsistence harvest. Inconsistent sampling methods and locations, and the many instances of low sample sizes of males and females, particularly for ageing structures, among study years preclude robust assessment of trends of biological parameters. Population abundance estimates suggest a decline in population size from the 1970s to the mid-1980s, which remained low throughout the 1990s. Male Dolly Varden captured by seining in the 1990s were often smaller than females. Reliable estimates of female age-at-maturity varied between 4 and 6 years, while male age-at-maturity was 6 years. Female spawners outnumbered males while the proportion of spawners among sampling years did not appear to change. Sex ratios were variable, however females generally outnumbered males 2:1. Trends in annual mortality were limited due to the paucity of ageing data in males; female mortality ranged between 0.42 and 0.37 over time. While Dolly Varden from the Big Fish River once yielded harvests of approximately  $\geq 8,000$  kg the current harvest may now be  $< 100$  fish. Although there was limited data suitable for assessment purposes, the results among years were standardized for capture method and location and any biases that could influence interpretations of the assessment were identified. The inconsistent approaches used in the past underscore the need for a consistent approach and methodology for future assessment and monitoring of Dolly Varden from the Big Fish River.

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## RÉSUMÉ

Les données biologiques sur la forme nordique anadrome du Dolly Varden (*Salvelinus malma malma*) recueillies dans la rivière Big Fish (Territoires du Nord-Ouest), de 1972 à 2000, de même que les statistiques sur la récolte sont résumées afin d'évaluer la population et d'examiner toute tendance au fil du temps. Les données comprennent l'abondance, la longueur, l'âge, la croissance, le sexe, la maturité, la mortalité ainsi que la récolte de subsistance estimée et rapportée. Le manque d'uniformité des méthodes et des lieux d'échantillonnage ainsi que les nombreuses occurrences de petites tailles d'échantillons de mâles et de femelles, particulièrement les structures pour la détermination de l'âge, relevés au cours des années d'étude empêchent de faire une évaluation solide des tendances des paramètres biologiques. Les estimations de l'abondance de la population semblent indiquer un déclin de la taille de la population, des années 1970 au milieu des années 1980, qui est demeurée basse tout au long des années 1990. Les Dolly Varden mâles capturés au moyen de la pêche à la senne dans les années 1990 étaient souvent plus petits que les femelles. Les estimations fiables de l'âge à la maturité des femelles ont varié entre quatre et six ans, alors que l'âge à la maturité des mâles a été de six ans. Les femelles génitrices ont dépassé les mâles en nombre alors que la proportion de géniteurs, au cours des années d'échantillonnage n'a pas semblé changer. Le sex-ratio ont varié, quoique les femelles aient généralement été plus nombreuses que les mâles dans une proportion de 2:1. Les tendances de la mortalité annuelle ont été limitées en raison du manque de données sur l'âge des mâles; la mortalité des femelles a varié entre 0,42 et 0,37 au fil du temps. Bien que les prises du Dolly Varden, dans la rivière Big Fish, aient déjà été égal ou supérieur à environ 8 000 kg, les prises actuelles peuvent maintenant se situer à moins de 100 poissons. Même si les données appropriées à l'évaluation ont été limitées, les résultats recueillis au fil des années ont été normalisés pour ce qui est de la méthode et des lieux d'échantillonnage, et tout biais susceptible d'influer sur les interprétations de l'évaluation a été relevé. Les approches irrégulières adoptées par le passé font ressortir la nécessité d'une approche et d'une méthodologie uniformes pour toute évaluation ou surveillance éventuelle du Dolly Varden dans la rivière Big Fish.

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## INTRODUCTION

The pre-COSEWIC assessment of Northern form Dolly Varden (*Salvelinus malma malma* (Walbaum 1792)) requires the review of all available information in order to (1) synthesize population abundance and harvest data of known Dolly Varden stocks, and (2) assess populations based on analyses of biological parameters (e.g., length, age, length-at-age, maturity, sex ratios and mortality) over time. Anadromous Dolly Varden from the Big Fish River are examined in this report. Biological information on resident and isolated life history types are presented separately in Part III of the assessment series (Gallagher *et al.* in prep.).

### NORTHERN FORM DOLLY VARDEN

In Canada, northern form Dolly Varden occurs west of the Mackenzie River in the Northwest Territories and Yukon Territory. Northern form Dolly Varden in Canada spawn and overwinter in tributaries of the Mackenzie River Delta and Peel River, and in rivers of the Yukon North Slope. These rivers or their tributaries are characterized by localized perennial groundwater inflows that maintain year-round stretches of open water used as spawning and over-wintering sites by Dolly Varden. Previously referred to as the Western form of Arctic char (*Salvelinus alpinus*), Dolly Varden holds cultural and dietary importance for Inuvialuit and Gwich'in peoples of Canada.

Northern form Dolly Varden in Canada exhibit three life-history types: anadromous, residual and isolated. Anadromous Dolly Varden are located in the Firth River/Joe Creek, Babbage, Big Fish, Rat and Vittrekwa rivers and also purportedly in the Fish River (Figure 1). They make annual migrations to the Beaufort Sea to feed in the summer, generally after three years of age. Anadromous Dolly Varden have faster growth rates and attain larger sizes compared to the other life history types. Non-anadromous residual (or resident) Dolly Varden remain in their natal stream and co-occur with anadromous fish during the fall and winter in spawning/overwintering areas of the Babbage, Big Fish, Firth/Joe Creek and Vittrekwa river systems. The residual fish life history type are typically smaller males that mature at a smaller size and younger age, and adopt a “sneaker” reproductive strategy when anadromous Dolly Varden spawn (Esteve 2005). The isolated life history type is also non-anadromous and occurs in the Babbage, Big Fish, Blackstone and Gayna river systems (Figure 1) (McCart and Bain 1974, Bain 1974, Mochnacz and Reist 2007). This type is isolated by physical barriers (such as waterfalls), or by distance and intervening unsuitable habitats (Sawatzky and Reist 2008). Isolated Dolly Varden are not sympatric with residual or anadromous Dolly Varden, however possible immigration downstream has not been confirmed (Reist 1989).

Genetically distinct populations of northern form Dolly Varden have been confirmed in the Firth, Babbage, Big Fish and Rat rivers (Reist 1989). Additionally, there is an indication that Dolly Varden from Joe Creek are distinct from fish that spawn in the Firth River (Reist 1989). Genetic studies completed to date have not included fish from the Vittrekwa or Fish rivers.

In the Big Fish River, tagging studies provide further support for strong philopatry (Sandstrom and Harwood 2002). For example, Dolly Varden from the Big Fish River that were Floy-tagged between 1984 and 1994 (n= 2,050) for population abundance studies have only been recaptured in the Big Fish River and by mixed-stock coastal fisheries along the Yukon North Slope (Sandstrom and Harwood 2002). Although minimal, straying by some overwintering Floy-tagged Dolly Varden has been observed between the Big Fish and Babbage rivers however these fish do not contribute to the reproductive potential of the stock (Sandstrom 1995; Sandstrom and Harwood 2002).

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## RIVER CHARACTERISTICS

The Big Fish River and its tributaries originate in the Richardson Mountains and flow north-east to drain into the Moose Channel of the Mackenzie River Delta. The upper reaches of the Big Fish River has numerous small fast flowing tributaries with gravel and cobble substrates. Tributaries are typically 1-5 m wide, 0.5-2 deep with moderate flows and gravel substrates (Gillman *et al.* 1985). The foothills area of the Big Fish River flows through a steep-sided gorge where gravel bars and boulders are common with depths between 0.5 and 1 m. The lower reaches of the river are slow flowing with mud banks and substrates with depths between 1-4 m (Gillman *et al.* 1985). Arctic grayling (*Thymallus arcticus*) and round whitefish (*Prosopium cylindraceum*) are also found in the Big Fish and Little Fish rivers (Gillman *et al.* 1985). MacDonell (1987) also reported the presence of Broad whitefish (*Coregonus nasus*).

The Little Fish River is the largest tributary to the Big Fish River and has the only known spawning and overwintering area (Fish Hole) for Dolly Varden. A 3-4 km stretch of the Fish Hole remains open throughout the winter due to perennial thermal springs located at and above a 3 m waterfall impassable to fish (McCart and Bain 1974). An aufeis (large area of overflow ice) below the waterfall has created braided channels which consist of pool and riffle habitat.

The sources of water to the Little Fish River are deep circulating sub-permafrost thermal groundwater (4-16 °C) discharging from bedrock along the river, shallow groundwater (4.9-9.0 °C) and suprapermafrost (surface water) runoff (0.4-3.5 °C) (Clark *et al.* 2001). The springs have high levels of dissolved solids (2,585-2,698 mg/L), high concentrations of Na<sup>+</sup>, K<sup>+</sup> and Cl<sup>-</sup> ions, high conductance (4531-4546 µmho/cm) and low oxygen levels (2.0-0.5 ppm) relative to other over-wintering sites for Dolly Varden along the North Slope (McCart and Bain 1974). Conversely, surface water has low TDS (20-195 mg/L) and negligible Na<sup>+</sup>, K<sup>+</sup> and Cl<sup>-</sup> concentrations (Clark *et al.* 2001).

Earthquake activity in the mid-1980s may have affected habitat availability by altering the volume of groundwater discharge (see Sandstrom and Harwood 2002). Community elders from Aklavik have also mentioned that changes in habitat may have resulted from the collapse of limestone cliffs above the waterfall (Sandstrom and Harwood 2002). Papik *et al.* (2003) described how water from the Big Fish River in the 1960s was undrinkable and how water levels were relatively high, which has since changed. Observations of lower water levels in the Big Fish River in the late 1980s by residents of Aklavik were reported by Byers (1993).

## FISHERIES

Dolly Varden from the Big Fish River have provided an important subsistence fishery, particularly for the inhabitants of Aklavik (Byers 1993). Historically, fishing for Dolly Varden occurred at Shingle Point (Yukon North Slope) during the summer, the mouth of Big fish River in August when Dolly Varden were migrating to spawning/overwintering areas, and at Fish Hole in October/November (Sandstrom and Harwood 2002). Harvesters at Shingle Point use gill nets to capture fish, which include Dolly Varden from multiple other stocks. It has been estimated that 50% of the Shingle Point harvest consists of Dolly Varden from the Big Fish River based on Floy tag returns (L. Harwood, pers. comm. in Stephenson 2003). Harvesters that fished at the mouth of the Big Fish River in the past have used 20-50 m long gill nets (76-127 mm mesh size) while a seine or small mesh gill net was used to sweep pools at Fish Hole to capture Dolly Varden (Sparling and Stewart 1986). The fishery mainly removed large fish (300-500 mm) from the population (DFO 2001). The past harvest of Dolly Varden from the Big Fish River ranged from



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several hundred to several thousand annually and it was consistently fished at Fish Hole for over 30 years (Stephenson 2003). A commercial quota of 900 kg was taken in 1973 however no other commercial activity has taken place since.

Harvesters noticed a gradual decline in population size and abundance from the 1970s to the mid 1980s (DFO 2003; Stephenson 2003). The Aklavik Hunters and Trappers Committee (HTC) and the Department of Fisheries and Oceans agreed to prohibit any harvesting of Dolly Varden from the Big Fish River, including the mouth, for a five year period beginning in 1987 to allow the stock to recover. Harvesting was restricted to an exploratory fishery at the mouth of the Big Fish River in 1992 and 1994-1996, and at the Fish Hole from 1993-1995 and 1997-2000, which produced minimal catches (<50/year) (Sandstrom and Harwood 2002). Fishing activity at the mouth of the river or at Fish Hole has not occurred since 2001 although Dolly Varden from the Big Fish River continue to be harvested at Shingle Point and likely at other traditional fishing sites along the Beaufort Sea coast.

## **SCIENTIFIC INVESTIGATIONS**

Studies to estimate the population size of Dolly Varden from the Big Fish River began in 1972 (Stein *et al.* 1973) and have been undertaken periodically up to 2000 (Stephenson 2003) (Table 1). The objectives of the majority of the studies conducted on the Big Fish River were to estimate population size, measure biological parameters (e.g. growth), obtain tissue samples for genetic analysis (Reist 1989, Reist *et al.* 1997), assay for detecting infectious pancreatic necrosis virus (Souter *et al.* 1986), or characterize the subsistence harvest (Table 1). Scientific studies on anadromous Dolly Varden from the Big Fish River from 1972-1994 are summarized by Sandstrom and Harwood (2002) while studies and local observations from 1995-2002 are summarized by Stephenson (2003). No additional scientific investigations have occurred since.

## **ASSESSMENT**

### **POPULATION SIZE AND TRENDS**

#### **Mark-recapture studies**

Population abundance of anadromous Dolly Varden from the Big Fish River has been estimated using mark-recaptures studies (Table 2). No population estimates exists for residual fish. Anadromous Dolly Varden were marked by a Floy tag with a T-bar anchor inserted under the base of the dorsal fin (1972-1993) or by punching a small hole in the upper portion of the caudal fin (1998). In most years, the fish were captured and recaptured in either the same or following year during the return migration using a weir, in the fall at the Fish Hole by seining, or visual counts of tags when surveying along shore.

#### **Single recapture event**

The Petersen method was used in most years to calculate the abundance. The basis of the method is that a number of individuals from a population are marked and then recaptured at a later time. If assumptions are met, the proportion of marked individuals among recaptures should be representative of the number of marked individuals in the entire population. The population abundance is then estimated as follows:

$$N = \frac{(M+1)(C+1)}{(R+1)} - 1$$

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where N= population size, M= number of individuals marked, C= total number of individuals captured while trying to collect marked fish, and R= number of individuals marked that were recaptured. The precision associated with the mark-recapture technique is inversely dependant on the number of marked fish recaptured. The uncertainty associated with the estimate is determined by calculating the variance (Var):

$$\text{Var} = \frac{(M+1)(C+1)(M-R)(C-R)}{(R+1)^2(R+2)} - 1$$

and subsequently 95% confidence intervals (C.I.):

$$N \pm (1.96) \times \sqrt{(\text{Var})}$$

The assumptions of the Petersen mark-recapture method are (Seber 1982):

- 1) The population is closed (i.e., no immigration or emigration),
- 2) All fish (anadromous Dolly Varden) have an equal chance of being caught in the first sample
- 3) The second sample is a single random sample
- 4) Marking the fish does not affect their catchability or natural mortality
- 5) Fish do not lose marks between the two sampling periods
- 6) All marks and total number caught are accurately reported in the second sample

Some of the assumptions of the Petersen method were not fully adhered to with respect to experiments conducted on Dolly Varden from the Big Fish River. In most instances, violations were adequately controlled for or were not considered serious enough to render the estimates unusable.

Assumption 1: Population is closed (i.e., no immigration or emigration)

Although possible, emigration or immigration of fish to or from other North Slope systems is not considered an issue as genetic and tagging studies have shown that movement between the populations is minimal (Reist 1989, Sandstrom and Harwood 2002). Additionally, it is important to note that there are no other documented overwintering sites in the Big Fish River that could be used by Dolly Varden. Hence, it is a relatively safe assumption that all available marks should be present during the recapture event.

Recruitment of smaller fish into the pool of marked fish due to growth between the marking and recapture event would have an adverse affect on the estimate by changing the ratio of marked to unmarked fish. This was corrected for the 1987 and 1993 Peterson estimates by excluding fish in the recapture event that would have been smaller than the size range marked in the previous tagging event. This adjustment (i.e., minimum size included in recapture event) was based on the observed growth rate of the smaller recaptured individuals (S. Sandstrom pers. comm.).

Unfortunately, it is not known if recruitment was controlled for prior to 1987. The 1984 estimate of 4,600 is erroneous because it evenly applied a 50% mortality rate based on results from

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subsistence harvest (assumed) to the population estimate of 9,300 that does not factor recruitment of fish  $\geq 350$  mm.

Assumption 2 and 3: Equal chance of capture and sample random

In many instances, Dolly Varden were tagged using one gear type and recaptured the same year or the following year with a different gear type (Table 2). Each gear type is likely different with respect to the size of fish that are vulnerable. However; it is not possible to evaluate the effects of gear type because the body length data from Dolly Varden that were marked and recaptured using the different gear types was not available. Population estimates were made using consistent methods to capture and re-capture Dolly Varden in 1972, 1984 (assumed that gill nets were used), 1987, 1993 and 1998 (Table 2). Regardless of gear type, the capture and re-capture from most years is likely not a random sample of the population due to the probable structure in size during return migration where large current-year spawners will be the first to return while smaller sized smolts will arrive later (Glova and McCart 1974, Griffiths *et al.* 1975, Macdonell 1987). Additionally, the 1972 estimate of 20,700 is likely not a random sample as fish tagged at the mouth were recaptured a week later at the mouth. It is hypothesized that the best time to randomly sample is when Dolly Varden are at the spawning area in the fall when all migrating fish have arrived. However, it is important to sample as much of the area as possible in order to encounter juveniles which appear to occupy lower reaches of spawning areas during spawning time (Sandstrom *et al.* 2001).

The only years when fish were tagged and re-captured at the spawning area was in 1988, 1993 and 1998. However, assumptions of random mixing of tagged and untagged fish were likely violated in 1988 and 1998 because re-captures were made within days. Among year comparisons are not only compromised due to the violation of assumptions, but also due to the differences in minimum sizes of tagged fish which range from  $\geq 150$  mm in 1972 to  $\geq 400$  mm in 1991.

Assumption 4: Marking does not affect catchability or natural mortality

Differential mortality of tagged and untagged fish between the marking and recapture period would be problematic, but the presence of a Floy tag is assumed to have a benign effect on the individual (see Mourning *et al.* 1994). Hence, marked and unmarked fish are lost between the sampling events (as a consequence of natural mortality) at similar rates, with the ratio of tagged to untagged fish (the measure of interest) remaining unchanged, and thus, not affecting the abundance calculation.

Assumption 5: Fish do not lose marks

The assumption of no tag loss between sampling periods was likely violated in almost all experiments where the period between marking and recapture exceeded three months. However this was controlled for by applying an empirically derived annual tag loss estimate of 11.3% to estimates in 1984, 1987 and 1993. This was based on results from other Dolly Varden tagging studies (Armstrong 1984) where a combination of Floy tags and adipose clips were used to derive an estimate.

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Assumption 6: All marks and catch were accurately reported

It is assumed that all marks were reported on discovery in the second sample as there was a monetary incentive to do so. Most of the recapture data used to estimate population size were from scientific investigations where personnel would report the presence of tagged fish.

#### Multiple recapture events

Multiple recaptures within one year made it possible to calculate Bailey's Triple-Mark-Recapture for an estimate of population size in 1988. The abundance is estimated as follows:

$$N_2 = \frac{(M_2)(N_2)(R_{3,1})}{(R_{2,1})(R_{3,2})}$$

where  $N_2$  = population size at second sampling interval,  $M_2$  = number of individuals marked on second sampling occasion,  $N_2$  = total number of individuals captured on second sampling occasion,  $R_{3,1}$  = number of recaptures on the third sampling occasion marked in the first occasion,  $R_{2,1}$  = number of recaptures on the second sampling occasion marked in the first occasion,  $R_{3,2}$  = number of recaptures on the third sampling occasion marked in the second occasion. The standard error is calculated:

$$S.E. = (N_2)^2 \left[ \frac{1}{R_{2,1}} + \frac{1}{R_{3,2}} + \frac{1}{R_{3,1}} - \frac{1}{C_2} \right]$$

The assumptions of Bailey's Triple-Mark-Recapture are the same as the Petersen method.

#### **ABUNDANCE**

Thirteen population estimates were generated in seven years between 1972 and 1998. Multiple population estimates were produced in 1972 (n= 2), 1984 (n= 2), 1987 (n= 2), 1988 (n= 3) and 1991 (n= 2), while single estimates were made in 1993 and 1998. The population estimates for Dolly Varden from the Big Fish River may lack accuracy due to violations of some of the assumptions which would likely overestimate population size. Abundance and confidence estimates presented in the results section (Table 2) do not equal the values calculated from the original reports because different variations of the formulae were used. Estimates were recalculated in order to standardize the information (for details see Table 2).

Abundance ( $\pm$  95% C.I.) of Dolly Varden from the Big Fish River appears to have declined between 1972 and 1998 (Table 2). In 1972, the two population estimates that were generated were highly variable: 20,683 (15,726-25,605) and 13,527 (11,732-15,322) anadromous fish  $\geq 150$  mm. Based on recaptures made in 1985, an estimate of abundance for 1984 was 8,455 (5,477-11,432) fish  $\geq 350$  mm (recalculated from original published value and adjusted for tag loss). In 1987, the two estimates of the population size for fish  $>200$  mm indicated that Dolly Varden likely numbered between 7,000 and 9,000 (Table 2). Two Petersen and one Bailey's estimates were done in 1988 and results from these ranged from 5,839 to 8,498 Dolly Varden  $>200$  mm (Table 2). Estimates in 1991 based on recapture of fish and a visual count of tagged fish during a streamside survey were 2,839 ( $>400$  mm) and 2,231 Dolly Varden, respectively at the Fish Hole. The 1993 abundance estimate was higher than 1991 with an estimated 4,476 fish  $\geq 370$  mm. In 1998 there was an estimated 4,025 Dolly Varden  $\geq 320$  mm (Table 2).

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Even with no fishing activity at the mouth of the Big Fish River or at the Fish Hole between 1987 and 1992, the population size appears to have decreased. Lack of recovery in abundance despite a five-year closure of the fishery could be a result of habitat change, particularly at spawning/over-wintering area, and/or due to fishing pressure on the anadromous component of the stock during a mixed-stock summer fishery at Shingle Point and other sites along the coast (Sandstrom and Harwood 2002).

## **LENGTH, AGE AND GROWTH DATA**

### **Data limitations**

Sampling of Dolly Varden from the Big Fish River since the early 1970s has been performed at different times of the year at various locations and using different collection methods which need to be taken into consideration before directly comparing results among studies. The primary methods used to collect information were subsistence gill nets, weir and seine. A subsistence gill net was used as a seine to sweep pools at the Fish Hole in 1999 (76 mm mesh size) and 2000 (114 mm mesh size).

In most years, Dolly Varden were collected between the months of August and September using gill nets or a weir (Table 1). However, sample collections in the 1970s were conducted during summer (i.e., July 1972 and June 1973 using gill nets at the mouth of the river) or winter (February 1974 using gill nets at Fish Hole) while between 1997 and 1998 sampling was conducted at Fish Hole in October or November (using a seine). Additionally, the database used for the assessment did not distinguish between sampling methods (i.e., seine/angling) in certain years. The use of different fishing gear introduces bias in the analysis of trends in biological parameters over time. In most instances, gear and location are associated as gill nets were set at the mouth of the river, the weir was situated in the lower reaches of the Little Fish River and seining occurred in the spawning/overwintering area (Fish Hole). The use of a gill net as a seine in 1999 and 2000 occurred in November and October, respectively.

Harvester's gill nets set at the mouth of the Big Fish River were sampled for biological information between 1972 and 1986, while a small number of Dolly Varden were sampled (n= 23) in 1992 during an exploratory fishery after the closure. Nets were typically set in August. The closure of the fishery in 1987 prohibited fishing activity resulting in the inability to use harvester's gill nets as a consistent means of further monitoring. Additionally, the data from harvester's gill nets limit meaningful interpretation of trends in biological parameters since mesh size, known to influence the size of captured fish, was not recorded. Unfortunately, catch effort from harvester's gill nets was also never recorded. In some years samples were only taken over a portion of the entire fishing period (e.g., August 10-16, 1972; and August 20-21, 1980), and thus may have been biased towards larger sized char which tend to migrate to spawning areas before smaller non-spawners (Glova and McCart 1974, Griffiths *et al.* 1975). It should be noted that gill nets were also used in 1973 and 1974 at the spawning/overwintering area.

Biological data from the studies using a weir as the method of capture in 1987, 1988 and 1991 may not necessarily provide an accurate representation of lengths and ages of the anadromous population. Comparison of weir results among years is uncertain because of the differences in the timing of the start of the weir and the amount of time the weir was operating. The uncertainty is further compounded by the stratified timing of migration by spawners and silvers, and larger and smaller sized fish (Glova and McCart 1974, Griffiths *et al.* 1975). In all years, the weir did not operate properly for long periods due to high water. MacDonell (1987) states that the weir established on August 13, 1987, likely missed earlier migrating larger-sized Dolly Varden, while

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weirs used in 1988 and 1991 began earlier but also operated intermittently due to high water (Fehr and Archie 1989). Ageing results were also not comparable among years because otoliths were collected based on a stratified sample rather than a random sample. A hoopnet was used in conjunction with the weir in 1987.

Compared to gill nets and the weir, seining likely was the best method to obtain a representative sample of anadromous Dolly Varden as sampling typically occurred in the fall when most, if not all, Dolly Varden had returned from the sea. Consistent collection by seining occurred in September 1972, 1992, 1993 and 1994. However, the biological data from males sampled from the subsistence catch at Fish Hole from seining between 1996 and 1998 was selective through the release of large spawning males and the retention of silvers and large females in order to help conserve the population (Stephenson 2003). In 1999, the harvest was not selective however, the gear was not consistent with earlier years as a gill net was used as a seine. The harvest in 2000 was selective as all fish <320 mm were released (Stephenson 2003).

In order to avoid confounding data, the examination of biological information was standardized by evaluating trends separately for each gear type from similar sampling seasons. Data were omitted in cases where methods were used only in a single year (e.g., hoopnet in 1987), infrequently (e.g., angling in 1972 and 1973), or were confounded in the database (e.g., capture method described as “seine and angling” or “seining/electrofishing”). Biases in gear type were statistically evaluated whenever multiple gear types were used in a similar year/location. Length and age characteristics among capture methods were separated by sex (male and female) for all maturity stages combined and for spawners only. Mean length-at-age was calculated for females and males among gear type for each year for all maturity stages combined and spawners only. Sex ratios, proportion of spawners, and mortality were examined separately for each gear type among sampling years.

Based on size and maturity information, we suspected that the samples of males captured in 1992, 1993 and 1994 by seining were likely comprised of both the residual and anadromous life history type. Unfortunately, the life history information for these years was not recorded in the database. Sandstrom and Harwood (2002) state that anadromous Dolly Varden from the Big Fish River smolt at approximately 286 mm. All of the males captured by seine in 1992 were  $\leq 280$  mm, while 15 out of 37 and 46 out of 158 males were <286 mm in 1993 and 1994, respectively. In order to address this problem, all pre-smolt (<286 mm) Dolly Varden were removed from the statistical analyses presented below. Information for residual males is included in part III of this synthesis (Gallagher *et al.* in prep.). Seining data from 1997, 1998 and 2000 are summarized but were not included in statistical analyses due to biased sampling where large fish, particularly males, were released from an exploratory subsistence fishery at the Fish Hole.

### **Statistical methods**

Summary statistics of size and age calculated by sex and sampling method/location are presented in Tables 3 to 5. Differences in mean fork length and age among sampling methods, locations and sampling years were tested by sex for all maturity stages and for current-year spawners using pairwise t-tests or one-way Analysis of Variance with Scheffe’s post-hoc pairwise comparisons. In cases where the data did not meet the assumptions of normality and homogeneity of variance, we compared groups using Mann-Whitney (U) tests or Kruskal-Wallis (H) tests with post hoc Mann-Whitney pairwise comparisons adjusted using the Bonferroni correction (at a level of significance of 0.05/number of comparisons). Differences in length and age frequency distributions among years were assessed using the Kolmogorov-Smirnov two-

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sample test and probability values adjusted for multiple comparisons using the Bonferroni correction. Statistical comparisons of frequency distributions were conducted using the total samples (different sexes and maturities pooled) due to the multiple incidences of low sample size, particularly among males. Differences in the ratio of males to females in a sample were evaluated by examining the confidence limits for binomial proportions that would indicate whether the observed differed significantly from 0.5 (i.e., 1:1) (Rohlf and Sokal 1995).

### **Available length data**

Generally low sample size for males and females, and different sampling methods both within and among sampling years weakened the trend analysis of length for Dolly Varden from the Big Fish River. Significant differences in mean length between sampling locations (i.e., river mouth versus spawning site) were partly attributed to the selectivity of different sampling gear. For example, gill nets sampled larger Dolly Varden than seine in 1992 (Mann-Whitney,  $U = 18.8$ ,  $p < 0.001$ ). However, no significant differences in size of fish were observed between gill nets and seine in 1972 (Mann-Whitney,  $U = 28836$ ,  $p = 0.07$ ). Significantly larger Dolly Varden were captured using a gill net as a seine compared to the seine when used at the spawning/overwintering area in 1999 (Mann-Whitney,  $U = 93.0$ ,  $p < 0.001$ ). Sample sizes were too low to compare sizes of fish captured between gill nets and seining at the mouth of the river (not included in Table 5) in 1972.

Males were larger than females in samples collected by gill nets at the river mouth in 1980 (Mann-Whitney,  $U = 32.5$ ,  $p = 0.002$ ) and 1986 (t-test,  $t = 2.262$ ,  $df = 103$ ,  $p = 0.026$ ), by weir in the Little Fish River in 1991 (Mann-Whitney,  $U = 14027.5$ ,  $p < 0.001$ ), and by seining at Fish Hole in 1972 (Mann-Whitney,  $U = 1221.5$ ,  $p = 0.001$ ) (see Tables 3, 4 and 5).

### **Female (all maturity stages combined)**

The mean length of females caught in gill nets at the mouth of the Big Fish River differed among sampling years (Kruskall Wallis,  $H(5) = 61.972$ ,  $p < 0.001$ ) however there was no clear trend in the data. In order to examine for a trend over time, post-hoc tests ( $\alpha = 0.01$ ) between 1972 and other years were conducted and showed smaller lengths in 1973, greater length in 1980, no differences in 1986, and greater length in 1992 (Figure 2a). Length of female Dolly Varden captured using a weir varied significantly among years (Kruskall Wallis,  $H(2) = 90.8$ ,  $p < 0.001$ ), with length increasing successively between 1987 and 1991. Length varied among females caught by seine between 1972 and 1994 (Kruskall Wallis,  $H(3) = 49.3$ ,  $p < 0.001$ ), with the greatest lengths observed in 1992. Higher mean fork lengths and a generally wider range of sizes characterized female Dolly Varden caught by seine at the Fish Hole between 1992 and 1994 relative to 1972 (Table 5, Figure 2a).

### **Female spawners**

The mean length of female spawners captured in gill nets in 1973, 1984, 1986 and 1992 differed among years (ANOVA,  $n = 203$ ,  $df(\text{years}) = 3$ ,  $F = 19.690$ ,  $p < 0.001$ ) with post-hoc analysis demonstrating that length increased significantly between 1973 and 1992 (Figure 3a). The mean length of female spawners captured by weir differed among years (ANOVA,  $n = 317$ ,  $df(\text{years}) = 2$ ,  $F = 69.5$ ,  $p < 0.001$ ). Post-hoc examination demonstrated that length was highest in 1991 while no differences were observed between 1987 and 1988. It appears that relatively few female spawners were captured (or identified as spawners) by seining at the spawning/overwintering area until 1992. Between 1992 and 1994, the length of female spawners did not appear to change (Kruskall Wallis,  $H(2) = 1.42$ ,  $p = 0.49$ ) (Figure 3a).

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### Male (all maturity stages combined)

The average length of male Dolly Varden captured among gear types did not demonstrate any discernable trend over time. Mean fork length of male Dolly Varden caught in gill nets at the mouth of the Big Fish River differed among years (ANOVA,  $n=250$ ,  $df(\text{years})=4$ ,  $F=8.118$ ,  $p<0.01$ ), however post-hoc testing did not demonstrate any significance among pair-wise comparisons (Table 3; Figure 2b). Similar to females, mean length of males captured by weir was significantly different among years (Kruskall Wallis,  $H(2)=84.5$ ,  $p<0.001$ ) with larger males collected in 1991 relative to 1987-1988. No significant difference in the length of males collected by seine was observed between 1972 and 1999 (Mann-Whitney,  $U=683.0$ ,  $p=0.59$ ).

### Male spawners

Similar to males with all maturity stages combined, the average length of male spawners demonstrated no directional trend over time (Figure 3b). Mean fork lengths of male spawners caught in gill nets at the mouth of the river did not differ among years (ANOVA,  $n=83$ ,  $df(\text{years})=3$ ,  $F=1.726$ ,  $p=0.168$ ), however, differences in length were observed in Dolly Varden collected by weir with an increase from 1987 to 1991 (Kruskall Wallis,  $H(2)=52.8$ ,  $p<0.001$ ). Sample sizes of male spawners captured by seine were too low in most years for meaningful analyses except in 1993 and 1994, where no significant differences in mean length were observed (ANOVA,  $n=52$ ,  $df(\text{years})=1$ ,  $F=0.173$ ,  $p=0.679$ ).

### Length frequency distributions

In order to obtain more meaningful statistical comparisons, length frequency distributions from each year and sampling method were only compared in cases where the total sample size was  $\geq 25$ , however data are graphically presented by year and sampling method/location for each sex and for the total sample (Figures 4-6; note that the total sample size includes individuals of undetermined sex).

#### Gill nets

The range of values from the length frequency distribution of Dolly Varden collected using gill nets overlapped among sampling years with the widest range observed in 1972 (280-730 mm) and the lowest range observed in 1986 (300-530 mm) with no clear trend with time (Figure 4). The frequency distribution was similar between 1972 and 1973 with a modal value of 380-400 mm, which increased to 400-420 mm in 1980 and again up to 440-460 mm in 1984. In 1986, proportionately fewer fish  $>500$  mm were captured compared to earlier years (Figure 4). The 1972 and 1973 length distributions differed significantly compared to later years (KS for 1972-1980  $D=0.259$ ,  $p<0.0001$ ; 1972-1984  $D=0.214$ ,  $p<0.0001$ ; 1972-1986  $D=0.172$ ,  $p=0.021$ ; 1973-1980  $D=0.386$ ,  $p<0.0001$ ; 1973-1984  $D=0.311$ ,  $p<0.0001$ ; 1973-1986  $D=0.250$ ,  $p=0.001$ ).

#### Seine

Length frequency distributions for Dolly Varden caught by seine were variable among years (Figure 5a). The 1972 distribution was characterized by a smaller mode (300-320 mm) and differed significantly from length distributions in subsequent years (KS 1972-1992  $D=0.506$ ,  $p<0.0001$ ; 1972-1993  $D=0.241$ ,  $p<0.0001$ ; 1972-1994  $D=0.163$ ,  $p<0.0001$ ; 1972-1997  $D=0.308$ ,  $p<0.0001$ ; 1972-1998  $D=0.309$ ,  $p<0.0001$ ). Likewise, the 1992 distribution differed from other years with a smaller range of sizes (370-550 mm) and larger mean (467 mm) and modal lengths



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(480-500 mm) (KS 1992-1993  $D=0.418$   $p<0.0001$ ; 1992-1994  $D=0.527$   $p<0.0001$ ; 1992-1997  $D=0.468$   $p<0.0001$ ; 1992-1998  $D=0.473$   $p<0.0001$ ).

Length frequency distributions of Dolly Varden captured by a gillnet used as a seine for sweeping pools at the spawning-overwintering site demonstrated a larger proportion of smaller fish in 1999 (modal length= 320-340 mm) compared to 2000 (modal length= 320-340 mm) (Figure 5b), even though mesh size was different.

### Weir

Examining for trends from the data collected by weir is questionable due to the inconsistent timing in sampling of upstream migrants among years. The length frequency distributions for Dolly Varden collected using a weir differed among years (KS for 1987-1988:  $D=0.676$ ,  $p<0.0001$ ; for 1987-1991:  $D=0.775$ ,  $p<0.001$ ; for 1988-1991:  $D=0.465$ ,  $p<0.0001$ ) with the mean and modal sizes increasing from 1987 to 1991 (Figure 6).

### **Length data: summary**

Tracking the length of Dolly Varden from the Big Fish River over time as a means of assessing the status of the population is confounded by differences in sampling gear, location and, in some instances, the timing of sampling events among years. Gear type can significantly influence the size of fish that are captured. Gill net data were used in earlier assessments but not in later ones. As well, mesh sizes were not reported and are likely to have influenced the sizes of captured fish, thus results should be treated cautiously. Dolly Varden collected using a weir increased in size in each successive sampling year (1987, 1988 and 1991) however irregular sampling over time and the presumed structure in the timing of the return migration for large adults and juvenile smolts (Macdonell 1987) likely biased results.

It is difficult to establish any clear temporal trend in mean length and length frequency distribution relative to the probable decrease in population abundance because of the inconsistent sampling methods and lack of biological data collected in most years. Traditional knowledge of harvesters describes a decrease in the size of Dolly Varden from the Big Fish River that was observed in the 1980s (Byers 1993; Papik *et al.* 2003). Results from seining of females in 1972, 1992, 1993 and 1994 provide the most consistent observations from a sampling method that provides a good representative sample of the population (compared to other methods) during a period when abundance likely decreased. Based on these data, the apparent decline in population did not appear to dramatically affect the mean and range of lengths of females (total female sample) as Dolly Varden collected in 1992-94 (mean= 434-459 mm) were similar in size to those collected in 1972 (mean= 400 mm) when the harvest rate was likely higher. The ranges of lengths of female Dolly Varden caught by seining were generally similar between 1972 and 1992-94 (Table 5) (after a five-year closure of the fishery). No obvious trend in the proportion of large-size ( $\geq 500$  mm) Dolly Varden is apparent, although data from seining may suggest a decrease (Figure 7); however inconsistent sampling methods after 1994 confounds robust time series examination. Although proportions differed among size intervals revealing multiple modes during those years, these modal values were similar (Figure 5a). These results suggest some degree of stability in length distributions. Highly exploited Arctic char also demonstrate stable length distributions (Johnson 1983, Johnson 1989, Dempson *et al.* 2008) and only show changes in the final stages of stock decline (Johnson 1989). Interestingly, current-year spawning females captured in gill nets increased between the 1970s (mean range 418-401 mm) and the early 1990s (mean= 493 mm), a pattern not observed in males.

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### **Available age data**

Instances of low sample sizes for both males and females divided among the multiple sampling methods and locations, both within and among sampling years, weaken the analysis of trends in age over time for Dolly Varden from the Big Fish River. No age information exists for the 1970s, a period when it appears the population abundance and harvest rate were relatively high. Data from the total sample and for male and female Dolly Varden in spawning condition were examined among gear type, excluding data from seining in 1982, 1994 (males only) and 1997-1999, and weir, for each sampling year. Examining temporal trends in age for Dolly Varden collected using a weir was not possible because dead samples, from which otoliths were taken, were collected using a stratified sampling approach. Age data from seining in 1982 and 1994 (males only) were too few for meaningful analyses and those from 1997 and 1998 were biased through size selection. Ages for samples collected in 1999 and 2000 were not available.

No differences in age were detected between male and female Dolly Varden (all maturity stages combined) captured using gill nets in 1984 (Mann-Whitney,  $U = 2393.5$ ,  $p = 0.065$ ), although female spawners were older (7.3 years) than male spawners (6.7 years) (Mann-Whitney,  $U = 587.0$ ,  $p = 0.021$ ) (Table 3). Similarly, in 1986 no differences were observed between males and females (Mann-Whitney,  $U = 517$ ,  $p = 0.93$ ), while insufficient data were available to evaluate differences between spawners.

#### **Females (all maturity stages combined)**

The mean age of female Dolly Varden was variable over time among sampling methods (Figure 8a). The mean age of females captured using gill nets in 1984, 1986 and 1992 differed among years (Kruskall-Wallis,  $H(2) = 22.4$ ,  $p < 0.001$ ) (Table 3). Post-hoc analyses (Mann-Whitney tests with a Bonferroni correction,  $\alpha = 0.0167$ ) indicated an increase in age between 1984 and 1986 ( $U = 5808$ ,  $p = 0.001$ ) while no differences were found between 1986 and 1992 (Mann-Whitney,  $U = 442$ ,  $p = 0.04$ ) (Table 3, Figure 8a). Ages of female Dolly Varden captured by seine between 1992-1994 differed (Kruskall-Wallis,  $H(2) = 96.4$ ,  $p < 0.001$ ) and post-hoc analyses ( $\alpha = 0.0167$ ) demonstrated no difference between 1992 and 1993 (Mann-Whitney,  $U = 572$ ,  $p = 0.55$ ) while younger females were captured in 1994 as compared to 1992 (Mann-Whitney,  $U = 173.5$ ,  $p < 0.001$ ) and 1993 (Mann-Whitney,  $U = 100$ ,  $p < 0.001$ ). Age data from samples collected by weir is presented in Table 5.

#### **Female spawners**

Similar to results for all maturity stages, the mean age of female Dolly Varden spawners was variable over time among sampling methods (Figure 9a). The mean age of female spawners caught by gill nets differed among years (Kruskall-Wallis,  $H(2) = 11.1$ ,  $p = 0.004$ ). Post-hoc analyses ( $\alpha = 0.0167$ ) demonstrated no differences between 1984 and 1986 (Mann-Whitney,  $U = 1932.5$ ,  $p = 0.05$ ), and 1986 and 1992 (Mann-Whitney,  $U = 440.5$ ,  $p = 0.07$ ), while older spawners were observed in 1992 as compared to 1984 (Mann-Whitney,  $U = 277.5$ ,  $p = 0.001$ ) (Figure 9a, Table 3). Ages of female Dolly Varden in spawning condition captured by seine between 1992-1994 differed significantly (Kruskall-Wallis,  $H(2) = 55.9$ ,  $p < 0.001$ ). The majority of females captured by seining were spawners and were younger in 1994 as compared to 1993 (Mann-Whitney,  $U = 99.5$ ,  $p < 0.001$ ).

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### Males (all maturity stages combined)

Although the mean age of male Dolly Varden among gear type varied over time there were no clear trends in the data (Figure 8b). The ages of males caught in gill nets in 1986 and 1984 were not significantly different (Mann-Whitney,  $U= 1932.5$ ,  $p= 0.052$ ), while the low sample size in 1992 precluded meaningful analyses (Table 3). No analyses could be done among males captured by seining due to low sample size in 1982 ( $n= 3$ ), 1994 ( $n= 1$ ) and the biased sampling in 1997, 1998 and 2000.

### Male spawners

The mean age of male spawners captured among gear type showed no obvious differences over time (Figure 9b). Similar to results from all maturity stages, no difference in age was observed in male spawners captured using gill nets in 1986 and 1984 (Mann-Whitney,  $U= 1932.5$ ,  $p= 0.052$ ).

### Age frequency distributions

Similar to length frequency, age frequency distributions from each year and sampling method were only compared in cases where the total sample size was  $\geq 25$ , however data are graphically presented by year and sampling method/location for each sex and for the total sample (Figures 10-12; note that the total sample size includes individuals of undetermined sex)

#### Gill nets

Sufficient age data for Dolly Varden caught in gill nets was only available in 1984 and 1986. Age frequency distributions differed between both years (Kolmogorov-Smirnov test:  $D=0.352$ ,  $p<0.0001$ ) and were dominated by a strong cohort (modal age 6 Dolly Varden in 1984 and modal age 8 Dolly Varden in 1986) suggesting strong recruitment in 1978 (Figure 10). A greater range of age classes (5-13) was observed in 1986 compared to 1984 (4-10).

#### Seine

Age frequency distributions for Dolly Varden caught by seine varied among years and were only statistically similar between 1992 and 1993, with a modal age of 7 (Figure 11) (KS for 1992-1994  $D=0.825$ ,  $p<0.0001$ ; 1992-1997  $D=0.539$   $p<0.0001$ ; 1992-1998  $D=0.691$   $p<0.0001$ ; 1993-1994  $D=0.787$ ,  $p<0.0001$ ; 1993-1997  $D=0.537$   $p<0.0001$ ; 1993-1998  $D=0.690$   $p<0.0001$ ; 1994-1997  $D=0.488$   $p<0.0001$ ; 1994-1998  $D=0.381$   $p<0.0001$ ; 1997-1998  $D=0.294$   $p=0.013$ ). Mean and modal age were higher in 1992-1993 ( $\geq 7$  years) compared to later years ( $\leq 6.1$  years) and lowest in 1994 (mean= 4.7 and mode= 4 years) (Figure 11). Only four age classes (4-7) characterized the 1998 sample, while greater ranges were observed in earlier years.

#### Weir

Data was not statistically analyzed because ageing structures were not randomly selected. Interestingly, older Dolly Varden and a greater range of age classes characterized the 1991 sample relative to 1987, and greater proportions of Dolly Varden  $\geq 6$  years of age were observed in 1991 relative to earlier years (Figure 12).

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### **Age data: summary**

Among similar gear types, no evident trend was observed from the limited age data that could be used to infer the status Dolly Varden from the Big Fish River. Subjectively, fewer older age classes ( $\geq 8$  years) were observed in the population in the late 1990s compared to earlier years. Ultimately, it is not possible to conclusively infer trends in the status of the population using the age data as collection methods varied among years and ageing structure samples sizes were typically low, particularly for males. Additionally, lack of age information from sampling events in the 1970s during a period when it is presumed that the population status was healthy that could be used as a benchmark weakens conclusive interpretation of this time series data.

### **Available length-at-age data**

All available length and age data by sex was used to study trends in growth of Dolly Varden from the Big Fish River. Limited age-ranges and small sample size by age class among sampling gear in most years did not permit the study of annual trends in growth by fitting length-at-age data to mathematical functions. Therefore, mean length-at-age was determined by year and gear type for male and female Dolly Varden using all maturity stages combined and for current-year spawners (Figure 13, Tables 6-8). Because no age data were available for samples collected during the 1970s, we were unable to examine length-at-age during a period when it is thought that the population abundance was relatively high.

Among Dolly Varden captured in gill nets, males appeared to have a similar length-at-age between 1984 and 1986 while females had a greater length-at-age in 1984 than in 1986 (Table 6). Males appeared to have a greater length-at-age than females in 1986 while no difference between sexes was observed in 1984.

Male Dolly Varden captured by weir had higher mean length-at-age values in 1988 and 1991 than in 1987 for samples  $\leq 5$  years of age (Figure 13, Table 7). A similar pattern was observed among females although the 1991 sample had smaller sizes at ages  $\leq 4$  years. No differences were apparent between males and females for any of the years where comparisons were made.

No clear differences among sampling years were observed among females captured by seining, while male sample sizes were too low to qualitatively assess (Figure 13, Table 8). An outlier in the 1997 seine sample measuring 680 mm at four years of age likely was either aged and/or measured incorrectly.

Among spawners captured using gill nets, males and females in 1984 had a higher length-at-age compared to 1986. The growth rate between sexes in 1984 was similar, although males demonstrated a higher rate of growth compared to females in 1986 (Figure 13, Table 7).

Age data of male spawners captured by weir was limited in 1987 and 1988. Length-at-age of female spawners captured by weir did not change considerably among years. No differences were apparent between male and female spawners in 1991.

Among female spawners captured by seining, no clear differences among sampling years were observed (Figure 13, Table 8).

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## AVAILABLE DATA FOR AGE-AT-MATURITY, PROPORTION OF SPAWNERS AND SEX RATIOS

Data collected  $\geq 1980$  was used to study trends in maturity parameters for Dolly Varden from the Big Fish River. Maturity data from the 1970s were considered unreliable due to uncertain collection methods.

### Age-at-maturity and fecundity

Age-at-maturity for females and males was assessed using both the age class where  $\geq 50\%$  of samples were current-year spawners and the minimum age when a Dolly Varden was sexually mature (Tables 9 and 10). Low sample numbers among age groups in most years generally limit the validity of age-at-maturity estimates as well as comparisons among years. Years for which a minimum of 10 fish were available within age groups were considered reliable estimates of age-at-maturity. Based on these criteria, there is only one reliable estimate of age-at-50% maturity for males in 1984 (6 years), and three reliable estimates for females captured by seining in 1992, 1994 and 1998 (6, 4 and 6 years, respectively). This could suggest variable age-at-maturity for female Dolly Varden from the Big Fish River. Minimum age-at-maturity values were similar to the results from the age-at-50% maturity. Due to the limited data in conjunction with the variability it is difficult to determine if there were any changes in age at maturity over time.

The age-at-50% maturity of males in the Big Fish River is younger than the Firth (7 years), Babbage (7 years) and Rat rivers (5-8 years) while older compared to Joe Creek (5 years). The age-at-maturity of females was similar compared to other systems although younger relative to Firth (7 years) and Rat (7 years) rivers (Gallagher *et al.* in prep., Roux *et al.* in prep.).

Fecundity information was available for Dolly Varden collected in 1987 (MacDonnell 1988), 1991 and 1993 (Sandstrom 1995). Average fecundity was similar among years with 2,186 eggs/female in 1987 and 2,329 and 2,313 eggs/female in 1991 and 1993, respectively. Compared to the Babbage River, Dolly Varden from the Big Fish River have lower average fecundity by approximately 500 eggs/female (Sandstrom 1995). The difference is a result of larger egg diameters in females from the Big Fish River population which may compensate for the higher and more vulnerable incubation temperatures in the river system (Sandstrom 1995). Interestingly, Glova and McCart (1974) reported a mean fecundity of  $4,954 \pm 462.7$  eggs per female (mean fork length of 530 mm). Armstrong and Morrow (1980) report fecundity in northern form Dolly Varden ranges between 1,500 to 7,000 eggs.

### Proportion of spawners

Proportions (expressed as % of total catch including all maturity stages) of mature, current-year male spawners captured at the mouth of the Big Fish River (gillnets) was highest in 1980 (68.8%) (Table 11). The proportion of male spawners at the mouth of the river decreased in subsequent years down to 8.7% in 1992 (Figure 14). In contrast, the proportion of female spawners collected in gill nets increased considerably from a low of 9.4% in 1980 to 80.0 and 78.0% in 1986 and 1992, respectively. Male spawners collected by weir ranged between 16.0 and 32.4% with no obvious trend over time while high (60.4-68.0%) proportions of female spawners were observed in 1988 and 1991. The percentage of male spawners captured by seine was lowest in 1997 (4%) and remained low relative to females (Figure 14). Female spawners captured by seine were high between 1992 and 1997 ( $>70\%$ ), yet decreased to the point where none were observed in 1999, although female spawners were captured at the overwintering area by gill net used as a seine (24.1%).

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## **Sex ratios**

Male to female ratios using all maturity stages and for fish in spawning condition only were highly variable among sampling years (Tables 3-5). These results should be interpreted cautiously due to low sample sizes in some years and the selective sampling between 1997 and 1998. For all maturity stages combined there was typically at least two females for each male Dolly Varden captured in gill nets with the exceptions of 1972, 1973 and 1980 (Table 3). Similarly, nearly twice as many females were observed in the weir sample in 1987 and 1991, with the exception of 1988 when the ratio of males to females was closer to 1:1 (Table 4). At least twice as many females were also observed among Dolly Varden captured by seining with the exception of 1972 (Table 5). The ratio of males to females among spawners followed a similar pattern. Females in spawning condition considerably outnumbered males in 1992 (gill nets). A higher number of females was also observed in 1997, but was likely due in part to a sampling bias against spawning males. Higher proportions of spawning females have also been observed in the Firth (Glova and McCart 1974), Babbage (Bain 1974) and Rat (Gillman *et al.* 1985) river systems. The higher proportion of anadromous female spawners may be attributed to the fact that most adopt an anadromous life history whereas a portion of the males may opt to remain in freshwater and mature as a freshwater residents (Glova and McCart 1974).

## **MORTALITY**

Prior estimates of instantaneous mortality ( $Z$ ) were calculated for Dolly Varden captured by gill net in 1984 (Gillman *et al.* 1985) and weir in 1987 (Macdonell 1987) using linearized catch curves generated from a combined sample of males and females. The mortality estimates were 0.70 and 0.57 in 1984 and 1987, respectively, however the 1987 mortality estimate does not reflect the actual mortality of the population because otoliths were collected from a stratified rather than a random sample (Macdonell 1987).

We calculated annual mortality ( $A$ ) by sex using Robson and Chapman's (RC) method:

$$A = 1 - \frac{T}{N+T-1}$$

where  $T$  is derived from the distribution of vulnerable ages in the sample ( $T = \sum(xN_x)$ ) and  $N$  is the total number of fish fully recruited to the gear (Miranda and Bettoli 2007). The RC method appears to have greater accuracy and lower bias compared to regression estimators (Dunn *et al.* 2002).

Annual mortality was calculated for females that were captured by seine ( $n = 4$ ) and gill net ( $n = 2$ ) while only a single estimate from a gill net sample in 1984 was possible for males (Table 12). The low number of age classes fully recruited to the fishery for males among sampling years did not allow for the calculation of mortality estimates for the majority of years. Female mortality ranged between 0.24 to 0.37 for samples caught by seine in the 1990s, and 0.35 and 0.37 from samples caught by gill net in 1984 and 1986, respectively, while annual mortality for males in 1984 was 0.40 (Table 12). Mortality values of Dolly Varden from the Big Fish River are lower compared to the Rat River which have ranged between 0.63 and 0.86 in the early 1990s (Roux *et al.* in prep.).

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## AVAILABLE HARVEST INFORMATION

The harvest of Dolly Varden from the Big Fish River was estimated in 1972, 1973 and 1980, and from 1984-2008 (Table 13). The total harvest was based on the sum of 50% of the summer harvest of Dolly Varden at Shingle Point (Sandstrom and Harwood 2002) and the estimated number of fish taken either at the mouth of the Big Fish River or at Fish Hole. The highest harvest estimate was in 1972 where between 8,000 and 12,000 fish were taken which represented an estimated 39-58% of the anadromous stock. Relatively high harvests were also taken in 1973 and 1986 when 41% and 21% of the anadromous stock  $\geq 150$  mm was captured. Between 1980-85 harvest levels were between 94 and 989 Dolly Varden annually, representing approximately 1-11% of the population. During the closure of the Big Fish River (1987-1991), the harvest at Shingle Point was assumed to be the only source of fishing mortality, which was estimated to be between 3 and 107 fish. Upon re-opening the Big Fish River in 1992, a quota of 700 Dolly Varden was established, which was reduced to 200 the following year at the mouth of the river or at Fish Hole. Between 1994 and 2000, the quota was set between 150 and 400 Dolly Varden. The recorded harvest surpassed the quotas in 1996, 1997, 1998 and 1999 although this is a result of the harvest at Shingle Point and not harvests at the mouth of the River or at Fish Hole. The only year the quota was reached in the river itself was in 1999 at Fish Hole ( $n= 196$ ) (Stephenson 2003). After the closure in 2001, the recorded catches of fish remained low ( $<25-349$ ), representing between  $<1$  and 10% of the stock  $\geq 320-370$  mm. Harvesting of Dolly Varden from the Big Fish River currently occurs at Shingle Point and at other sites along the Beaufort Sea coast, although harvest information is based on what is reported by harvesters and there is uncertainty whether what is reported represents an accurate harvest level. The current rate of harvest of Dolly Varden from the Big Fish River is unknown.

## CONCLUSIONS

Inconsistent sampling methods and locations, and the many instances of low sample sizes of males and females, particularly for age related data, among study years preclude robust assessment of trends of biological parameters of anadromous Dolly Varden from the Big Fish River over time. Examples of inconsistent methods include uncertainties in mesh size for subsistence nets and the selective harvest of Dolly Varden by seining in 1997 and 1998 when large sized males were released.

Based on the mark-recapture estimates, a decline in the population likely occurred although evaluating the extent is limited by inconsistencies in capture and recapture methods (location) that likely affected the sampled segment of the population. Although it is difficult to evaluate the biological parameters in conjunction with years where a population estimate was obtained the following general patterns were noted:

- Males were typically larger in length compared to females prior to 1991,
- The apparent decline in population did not appear to dramatically affect the mean length of females,
- While it is difficult to evaluate trends in age over time, fewer older age classes ( $\geq 8$  years) were observed in the population in the late 1990s compared to earlier years,
- Although patterns in length-at-age are difficult to assess, it appears that the growth of females captured by seining did not change over time,
- Age-at-maturity of Dolly Varden from the Big Fish River ranged between 4 and 6 years for females and was equal to 6 years for males,

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- Over time, the proportion of male spawners decreased at the mouth of the river and remained consistently low at the spawning/overwintering area. The proportion of female spawners remained high among most years yet a noticeable decrease was observed in the late 1990s,
  - Females typically outnumbered males, even among spawners.

It is estimated that the harvests of Dolly Varden from the Big Fish River since the closure of the fishery in 1987 have ranged between <1% and 9% of the adult anadromous component of population. The effect of the current harvest at Shingle Point and other possible sites along the coast on the population is unclear. Further monitoring of coastal fisheries is required to obtain an accurate estimate of current harvest levels. Additional information on the contribution of the Big Fish River stock to the Shingle Point and other coastal locations is essential.

An assessment of the anadromous stock, summarized by DFO (2003), described the decrease in population abundance between 1972 and 1998, and stated that the stock may have reached a stable population size at a lower level and that habitat alteration may limit the size of the stock. The re-evaluation of the data does not provide further insight to the conclusions reached on the anadromous population in the stock status report (DFO 2003).

The scientific results are similar to the traditional knowledge that has been recorded from people who have harvested Dolly Varden from the Big Fish River (see: Byers 1993, Papik *et al.* 2003, Sandstrom and Harwood 2002, and Stephenson 2003). Locals reported a decrease in the abundance of Dolly Varden from the Big Fish in the 1980s in conjunction with a decrease in size of fish. Additionally, changes to habitat characteristics such as water quality and quantity that may influence Dolly Varden abundance were also observed.

The information presented in this research document synthesizes the available information on Dolly Varden from the Big Fish River. Although the data is limited for assessment purposes, the results among years were standardized for capture method and location. Biases that influence interpretations of the assessment have been identified and the inconsistent approaches used in the past underscore the need for a consistent approach and methodology for assessment and monitoring of Dolly Varden from the Big Fish River in the future.

## **ACKNOWLEDGEMENTS**

We wish to acknowledge all principle investigators, personnel and harvesters that have been involved in collecting biological information on Dolly Varden from the Big Fish River. Funding for this synthesis was provided through the DFO Species at Risk program (SARCEP).

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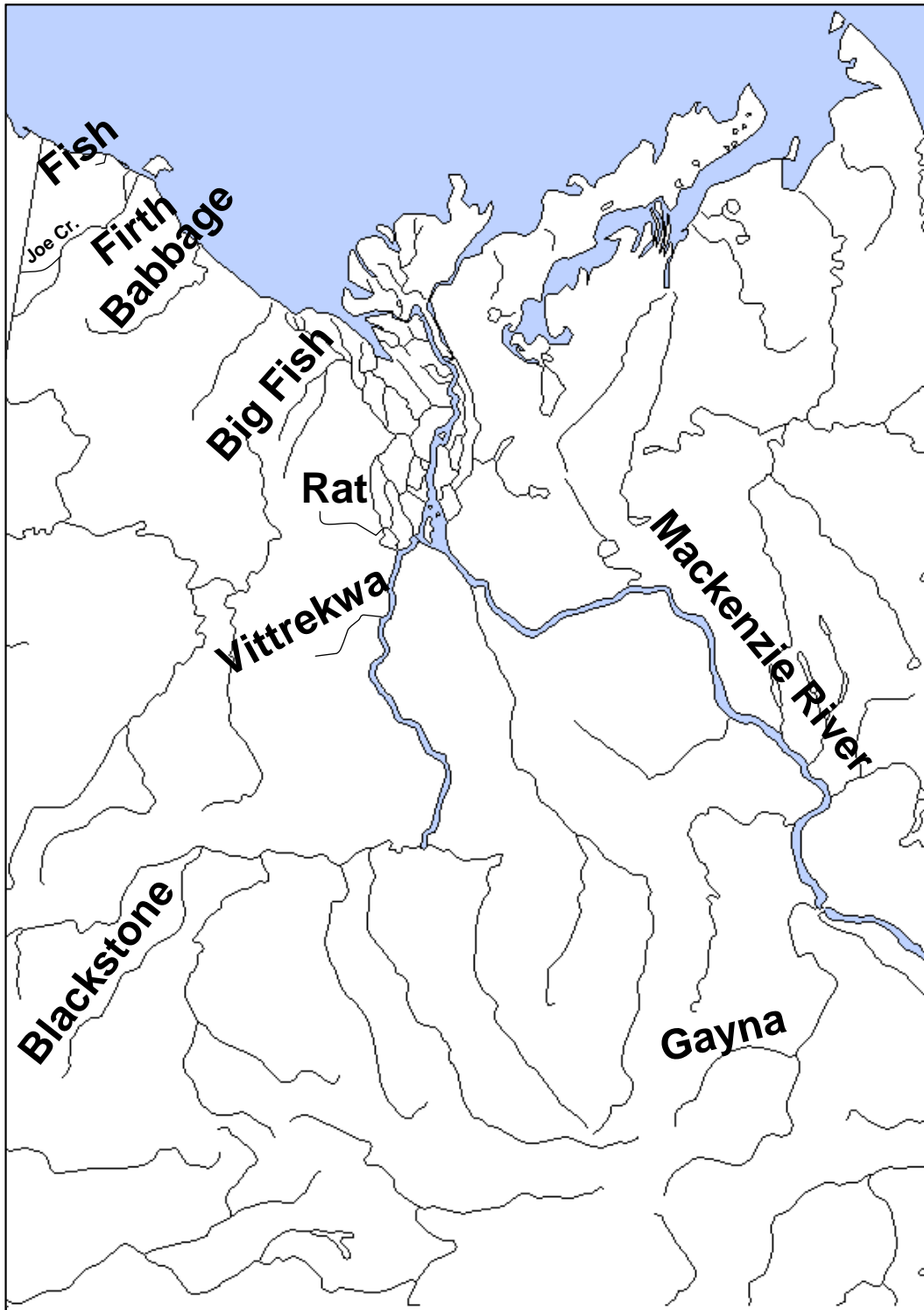


Figure 1. Rivers inhabited by northern form Dolly Varden in Canada.

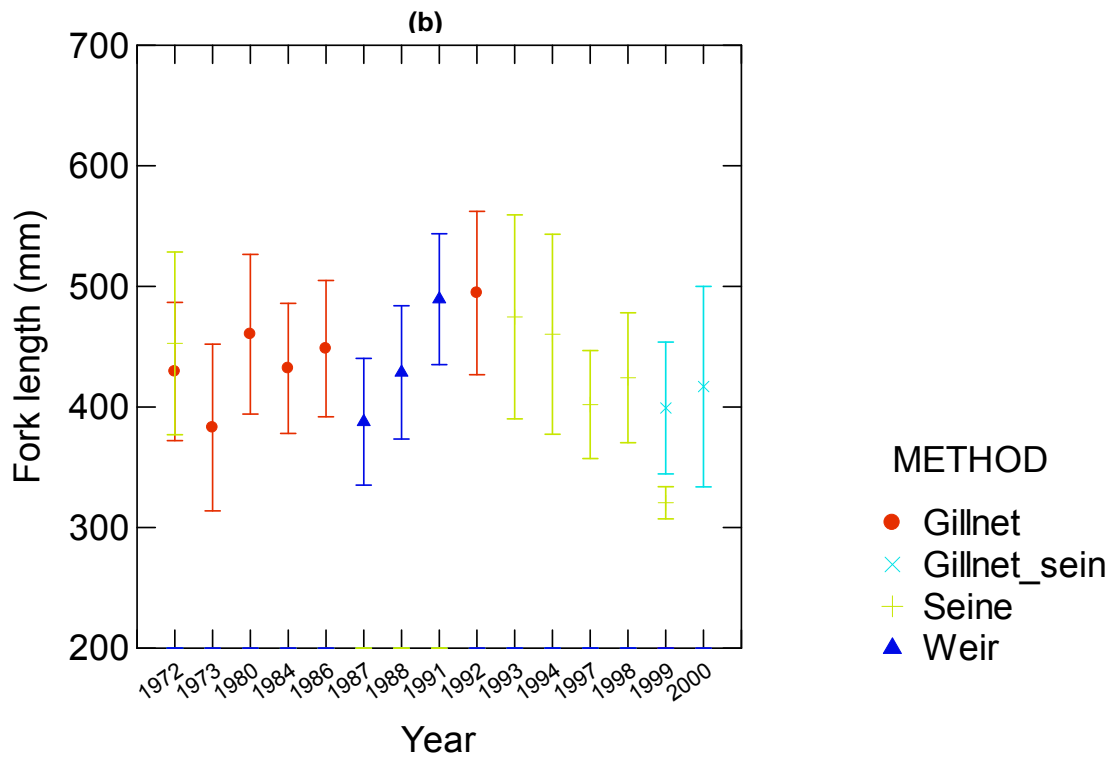
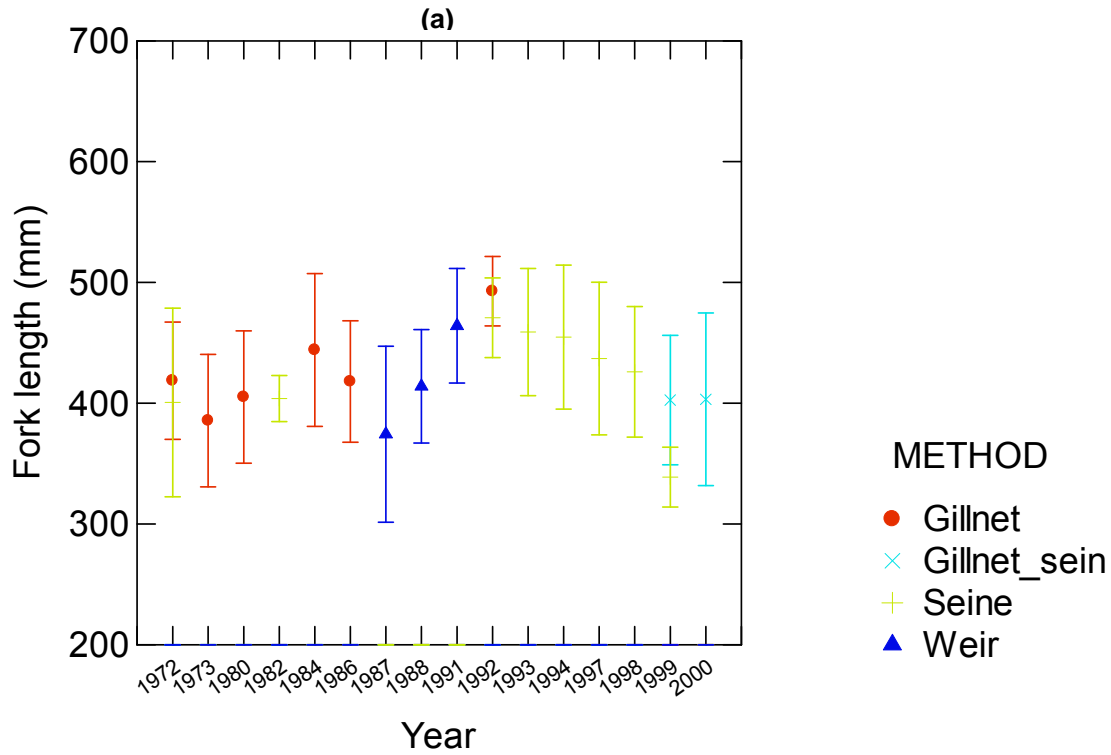


Figure 2. Mean fork length among study years and sampling methods for  $\geq 286$  mm (a) female and (b) male Dolly Varden from the Big Fish River (maturity stages combined) (error bars= 1 standard deviation). Only years for which sample size was  $\geq 5$  are shown and compared. Note: seining was done in 1991 yet fish were likely not measured.

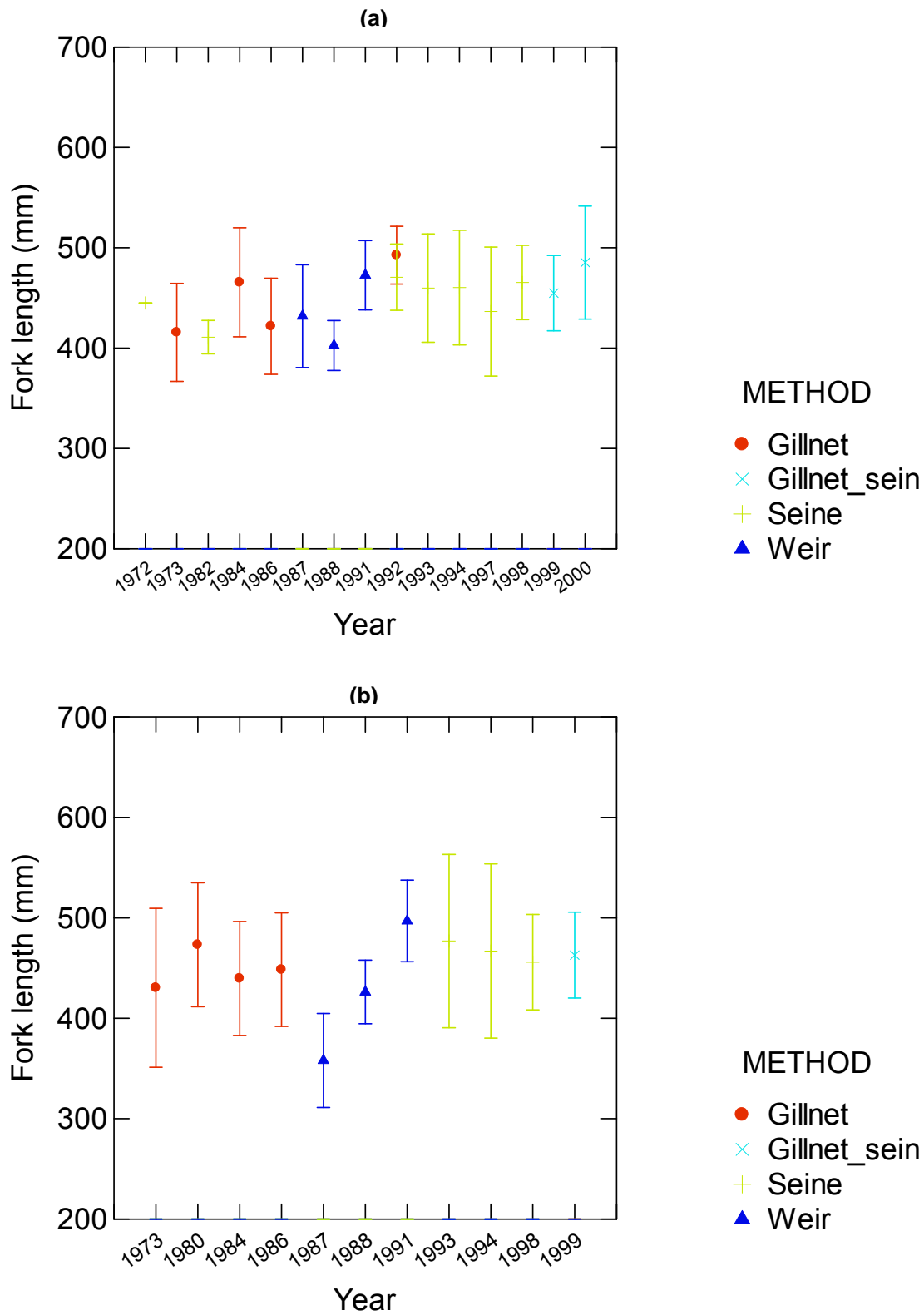


Figure 3. Mean fork length among study years and sampling methods for  $\geq 286$  mm current-year (a) female and (b) male Dolly Varden spawners from the Big Fish River (error bars= 1 standard deviation). Only years for which sample size was  $\geq 5$  are shown and compared.

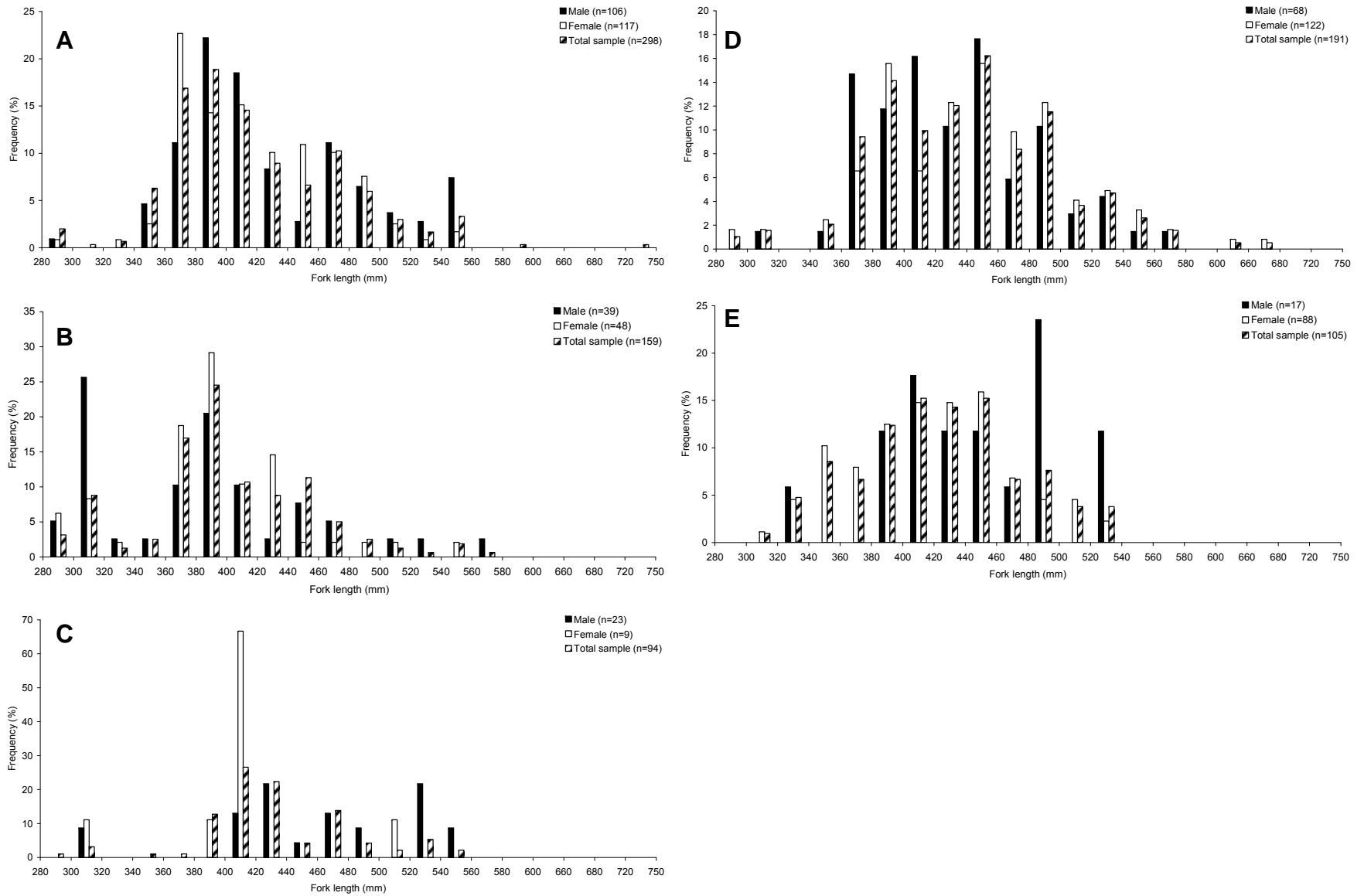


Figure 4. Length frequency distributions of  $\geq 286$  mm Dolly Varden from the Big Fish River captured using gill nets at the mouth of the river in A) 1972, B) 1973, C) 1980, D) 1984 and E) 1986.

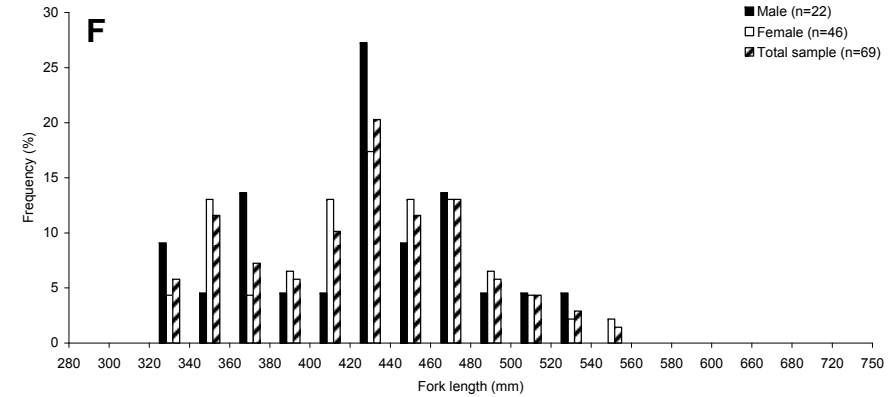
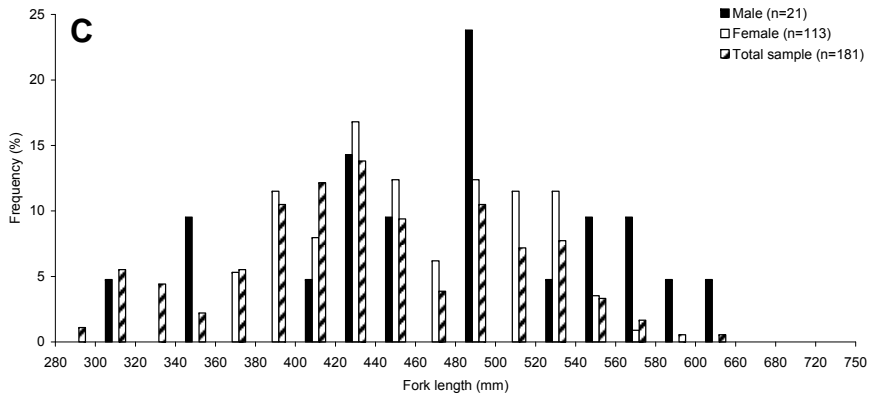
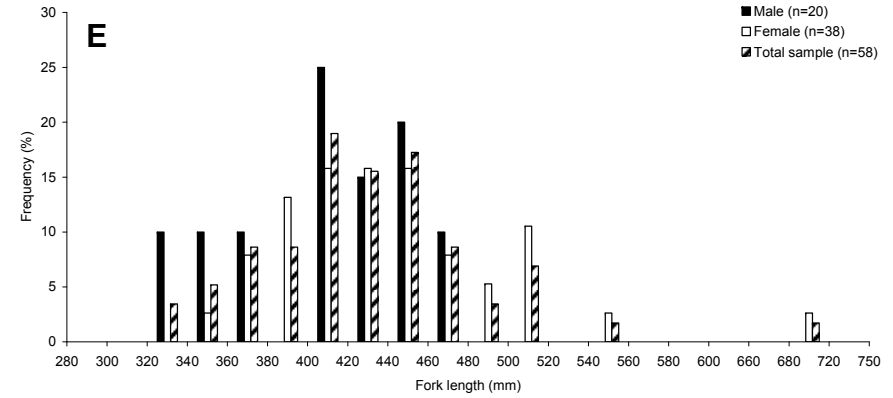
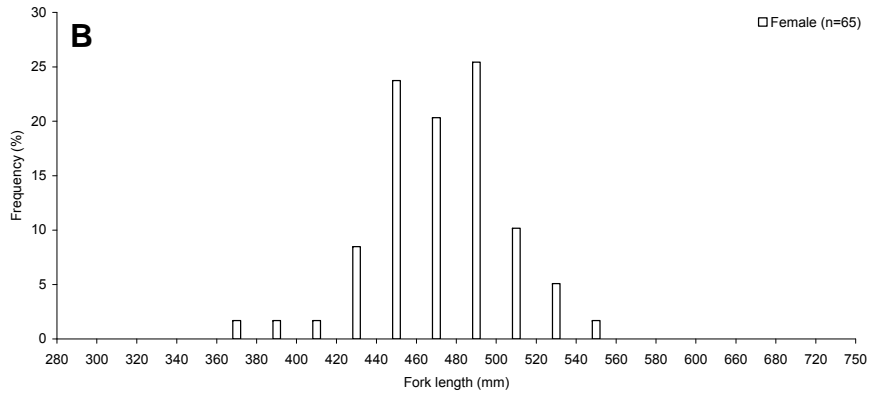
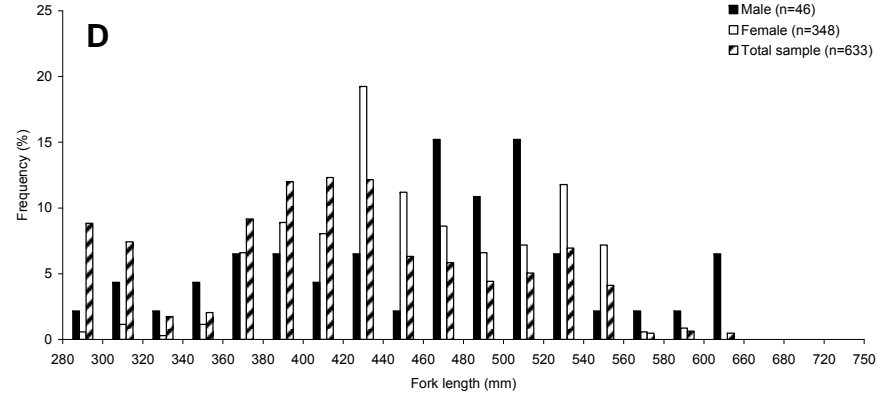
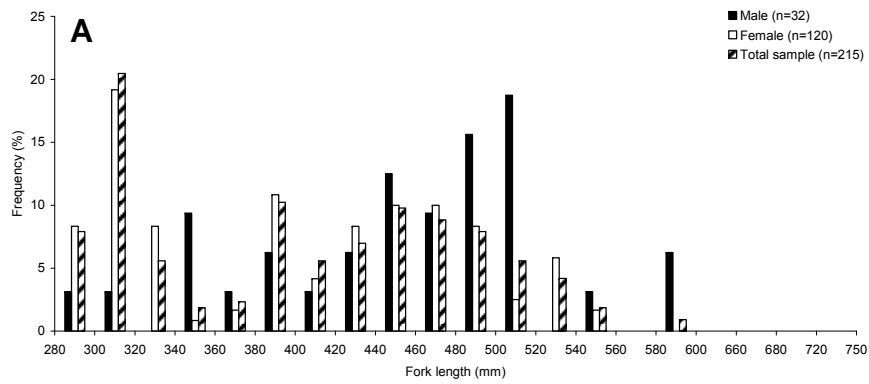


Figure 5a. Length frequency distributions of Dolly Varden  $\geq 286$  mm from the Big Fish River captured using a seine in A) 1972, B) 1992, C) 1993, D) 1994, E) 1997 and F) 1998.



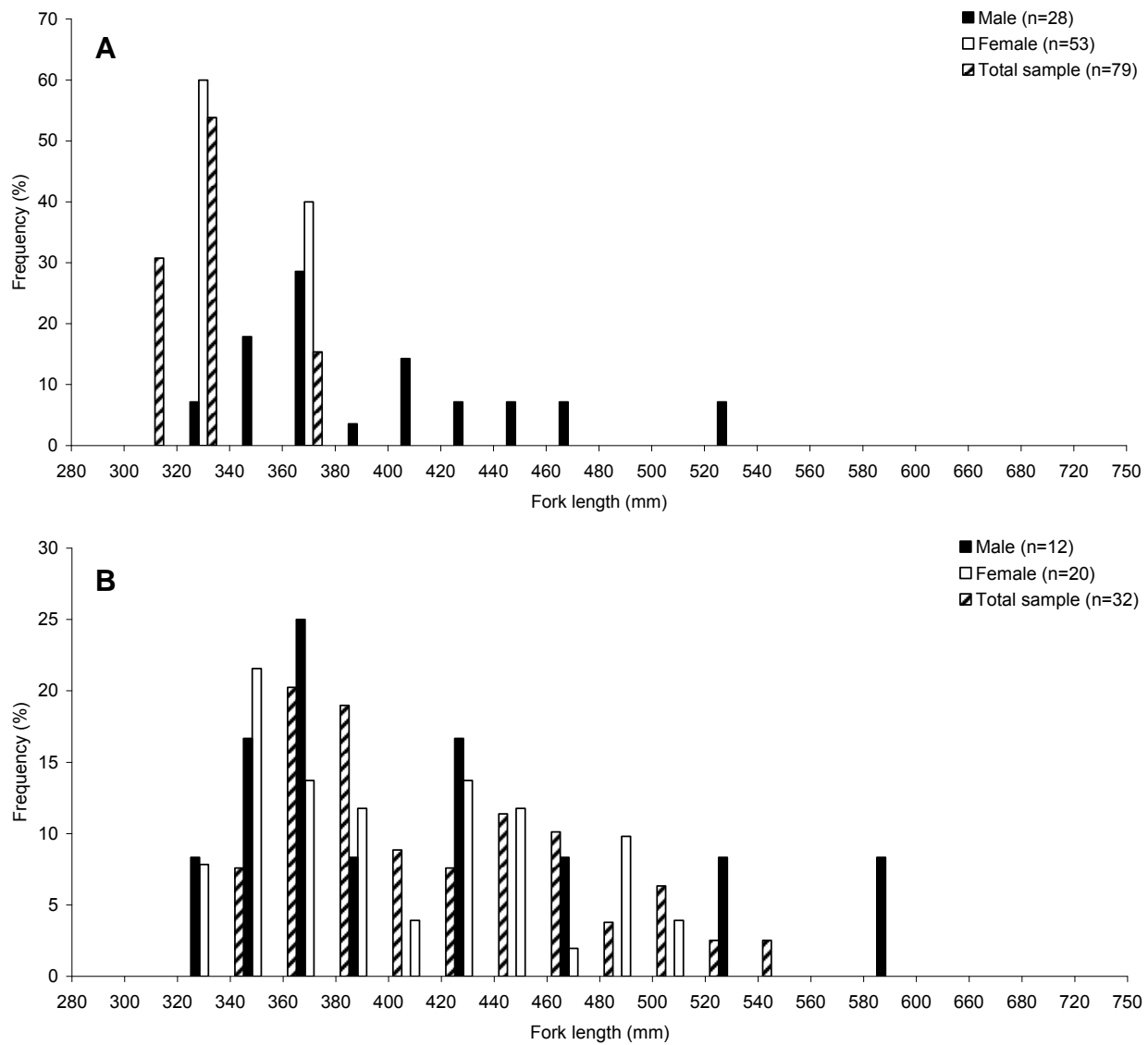


Figure 5b. Length frequency distributions of Big Fish River Dolly Varden  $\geq 286$  mm captured using a gillnet for sweeping spawning-overwintering pools at Fish Hole in A) 1999 and B) 2000.

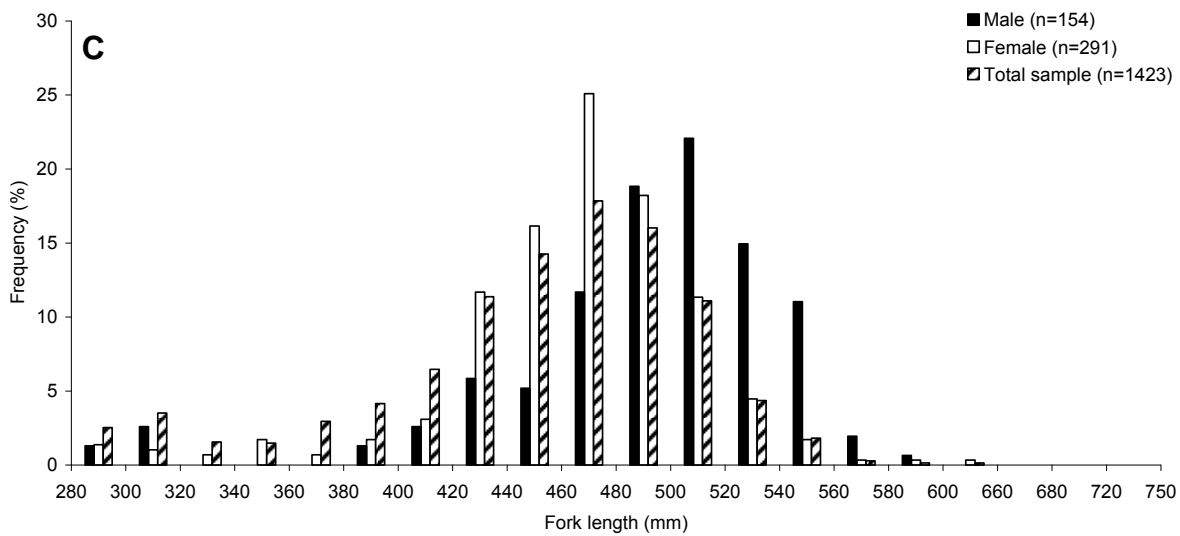
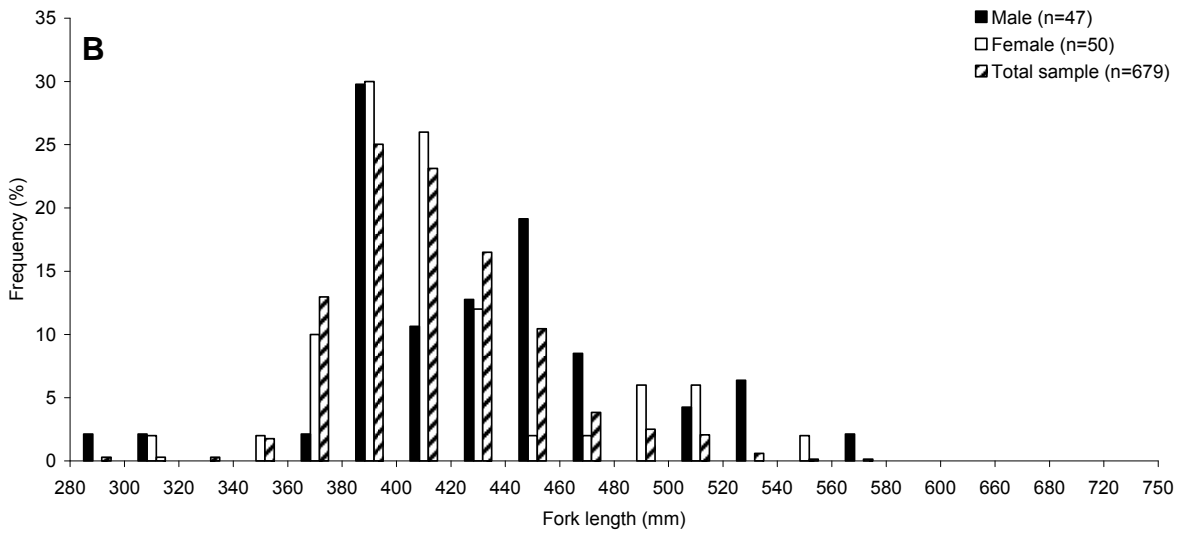
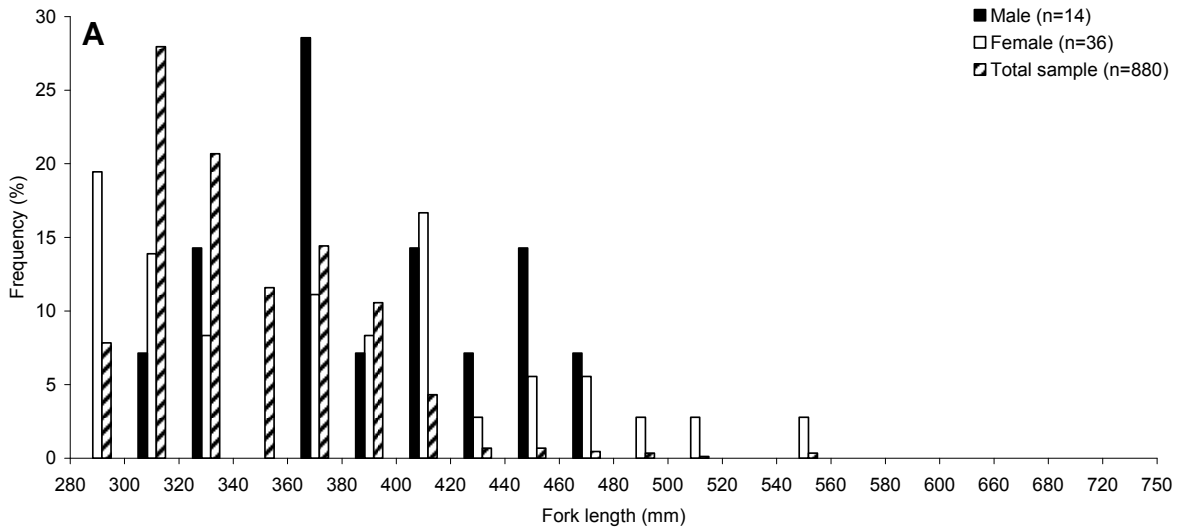


Figure 6. Length frequency distributions of  $\geq 286$  mm Dolly Varden from the Big Fish River captured using a weir in A) 1987, B) 1988 and C) 1991.

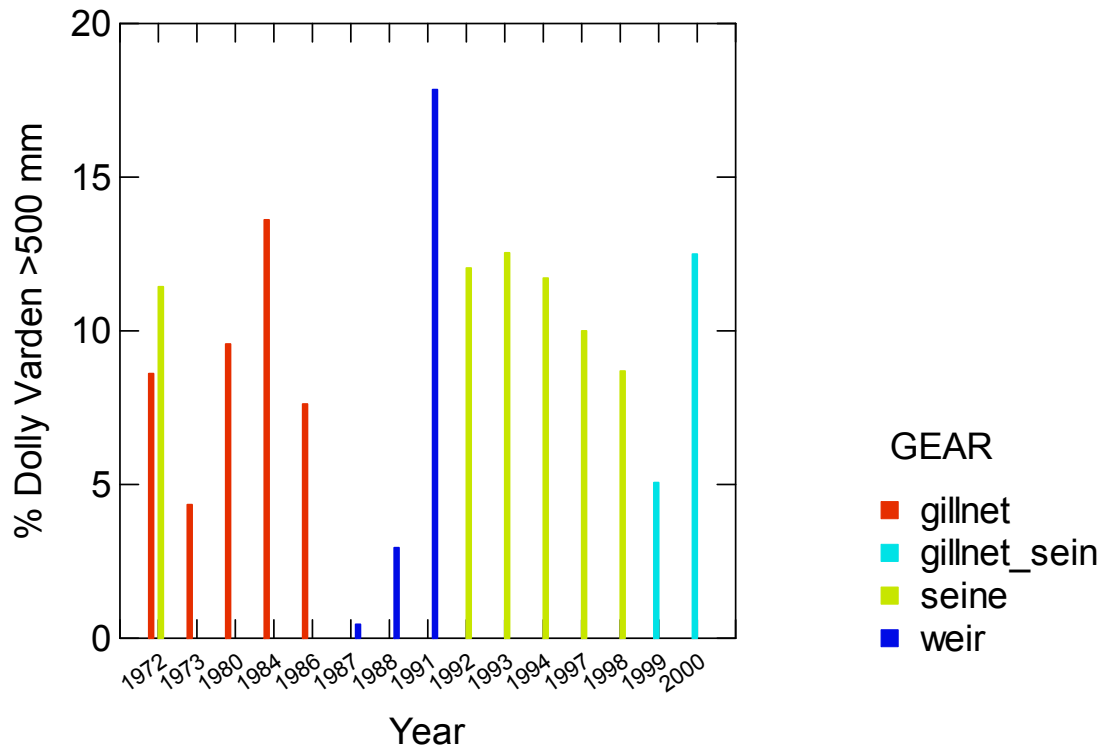


Figure 7. Proportion (%) of large size ( $\geq 500\text{mm}$ ) Dolly Varden from the Big Fish River captured among study years and gear type (combined sexes). Gill nets used between 1972 and 1986 were set at the mouth of the river. Gillnet\_sein corresponds to the use of gillnets for sweeping overwintering-spawning pools at Fish Hole in 1999 and 2000.

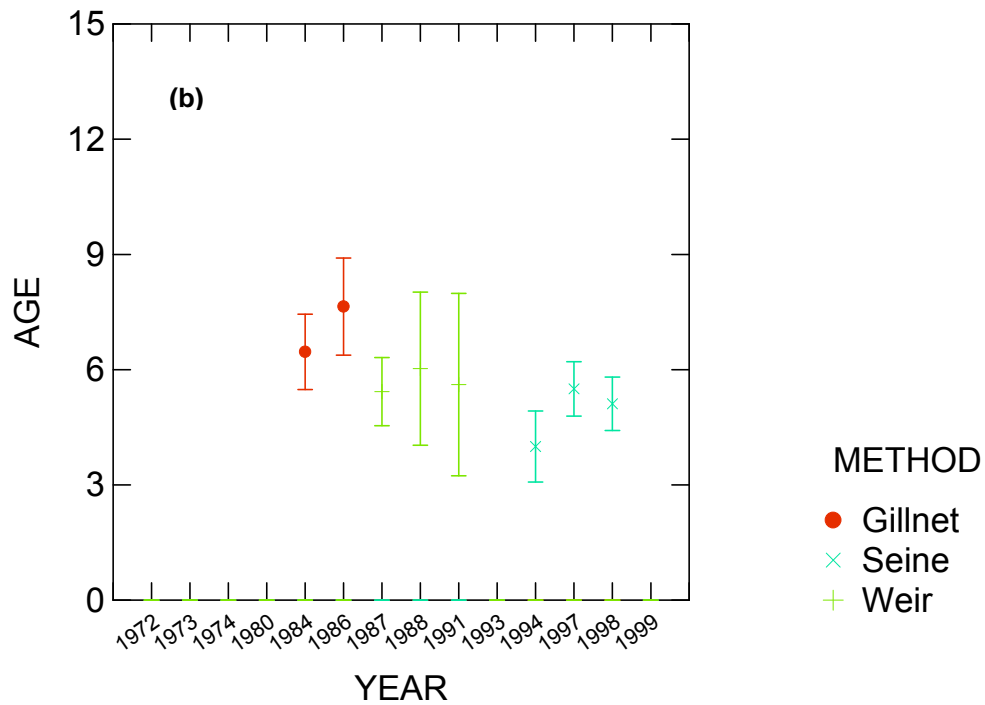
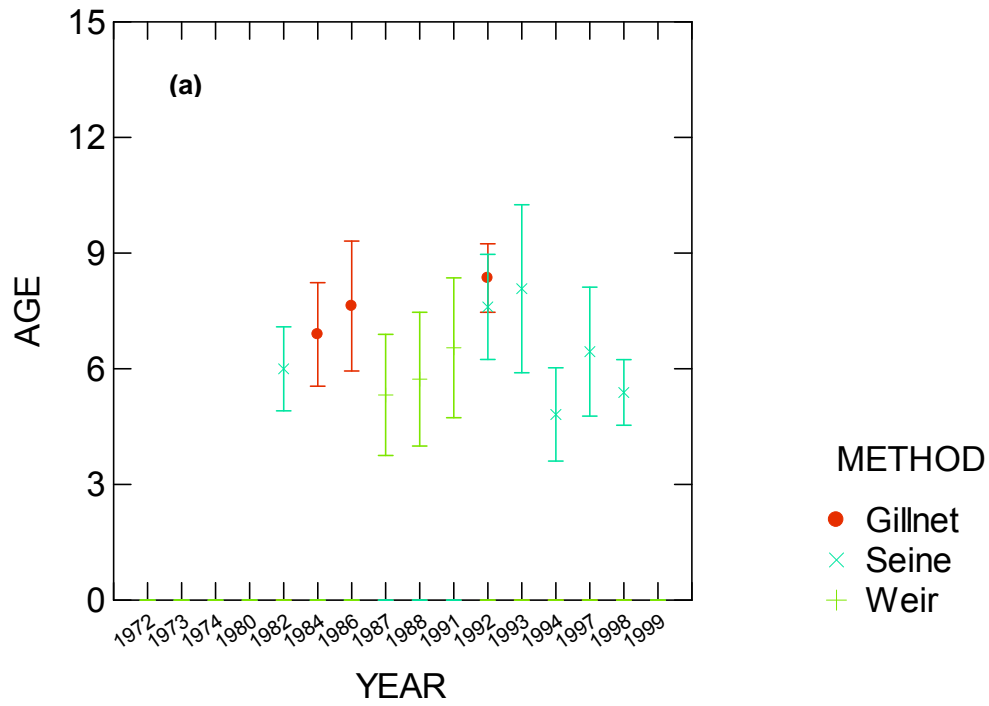


Figure 8. Mean age among study years and sampling methods for  $\geq 286$  mm (a) female and (b) male Dolly Varden (maturity stages combined) (error bars= 1 standard deviation). Only years with sample size  $\geq 5$  are shown and compared.

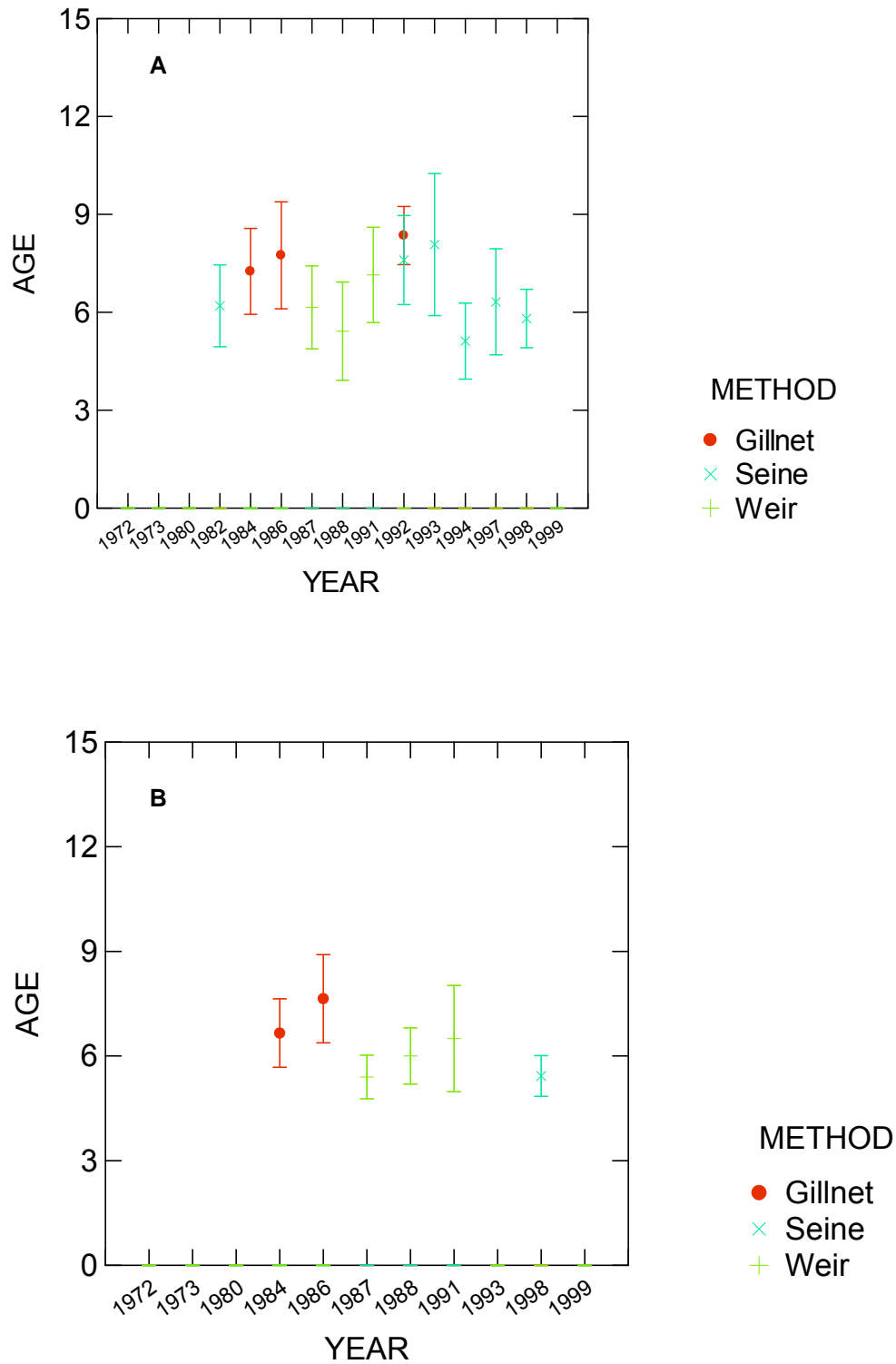


Figure 9. Mean age among study years and sampling methods for  $\geq 286$  mm current-year A) female and B) male Dolly Varden spawners from the Big Fish River (error bars= 1 standard deviation). Only years with sample size  $\geq 5$  are shown and compared.

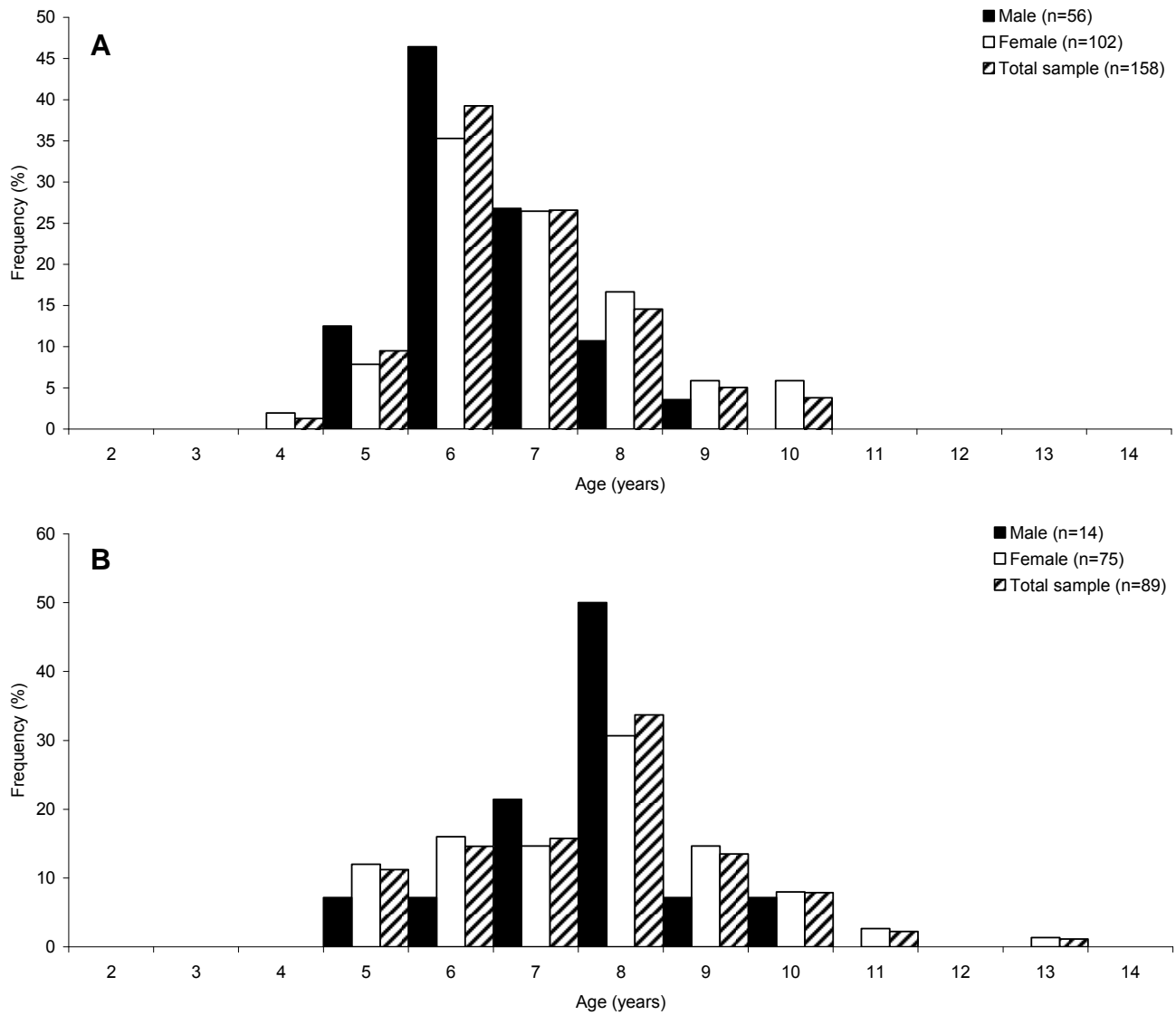


Figure 10. Age frequency distributions of  $\geq 286$  mm Dolly Varden from the Big Fish River captured using gill nets in A) 1984 and B) 1986.

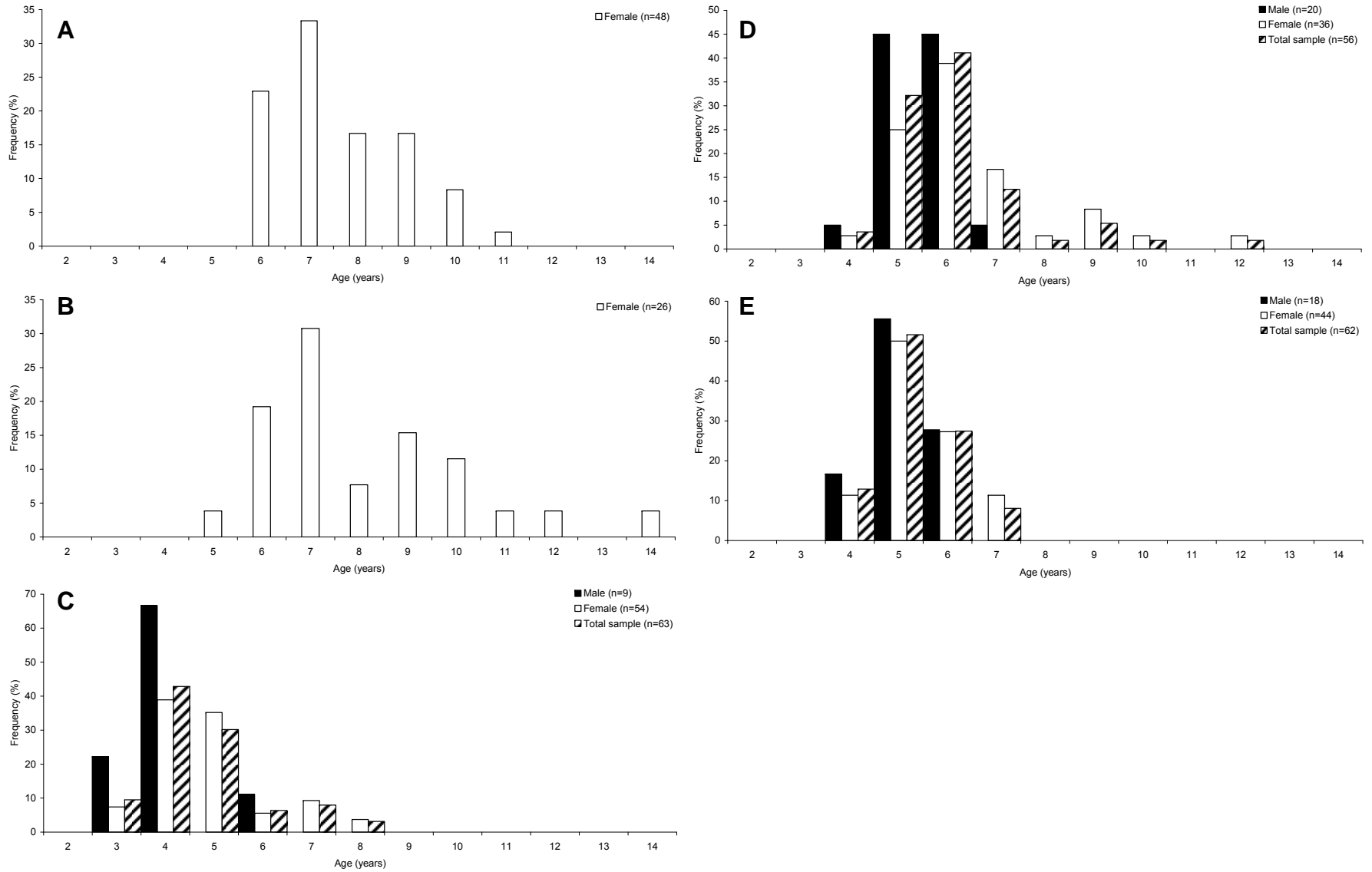


Figure 11. Age frequency distributions of  $\geq 286$  mm Dolly Varden caught using a seine in A) 1992, B) 1993, C) 1994, D) 1997 and E) 1998.

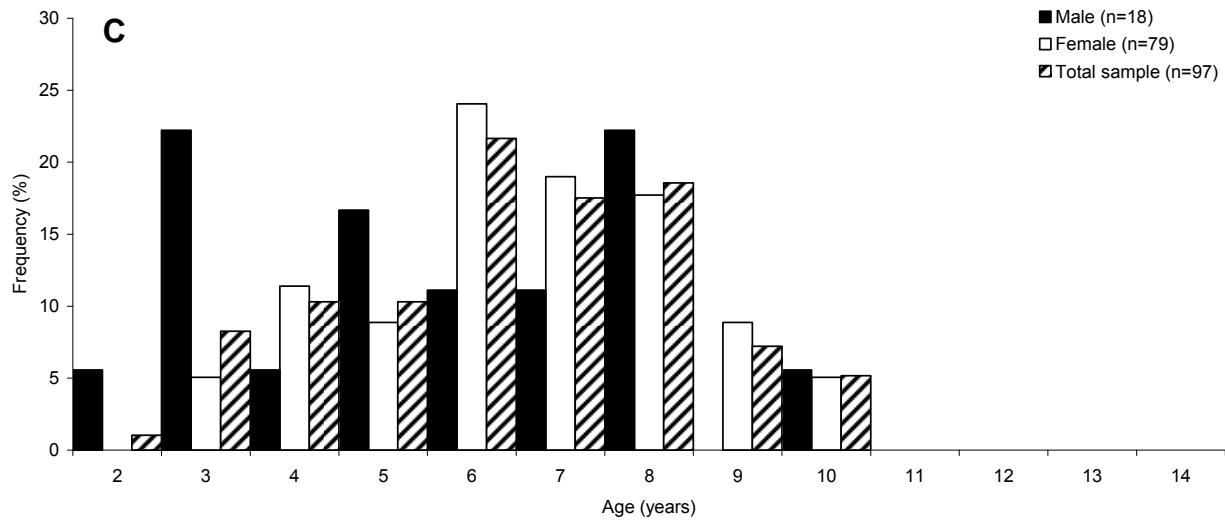
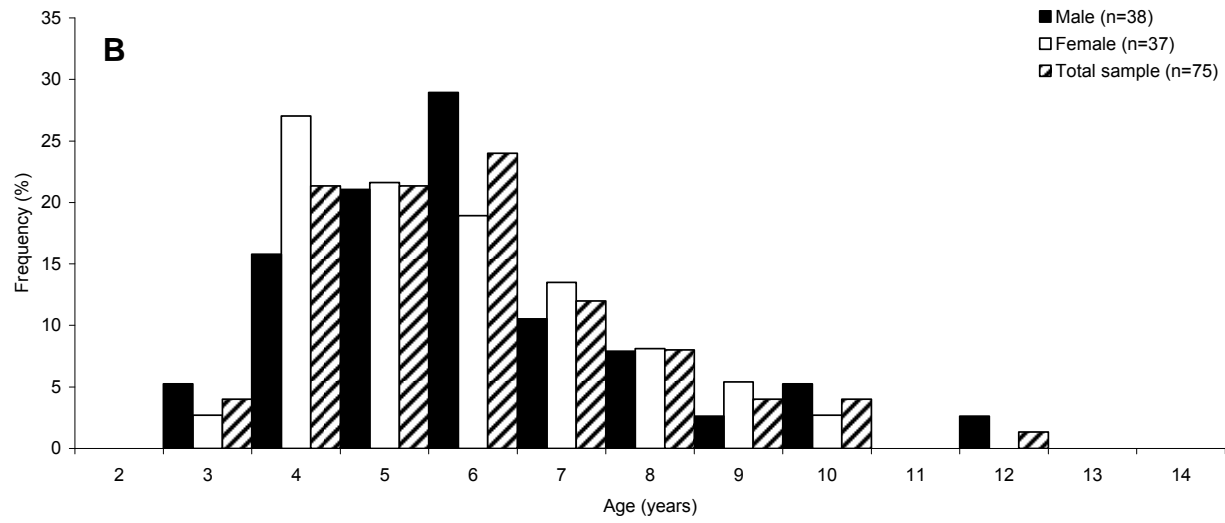
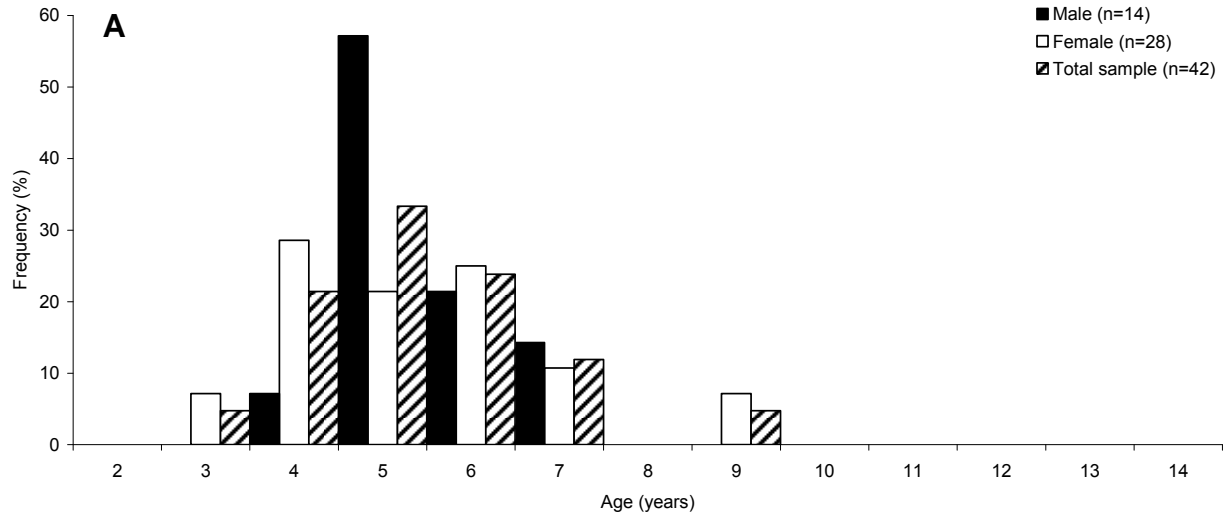


Figure 12. Age frequency distributions of  $\geq 286$  mm Dolly Varden from the Big Fish River captured using a weir in A) 1987, B) 1988 and C) 1991.



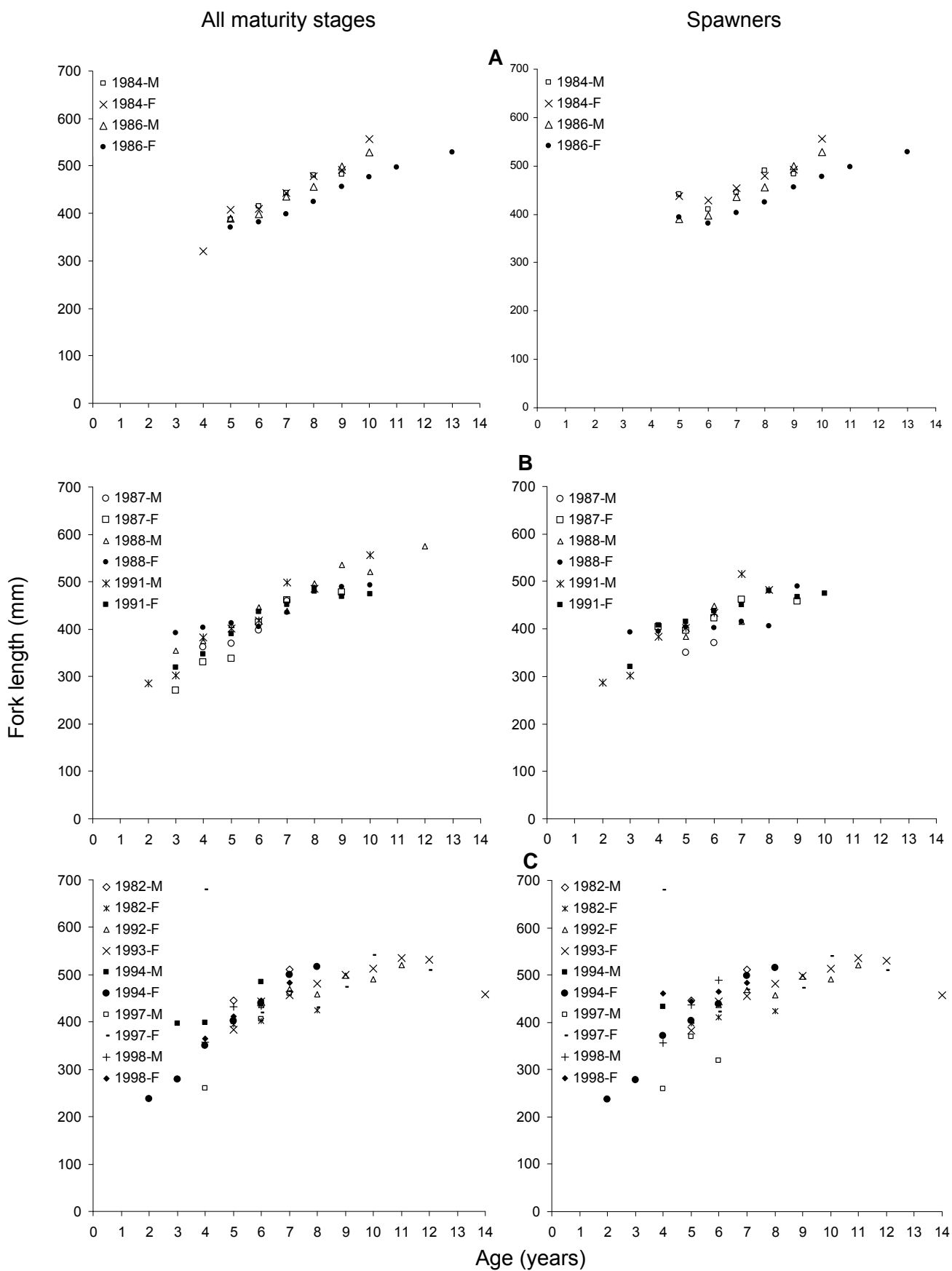


Figure 13. Length (mm) at age (years) of male (M) and female (F) Dolly Varden from the Big Fish River captured by gill net A), weir B) and seine C) among sampling years using data from all maturity stages combined and spawners only.

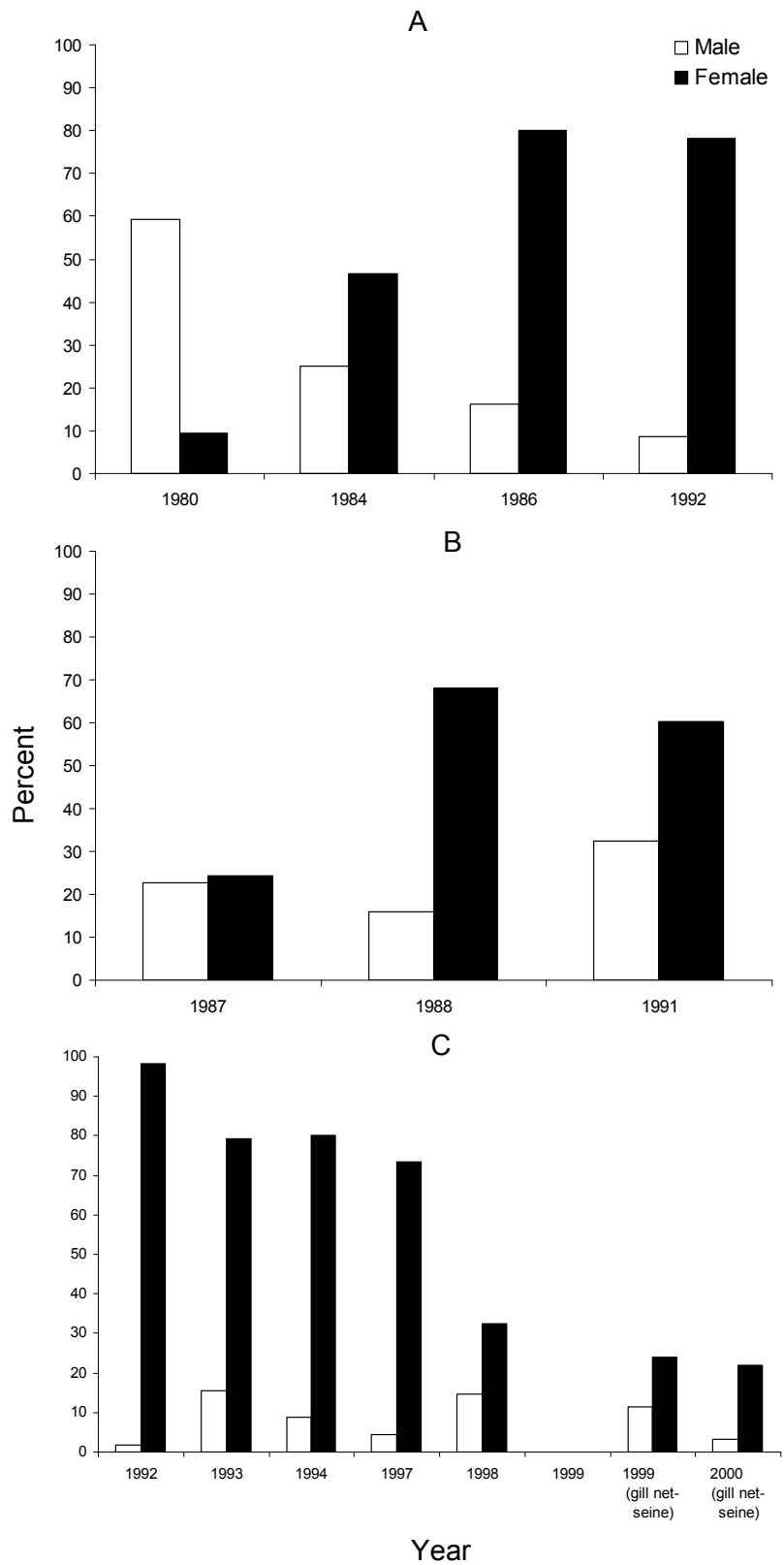


Figure 14. Percent current-year male and female Dolly Varden spawners collected using gill nets A), weir B) and a seine C) (Note: only sampling years where total sample size is  $\geq 10$  are presented in graphs; no spawners were captured by seine at the overwintering area in 1999).

Table 1. Summary of information on available data sets for Dolly Varden from the Big Fish River.

Year	Month	Location	Type of collection	Method	Publication or report
1972	08-09	RM, CC	Biological analysis (population)	seine, gill net	Stein <i>et al.</i> 1973
1972	07, 09	SS	Biological analysis (population)	seine, angling	Stein <i>et al.</i> 1973
1973	06, 08-09	RM, RJ	Biological analysis (population)	gill net	Stein <i>et al.</i> 1973
1973	09-10	SS	Biological analysis (population)	seine, angling, gill net	Stein <i>et al.</i> 1973
1974	02	SS	Biological analysis (population)	electrofishing, gill net	Unpubl. data
1980	08	RM	Subsistence harvest monitoring	gill net	Kristofferson 1988 and Kristofferson and Baker 1988 (unpubl.)
1982	09	SS	Biological analysis (fish health)	seine	Souter <i>et al.</i> 1986
1984	08	RM	Subsistence harvest monitoring	gill net	Gillman <i>et al.</i> 1985
1984	09	SS	Biological analysis (population)	seine, angling	Gillman <i>et al.</i> 1985
1986	09	RM	Subsistence harvest monitoring	gill net	Sparling and Stewart 1986
1986	09	SS	Biological analysis (genetic)	seine, angling	Reist 1989
1987	08-09	CC, SS	Biological analysis (population)	hoopnet, weir, seine	MacDonell 1987
1988	08	CC	Biological analysis (population)	weir	Fehr and Archie 1989
1988	09	SS	Biological analysis (population)	seine, electrofishing	Reist <i>et al.</i> 1997
1991	07-09	CC, SS	Biological analysis (population)	weir	Sandstrom and Harwood 2002
1992	08	RM	Subsistence harvest monitoring	gill net	Sandstrom and Harwood 2002
1992	05,10	SS	Biological analysis (population)	seine	Sandstrom and Harwood 2002
1993	08-10	SS	Biological analysis (population)	seine, electrofishing	Sandstrom and Harwood 2002
1994	09	SS	Biological analysis (population)	seine	Sandstrom and Harwood 2002
1997	10	SS	Subsistence harvest monitoring	seine	Stephenson 2003
1998	11	SS	Subsistence harvest monitoring	seine	Stephenson 2003
1999	11	SS	Subsistence harvest monitoring	gill net, seine	Stephenson 2003
2000	10	SS	Subsistence harvest monitoring	seine	Stephenson 2003

Location legend: CC = Little Fish River (previously called Cache Creek), RJ=junction Big Fish/Cache Creek, RM= River Mouth, SS = spawning site.

Note: information collected in 1996 by S. Stephenson was not available

Table 2. Summary of available population estimates for Dolly Varden from the Big Fish River.

Year	Population estimate (± 95% CI)	Original published estimate	Length of fish	Method	Capture method	Recapture method
1972	20,683 (15,762-25,605)	20,700 (15,800-27,600) <sup>a</sup>	≥150 mm	Petersen	Gill net (mouth of river, 1972)	Gill net (mouth of river, 1972)
1972	13,527 (11,732-15,322)	13,500 (11,300-16,000) <sup>a</sup>	≥150 mm	Petersen	Gill net (mouth of river, 1972) and seining (overwintering site, 1972)	Seine (overwintering site, 1972)
1984 <sup>+</sup>	8,455 (5,477-11,432) <sup>1</sup> 9,370 (5,883-12,858)	9,300 (6,300-14,300) <sup>a</sup>	≥350 mm	Petersen	Not specified, assumed Gill net (mouth of river, 1984)	Gill net (mouth of river, 1985)
1984		4,600 (3,100-7,100) <sup>a</sup>	≥350 mm	Petersen <sup>2</sup>	Not specified, assumed Gill net (mouth of river, 1984)	Gill net (mouth of river, 1985)
1987	9,075 (6,068-15,143)	9,076 (6,332-13,790) <sup>b</sup>	≥200 mm	Petersen	Weir (river, 1987)	Seine (overwintering site, 1987)
1987	7,374 (5,600-9,149)	7,379 (6,429-8,329) <sup>c*</sup>	≥200 mm	Petersen <sup>1</sup>	Weir (river, 1987)	Weir (river, 1988)
1988	5,839 (4,199-7,478)	5,827 (4,293-8,122) <sup>d</sup>	≥200 mm	Petersen	Seine (overwintering site, 1988)	Seine (overwintering site, 1988)
1988	8,498 (5,521-11,476)	8,499 (5,846-12,848) <sup>d</sup>	≥200 mm	Petersen	Weir (river, 1988)	Seine (overwintering site, 1988)
1988	6,766 (1,944-11,588)	6,766 (1,845-11,687) <sup>c*</sup>	≥200 mm	Bailey	Weir (river, 1987 & 1988)	Seine (overwintering site, 1988)
1991	2,839 (2,066-3,611)	2,840 (2,427-3,253) <sup>c*</sup>	≥400 mm	Petersen	Weir (river, 1991)	Seine (overwintering site, 1991)
1991	2,231 (1,760-2,702)	2,232 (1,947-2,490) <sup>c*</sup>		Petersen	Weir (river, 1991)	Visual observation (overwintering site, 1991)
1993	4,476 (2,472-6,480)	4,477 (3,397-5,563) <sup>c*</sup>	≥370 mm	Petersen <sup>1</sup>	Seine (overwintering site, 1993)	Seine (overwintering site, 1994)
1998	4,025 (2,959-5,092)	4,026 (2,988-5,563) <sup>e</sup>	≥320 mm	Petersen	Seine (overwintering site, 1998)	Seine (overwintering site, 1998)

<sup>+</sup> recalculated estimate from original published value is presented with and without an adjustment for tag loss.

Petersen<sup>1</sup> = adjusted for tag loss (11.3%) and recruitment. Petersen<sup>2</sup> = adjusted for mortality.

<sup>a</sup> Kristofferson and Baker (1988), <sup>b</sup> MacDonell (1987), <sup>c</sup> Sandstrom and Harwood (2002), <sup>d</sup> Fehr and Archie (1989), <sup>e</sup> Stephenson (2003).

\* all originally published values calculated 95% confidence intervals except for Sandstrom and Harwood (2002) who calculated 68% confidence intervals.

Table 3. Summary statistics of size (mm) and age (years) among sampling years for male and female Dolly Varden from the Big Fish River captured by gill nets using data from all maturity stages combined and spawners only (in brackets).

Year	Location	Male							Female							Sex ratio M:F
		Fork length			Age				Fork length			Age				
		n	Mean / Median	Range	n	Mean / Median	Mode	Range	n	Mean / Median	Range	n	Mean / Median	Mode	Range	
1972	RM	106 (0)	429 / 413	297-558	0				117 (0)	418 / 408	296-552	0				1:1.1 <sup>a</sup>
1973	RM	27 (8)	417 / 396 (430 / 442)	334-569 (334-569)	0				42 (25)	401 / 395 (416 / 418)	304-540 (310-540)	0				1:1.5 <sup>a</sup> (1: 3.1) <sup>b</sup>
1973	RJ	14 (0)	300 / 308	252-317	0				6 (0)	301 / 296	292-323	0				1:0.4 <sup>a</sup>
1973	SS	0			0				2	310 / 310	297-323	0				
1974	SS	1 (0)	400		0				2 (0)	384 / 384	360-407	0				1:2
1980	RM	23 (19)	460 / 463 (473 / 470)	314-550 (314-550)	0				9 (3)	405 / 408 (435 / 410)	305-508 (386-508)	0				1:0.4 <sup>b</sup> (1:0.2) <sup>b</sup>
1984	RM	68 (43)	432 / 431 (436 / 432)	309-568 (360-568)	56 (35)	6.5 / 6.0 (6.7 / 6.0)	6 (6)	5-9 (5-9)	122 (80)	443 / 444 (466 / 470)	283-660 (343-660)	102 (67)	6.9 / 7.0 (7.3 / 7.0)	6 (7)	4-10 (5-10)	1:1.8 <sup>b</sup> (1:1.9) <sup>b</sup>
1986	RM	17* (8)	448 / 445 (426 / 432)	325-539 (383-455)	14 (5)	7.6 / 8.0 (6 / 6)	8 (6)	5-10 (5-7)	88 (84)	418 / 419 (421 / 424)	305-529 (327-529)	75 (71)	7.6 / 8.0 (7.7 / 8.0)	8 (8)	5-13 (5-13)	1:5.2 <sup>b</sup> (1:4.9) <sup>b</sup>
1992	RM	5 (2)	495 / 512 (523 / 523)	393-539 (533-512)	2 (1)	5 / 5 (6)	-	4-6	18* (270)	493 / 499 (473 / 471)	428-537 (380-600)	17 (61)	8.4 / 8.0 (7.1 / 7.0)	8,9 (6)	7-10 (4-10)	1:3.6 <sup>b</sup> (1:9.0) <sup>b</sup>

Location legend: RM= River Mouth, RJ=junction Big Fish/Cache Creek, SS = spawning site.

\* denotes that all of these samples were also spawners.

<sup>a</sup> statistically significant, <sup>b</sup> not statistically significant (for male and female cumulative samples sizes of length ≥20).

Table 4. Summary statistics of size (mm) and age (years) among sampling years for male and female Dolly Varden from the Big Fish River captured by weir using data from all maturity stages combined and spawners only (in brackets).

Year	Location	Male							Female							Sex ratio M:F
		Fork length			Age				Fork length			Age				
		n	Mean / Median	Range	n	Mean / Median	Mode	Range	n	Mean / Median	Range	n	Mean / Median	Mode	Range	
1987	CC	25 (15)	323 / 320 (279 / 245)	217-477 (217-410)	22 (13)	5.1 / 5.0 (4.8 / 5.0)	5 (4)	3-8 (3-8)	40 (16)	361 / 368 (432 / 412)	203-550 (372-550)	31 (13)	5.2 / 5.0 (6.2 / 6.0)	4 (6)	3-9 (4-9)	1:1.6 <sup>a</sup> (1:1.1) <sup>a</sup>
1988	CC	48 (8)	425 / 420 (426 / 432)	256-575 (383-455)	39 (5)	6 / 6 (6 / 6)	6 (6)	3-12 (5-7)	50 (34)	414 / 404 (403 / 400)	305-552 (361-489)	37 (26)	5.8 / 5.0 (5.4 / 5.0)	4 (4)	3-10 (3-9)	1:1.0 <sup>a</sup> (1:1.9) <sup>b</sup>
1991	CC	155 (145)	488 / 500 (495 / 501)	260-580 (260-580)	18 (8)	5.6 / 5.5 (6.5 / 6.5)	3,8 (5,8)	2-10 (5-8)	292 (270)	463 / 469 (473 / 471)	280-600 (380-600)	80 (61)	6.5 / 6.5 (7.1 / 7.0)	6 (6)	3-10 (4-10)	1:1.9 <sup>b</sup> (1:1.9) <sup>b</sup>

CC = Little Fish River (previously called Cache Creek)

<sup>a</sup> statistically significant, <sup>b</sup> not statistically significant (for male and female cumulative samples sizes of length ≥20).

Table 5. Summary statistics of size (mm) and age (years) among sampling years for male and female Dolly Varden from the Big Fish River captured by seine and gill net used as a seine<sup>+</sup> using data from all maturity stages combined and spawners only (in brackets).

Year	Location	Male							Female							Sex ratio M:F
		Fork length			Age				Fork length			Age				
		n	Mean / Median	Range	n	Mean / Median	Mode	Range	n	Mean / Median	Range	n	Mean /Median	Mode	Range	
1972	SS	32 (2)	453 / 418 496	288-595 (478-514)	0				121 (1)	400 / 405 445	283-545	0				1:3.8 <sup>b</sup> (1:0.5)
1973	SS	0			0				1	390		0				
1982	SS	3*	392 / 446	219-511	3*	5.7	5	5-7	7 (5)	404 / 397 (411 / 413)	379-426 (395-426)	7 (5)	6.0 / 6.0 (6.2 / 6.0)	6 (6)	5-8 (5-8)	1:2.3 (1:1.7)
1987	SS	0			0				4 (3)	399 / 437 (454 / 450)	235-488 (424-488)	0				
1992	SS	18 <sup>c</sup> (16) <sup>c</sup>	151 / 126 (167 / 132)	24-280 (59-280)	0				65*	435 / 473	38-551	48	7.6 / 7.0	7	6-11	1:3.6 <sup>b</sup> (1:3.8) <sup>b</sup>
1993	SS	21 <sup>d</sup> (20) <sup>d</sup>	475 / 485 (475 / 485)	(301-601) (301-601)	0				113 (107	459 / 452 (460 / 457)	366-564 (366-564)	26*	8.1 / 7.0	7	5-14	1:5.4 <sup>b</sup> (1:5.4) <sup>b</sup>
1994	SS	46 <sup>d</sup> (34) <sup>d</sup>	460 / 476 (467 / 476)	287-606 (287-606)	9 (1)	4.0/4.0 (4.0)	4	3-6	385 (318	434 / 438 (460 / 454)	286-595 (337-595)	80 (42)	4.3 / 4.0 (5.1 / 5.0)	3,4 (5)	2-8 (4-8)	1:8.4 <sup>b</sup> (1:9.4) <sup>b</sup>
1997	SS	20 (2)	402 / 405 (345)	200-460 (320-370)	20 (2)	5.4 / 5.0 (5.5)	5,6	4-7 (5-6)	38 (33)	437 / 430 (437 / 430)	340-680 (340-680)	36 (31)	6.4 / 6.0 (6.3 / 6.0)	6 (6)	4-12 (4-12)	1:1.7 <sup>a</sup> (1:16.5) <sup>b</sup>
1998	SS	22 (10)	424 / 429 (456 / 455)	337-533 (382-533)	18 (7)	5.1 / 5.0 (5.4 / 5.0)	5	4-6 (5-6)	46 (22)	426 / 431 (465 / 462)	324-540 (405-540)	44 (21)	5.4 / 5.0 (5.8 / 6.0)	5 (6)	4-7 (4-7)	1:2.1 <sup>b</sup> (1:2.2) <sup>a</sup>
1999	SS	8 (0)	321	306-338	0				5 (0)	339	321-363	0				1:1.1 (n.a.)
1999 <sup>+</sup>	SS	28 (9)	399 / 377 (463 / 454)	330-529 (419-529)	0				53 (19)	396 / 388 (455 / 450)	204-512 (370-512)	0				1:1.9 <sup>b</sup> (1:2.1) <sup>a</sup>
2000 <sup>+</sup>	SS	12 (1)	417 / 386 (585)	328-585	0				20 (7)	403 / 367 (485 / 495)	340-545 (397-545)	0				1:1.7 (1:7)

SS = spawning site/overwintering area.

\* denotes that all of these samples were also spawners.

<sup>a</sup> statistically significant, <sup>b</sup> not statistically significant (for male and female cumulative samples sizes of length ≥20).

<sup>c</sup> It is assumed that males in 1992 were all the residual life history type

<sup>d</sup> The 1993 and 1994 data for males are for samples that were ≥280 mm.

*Table 6. Mean length (mm) at age (years) of male and female Dolly Varden sampled from gill nets in 1984 and 1996 at the mouth of the Big Fish River using data from all maturity stages combined and spawners only (in brackets).*

Age (years)	1984				1986			
	M		F		M		F	
	Mean	n	Mean	n	Mean	n	Mean	n
4		0	321	3		0		0
5	387 (441)	7 (2)	407 (437)	8 (4)	390	1*	371 (393)	9 (6)
6	416 (411)	26 (16)	409 (429)	36 (17)	398	1*	381	12*
7	444 (445)	15 (11)	443 (453)	27 (20)	436	3*	398 (402)	11 (10)
8	480 (490)	6 (4)	478 (479)	17 (15)	456	7*	425	23*
9	483	2*	492 (492)	6 (5)	499	1*	456	11*
10		0	556 (556)	6 (5)	528	1*	477	6*
11		0		0		0	498	2*
12		0		0		0		0
13		0		0		0	529	1*

\* indicates that the results are the same between all maturity stages and spawners.

*Table 7. Mean length (mm) at age (years) of male and female Dolly Varden sampled from the weir in 1987, 1988 and 1991 from the Little Fish River using data from all maturity stages combined and spawners only (in brackets).*

Age (years)	1987				1988				1991			
	M		F		M		F		M		F	
	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n
2		0		0		0		0	286	1		0
3		0	270	4	354	2	392	1*	302	4	320	4
4	363	1	330 (404)	8 (1)	375	7	404 (394)	10 (8)	383	1	348 (407)	10 (2)
5	369 (350)	8 (3)	338 (396)	7 (2)	408 (383)	8 (1)	412 (404)	8 (5)	402	3*	391 (415)	7 (4)
6	398 (370)	3 (2)	415 (423)	7 (6)	446 (449)	11 (3)	406 (403)	7 (6)	418 (433)	2 (1)	437 (437)	19 (16)
7	459	2	462	3*	438 (416)	4 (1)	435 (416)	5 (4)	499 (515)	2 (1)	451	15*
8		0		0	496	3	488 (406)	3 (1)	486 (483)	4 (3)	480 (481)	14 (13)
9		0	477 (458)	2 (1)	536	1	489 (489)	2 (1)		0	468	7*
10		0		0	521	2	493	1	557	1	475	4*
11		0		0		0		0		0		0
12		0		0	575	1		0		0		0

\* indicates that the results are the same between all maturity stages and spawners.

Table 8. Mean length-at-age of male and female Dolly Varden sampled from using a seine in 1982, 1992, 1993, 1994, 1997 and 1998 from the spawning/overwintering area of the Big Fish River using data from all maturity stages combined and spawners only (in brackets).

Age (yrs)	1982		1992		1993		1994		1997		1998											
	M	F	M	F	M	F	M	F	M	F	M	F										
	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n								
2	0	0	0	0	0	0	0	237	1	0	0	0	0									
3	0	0	0	0	0	0	397	2	278	25	0	0	0									
4	0	0	0	0	0	0	398	6	350	25	260	2	680	1*	357	3	365	5				
5	446	1*	395	2	0	0	0	383	1*	0	403	19	401	9	396	9	432	10	411	22		
			(397)	(1)							(403)	(18)	(370)	(1)	(398)	(8)	(436)	(4)	(445)	(7)		
6	0	0	403	4	0	436	11*	0	444	5*	485	1	439	3*	406	9	420	14	434	5	445	12
			(411)	(3)											(320)	(1)	(421)	(13)	(489)	(3)	(464)	(8)
7	511	1*	0	0	0	469	16*	0	456	8*	0	499	5*	460	1	465	6	0	483	5*		
																(468)	(5)					
8	0	0	424	1*	0	458	8*	0	481	2*	0	516	2*	0	430	1	0	0	0	0	0	
9	0	0	0	0	0	497	8*	0	499	4*	0	0	0	0	473	3*	0	0	0	0	0	
10	0	0	0	0	0	491	4*	0	513	3*	0	0	0	0	540	1	0	0	0	0		
11	0	0	0	0	0	520	1*	0	535	1*	0	0	0	0	0	0	0	0	0	0		
12	0	0	0	0	0	0	0	0	531	1*	0	0	0	0	510	1*	0	0	0	0		
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
14	0	0	0	0	0	0	0	0	458	1*	0	0	0	0	0	0	0	0	0	0		

\* indicates that the results are the same between all maturity stages and spawners.



Table 9. Age-at-maturity\* among study years for female Dolly Varden from the Big Fish River.

Year	Capture method (location)	n <sup>1</sup>	available age-range	age-at-maturity	n(sp)/n(total) <sup>2</sup>	Minimum age-at-maturity of spawners
1982	Seining (spawning/overwintering)	7	5-8	5	1/2	5
1984	Gill net (mouth of river)	92	4-10	5	4/8	5
1986	Gill net (mouth of river)	75	5-13	5	6/9	5
1987	Weir (Little Fish River)	31	3-9	6	6/7	4
1988	Weir (Little Fish River)	26	3-9	3	1/1	3
1991	Weir (Little Fish River)	80	3-10	5	4/7	4
1992	Gill net (mouth of river)	17	7-10	7	3/3	7
1992	Seining (spawning/overwintering)	48	6-11	6	11/11	6
1993	Seining (spawning/overwintering)	26	5-14	5	1/1	5
1994	Seining (spawning/overwintering)	80	2-8	4	14/25	4
1997	Seining (spawning/overwintering)	31	4-12	4	1/1	4
1998	Seining (spawning/overwintering)	44	4-7	6	8/12	4

\* age group at which ≥50% of fish are mature, current-year spawners.

<sup>1</sup>= total number of DV sampled for age and maturity in a given year.

<sup>2</sup>= number of current-year spawners versus total number of fish sampled within the age group defined as age-at-maturity.

Table 10. Age-at-maturity\* among study years for male Dolly Varden from the Big Fish River.

Year	Capture method (location)	n <sup>1</sup>	available age-range	age-at-maturity	n(sp)/n(total) <sup>2</sup>	Minimum age-at-maturity of spawners
1982	Seining (spawning/overwintering)	3	5,7	5	2/2	5
1984	Gill net (mouth of river)	52	5-9	6	16/23	5
1986	Gill net (mouth of river)	28	2-10	5	1/1	5
1987	Weir (Little Fish River)	22	3-8	4	4/5	3
1988	Weir (Little Fish River)	9	3-7	5	1/2	5
1991	Weir (Little Fish River)	18	2-10	5	3/3	5
1992	Gill net (mouth of river)	2	4,6	6	1/1	6
1992	Seining (spawning/overwintering)	0		n.a.		
1993	Seining (spawning/overwintering)	0		n.a.		
1994	Seining (spawning/overwintering)	18	3-6	n.a.		4
1997	Seining (spawning/overwintering)	11	4-6	n.a.		5
1998	Seining (spawning/overwintering)	18	4-6	6	3/5	5

\* age group at which ≥50% of fish are mature, current-year spawners.

<sup>1</sup>= total number of DV sampled for age and maturity in a given year.

<sup>2</sup>= number of current-year spawners versus total number of fish sampled within the age group defined as age-at-maturity.

n.a. = % spawners did not reach or exceed 50% in any age group

Table 11. Percent spawners, with numbers examined for maturity in brackets, of male and female (and sexes combined) Dolly Varden collected using various sampling gear at the Big Fish River.

Year	Gill net (mouth of river)			Seine and gill net used as seine <sup>+</sup> (spawning/overwintering area)			Weir (Little Fish River)		
	Male	Female	Total	Male	Female	Total	Male	Female	Total
1980	59 (23)	9 (9)	69 (32)						
1982				30 (3)	50 (7)	80 (10)			
1984	25 (62)	47 (110)	72 (172)						
1986	16 (17)	80 (88)	96 (105)						
1987							23 (25)	25 (40)	48 (65)
1988							16 (13)	68 (37)	84 (50)
1991							32 (155)	60 (292)	93 (447)
1992	9 (5)	78 (18)	87 (23)	19 (18)	73 (65)	93 (83)			
1993				23 (37)	71 (113)	95 (150)			
1994				25 (161)	58 (385)	83 (546)			
1997				4 (12)	73 (33)	78 (45)			
1998				15 (22)	32 (46)	47 (68)			
1999				0 (8)	0 (5)	0 (13)			
1999 <sup>+</sup>				11 (28)	23 (53)	35 (81)			
2000 <sup>+</sup>				8 (12)	35 (20)	25 (32)			

Table 12. Annual mortality (A) ( $\pm$  95% confidence interval) of male, female and combined sample of Dolly Varden from the Big Fish River captured by gill net<sup>1</sup> and seine<sup>2</sup> among sampling years.

Sex	Method	Year	A	Age range (years)	
Male	Gill net	1984	0.40 $\pm$ 0.13	7-9	
Female	Gill net	1984	0.35 $\pm$ 0.07	7-10	
		1986	0.37 $\pm$ 0.13	9-13	
	Seine	1992	0.33 $\pm$ 0.12	8-11	
		1993	0.24 $\pm$ 0.13	8-14	
		1994	0.37 $\pm$ 0.11	5-8	
		1997	0.30 $\pm$ 0.15	7-12	
		Total sample	Seine	1992	0.33 $\pm$ 0.12
		1993	0.24 $\pm$ 0.13	8-14	
		1994	0.37 $\pm$ 0.11	5-8	
		1997	0.31 $\pm$ 0.15	7-12	
		Gill net	1984	0.36 $\pm$ 0.06	7-10
		1986	0.37 $\pm$ 0.13	9-13	

<sup>1</sup> mouth of the Big Fish River.

<sup>2</sup> spawning/overwintering area.

Table 13. Summary of harvest information of Dolly Varden from the Big Fish River.

Year	Total Harvest <sup>1</sup>	Exploitation rate <sup>2</sup>	Management measure
1972	8,000-12,000	39-58	
1973	3,850	41	
1980	94	1	
1984	343	4	
1985	989	11	
1986	1,875	21	
1987			5-year closure
1988	73	1.3	
1989	15	0.5	
1990	107	3.8	
1991	3	0.1	
1992	33	0.7	Quota 700
1993	100	2.2	Quota 200
1994	53-91	1.3-2.3	Quota 200
1995	72-125	1.8-3.1	Quota 200
1996	421	10	Quota 200
1997	161	4	Quota 150
1998	349	8.7	Quota 150
1999	321	8	Quota 200
2000	39	1	Quota 400
2001	<25	<0.6	Closure
2002	<25	<0.6	Closure
2006	64	1.6	Closure
2007	53	1.3	Closure
2008	15	0.4	Closure

<sup>1</sup>Total harvest= 50% of Dolly Varden caught at Shingle point + 100% of Dolly Varden caught in the Big Fish river fishery (See DFO 2001, Eddy *et al.* 2001, Stephenson (2003), and K. Bill (pers comm.) for detailed information).

<sup>2</sup>Exploitation rate= percent of current (or subsequent) year population estimate that was harvested (except for 1999-2002: last (1998) population estimate was used).