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Dolly Varden (*Salvelinus malma malma*) from the Big Fish River: abundance estimates, effective population size, biological characteristics, and contribution to the coastal mixed-stock fishery

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

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ABSTRACT

The population of Dolly Varden (*Salvelinus malma malma*) from the Big Fish River, Northwest Territories was assessed using mark-recapture, biological, genetic, and harvest data. Mark-recapture studies conducted in the fall of 2009, 2010 and 2011 indicate there are between 1,477 and 7,265 anadromous Dolly Varden ≥365 mm present at the spawning and overwintering site. The stock appears to have a low and stable abundance, which has not changed considerably over the past 20 years. Counts of migrating Dolly Varden collected using a DIDSON camera in the summer of 2010 likely underestimated abundance due to timing of camera deployment. Microsatellite data were used to determine that the effective population size (N_E) was between 210 and 615 adults, suggesting current estimated abundance is sufficient to maintain long-term genetic sustainability. Two independent abundance calculations were done using the N_E data which produced estimates between 1,500 and 4,393 fish, similar to the mark-recapture estimates. Biological data collected in the fall at the spawning and overwintering area found an increase in both the proportion of spawning males and those ≥550 mm compared to previous surveys in the 1980s and 1990s. Data from recaptured fish indicates that growth has also not changed significantly from past surveys. Contribution of the Big Fish River population to the harvest along the Beaufort Sea coast in 2011 was examined using genetic mixed-stock analysis. The results, combined with catch information collected from a harvest monitoring program and the abundance estimates, revealed the population experienced a harvest rate of approximately 0.77% in 2011. Overall, results presented here indicate the population is stable, with improvement in some measures, since its decline in the 1980s.

Dolly Varden(*Salvelinus malma malma*) de la rivière Big Fish : estimations de l'abondance, taille effective de la population, caractéristiques biologiques et contribution à la pêche côtière de stocks mélangés

RESUME

La population de Dolly Varden (*Salvelinus malma malma*) de la rivière Big Fish, aux Territoires du Nord-Ouest, a été évaluée à l'aide de données tirées des pêches, du marquage et de la recapture, de même que de données biologiques et génétiques. Les études de marquage et de recapture menées à l'automne 2009, 2010 et 2011 indiquent qu'il y a entre 1 477 et 7 265 Dolly Varden anadromes de ≥ 365 mm au site de frai et d'hivernage. L'abondance du stock semble faible et stable, n'ayant pas vraiment changé au cours des vingt dernières années. Les dénombrements de Dolly Varden en migration effectués à l'aide d'une caméra DIDSON à l'automne 2010 ont vraisemblablement sous-estimé l'abondance en raison de la période de déploiement de la caméra. On a utilisé les données de microsatellites pour déterminer que la taille effective de la population (N_E) se situait entre 210 et 615 adultes, ce qui permet de penser que l'abondance actuelle estimée est suffisante pour maintenir la durabilité génétique à long terme. Deux calculs indépendants de l'abondance exécutés à l'aide des données sur la N_E ont donné des estimations se situant entre 1 500 et 4 393 poissons, ce qui est similaire aux estimations découlant du marquage et de la recapture. Les données biologiques recueillies à l'automne dans la zone de frai et d'hivernage affichent une augmentation de la proportion de mâles reproducteurs et d'individus mesurant ≥ 550 mm par rapport aux relevés menés dans les années 1980 et 1990. La croissance déterminée d'après les poissons recapturés indique que cet aspect n'a pas non plus vraiment changé depuis les derniers relevés. On a étudié la contribution de la population de la rivière Big Fish à la pêche le long de la côte de la mer de Beaufort en 2011 au moyen d'analyses génétiques de stocks mélangés. Les résultats, combinés aux estimations de l'abondance et à l'information sur les prises recueillie dans le cadre d'un programme de surveillance de la pêche, révèlent que la population a subi un taux de récolte d'environ 0,77 % en 2011. Dans l'ensemble, les résultats présentés ici indiquent que la population est stable et s'améliore sur certains points depuis son déclin survenu dans les années 1980.

INTRODUCTION

Northern form Dolly Varden (*Salvelinus malma malma*) populations with an anadromous life history have been confirmed in six river systems in the North Slope of the Yukon Territory, and in the Northwest Territories in areas west of the Mackenzie River Delta and Peel River. Among these, the Big Fish River is situated in the Richardson Mountains in the Inuvialuit Settlement Region (ISR) and flows into the Mackenzie River Delta approximately 68 km northeast of Aklavik, NT (Figure 1). In addition to the anadromous, two freshwater life history types (resident and isolated) have also been identified in the Big Fish River. All life history types use the Little Fish River, a tributary to the Big Fish River, for spawning, overwintering and rearing. This population, similar to others, depends on perennial groundwater springs to maintain overwintering habitat for all life stages, including fertilized eggs. The groundwater coming into the Little Fish River is characterized as being between 8 and 16°C, containing a high mineral content (2,600 ppm), is slightly basic (pH 7.6 - 8.1) and having dissolved oxygen levels ranging from 0.2 to 6.8 ppm (McCart and Bain 1974, Clark et al. 2001). Spawning and overwintering habitats are inextricably linked, and in the Little Fish River, for the anadromous and resident life history types, these habitats are delineated by a 3 m waterfall and the upper margins of an aufeis area approximately 4 km downstream. Upon smoltification at approximately 3 to 4 years of age, Dolly Varden from the Big Fish River undertake annual seasonal migrations, travelling approximately 131 km in the spring in order to reach the marine waters of the Beaufort Sea to feed over the summer. The migration back to the Big Fish River in order to spawn and/or overwinter occurs from late July or early August and into September.

Anadromous Dolly Varden from the Big Fish River are culturally important for the subsistence of Inuvialuit people, particularly for those residing in Aklavik, reportedly since the 1890s (Byers 1993, Stephenson 2003). Prior to the 1980s, the population was fished during the winter at the overwintering area, the summer in a mixed-stock fishery along the Beaufort Sea coast, and in the fall during the upstream/return migration in Moose Channel near the mouth of the Big Fish River. The subsistence fishery appeared to be sustainable during this time until a decline in population abundance, observed by the harvesters, in the early 1980s prompted studies (e.g., Gillman et al. 1985) to examine the harvest and collect biological information. The reason for the decline is unclear, however it is hypothesized that either harvest levels were too high, the spawning and overwintering habitat was altered due to earthquake activity resulting in reduced water flows and loss of pools used by Dolly Varden to overwinter, or a combination of both (Sandstrom and Harwood 2002, Stephenson 2003).

Fisheries and Oceans (DFO) in partnership with the Aklavik Hunters and Trappers Committee (HTC) prohibited fishing activity in the Big Fish River, including the Little Fish River, and areas adjacent to its mouth in the Mackenzie River Delta in 1987 in order to protect the stock. Currently, Dolly Varden from the Big Fish River are harvested along the Beaufort Sea coast during the summer. The main harvesting location is Shingle Point, YT (Figure 1) where harvesters primarily target Arctic cisco (*Coregonus autumnalis*). The contribution of the Big Fish River population to the total Dolly Varden harvest was unknown, however previous tagging information has suggested the stock may contribute up to 50% (L. Harwood, pers. comm. in Stephenson 2003).

Previous assessments of Dolly Varden from the Big Fish River (DFO unpublished data) concluded that the population abundance in 1987 was considerably lower compared to the early 1970s. A subsequent assessment in 2003 (DFO 2003) concluded that the population had not recovered and that habitat changes due to natural causes may be limiting population size. The assessment also emphasized the need to determine the number of Dolly Varden from the Big Fish River that were harvested at Shingle Point. Between 1999 and 2008, no data were collected that could be used to assess population status.

As a result of the decline in the Big Fish River in the 1980s combined with the considerable fluctuation in population abundance observed in the Rat River between 2001 and 2007, the low number of anadromous populations in the Western Arctic, and the limited area/volume of critical freshwater habitats for Dolly Varden, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) listed northern form Dolly Varden as a species of Special Concern in 2010 (COSEWIC 2010). This prompted, in part, the development of a collaborative Integrated Fisheries Management Plan (IFMP) among the Fisheries Joint Management Committee, Gwich'in Renewable Resources Board, DFO and Parks Canada for Dolly Varden populations in the ISR and Gwich'in Settlement Area (DFO 2010). The IFMP provides objectives, strategies and measures for managing stocks and also presents a research and monitoring plan. Information required for the assessment of Dolly Varden populations in the ISR is outdated. The proper implementation of the IFMP and any future evaluation by COSEWIC requires updated assessments, which includes the Big Fish River.

OBJECTIVES

The purpose of this research document was to collate information collected between 2009 and 2011 to conduct an updated assessment of anadromous Dolly Varden from the Big Fish River, specifically:

1) Calculate population abundance estimates for 2009 and 2010 from a mark-recapture study, and compare with prior mark-recapture estimates;

2) Estimate counts of Dolly Varden during the 2010 upstream migration from a Dual Frequency Identification Sonar (DIDSON);

3) Calculate the effective population size (N_E) using genetic information and generate a population estimate using this datum;

4) Summarize biological characteristics of the population from live-sampling conducted at the spawning and overwintering area in September in 2009, 2010 and 2011 (length, sex, maturity, and growth), and compare with data collected at the same location in prior years;

5) Tabulate recent Dolly Varden harvest statistics from a harvest monitoring program conducted at Shingle Point and other locations along the Beaufort Sea coast between 2009 and 2011;

6) Examine the contribution of Dolly Varden from the Big Fish River to the mixed-stock-fishery along the Beaufort Sea coast based on results from genetic mixed-stock analysis of samples collected in 2011;

7) Estimate the harvest rate of the stock in 2011.

METHODS

THE CAPTURE AND SAMPLING OF FISH AT THE SPAWNING AND OVERWINTERING AREA

The capture and live-sampling of Dolly Varden in the Little Fish River was consistent with the methods described by Sandstrom et al. (2009) used to sample those from Fish Creek, the spawning tributary of the Rat River. Briefly, a 16 m long seine net was deployed at multiple locations in the river using a crew of three people; one on both ends and another in the middle to assist if the net became snagged. At each sampling location, the net was stretched across the width of the stream at the upstream end of a pool and it was slowly pulled downstream at an angle towards the other end of the pool. When the seine approached the end of the pool, the person on the one side that was walking ahead would quickly drag the net across towards the opposite shore while a fourth person would begin running upstream from the riffle area below splashing a long branch in the water to discourage the fish from swimming away from the net and towards the riffle area. Upon reaching the shore, both ends of the seine were pulled out of the water leaving enough of the net in the water to create a pen for all the captured fish and facilitate processing.

Each fish captured in the net was identified to species and measured for fork length (± 5 mm). The life history type of each Dolly Varden was identified and, for anadromous fish, the reproductive status was recorded (‘non-spawner’ or ‘spawner’) along with the sex if it was in spawning condition. In general, non-spawners (also termed ‘silvers’) are either immature smolts or resting adults that are silver in colour. Each anadromous fish was examined for the presence of a tag near the base of the dorsal fin and, if present, the number written on the tag and its colour were recorded. If a Dolly Varden had no tag and was >300 mm, it was tagged with an individually coded 50 mm long t-bar plastic tag (Hallprint Pty. Ltd., Hindmarsh Valley, Australia). Once measured and/or tagged, fish were immediately returned to the water. In 2009, a piece of the adipose fin was removed from 190 anadromous Dolly Varden and placed in a vial of 95% ethanol for genetic analyses.

The sampling objective for the Big Fish River was to capture and tag up to 500 Dolly Varden each year at the end of September; however, this depended on the amount of time available to seine during the day. Five hundred was the target as this was a reasonable number given the limited time and resources. Access to the site was only possible by helicopter and the daily weather conditions (fog or freezing rain) were factors that determined whether a trip to the site was possible. The amount of time spent working was limited by the weather conditions in the morning which affected the time of arrival and the remaining amount of daylight hours. Also, the water levels in 2010 were initially too high for effective seining which required additional trips later in the month once water levels decreased. Live-sampling of Dolly Varden was conducted on September 26 in 2009, 19, 25 and 28 in 2010, and 26 in 2011.

POPULATION ESTIMATES USING MARK-RECAPTURE

Population abundance estimates were undertaken by capturing and tagging a sample of Dolly Varden in the fall (2009 and 2010) at the spawning and overwintering area of the Little Fish River and sampling again one year later (2010 and 2011) at the same location in order to record the number of marked and unmarked fish encountered. The models used to estimate the population size were based on single-year (Petersen model) and multiple-year (Bailey’s triple-catch model) censuses.

The Petersen model is used for closed populations where it is assumed that there is no immigration or emigration, all fish susceptible to the sampling gear have the same probability of being captured in the first sample, the t-bar tag does not affect catchability, the recapture sample is random where all tagged and untagged fish have an equal chance of being captured, there is no tag loss, and all recaptured tags are reported (Seber 1982). In the context of the mark-recapture studies on Dolly Varden, some of the assumptions were not met (e.g., no recruitment into the population and tag loss) and corrections were made (see Sandstrom et al. 2009, Gallagher et al. 2011).

The Chapman modification of the Petersen equation was used to estimate population size (N):

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

where 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 uncertainty of N is determined by calculating the variance (Var):

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

Seber (1982, Appendix A1) recommends as a guide that the Poisson distribution should be used to calculate 95% confidence intervals (C.I.) if R/C< 0.1 and R/M< 0.1, which applies in this study. To calculate the intervals, coefficients were determined, based on the frequency of R, according to Seber (1982) and applied to the product of MC to determine the lower and upper limits. To control for the issue of recruitment of unmarked individuals into the component of the population being evaluated (i.e., due to growth between sample 1 and sample 2), the lower end of the size range was adjusted (up) using the established growth relationship observed from tag recaptures to exclude those fish in the recapture that would not have been a size eligible (i.e., too small) for tagging in sample 1.

Bailey's triple-catch model (Bailey 1951, 1952) requires sampling the population on three separate occasions in order to generate an estimate of the population size at the second sampling event. A sample of fish is marked in the first sampling event, while in the second sample, the number of recaptures from the first sample is recorded and unmarked fish are marked with distinguishable tags from the first sample. During the third sampling event, the number of tags deployed in the earlier samples is recorded as well as the number of unmarked fish. The assumptions of the model are similar to Petersen's, and the population estimate is determined by:

$$N_2 = \frac{M_2(C_2+1)(R_{13})}{(R_{12}+1)(R_{23}+1)}$$

where N_2 is the population size at the second sampling period, M_2 is the number of fish marked in the second sample, C_2 is the number of fish examined for marks in the second sample, R_{13} is the number of recaptures from the first marking observed in the third sample, R_{12} is the number of recaptures from first marking in the second sample, and R_{23} is the number of recaptures from the second marking observed in the third sample (see Ricker 1975). Variance was estimated by:

$$Var\ N_2 = N_{2^2} \frac{M_{2^2}(C_2+1)(C_2+2)R_{13}(R_{13}-1)}{(R_{12}+1)(R_{12}+2)(R_{23}+1)(R_{23}+2)}$$

An annual tag loss rate of 8% was incorporated into the calculations based a study done on a neighbouring Dolly Varden system (Sandstrom et al. 2009). Separate estimates were provided for two size ranges, fish greater than the smallest size tagged and fish ≥365 mm, in order to provide comparable values between years.

To examine whether the model's assumption of equal catchability of all tagged fish were met, recaptures for both survey years were combined and the relative recapture rate compared for each 25mm length interval. Mean catchability among all size classes was weighted by the proportion of recaptures for each size category. To compare with prior population estimates from the Big Fish River (see Gallagher et al. 2011), the 95% confidence intervals from past Petersen estimates were re-calculated from a normal to a Poisson distribution only if R/C< 0.1 and/or R< 50.

COUNTS OF MIGRATING DOLLY VARDEN USING DUAL FREQUENCY IDENTIFICATION SONAR (DIDSON)

The DIDSON (Sound Metrics Corporation, Lake Forest Park, Washington) is a multibeam sonar that transmits pulses of sound and converts the returning echo into digital images. The pulses of sound are emitted at a high frequency thereby providing an improved resolution over a relatively long distance compared to optical devices, particularly in turbid or low-light conditions. The DIDSON can record high resolution images at a fast continuous rate which provide near-video top-down imaging of objects in the water. The DIDSON has many applications, and has been used to study fish abundance (Moursund et al. 2003), movement (Crossman et al. 2011), behaviour (Mueller et al. 2010) and habitat (Tiffan et al. 2004).

The Long-Range (L-R) model of the DIDSON was used to enumerate the upstream movements of fish. The L-R operates at a frequency of 0.7 MHz (low frequency) and 1.2 MHz (high frequency) and constructs a single image by transmitting a pulse of 48 beams of sound at a rate of between 2 and 10 per second. An image can be captured over a range of distances, which can be changed by the user, by modifying the window start (the distance away from the camera where the start of an image is recorded) and window length (the length of the area that is viewed by the camera (i.e., the distance between the start length up to the maximum operating distance). The difference between a low and high frequency setting is related to the width of the 48 beams that are emitted which influence the resolution of the image. At a high frequency setting (window length ≤15 m), the quality of the images (i.e., resolution) is higher compared to low frequency. The L-R model DIDSON can capture an image from 0.83 m away from the camera to a distance of between 10 and 72 m.

A site was chosen on the Little Fish River (N 68° 20.189", W 136° 14.056"), approximately 1.7 river-kilometers from the downstream margin of an aufeis field (Figure 1). The site consisted of a gravel bar accessible by a Twin Otter plane where the river was no wider than the maximum distance the DIDSON could insonify. Daily, sometimes twice-daily, measurements of river width and depth were taken. Width was recorded using a range finder while depth was measured from a piece of rebar staked in the river. The camera was deployed from a gradually sloping cobble shoreline with no obstructions in the river channel that would result in acoustic shadowing effects.

The camera was attached to a metal mount and secured with rock-filled polypropylene woven bags in order to keep the camera stationary in the water while recording. The camera had to be positioned in a manner where it was completely submerged in the water and set perpendicular to shore in order to insonify to the other side of the river. Given the slope of the shoreline the camera was deployed from, and the variable water levels of the river, the camera had to be placed between approximately 0.3 to 12 meters away from shore over the summer and fall in order to be fully submerged. A length of wire fencing (1.2 m high, 25.4 mm mesh) was erected immediately downstream of the camera and perpendicular from shore to a distance of 1 m further than the camera in order to prevent non-detection of fish that passed too close to (<0.83 m) or behind the camera (Figure 2).

The DIDSON was set to record at a frame rate of 6 to 8 per second with a window start of 0.83 m and a window length of between 10.84 m (operating at high frequency) and 20.84 m (operating at low frequency) depending on the distance of the camera from the other side of the river which itself was dependent on the width of the river. A small tent was placed near the shore which housed a plastic storage box containing the DIDSON components (e.g., topbox) and laptop computer. The camera, computer and external hard drives were powered using a 2000 watt generator. All data files were logged directly to a large capacity external hard drive which was backed-up daily to a separate hard drive without disruption to the real-time recording. Data were examined in the field using a second laptop computer in order to confirm the presence of fish and obtain a preliminary indication of the number of fish passing.

The DIDSON data files were processed at DFO's Freshwater Institute using a desktop computer to enumerate, determine the direction of movement and measure fish that passed in front of the DIDSON. The DIDSON software V5.25.05 (Sound Metrics Corporation) was used to create an echogram of every hour-long file with background subtraction. The entire echogram was visually inspected for fish and each fish that was detected was enumerated. Measurements were only done in frames where fish were displaying their full length and positioned, as much as possible, in the centre of the field of view.

Species identification using the DIDSON data was not possible because Dolly Varden have similar body shapes to the other species known to occupy the river. In order to estimate the number of species other than Dolly Varden that may have been enumerated, results from weir studies conducted in 1987 (MacDonell 1987), 1988 (Fehr and Archie 1989) and 1991 (Harwood and Sandstrom 2002) were examined to determine the proportion of species other than Dolly Varden that were moving upstream during the migration period. Species other than Dolly Varden [Arctic grayling (*Thymallus arcticus*), Round whitefish (*Prosopium cylindraceum*) and Broad whitefish (*Coregonus nasus*)] consisted of a relatively small proportion of all fish encountered by the weir in 1987 (8.2%), 1988 (2.3%) and 1991 (9.4%). In order to correct the DIDSON total counts, the 9.4% value from 1991 (chosen because it was the most recent year with this type of information) was subtracted from the number of fish that were immeasurable and from all fish <400 mm. The <400 mm threshold was chosen because length information of Arctic grayling from the Big Fish River indicate maximal lengths of approximately this size (Gallagher and Howland, unpubl. data), while round whitefish in river systems that are relatively close to the Big Fish River rarely attain sizes >400 mm (Jessop et al. 1973). Instances of Broad whitefish in past studies were rare [n= 3 in 1987 (MacDonell 1987) and n= 1 in 1988 (Fehr and Archie 1989)] (Broad whitefish were not measured) and their possible effects on the counts of fish >400 mm were considered negligible.

EFFECTIVE POPULATION SIZE

Dolly Varden DNA was extracted using Qiagen DNeasy tissue extraction kits (Qiagen Inc., Valencia, CA) following manufacturer protocols. Fluorescently-labelled primers were used to amplify alleles at 16 microsatellite loci and PCR products were visualized using an automated sequencer (ABI 3130xl Genetic Analyzer; Applied Biosystems, Foster City, CA) with the LIZ 600 size standard. All genotypes were scored using GeneMapper (ver. 4.0, Applied Biosystems) software.

Contemporary N_E was first calculated using the linkage disequilibrium method implemented in LDNe version 1.31 (Waples and Do 2008) and the approximate Bayesian approach implemented using the program ONeSAMP (Tallmon et al. 2008). These methods have the advantage of requiring only a single sample in comparison to temporal methods in which two temporally spaced samples (> one generation) are needed (e.g., Jorde and Ryman 1995).

Results of the point estimates for calculating N_E were, however, inconsistent and biologically unclear (i.e., negative values and values approaching infinity). As such, to estimate N_E using genetic data, a temporal approach was used whereby samples from two separate sampling periods, at least one generation apart (1994 and 2009), were analyzed. For the estimation of N_E in Dolly Varden from the Big Fish River, two independent temporal methods (using the programs MLNE version 1.1 (Wang 2001) and TM3 (*Berthier* et al. 2002) were applied to the microsatellite DNA data set. A ratio for N_E/N_C of 0.14 (Palstra and Ruzzante 2008) was used to provide an estimate of abundance (i.e., census population size).

BIOLOGICAL INFORMATION FROM LIVE-SAMPLING AT THE SPAWNING AND OVERWINTERING AREA

The biological data obtained from seining Dolly Varden were used to calculate median/mean length, create length frequency distributions, and determine the proportion of female and male spawners, and non-spawners, for comparison among sampling years. Differences in the length of male and female spawners were statistically examined separately and between sexes among years of capture. The type of test utilized (analysis of variance F test, Mann-Whitney U test, Kruskall-Wallace H test) depended on whether the data followed a parametric or non-parametric distribution and the number of independent groups.

The recapture of tagged fish at the spawning and overwintering area allowed for the examination of annual growth among a range of sizes. Any samples where the recapture length was smaller than the capture length were removed from calculations due to recording error. Analysis of covariance (ANCOVA) was performed to determine if there were significant differences in the growth between sexes and among years using length at initial capture as a covariate.

Length-at-50%-maturity for male and female Dolly Varden (2009-2011 data combined) was determined according to Cardinale and Modin (1999). The cumulative proportion of mature fish (identified as “spawners”) was plotted against length classes (25 mm intervals). A logistic equation was used to estimate the length at which 50% of the individuals were mature:

$$y = a / (1 + b \cdot e^{(-kx)})$$

where y= expected proportion of mature individuals, x= observed cumulative proportion of mature individuals in a length class, a= asymptote of the curve (i.e., 1), and b and k are constants. The b and k parameters were determined by minimizing the sum of square differences between observed and fitted curves. The length-at-50%-maturity was calculated by setting y at 0.5 and solving for x. The recapture of tagged Dolly Varden at the spawning and overwintering area allowed for the examination of the incidence of repeat-spawning for both males and females.

In order to compare the biological data from 2009-2011 to earlier sampling years, the historic data set had to be standardized so sex and maturity classification for dead-sampled fish would be analogous to that collected for the contemporary live-sampled data (e.g., dead-sampled immature anadromous males were changed to non-spawners, while spawning anadromous males were not changed). For instances in the historic data set where a fish did not have sex and/or maturity information these were only included in combined length frequency summaries. Additionally, because not all fish had sex and or maturity recorded, the percent frequency of non-spawners, female spawners and male spawners did not sum to 100% (1986= 92%, 1993= 74%, 1994= 62%, 1997= 76% and 1998= 99%). It is also noted that the sample taken in 1984 at the spawning and overwintering area was done by angling and seining (Gillman et al. 1985); however, there was no means of separating these methods in the database.

Using ANCOVA, changes in annual growth over the last 24 years was examined using current tagging results and those collected during a weir survey on the Big Fish River in 1987 and 1988 (Fehr and Archie 1989) and seining surveys at the spawning and overwintering area in 1993 and 1994 (unpubl.).

Statistical analyses of the biological data were done using SPSS and results were considered significant at $p < 0.05$.

HARVEST MONITORING OF DOLLY VARDEN ALONG THE BEAUFORT SEA COAST

The collection of harvest and biological information from Dolly Varden along the Beaufort Sea is important for the assessment of all stocks with anadromous life history. In Canada, locations where Dolly Varden are either annually or periodically harvested during the summer are Komakuk Beach, Nunaluk Spit, Herschel Island (Thetis Bay), Ptarmigan Bay, Phillips Bay (e.g., Niakolik Point), King Point, Sabine Point, Shingle Point, and near the mouth of Running River. Between 2009 and 2011, known locations where the harvest of Dolly Varden occurred were Herschel Island, Ptarmigan Bay, King Point, Shingle Point and mouth of the Running River (Figure 1).

The total harvest of Dolly Varden at Herschel Island has been consistently monitored by the Rangers working at Herschel Island Territorial Park for over 25 years. In 2011, the monitoring program was enhanced with the collection of catch-effort and biological information (otoliths, length, weight, sex and maturity) and the collection of tissue samples for genetic mixed-stock fishery analysis.

A sampling program for Dolly Varden was implemented in 2011 at Ptarmigan Bay with the help of a harvester that has been fishing at the location for many years. The harvester was instructed to sample his subsistence catch and record catch-effort and biological information (otoliths, length, weight, sex and maturity) and collect tissue samples for genetic mixed-stock fishery analysis.

Since the late 1980s, Dolly Varden harvest information at Shingle Point has been collected via monitors hired to enumerate harvester's catches or by harvester's voluntarily reporting total catches directly to the Aklavik HTC. In addition, fishing diaries were periodically distributed by the Aklavik HTC and the monitors to the harvesters who were encouraged to voluntarily record the daily number of Dolly Varden and other species captured in their gill nets.

In 2009 and 2010, an individual from the community of Aklavik who spent the summer at Shingle Point was hired to record the number of Dolly Varden that were reported to them or directly enumerated from gill nets. Some harvesters who set up camp on the coast near the mouth of the Running River had their catches of Dolly Varden counted with those from Shingle Point because of its close proximity (3.5 km east) to Shingle Point. In 2011, a more comprehensive harvest monitoring program was initiated at Shingle Point/Running River. A monitor from the community of Aklavik, hired through the Aklavik HTC, worked in cooperation with a DFO staff member over the entire fishing period to collect harvest totals along with catch-effort, biological and tag return information from Dolly Varden at Shingle Point. Biological sampling included length, weight, sex and maturity, and collection of otoliths, muscle tissue, stomachs for diet analysis, and preserved tissue for genetic mixed-stock fishery analysis. The pair also worked in partnership to collect data with another Aklavik HTC hired monitor and DFO staff member whose primary focus was to collect marine benthic invertebrates, water samples, and biological data and tissue samples from various fish species, for an ecosystem study of the Beaufort Sea (Arctic Coastal Ecosystem Studies, ACES).

King Point is a relatively short distance by boat from Shingle Point (approximately 25 km west) and people camping at Shingle Point periodically go to King Point to harvest fish. In 2011, the harvest monitors from Shingle Point recorded harvest information and subsampled Dolly Varden captured at King Point.

MIXED-STOCK FISHERY ANALYSIS

Previous to mixed-stock analysis (MSA), genetic stock identification (GSI) was performed to delineate the genetic stock structure of anadromous Dolly Varden (Bajno et al., unpubl. data). Success of MSA relies on a reasonable understanding of the stocks (i.e., unit-stocks) that contribute to the mixed-stock fishery (Utter and Ryman 1993). The accuracy and precision of contribution estimates to a mixed-fishery improves with the inclusion of putative contributing unit-stocks in a genetic baseline used to characterize the genotypes and allele frequencies of selected genetic markers within stocks and identify genetic differences between unit-stocks.

Samples from presently know Canadian anadromous stocks (Firth River drainage, Babbage River, Big Fish River, Rat River and the Vittrekwa River) were used in the development of the genetic baseline using microsatellite markers (Bajno et al., unpubl. data). Subsets of Dolly Varden samples from rivers on the North Slope of Alaska were also included for baseline development as they have been previously reported to contribute to Canadian coastal fishing sites (Krueger et al. 1999). The program ONCOR (Kalinowski et al. 2007) was used to perform data analysis, simulate mixture analyses and perform assignment tests to estimate the population origin of individuals. To estimate 95% confidence intervals, 1000 bootstrap replicates were employed. The program GENECLASS ver2.0 (Piry et al. 2004) was also used to assign individuals to contributing unit-stocks and confirm assignment results from the MSA analysis in ONCOR. Assignment of individuals to baseline stocks was performed using the Bayesian method of Rannala and Mountain (1997) and the resampling procedure of Paetkau et al. (2004) using a type I error probability threshold of α=0.05. The contribution of Dolly Varden from the Big Fish River to the coastal harvest caught at Herschel Island (n= 84 samples), Ptarmigan Bay (n= 90 samples), King Point (n= 24 samples) and Shingle Point/Running River (n= 165 samples) in 2011 were reported. Due to the limited number of samples from King Point and its proximity to Shingle Point/Running River, samples from these locations were combined (n= 189 samples) for the MSA.

RESULTS

POPULATION ESTIMATES USING MARK-RECAPTURE

The percent relative catchability of the total sample of tagged Dolly Varden among size classes vulnerable to the seine net demonstrated that many values among the most abundant size classes that were tagged were similar to the mean value indicating that catchability was approximately equal (Figure 3). Higher values of catchability at the extremes of the length distribution were viewed as a lesser concern because these only constitute a small proportion of the total sample. The Petersen method estimated the population of Dolly Varden ≥365 mm in length to be 3,855[1] (95% C.I. 2,758-6,497) in 2009 and 4,341[2] (95% C.I. 3,084-7,265) in 2010 (Table 1, Figure 4). The 2010 estimate of Dolly Varden ≥365 mm using Bailey's triple-catch method was 3,930 (95% C.I. 1,477-6,382) (Figure 4).

COUNTS OF MIGRATING DOLLY VARDEN USING DIDSON

The DIDSON camera operated successfully for a total of 815.56 hours between August 6 and September 13, 2010. The camera did not record video for a total of 82.94 hours (9.23% of the total time), mainly due to a high water event in the river which increased the velocity of the water. The camera was knocked down and could not be retrieved for 55 hours between August 7 and 9, and for 27 hours and 17 minutes between August 22 and 23. Another disruption was for maintenance of the equipment in the late morning of September 6 for forty minutes.

Passing fish were enumerated moving either upstream or downstream (Table 2). The total number of fish passing in front of the camera was calculated by subtracting the downstream from the upstream counts to prevent the double-counting of a fish. After subtracting fish moving downstream, the total number of fish was 1,708. From the total, 1,650 fish were measured for length, while 58 were not measured because they passed too close in front of the camera to obtain a reliable measurement. After adjusting to account for possible other species (subtracting 9.4%), the number of Dolly Varden was approximately 1,638 (Table 2).

Sandstrom and Harwood (2002) state that Dolly Varden from the Big Fish River smolt at a length of approximately 280 mm. The number of fish ≥280 mm was 1,492, decreasing to 1,444 when adjusted for possible other species. The 1,444 value is the estimate of anadromous Dolly Varden counted during their migration to the spawning and overwintering habitat between August 6 and September 13, 2010. Fish <280 mm enumerated by the DIDSON were assumed to be pre-smolt juveniles, the resident life history type of Dolly Varden, or other species.

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[1] The estimate differs from 3,865 (DFO 2012) due to a rounding error detected following the regional advisory process.

[2] The estimate differs from 4,338 (DFO 2012) due to a rounding error detected following the regional advisory process.

The upstream counts were summed and plotted against date in order to illustrate the upstream/return migration pattern (Figure 5). As the DIDSON provided data that were analogous to a weir, the pattern was similar to results from studies that used a weir to enumerate migrating Arctic char (McGowan 1987, McGowan 1990, Read 2004), where initial daily counts are 0 and then increase to a high peak and decrease thereafter. Between August 5 and 9, 2010 no fish were observed. Fish (n= 1) started appearing on August 10, increasing gradually and peaking at 404 fish on August 19, 2010. Daily counts dropped precipitously to 0 fish per day by the 25th, then again increased gradually to >60 per day by September 1 before gradually decreasing to nearly 50 fish per day by September 13. The entire run was not counted as fish were still moving upstream on the last day of the camp. The camp could not continue beyond September 13 because of budget limitations and due to concerns about access using Twin Otter aircraft in the Richardson Mountains in the fall.

A significant negative correlation between stream width and number of fish passing upstream was detected (Pearson correlation, $r = -0.38$, $p = 0.02$). When stream width is plotted against fish counts, very few or no fish were observed passing by the camera when the river was wider than approximately 23 m at the site where the camera was deployed.

The average length (± 1 standard deviation) of fish that moved upstream was 429 mm (± 155), and ranged between 117 and 802 mm. The average length (± 1 standard deviation) of fish that moved downstream was 401 mm (± 9 mm), and ranged between 204 and 599 mm. The length frequency distribution was bell-shaped with a modal value at the 425-450 mm interval. Dolly Varden ≥400 mm and ≥500 mm accounted for 60.0% and 27.8% of upstream counts, respectively (Figure 6).

It is difficult to compare the results from the DIDSON with those from the weir in 1987, 1988 and 1991. The weir projects were limited in their success either due to late deployment of the weir which would result in missing larger-sized earlier migrants (i.e., 1987) or intermittent operation due to high water levels which submerged the weir and presumably resulted in partial enumeration (all years). Although any comparisons in length should be treated cautiously because of the combination of size-structuring in the migration of Dolly Varden (Glova and McCart 1974, Griffiths et al. 1975) with only partial enumeration, it appears that in 2010 there was a greater proportion of Dolly Varden ≥400 mm, ≥475 mm, ≥525 mm compared to 1987, 1988 and 1991, respectively (Figure 7).

EFFECTIVE POPULATION SIZE

Using the two temporal approaches, N_E was estimated to be 327 (95% CI= 210-565; TM3 method) and 357 (95% CI= 241-615; MLNE method). Employing a ratio for N_E/N_C of 0.14 (Palstra and Ruzzante 2008), it is possible to provide an estimate census population size. Accordingly, this results in census population size estimates of 2,336 (95% CI= 1,500 – 4,035; TM3 method) and 2,550 (95% CI= 1,721 – 4,393; MLNE method).

BIOLOGICAL INFORMATION FROM LIVE-SAMPLING AT THE SPAWNING AND OVERWINTERING AREA

Length characteristics

Female spawners median fork length differed among sampling years ($H(2) = 23.5$, $p < 0.001$) (Table 3), with post-hoc tests revealing those sampled in 2010 (median 480 mm) were larger than both 2009 (median 460 mm) ($U = 12273$, $p < 0.001$) and 2011 (median 455 mm) ($U = 22042$, p< 0.001). No differences were observed between 2009 and 2011 ($U= 1499$, $p= 0.18$). In contrast to female spawners, the mean length of male spawners was similar among sampling years ($F= 0.997$; d.f.= 1, 211; $p= 0.37$), as was that of non-spawners ($H(2)= 5.05$, $p= 0.08$) (Table 3). Non-spawners were relatively abundant among the smaller size classes of the sample (<400 mm), but only accounted for <10% of Dolly Varden >450 mm in length (Figure 8). Males in spawning condition were on average 52 mm (range 45 to 58 mm) larger than female spawners, a difference that was statistically significant in 2009 ($U= 1099.5$, $p< 0.001$), 2010 ($U= 4937$, $p< 0.001$) and 2011 ($U= 4688$, $p< 0.001$).

The median and modal lengths from 2009-2011 were similar to those observed after the population decline in the 1980s (Figures 9, 10 and 11). The range of sizes of females among all sampling years has not changed considerably nor has the proportion of large-size females (arbitrarily set at ≥500 mm). However, visual comparison of spawning male length distributions indicate a higher proportion of larger males (arbitrarily set at ≥550 mm) in the population compared to earlier years (Figure 12). When the 2009-2011 data are compared to 1972, considered to be the only sampling year representing a baseline prior to the decline of the population, there were a relatively large number of juveniles and moderately high proportion of Dolly Varden >500 mm (Figure 10).

Annual growth

Annual growth was examined based on the recapture of 27 fish tagged in 2009 and 23 fish tagged in 2010 after one year at large. No significant difference was observed in the annual growth between 2009 and 2011 ($F= 0.48$; d.f.= 1, 47; $p= 0.48$) (Figure 13). Therefore, data were pooled and the expected annual growth in length of Dolly Varden (sexes combined) ≥310 mm is described by the following linear equation:

$$\text{Length (mm)}_{\text{year2}} = 0.75 \times \text{Length (mm)}_{\text{year1}} + 155$$

Sufficient data from 2009-2011 were available to compare growth between males ($n= 17$) and females ($n= 30$), regardless of reproductive status from one year to the next (i.e, includes non-spawners and spawners). Males grew at a higher rate than females ($F= 25.08$; d.f.= 1, 44; $p< 0.001$) (Figure 14). The expected annual change in length of male and female Dolly Varden ≥310 mm is described as:

$$\text{Male: Length (mm)}_{\text{year 2}} = 0.78 \times \text{length (mm)}_{\text{year 1}} + 150$$

$$\text{Female: Length (mm)}_{\text{year 2}} = 0.69 \times \text{length (mm)}_{\text{year 1}} + 172$$

The growth of repeat-spawning fish was examined and also found males ($n= 14$) exhibited a higher growth than females ($n= 22$) ($F= 13.5$; d.f.= 1, 33; $p= 0.001$) (Figure 15). The expected annual change in length is described as follows:

$$\text{Male: Length (mm)}_{\text{year 2}} = 0.90 \times \text{length (mm)}_{\text{year 1}} + 84$$

$$\text{Female: Length (mm)}_{\text{year 2}} = 0.78 \times \text{length (mm)}_{\text{year 1}} + 129$$

When growth from 2009-2011 was compared to 1987-1988, no differences were observed for both males ($F= 0.42$, d.f.= 1, 22, $p= 0.53$) and females ($F= 0.09$, d.f.= 1, 64, $p= 0.77$) (Total sample: $F= 0.28$; d.f.= 1, 93; $p= 0.60$) (Figure 16). Similarly, no difference was observed between 2009-2011 and 1993-1994 for females (F= 0.7, d.f.= 1, 29; p= 0.4) (Figure 16). The male sample size was insufficient to test (n= 3).

Length-at-50%-maturity and prevalence of repeat-spawning

Based on the logistic regression model, the length-at-50%-maturity of female Dolly Varden from the Big Fish River was 421 mm while 50% of males were mature by 479 mm in length.

There were only three instances where a fish was captured and then re-captured the following year as a non-spawner (Table 4). The length of these fish when first captured ranged between 310 and 380 mm, and between 425 and 465 mm at recapture. Given that their lengths at initial capture were among sizes considered to be sexually immature and their lengths at recapture were among sizes where the majority were reproducing (Figure 8), it is assumed that these three were virgins when initially captured.

Instances where non-spawners were recaptured the following year as a spawner were observed for 8 females and 5 males (Table 4). Whether these Dolly Varden had spawned the year prior to first capture is unknown, however, it is possible to incorporate length information that could provide some indication. Using the linear regression equation for both males and females, it is possible to estimate the length of the non-spawners the year prior to their first capture. Among females, the expected length ranged between 330 and 345 mm, while in males, the expected length was between 315 and 438 mm. The predicted lengths of females fell among length classes where none or very few spawners were observed (Figure 8). Most of the predicted lengths for males were among sizes where relatively few Dolly Varden were sexually mature, although one predicted to measure 438 mm was within a size class where proportion of spawners was greater than non-spawners. These results suggest that all of these Dolly Varden were likely first time spawners when they were recaptured.

Three spawning fish (2 females and 1 male) tagged in 2009 were subsequently recaptured in both 2010 and 2011 as spawners. The lack of documented resting in recaptured spawning fish and the paucity of non-spawners in the size classes above size of maturity suggest the incidence of repeat-spawning in the Big Fish River is relatively high.

Length-at-50% maturity from past surveys was re-calculated for this document using the logistic approach, which found the majority of females attained maturity around 379 mm (1986 data), 380 mm (1991 data) and 337 mm (1994 data). Males reached maturity closer to 449 mm (1994; only year with sufficient data for males). Using length frequency information of non-spawning and spawning Big Fish River females between 1991 and 1994, Sandstrom and Harwood (2002) concluded these fish spawned in consecutive years, similar to the conclusions from this study.

Proportion of non-spawners, female spawners and male spawners

In all three sampling years, female spawners (46.3 - 56.9%) were the most abundant Dolly Varden sampled, followed by non-spawners (22.7 - 40.7%) (Table 5). Male spawners and non-spawners were captured in near equal proportions (20 - 28.1%) in 2010 and 2011. The sample in 2009 yielded the highest and lowest proportion of non-spawners (40.7%) and male spawners (13%), respectively. Anadromous females were 2.6 to 3.6 times more abundant in the sample compared to males (Table 5). If the assumption that upon reaching sexual maturity Dolly Varden will repeat-spawn and that all non-spawners are sexually immature is correct, then it is possible to examine the proportion of mature and immature Dolly Varden in the sample among years. Males and females in spawning condition were consistently more abundant in the sample compared to immature Dolly Varden, as the average proportion of spawners among sampling years was 69.5 % (Table 5).

When the 2009-2011 data are compared to earlier years, the proportion of females in the total sample does not appear to have changed considerably, apart from a relatively high proportion (82.5%) of females in 1982 (Figure 17). While anadromous males have always been less abundant compared to females, the 2009-2011 samples are among the highest observed in all years (note that in 1997 and 1998 males were selectively and minimally sampled and were not representative of the population) (Figure 17). It appears there was more variability in the earlier sampling years where the proportion of male spawners in the sample could be as low as 5%, a level not witnessed in recent samples. Between 2009 and 2011, resident Dolly Varden were not captured in high abundance relative to anadromous Dolly Varden, ranging in number from 4 to 35 (Table 5).

HARVEST MONITORING OF DOLLY VARDEN ALONG THE BEAUFORT SEA COAST

Between 2009 and 2011, the harvest of Dolly Varden along the Beaufort Sea coast varied among locations and years, with the majority of harvesting occurring at Shingle Point and Herschel Island (Table 6). The 2011 harvest estimate along the coast is considered the most accurate because of the comprehensive monitoring program in place. At Shingle Point, Dolly Varden were harvested between July 9 and September 9 in 2009, July 13 and August 2 in 2010, and July 22 and August 9 in 2011. The average number harvested between 2009 and 2011 was 251, and ranged between 193 and 307 (Table 6). At Herschel Island, Dolly Varden were generally harvested between mid-June and early August. Harvest monitoring activities at Herschel Island cease once the station was closed for the season in August. The average number harvested at Herschel Island between 2009 and 2011 was 155, and ranged between 80 and 256 (Table 6). At Ptarmigan Bay, the dates when harvesting occurred were not recorded apart from 2011 when harvesting occurred between July 1 and 4. Annual catches appeared to fluctuate considerably at Ptarmigan Bay and did not exceed 100 Dolly Varden. Tagged fish from the Big Fish River were captured in 2010 (n= 2) and 2011 (n= 1) at Shingle Point only (all tagged in 2009).

MIXED-STOCK FISHERY ANALYSIS

Genetic MSA results indicated that Dolly Varden from the Big Fish River contributed 13.2% (95% CI= 8.9 - 18.5%) of char caught at Shingle Point/Running River/King Point. Dolly Varden harvested at Herschel Island or Ptarmigan Bay did not include any from the Big Fish River. Comparison of individual assignment results from both the ONCOR and GENECLASS analyses did not reveal significant discrepancies. Genetic results also corroborated source of origin for individual tagged Dolly Varden recaptured and sampled at Shingle Point.

Using the harvest data from Shingle Point/Running River/King Point, it is estimated that 31 of the 236 Dolly Varden collectively captured at these locations in 2011 were from the Big Fish River stock. Based on averaging the 2009 and 2010 population estimates from mark-recapture

(~4,042)[3], and incorporating the 31 Dolly Varden from the Big Fish River harvested in 2011, it is estimated that the rate of harvest in 2011 was approximately 0.77[4]% (95% CI= 0.5% -1.1%).

DISCUSSION

The level of confidence associated with the Petersen and Bailey estimates are relatively high given the number of tags that were recaptured was >10 (see Seber 1982, Ricker 1975). Catchability appears similar across a wide range of sizes and approximately 7% of the population was tagged. Assuming proper adjustments were made to address the model's assumptions, the magnitude of error in abundance estimates would have been minimal had 10% of the population been tagged (Gatz and Loar 1988). Error (overestimate or underestimate) in the mark-recapture population estimate can increase in order of magnitudes if any of the assumptions are violated (Gatz and Loar 1988). When compared to the time-series of population estimates based on tagging over the past twenty years, it appears that the population abundance has remained low but stable for this period. They are, however, considerably lower than estimates from 1972, but it is noted that these estimates have wide confidence ranges (11,300 and 27,600) (Figure 4).

There is a high degree of confidence in the number of fish enumerated with the DIDSON camera because of the visibility of passing fish. The window length of 10.84 m provided clear visualization of fish and was the setting used for 74% of the observed fish. However, there is low confidence in using the number of fish enumerated as a population estimate because not only was it assumed that not all of the fish were enumerated, it was also difficult to confidently quantify the level of certainty around the number of fish that were not enumerated. The large disparity in the number of fish ≥365 mm between the mark-recapture (~ 3930-4,341) estimate and DIDSON count (1,243) may be a result of the underestimate of the population using the DIDSON and/or an overestimate of the population size using mark-recapture. Even when the DIDSON count is compared to the lower 95% confidence estimate of the 2010 Petersen estimate, there is still a discrepancy of 1,841. However, the discrepancy is lower (234) when comparing with the lower 95% confidence from the triple-catch method. The underestimation from the DIDSON is the most plausible reason for the difference because there was not an entire census as some Dolly Varden may have moved upstream prior to August 6, there were periods of time when the camera was not operational, and Dolly Varden (i.e., fish ≥400 mm) were still observed on the last day of recording (September 13).

There has been debate regarding the ratio of effective to census population size (N_E/N_C) and in the present study, we based this number on Palstra and Ruzzante (2008). Although limited information is available, Palstra and Ruzzante (2008) reviewed 83 studies across a variety of taxa and report an N_E/N_C ratio of 0.14. Until more data become available for this value in salmonid fishes, and for Dolly Varden in particular across a number of systems, we suggest that the abundance estimates produced from results based on N_E be interpreted with caution. The population estimates based on the effective population size data (2,336 – 2,550) were smaller than estimates from mark-recapture studies (3,853 – 4,338). However, there was considerable

[3] This estimate differs from 4,096 (DFO 2012) because it includes the Bailey's triple catch estimate.

[4] The estimate differs from 0.75% (DFO 2012) as population estimates changed slightly following the regional advisory process.

overlap in 95% confidence intervals between the lower and upper confidence intervals from the mark-recapture and effective population size, respectively, indicating that both methods provide generally similar results to one another, suggesting a degree of accuracy in either method.

The N_E of a population determines the rate at which genetic variation (e.g., heterozygosity) is lost in finite populations as a result of random genetic drift and is a pertinent topic when evaluating the long-term plans for conserving biological diversity (Allendorf and Luikart 2007). This is particularly true for small and/or isolated populations vulnerable to extinction or extirpation as a result of inbreeding (Sherwin and Moritz 2000; Consuegra et al. 2005). The analysis of N_E for Dolly Varden is preliminary in nature and more comprehensive work to detail population structure and genetic variation for Dolly Varden from the North Slope is presently underway (Bajno et al., unpubl. data, Harris et al., unpubl. data). Decreases in the effective size of a population often result in decreased genetic variation and have been associated with inbreeding depression, the accumulation of deleterious mutations, decreased fitness and survival, and the ability to adapt to environmental change (Frankham et al. 2003; Frankham 1996; Reed and Frankham 2003). Therefore, determining N_E and monitoring this parameter over time may be crucial for population persistence. Conservation biologists often adopt the "50/500 rule" as a guideline for the preservation of genetic diversity within populations or species, although this rule should be considered cautiously in management frameworks (Templeton 1994, Jamieson and Allendorf 2012). This rule, concomitantly advanced by Franklin (1980) and Soule (1980) suggests that a short-term minimum N_E of 50 is necessary to prevent detrimental levels of contemporary inbreeding and a minimum long-term N_E of 500 is required for maintaining the overall genetic variability of the population to allow future adaptive change (i.e., evolutionary potential) (Jamieson and Allendorf 2012). In this study, contemporary estimates, for the most part, fall well within the theoretical ranges important for avoiding inbreeding depression (N_E >50) and upper limits fell within ranges for maintaining long-term genetic diversity (N_E >500), suggesting that there are no immediate conservation concerns (e.g., reductions in fitness as a result of inbreeding) for Dolly Varden from the Big Fish River and long-term population persistence is likely if abundance levels remain the same. However, the median estimates of contemporary N_E (<500) do fall below 500 and raise possible concern regarding the maintenance of genetic diversity and therefore adaptive potential. This concern has also been mentioned for other post-glacial salmonids (Shrimpton and Heath 2002; Peterson and Ardren 2009) underscoring the importance of periodically monitoring this parameter to assess long-term population viability.

While the genetic MSA for 2011 suggest that the current harvest level for Dolly Varden from the Big Fish River is low, these results should be interpreted cautiously as there is a possibility that there could be considerable annual variability in coastal subsistence fisheries. The proportion of contributing stocks caught in mixed-stock fisheries can be sporadic due to, for example, temporal variation of fish movements and fishing effort. Therefore, a single year of sample collection and genetic analysis may not be representative of the coastal run over a long period of time. Also, the accuracy of MSA composition estimates relies on the reasonable understanding of putative stocks contributing to the mixed-fishery. The omission of a stock that may contribute to the harvest at Herschel Island and Shingle Point may lead to a misrepresentation of actual contribution rates. Therefore, the genetic baseline needs to be considered as an evolving catalogue that requires updating as new information (i.e., discovery of new unit-stocks and temporal changes in the genetic composition in unit-stocks) is identified.

Although population abundance is lower than recorded in the 1980s, and remains unchanged over the past 20 years, there have been improvements in some demographics of the population. Length data from seining, DIDSON camera and the weir show a higher proportion of Dolly

Varden ≥550 mm present in the population. There is also a higher proportion of anadromous spawning males ≥550 mm sampled between 2009 and 2011 compared to earlier years. Additionally, it appears that anadromous males are relatively more abundant than in previous years. The median size of spawning females does not appear to have changed considerably since the 1980s, nor has their contribution to the proportion of the total sample from seining.

Given that females rarely attain lengths >550 mm and their growth has not changed, it is possible that the increase in the proportion of fish >550mm is a result of an improvement in the survival of anadromous males in the population since the decline in the 1980s. Sandstrom et al. 2009 and Roux et al. 2012 also noted a paucity of anadromous male spawners during a period of population decline in Dolly Varden from the Rat River. If harvest levels were an issue in the past then it is possible the larger-sized males were more vulnerable to subsistence gill nets and were removed from the population at a higher rate. Alternatively, given the belief that there was a decrease in the volume of available spawning and overwintering habitat in the 1980s, this occurrence may have impacted the survival of large-sized individuals. Another possibility is a decrease in mortality among larger-size males from predators either in the ocean or in freshwater during migration/spawning. Although 2011 is the only year with accurate harvest rate information for the population and that past estimates were based on both reported harvest and an assumption of the population's contribution to the mixed-stock fishery, it is assumed that the current level of harvest experienced by the population is considerably lower than in the past.

The proportion of the population that was in spawning condition (extrapolated from what was observed in the sample) appeared to be high with average of >70% in 2010 and 2011, suggesting, in combination with a repeat-spawning strategy, poor reproductive capacity does not limit population growth. To further illustrate this point, it is possible to estimate the number of eggs deposited during spawning, assuming that the fecundity of females has not changed since the last time fecundity was examined in 1991 and 1993 (Sandstrom 1995) and that the mark-recapture population estimates are correct. If the proportion of spawning females sampled is representative of the population, then (for Dolly Varden ≥365 mm) it is possible to estimate the number of eggs that could have been deposited among length classes, based on the middle values among the 25 mm intervals from the length frequency distributions in 2009 and 2010, using the equation:

$$\text{Fecundity} = -3{,}350.20 + 12.29 \times \text{fork length (mm)}$$

The calculations provide estimates that suggest between 4.6 and 7.3 million eggs could have been deposited in 2009 and 2010, respectively (Table 7), although it is unknown what proportion of these would be successfully fertilized. While spawning anadromous males do not appear to be as abundant as females, this does not mean that fertilization of eggs is limited. It is likely that resident males are an important contributor to the fertilization of eggs, although this aspect of the reproductive ecology of Dolly Varden is poorly understood. It is noted that one of the most probable reasons residents were relatively low in abundance in the samples is because they are not as vulnerable to the sampling gear compared to anadromous Dolly Varden due to their small size, and that it is highly probable that the relative abundance of residents is much greater than what is demonstrated by the catches in the seine net. If fecundity has remained the same over the years along with population abundance, then this suggests that a population size of several thousand can be maintained by annual production/ deposit of 4.6 to 8.2 million eggs. The frequency of spawning along with the number of eggs produced may decrease the susceptibility of Dolly Varden in the Big Fish River to fluctuations in population abundance, as suggested by the lack of variation in abundance since the 1990s.

Although reproductive capacity does not appear restricted, the success of the fertilized eggs in hatching and yielding juveniles that grow to become adults and increase population size appears limiting. This suggests poor egg/juvenile survival or a limiting habitat (e.g., overwintering) with a current carrying capacity that restricts further population growth. Although studies on the interactions between the environmental/habitat conditions and egg/juvenile survival are required, it is possible to postulate that water characteristics such as total dissolved solids and total suspended solids may currently not be as favourable in the Big Fish River compared to pre-1980s.

Dolly Varden from the Rat River have shown resilience by demonstrating the capacity to increase to an abundance of >8,000 from a low of 2,911 within a three year time-span. The Big Fish River does not currently appear to be resilient to the same extent; however there is no indication that this is a result of a limiting factor in the biology of the population. The lack of population growth at relatively low harvest levels (compared to prior to the closure) strengthens the hypothesis stated in Sandstrom and Harwood (2002) and Stephenson (2003) that numbers of pools (carrying capacity) used by overwintering Dolly Varden has changed, possibly due to earthquake activity, which may have decreased the volume of water and even altered the elemental properties (based on the reported taste of the water by Elders, see Byers 1993) of ground water.

CONCLUSION

The population abundance of Dolly Varden from the Big Fish River remains at a relatively low yet stable level and has not changed considerably over the past 20 years. The low abundance does not appear to have produced adverse effects due to inbreeding and the amount of genetic variation necessary for long-term sustainability has been maintained. Compared to earlier decades (1980s and 1990s), there has been an increase in both the proportion of larger size (≥500 mm) and anadromous males in spawning condition in the Big Fish River. Given that the growth among decades does not appear to have changed, it implies that the increase in sizes/proportion of male spawners may be a result of an improvement in the survival of these individuals in order to attain the observed larger sizes. Additionally, the increase in length-at-50% maturity of females combined with no obvious change in growth and population density, and the likelihood that harvest levels have decreased since the late 1980s/early 1990s, suggest total mortality levels are now lower. Currently, Dolly Varden from the Big Fish River do not appear to contribute very much to the harvest along the Beaufort Sea coast or migrate as far as Hershel Island/Ptarmigan Bay, however additional sampling is required to examine inter-annual variation in order to confirm this. Based on a single year of information, it appears the population currently experiences a very low rate of harvest (0.77%), which is lower than the safe harvest rate of 5% (when a stock is considered healthy) outlined in the IFMP for Dolly Varden. These preliminary results suggest that the population does not remain depleted due to harvesting activities and supports a hypothesis that freshwater habitat (spawning and overwintering) characteristics are currently limiting productivity.

Annual data collection should continue for Dolly Varden from the Big Fish River with an aim towards having an ecosystem approach to the management of the population (Howland et al. 2012). The multi-disciplinary research examining, but not limited to, habitat, genetics, harvest and biology increases our understanding of their ecology, life history, population dynamics, species-interactions (i.e., Arctic grayling and others), and freshwater habitat characteristics (e.g., carrying capacity). Any future subsistence harvesting at the Big Fish River should be accompanied with the collection of catch-effort information and biological sampling, including otoliths, in order to update age-related population metrics which are currently lacking. Together with the local knowledge of experienced harvesters, the results from the multiple research activities will improve both management decisions and the ability to predict and/or mitigate anthropogenic impacts.

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LITERATURE CITED

Allendorf, F.W., and Luikart, G. 2007. Conservation and the Genetics of Populations. Blackwell, Malden, MA.

Bailey, N.T.J. 1951. On estimating the size of mobile populations from capture-recapture data. Biometrika 38: 293-606.

Bailey, N.T.J. 1952. Improvements in the interpretation of recapture data. J. Anim. Ecol. 21: 120-127.

Berthier, P., Beaumont, M.A., Cornuet, J.M., and Luikart, G. 2002. Likelihood-based estimation of the effective population size using temporal changes in allele frequencies: a genealogical approach. Genetics 160: 741-751.

Byers, T. 1993. Aklavik Traditional Knowledge- Big Fish River: a study of indigenous wisdom in fishery science. Report produced for the Aklavik Hunters and Trappers Committee, Aklavik, NT. 34 p.

Cardinale, M., and Modin, J. 1999. Changes in size-at-maturity of Baltic cod (*Gadus morhua*) during a period of large variations in stock size and environmental conditions. Fish. Res. 41: 285-295.

Clark, I.D., Lauriol, B., Harwood, L., and Marschner, M. 2001. Groundwater contributions to discharge in a permafrost setting, Big Fish River, N.W.T., Canada. Arct. Antarct. Alp. Res.: 33: 62-69.

Consuegra S., Verspoor, E., Knox, D., García de Leaniz, C. 2005. Asymmetric gene flow and evolutionary maintenance of genetic diversity in small, peripheral Atlantic salmon populations. Conserv. Genet. 6: 823-842.

COSEWIC. 2010. COSEWIC assessment and status report on the Dolly Varden *Salvelinus malma malma* (Western Arctic populations) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 65 p.

Crossman, J.A., Martel, G., Johnson, P.N., and Bray, K. 2011. The use of a Dual-frequency Identification SONar (DIDSON) to document white sturgeon activity in the Columbia River, Canada. J. Appl. Ichthyol. 27 (suppl. 2): 53-57.

DFO 2003. Big Fish River Dolly Varden. DFO Sci. Stock Status Report D5- 60(2002).

DFO. 2010. Integrated Fisheries Management Plan for Dolly Varden (*Salvelinus malma malma*) of the Gwich'in Settlement Area and Inuvialuit Settlement Region Northwest Territories and Yukon North Slope 2011-2015. Volume 1: the plan. 25 p.

DFO. 2012. Assessment of Dolly Varden from the Big Fish River, NT 2009-2011. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/065.

Fehr, A. and B. Archie. 1989. Enumeration and biological data on arctic charr (*Salvelinus alpinus*) from Cache Creek, Northwest Territories, 1988. Department of Fisheries and Oceans, Inuvik, Northwest Territories. Fisheries Joint Management Committee report. 89-001: 1-57 p.

Frankham, R. 1996. Relationship of genetic variation to population size in wildlife. Conserv. Biol. 10: 1500-1508.

Frankham, R., Ballou, J.D., Briscoe, D.A. 2003. Introduction to conservation genetics. Cambridge University Press, Cambridge, U.K.

Franklin, I.R. 1980. Evolutionary change in small populations. *In* Conservation biology: an evolutionary-ecological perspective. Edited by M.E. Soule and B.A. Wilcox. Sinauer Associates, Sunderland, Massachusetts. p. 135-140.

Gallagher, C.P., Roux, M.-J., Howland, K.L., and Tallman, R.F. 2011. 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. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/115. 45 p.

Gatz, A.J., and Loar, J.M. 1988. Petersen and removal population size estimates: combining methods to adjust and interpret results when assumptions are violated. Env. Biol. Fishes 21: 293-307.

Gillman, D.V., Sparling. P., and Gillis, B. 1985. Arctic charr population studies 1) Big Fish River 2) River system survey. Northern Oil and Gas Action Plan (NOGAP) Project 2-109. Fisheries and Oceans Canada 57 p.

Glova, G., and McCart, P.J. 1974. Life history of Arctic char (*Salvelinus alpinus*) in the Firth River, Yukon Territory. Canadian Arctic Gas Study Limited; Alaskan Arctic Gas Study Company. Biological report series 20. 50 p.

Griffiths, W.B., Craig, P.C., Walder, G., and Mann, G.J. 1975. Fisheries investigations in a coastal region of the Beaufort Sea (Nunaluk Lagoon, Yukon Territory). Arctic Gas Biological Report Series 34. 219 p.

Howland, K. Mochnacz, N. Gallagher, C. Tallman, R. Ghamry, H., Roux, M-J. Sandstrom S., and Reist, J. 2012. Developing strategies for improved assessment and ecosystem-based management of Canadian northern Dolly Varden. *In* Global progress in ecosystem-based fisheries management. Edited by G.H. Kruse, H.I. Browman, K.L. Cochrane, D. Evans, G.S. Jamieson, P.A. Livingston, D. Woodby, and C.I. Zhang. Alaska Sea Grant College Program, University of Alaska Fairbanks. p. 169-188.

Jamieson, I.G., and Allendorf, F.W. 2012. How does the 50/500 rule apply to MVPs? Trends Ecol. Evol. 27: 578-584.

Jessop, C.S., Porter, T.R., Blouw, M., and Sopuck, R. 1973. Fish Resources of the Mackenzie River valley. Special report: An intensive study of the fish resources of two main stem. Environmental-Social Committee Northern Pipelines, Task Force on Northern Oil Development. Special Report. 148 p.

Jorde, P.E., and Ryman, N. 1995. Temporal allele frequency change and estimation of effective size in populations with overlapping generations. Genetics 139: 1077–1090.

Kalinowski, S.T., Manlove, K.R., and Taper, M.L. 2007. ONCOR: software for genetic stock identification. Montana State University, Bozeman, MT.

Krueger, C.C., Wilmot, R.L., and Everett, R.J. 1999. Stock origins of Dolly Varden collected from Beaufort Sea coastal sites of Arctic Alaska and Canada. Trans. Am. Fish. Soc. 128: 49-57.

MacDonell, D.S. 1987. Report on the enumeration of the 1987 upstream migration of arctic char (*Salvelinus alpinus* L.) in the Big Fish River, N.W.T. A report prepared for Fisheries and Oceans Canada by North/South Consultants. 67 p.

McCart, P., and Bain, H. 1974. An isolated population of arctic char (*Salvelinus alpinus*) inhabiting a warm mineral spring above a waterfall at Cache Creek, Northwest Territories. J. Fish. Res. Board Can. 31: 1408-1414.

McGowan, D.K. 1987. Data on Arctic charr, *Salvelinus alpinus* (L.), from the Diana River, Northwest Territories, 1986. Can. Data Rep. Fish. Aquat. Sci. 666. 19 p.

McGowan, D.K. 1990. Enumeration and biological data from the upstream migration of Arctic charr, *Salvelinus alpinus* (L.), in the Cambridge Bay area, Northwest Territories, 1979-1983. Can. Data Rep. Fish. Aquat. Sci. 811. 27 p.

Moursund, R. A., Carlson, T. J., and Peters, R. D. 2003. A fisheries application of a dual-frequency, identification-sonar acoustic camera. ICES J. Mar. Sci. 60: 678-683.

Mueller, A., Burwen, D.L., Boswell, K.M., and Mulligan, T. 2010. Tailbeat patterns in Dual-Frequency Identification Sonar Echograms and their potential use for species identification and bioenergetics studies. Trans. Am. Fish. Soc. 139: 900-910.

Palstra, F.P., and Ruzzante, D.E. 2008. Genetic estimates of contemporary effective population size: what can they tell us about the importance of genetic stochasticity for wild population persistence? Mol. Ecol. 17: 3428-3447.

Paetkau, D., Slade, R., Burden, M., and Estoup, A. 2004. Genetic assignment methods for the direct, real-time estimation of migration rate: a simulation-based exploration of accuracy and power. Mol. Ecol. 13: 55-65.

Peterson, D.P., and Ardren, W.R. 2009. Ancestry, population structure, and conservation genetics of Arctic grayling (*Thymallus arcticus*) in the upper Missouri River, USA. Can. J. Fish. Aquat. Sci. 66: 1758-1774.

Piry, S., Alapetite, A., Cornuet, J.-M., Paetkau, D., Baudouin, L., and Estoup, A. 2004. GeneClass2: A software for genetic assignment and first-generation migrant detection. J. Hered. 95: 536-539.

Rannala, B., and Mountain, J.L. 1997. Detecting immigration by using multilocus genotypes. Proc. Natl. Acad. Sci. U.S.A. 94: 9197-9221.

Read, C.J. 2004. An assessment of the Arctic char population of Tugaat River, Nunavut. Can. Manuscr. Rep. Fish. Aquat. Sci. 2699. 35 p.

Reed, D.H., and Frankham, R. 2003. Correlation between fitness and genetic diversity. Conserv. Biol. 17: 230-237.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Board Can. Bulletin 191. Ottawa. 382 p.

Roux, M.-J., Howland, K.L., Gallagher, C.P., and Tallman, R.F. 2012. Synthesis of biological and harvest information used to assess populations of northern form Dolly Varden (*Salvelinus malma malma*) in Canada. Part I: Rat River. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/132. 77 p.

Sandstrom, S. 1995. The effect of overwintering site temperature on energy allocation and life history characteristics of anadromous female Dolly Varden (*Salvelinus malma*), from the Yukon and Northwest Territory north slope, Canada. Thesis (M.Sc), University of Manitoba, Winnipeg, MB. 137 p.

Sandstrom, S., and Harwood. L.A. 2002. Studies of anadromous Dolly Varden (*Salvelinus malma*) (W.) of the Big Fish River, NT, Canada, 1972-1994. Can. Manuscr. Rep. Fish. Aquat. Sci. 2603. 39 p.

Sandstrom, S., Harwood, L., and Howland, K. 2009. Status of anadromous Dolly Varden char (Salvelinus malma) of the Rat River, Northwest Territories, as assessed through mark-recapture and live-sampling at the spawning and overwintering site (1995-2007). Can. Tech. Rep. Fish. Aquat. Sci. 2842. 23 p.

Seber, G. A. F. 1982. The Estimation of Animal Abundance and Related Parameters. 2nd Edition. Blackburn Press, Caldwell, New Jersey.

Sherwin, W., and Moritz, C. 2000. Managing and monitoring genetic erosion. *In* Genetics, demography and viability of fragmented populations. Edited by A.G. Young and G.M. Clarke. Cambridge University Press, Cambridge, U.K. p. 9-34.

Shrimpton, J.M., and Heath, D.D. 2003. Census vs. effective population size in chinook salmon: large- and small-scale environmental perturbation effects. Mol. Ecol. 12: 2571-2583.

Soule, M.E. 1980. Thresholds for survival: maintaining fitness and evolutionary potential. *In* Conservation biology: an evolutionary-ecological perspective. Edited by M.E. Soule and B.A. Wilcox. Sinauer Associates, Sunderland, Massachusetts. p. 151-169.

Stephenson, S.A. 2003. Local and scientific observations of Dolly Varden (*Salvelinus malma*) (W.) in the Big Fish River, Northwest Territories, Canada: 1995-2002. Can. Manuscr. Rep. Fish. Aquat. Sci. 2644. 20 p.

Tallmon, D.A., Koyuk, A., Luikart, G., and Beaumont, M.A. 2008. ONESAMP: a program to estimate effective population size using approximate Bayesian computation. Mol. Ecol. Resour. 8: 299-301.

Templeton, A.R. 1994. Biodiversity at the molecular genetic level: experiences from disparate macroorganisms. Philos. Trans. R. Soc. Lond. B Biol. Sci. 345: 59-64.

Tiffan, K.F., Rondorf, D.W., and Skalicky, J.J. 2004. Imaging fall Chinook salmon redds in the Columbia River with a Dual-Frequency Identification Sonar. N. Am. J. Fish. Manag. 24: 1421-1426.

Utter, F., and Ryman, N. 1993. Genetic markers and mixed stock fisheries. Fisheries 18: 11-21.

Wang, J. 2001. A pseudo-likelihood method for estimating effective population size from temporally spaced samples. Genet. Res. 78: 243-257.

Waples, R.S., and Do, C. 2008. LDNE: a program for estimating effective population size from data on linkage disequilibrium. Mol. Ecol. Resour. 8: 753-756.

Table 1. Calculations of the Petersen model used to estimate the population abundance and 95% confidence intervals (C.I.) (Poisson distribution) of Dolly Varden from the Big Fish River in 2009 and 2010 for fish ≥minimum size tagged and ≥365 mm.

	2009		2010		
Minimum fork length (mm) of tagged Dolly Varden included in recapture sample	310	365	320	365	
Estimated length (mm) of the smallest tagged fish the following year rounded to nearest 5 mm	395	430	395	430	
Recapture year	2010	2010	2011	2011	
Total catch > minimum size examined in recapture year	390	347	397	310	C
Number of tags observed in recaptured	24	24	24	24	R
Number of tags applied	310	302	395	378	
Estimated annual tag loss rate (%)	8	8	8	8	
Reported previous year tags captured in subsistence fishery	2	2	0	0	
Number of tags available for recapture	283	276	363	348	M
Abundance estimate	4,441	3,855	5,794	4,341	N
Lower 95% C.I.	3,182	2,758	4,127	3,084	
Upper 95% C.I.	7,496	6,497	9,723	7,265	
Percent of population tagged > minimum size	7.0	7.8	6.8	8.7	
Percent of tags observed in recaptured	8.5	8.7	6.6	6.9	

Table 2. Population abundance estimates of Dolly Varden from the Big Fish River obtained using a dual frequency identification sonar (DIDSON) camera deployed between August 5 and September 13, 2010.

	Directional movements		Total
	Upstream	Downstream	
Count of immeasurable fish	66	8	58
Count of measured fish	1,686	36	1,650
Total count	1,752	44	1,708
9.4% grayling/ other species subtracted from total count*	1,679	41	1,638
Count of fish ≥280 mm in length. These would be considered as the anadromous component of the population	1,526	34	1,492
9.4% grayling/ other species subtracted from count of fish ≥280 mm in length‡	1,477	33	1,444
Count of fish ≥365 mm in length	1,293	24	1,269
9.4% grayling/ other species subtracted from count of fish ≥365 mm in length†	1,266	23	1,243
Count of fish ≥400 mm in length	1,004	18	986

* Total count adjustment for 9.4% Arctic grayling/other species:
Immeasurable fish moving upstream: 66 - 9.4% = 57
Immeasurable fish moving downstream: 8 - 9.4% = 7
Measured fish moving upstream: 682 - 9.4% = 618 Dolly Varden <400 mm + 1,004 Dolly Varden ≥400 mm = 1,622
Measured fish moving downstream: 18 - 9.4% = 16 Dolly Varden <400 mm + 18 Dolly Varden ≥400 mm = 34

‡ ≥280 mm adjustment for 9.4% Arctic grayling/other species:
Upstream: 522 - 9.4% = 473 Dolly Varden between 280 and 399 mm + 1,004 ≥400 mm = 1,477
Downstream: 16 - 9.4% = 15 Dolly Varden between 280 and 399 mm + 18 ≥400 mm = 33

† ≥365 mm adjustment for 9.4% Arctic grayling/other species:
Upstream: 289 - 9.4% = 262 Dolly Varden between 365 and 399 mm + 1,004 ≥400 mm = 1,266
Downstream: 6 - 9.4% = 5 Dolly Varden between 320 and 399 mm + 18 ≥400 mm = 23

Immeasurable fish (n = 58) are not incorporated in the tabulation of fish above size thresholds because it is impossible to determine if they are above or below the threshold, therefore all estimates of counts above a certain size are ± 58.

Table 3. Median and mean fork length (± 1 standard deviation) and sample size (n) of Big Fish River Dolly Varden identified as non-spawners, female spawners and male spawners captured at the spawning and overwintering area using a seine net in late September between 2009 and 2011.

Year		Non-spawner	Female spawner	Male spawner	Total
2011	Median	420	455	525	455
	Mean	412 ± 57	463 ± 47	521 ± 63	460 ± 65
	n=	124	229	88	441
2010	Median	420	480	525	480
	Mean	431 ± 59	479 ± 47	524 ± 53	477 ± 60
	n=	96	239	86	421
2009	Median	410	460	507	440
	Mean	417 ± 44	457 ± 42	509 ± 48	448 ± 53
	n=	125	142	40	307

Table 4. Counts of reproductive condition of tagged female, male and sex-unknown Dolly Varden from the Big Fish River recaptured one and two years later.

Year tagged/ year recaptured	Sex	Reproductive condition (capture → recapture)		
		non-spawner →non-spawner	non-spawner → spawner	spawner →spawner
2009/2010	Female	-	6	11
	Male	-	0	5
	Unknown	2	-	-
2009/2011	Female	-	2	9
	Male	-	4	2
	Unknown	0	-	-
2010/2011	Female	-	2	11
	Male	-	4*	9
	Unknown	1	-	-

*Length information from one sample was not used because length at recapture was shorter than length at tagging.

Table 5. Percent (frequency in brackets) of live-sampled Dolly Varden from the Big Fish River identified as non-spawners, female spawners and male spawners captured at the spawning and overwintering area using a seine net in late September between 2009 and 2011. The ratio of female:male spawners, and proportion of spawners are calculated, and the number of resident life history type Dolly is provided.

Year	Non-spawner	Female spawner	Male spawner	Total n=	F:M spawner	% Spawner	Resident Dolly Varden
2011	28.1 (124)	51.9 (229)	20.0 (88)	441	2.6:1	71.9	4
2010	22.7 (96)	56.9 (240)	20.4 (86)	422	2.8:1	77.7	35
2009	40.7 (125)	46.3 (142)	13.0 (40)	307	3.6:1	59.3	27

Table 6. Harvest statistics for Dolly Varden from multiple locations along the Beaufort Sea coast in the Yukon 2009-2011.

	Herschel Island	Ptarmigan Bay	Phillips Bay	King Point	Shingle Point	Total
2011	129	93	0	43	193	458
2010	256	-	-	-	252*	508
2009	80	6*	2*	-	307*	395

* = reported harvest values.
- = unreported harvest and/or not known to have been fished.

Table 7. Estimated number of eggs produced by Dolly Varden from the Big Fish River in 2009 and 2010 among various size intervals.

Length interval	**Fecundity**	**% females in 2009**	**% females in 2010**	**Number of females**			**Number of eggs produced**		
				Petersen estimate		**Bailey's estimate**	**Petersen estimate**		**Bailey's estimate**
				2009	**2010**	**2010**	**2009**	**2010**	**2009**
362.5	1,333	2.1	1.3	38	32	29	51,037	43,044	38,969
387.5	1,656	6.3	1.7	115	43	39	190,202	71,296	64,546
412.5	1,979	11.3	6.3	204	161	146	404,078	319,498	289,248
437.5	2,302	19.7	12.6	357	323	292	822,534	743,272	672,900
462.5	2,625	28.2	26.9	510	689	624	1,339,901	1,808,105	1,636,916
487.5	2,948	16.2	18.5	293	473	429	865,234	1,396,012	1,263,840
512.5	3,271	10.6	16.4	191	420	380	626,103	1,372,935	1,242,947
537.5	3,594	4.2	10.1	77	258	234	275,169	928,304	840,414
562.5	3,917	1.4	3.4	26	86	78	99,966	337,242	305,312
587.5	4,240		1.7	0	43	39	0	182,525	165,243
612.5	4,563		0.4	0	11	10	0	49,107	44,458
662.5	5,209		0.4	0	11	10	0	56,059	50,751
687.5	5,532		0.4	0	11	10	0	59,535	53,898
Total				**1,812**	**2,561**	**2,319**	**4,674,223**	**7,366,934**	**6,669,442**

2009 Petersen population estimate for Dolly Varden ≥365 mm= 3,855, proportion of females spawners= 47%, approximate number of females= 1,812

2010 Petersen population estimate for Dolly Varden ≥365 mm= 4,341, proportion of females spawners= 59%, approximate number of females= 2,561

2010 Bailey's triple capture population estimate for Dolly Varden ≥365 mm= 3,930, proportion of females spawners= 59%, approximate number of females= 2,319

Fecundity= -3,350.20 + 12.29 x fork length (mm)

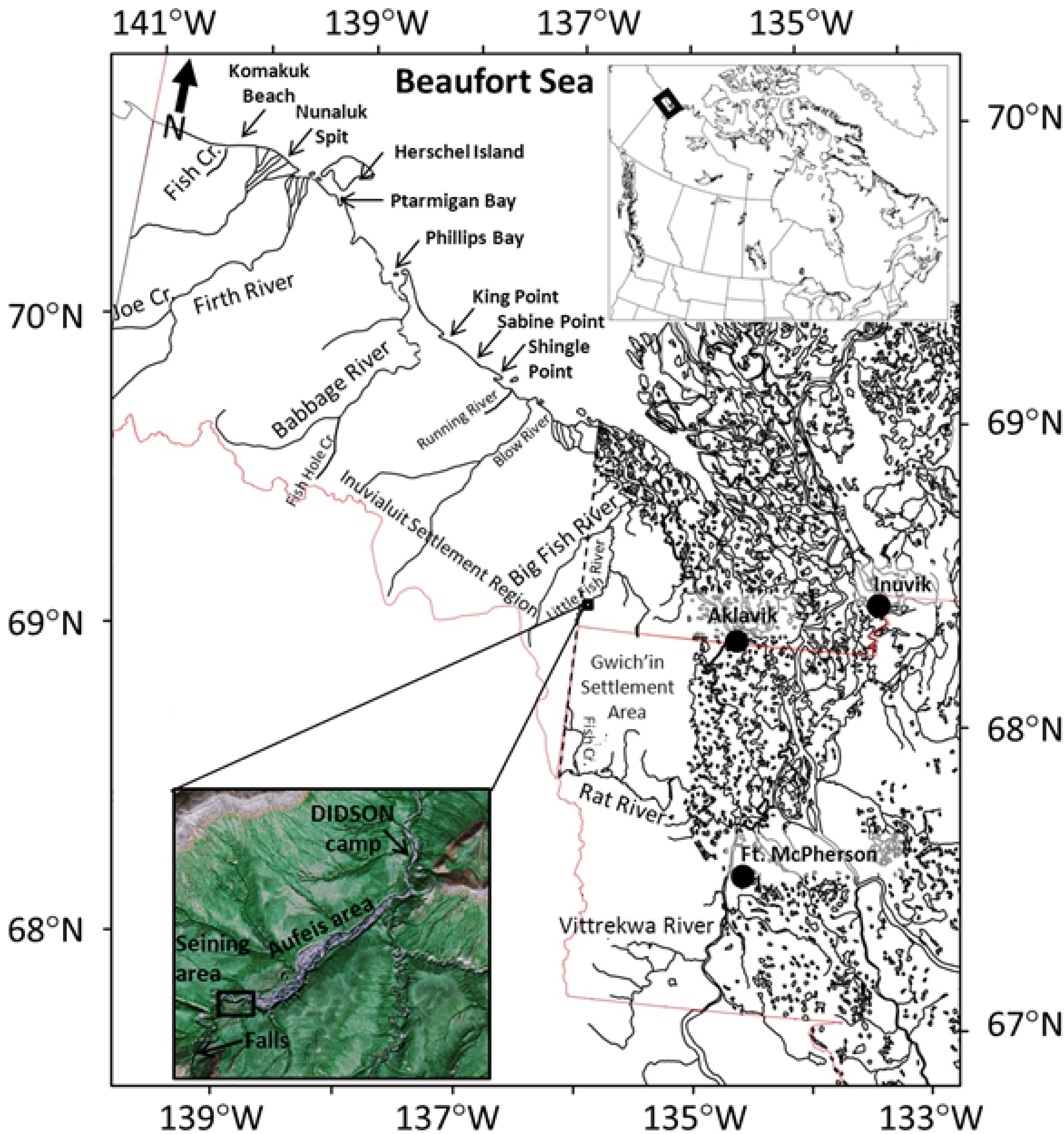

Figure 1. Location of rivers and creeks in the Inuvialuit Settlement Region and Gwich'in Settlement Area (red lines delineate borders) known to have anadromous Dolly Varden and locations along the Beaufort Sea coast where harvesting of Dolly Varden occur. Insert on lower left is a satellite image (Google Earth) of the spawning and overwintering area of the Big Fish River stock in Little Fish River showing the location of the aufeis area, DIDSON camp in 2010 and seining area. * Fish Cr., Joe Cr., Firth R., Babbage R., Big Fish R., Rat R. and Vittrekwa R.*

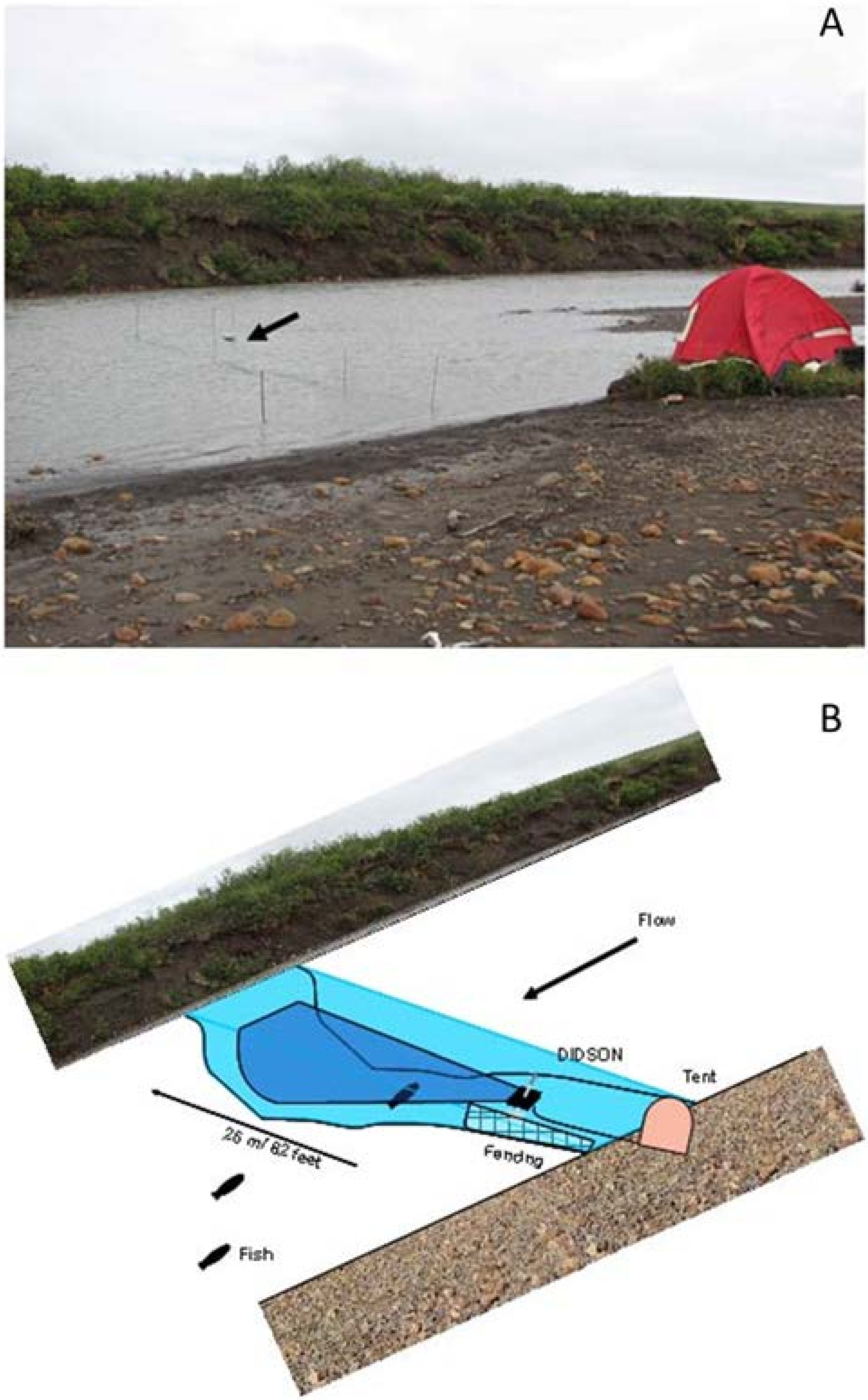

Figure 2. A) Image of DIDSON setup showing submerged camera (arrow), fencing and tent, and B) schematic showing direction of flow and the area that is insonified by the camera to detect fish passage. Note: image was taken in August 2009 while testing the camera on lower reach of the Little Fish River.

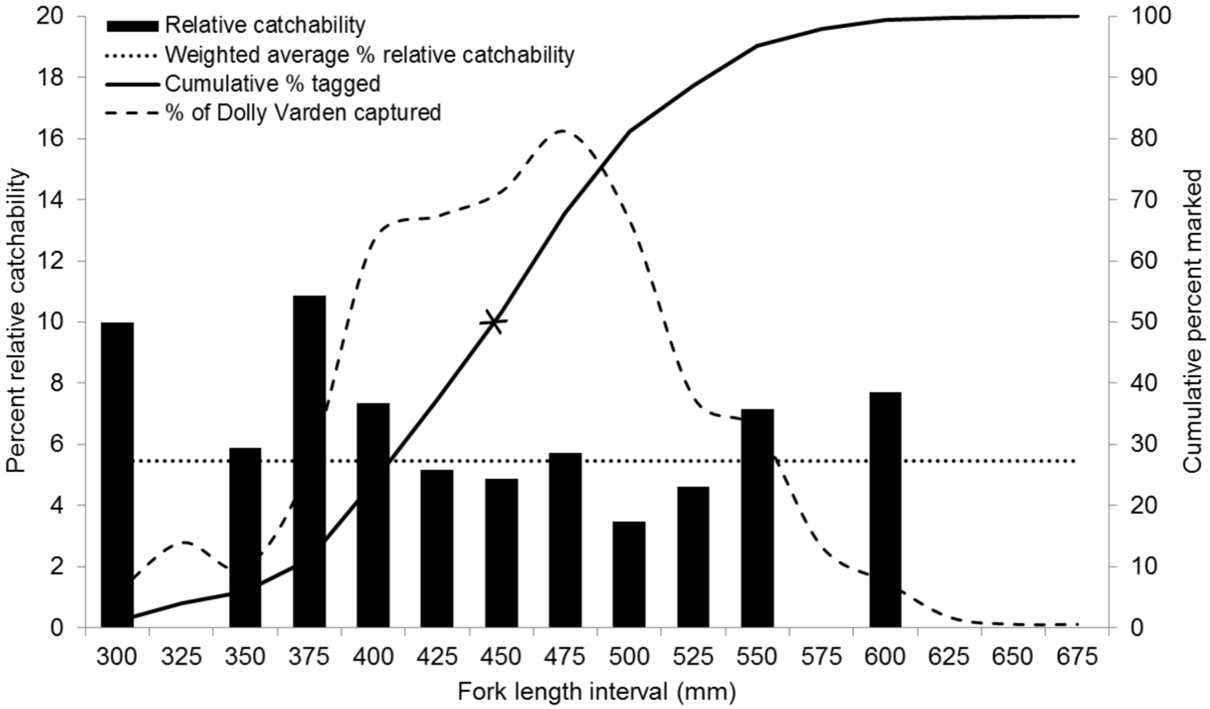

Figure 3. Percent relative catchability of recaptured Dolly Varden in 2010 and 2011 among size classes. The length frequency distribution of the 2010 and 2011 combined sample (% captured) is read using the same scale as percent relative catchability. The 50% cumulative percent marked with a tag is indicated by the X.

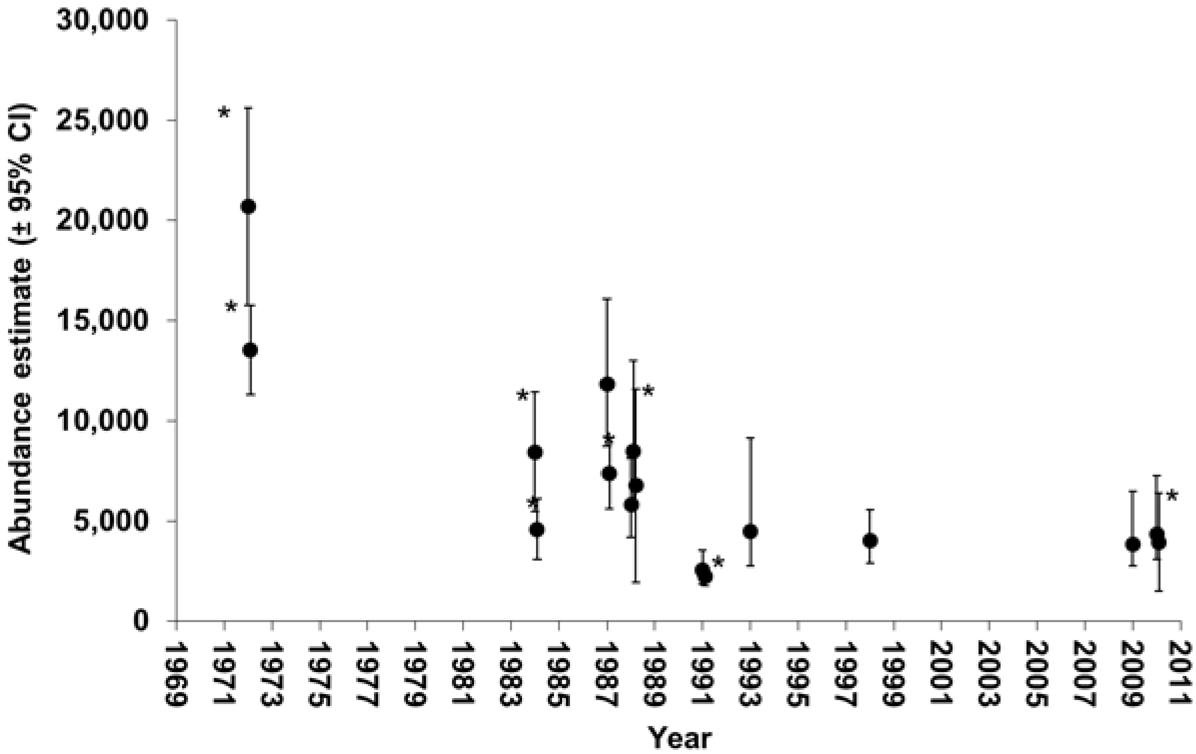

Figure 4. Population abundances of Dolly Varden from the Big Fish River among years estimated periodically between 1972 and 2010. The 95% confidence intervals were calculated based on the probability of recapture following a Poisson distribution unless recaptures were >50 in which case the intervals were calculated based on the normal distribution (∗).The confidence intervals for the Bailey's triple catch estimate for 1988 and 2010 assumed a normal distribution. Data prior to 2009 were found in Kristofferson and Baker (1988), MacDonell (1987), Sandstrom and Harwood (2002), Fehr and Archie (1989), and Stephenson (2003).

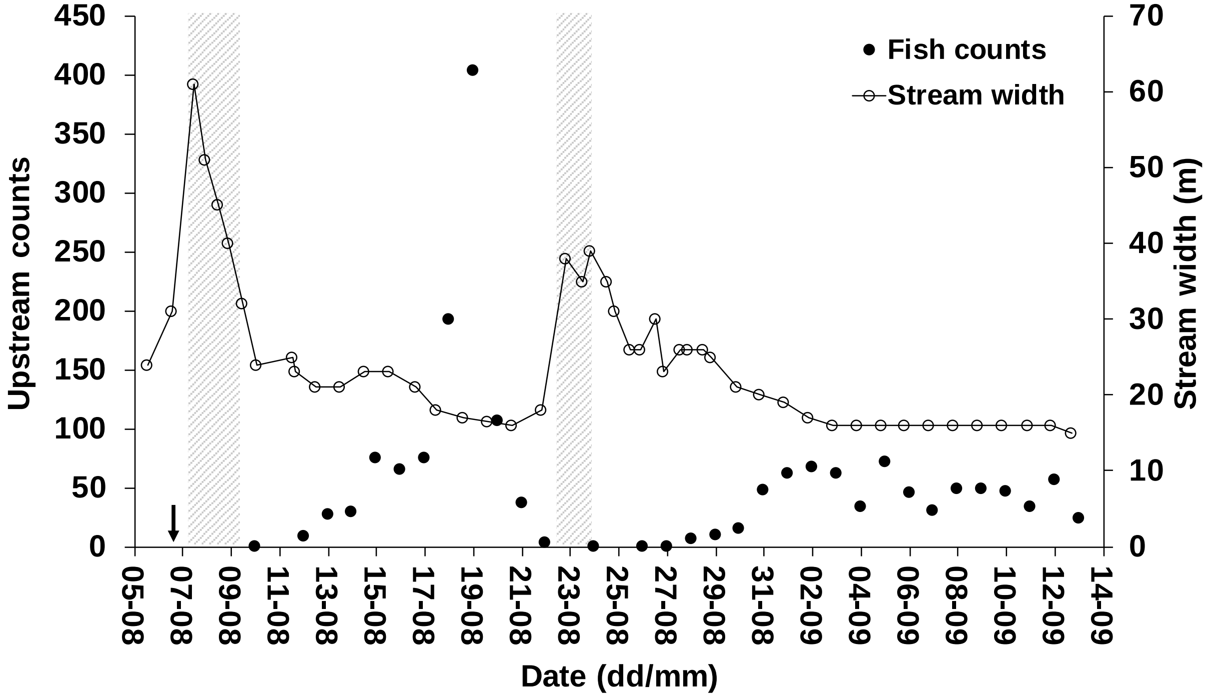

Figure 5. Daily number of fish enumerated moving upstream in the Little Fish River using the DIDSON camera and measurement of stream width. Arrow is the deployment date of the DIDSON and the shaded areas denotes periods of time when the camera was not operating.

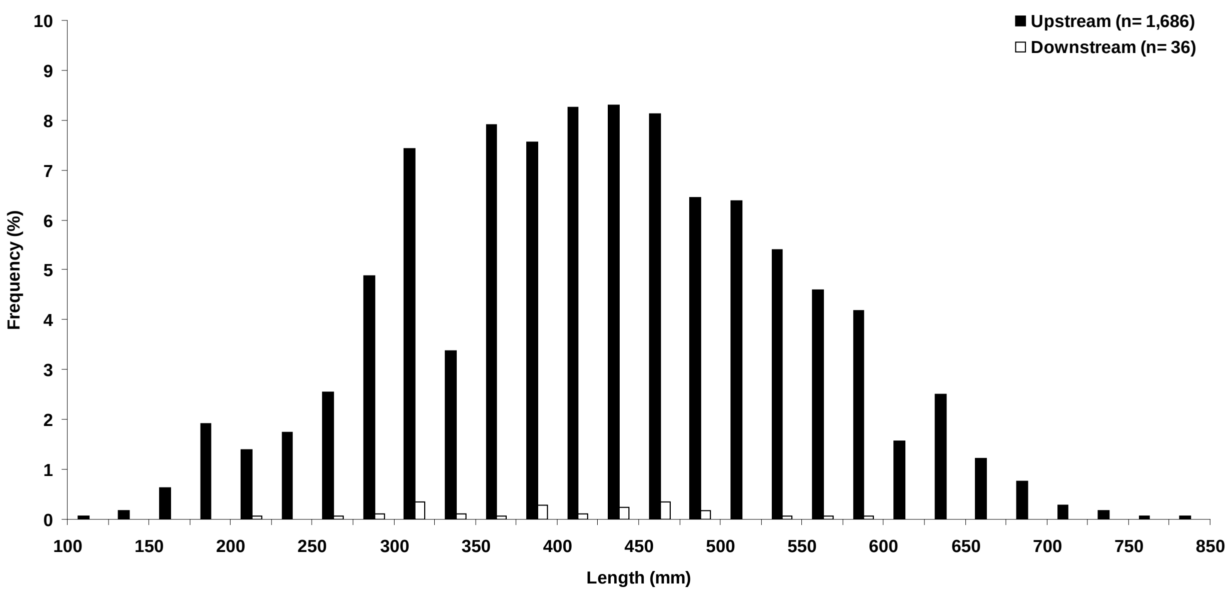

Figure 6. Length frequency distribution of fish moving upstream and downstream in Little Fish River observed with the DIDSON camera.

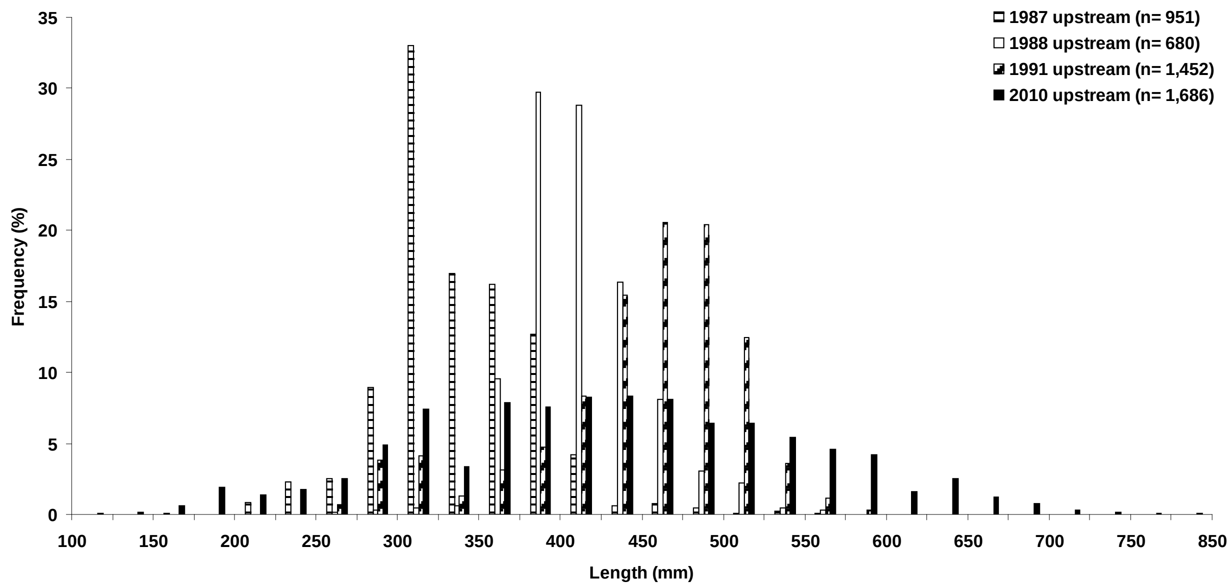

Figure 7. Length frequency distribution of Dolly Varden captured using a weir in 1987, 1988 and 1991, and observed using a DIDSON in 2010.

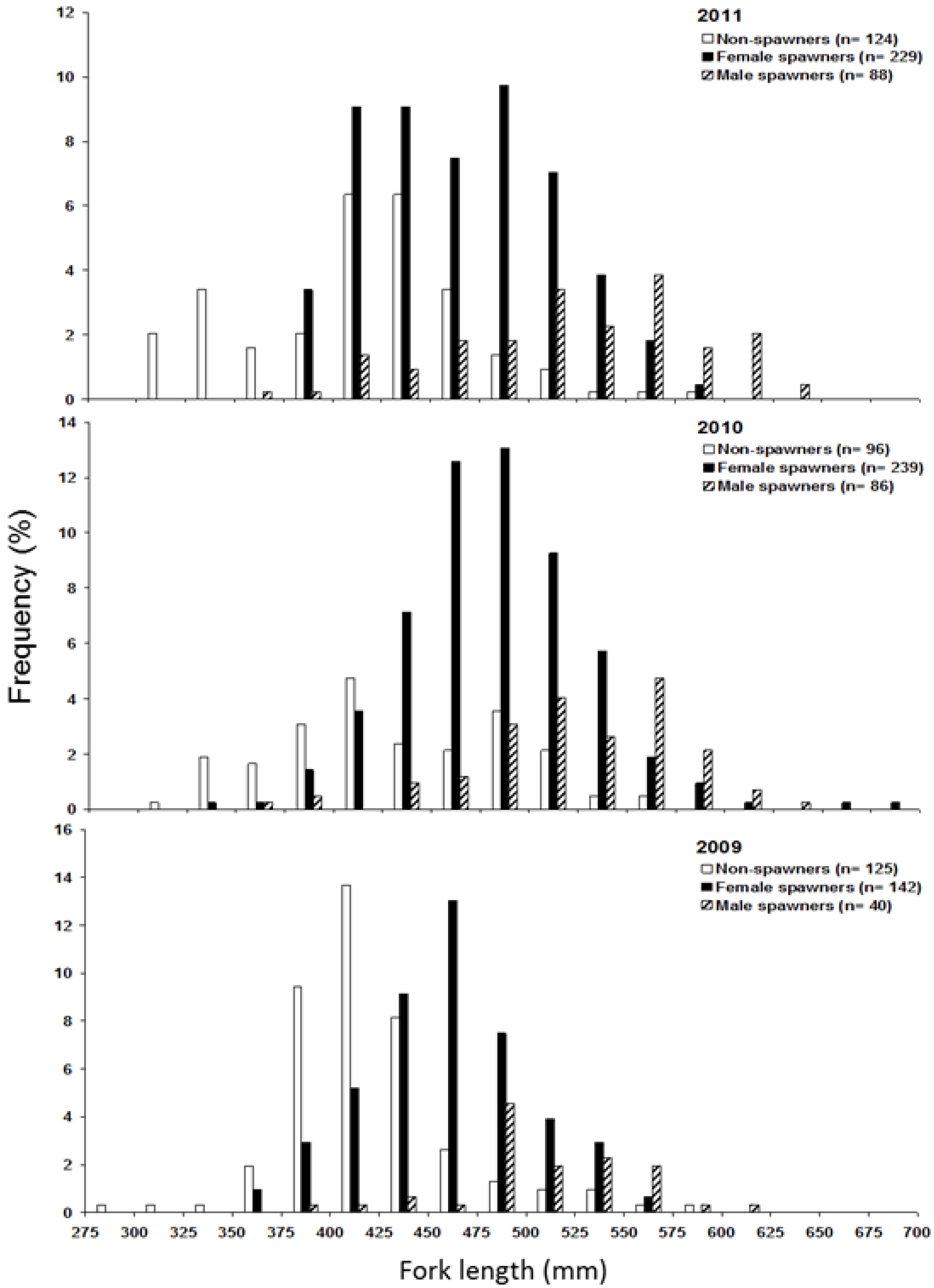

Figure 8. Length frequency distribution of Dolly Varden from the Big Fish River seined at the spawning and overwintering area in 2009, 2010 and 2011.

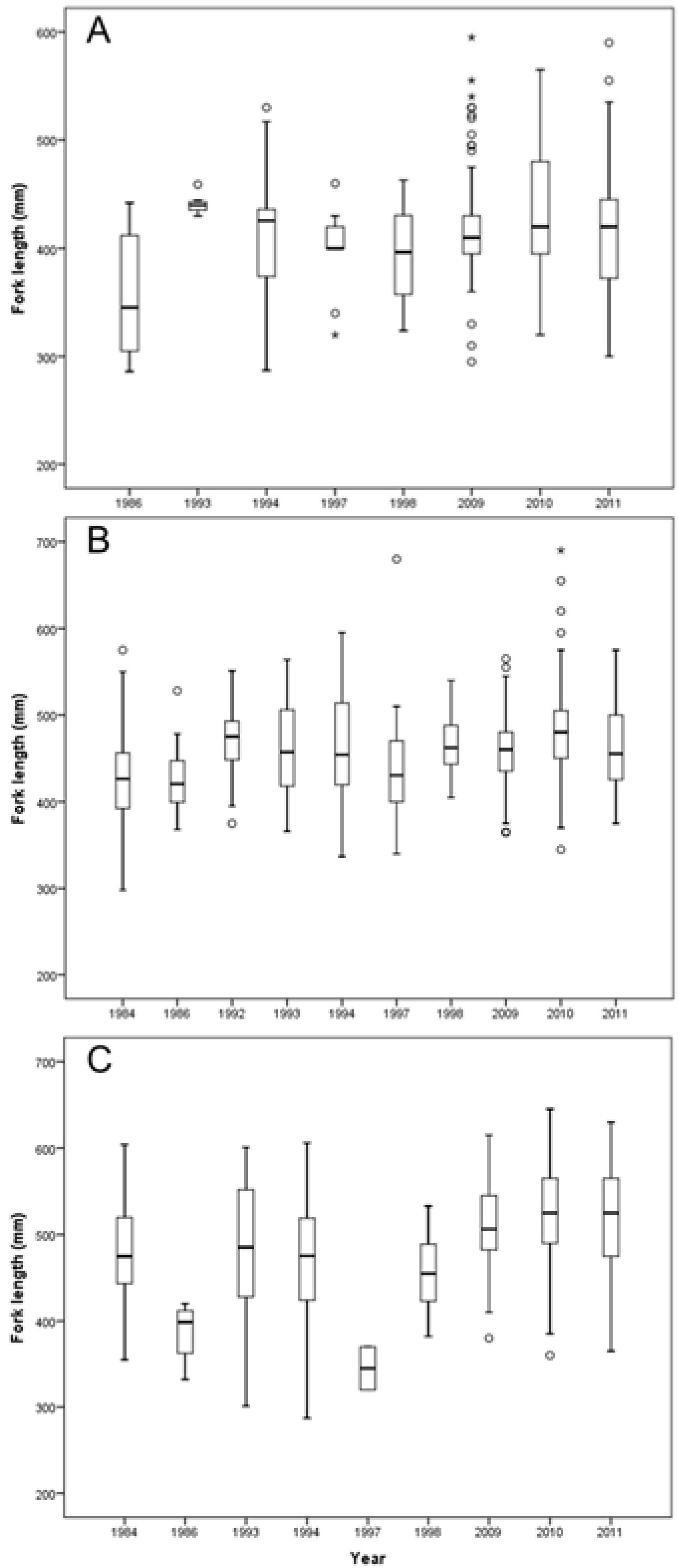

Figure 9. Box plot of length (median, quartiles and outliers (○, ★)) of Dolly Varden from the Big Fish River identified as A) non-spawners, B) female spawners, and C) male spawners seined at the spawning and overwintering area between 1984 and 2011.

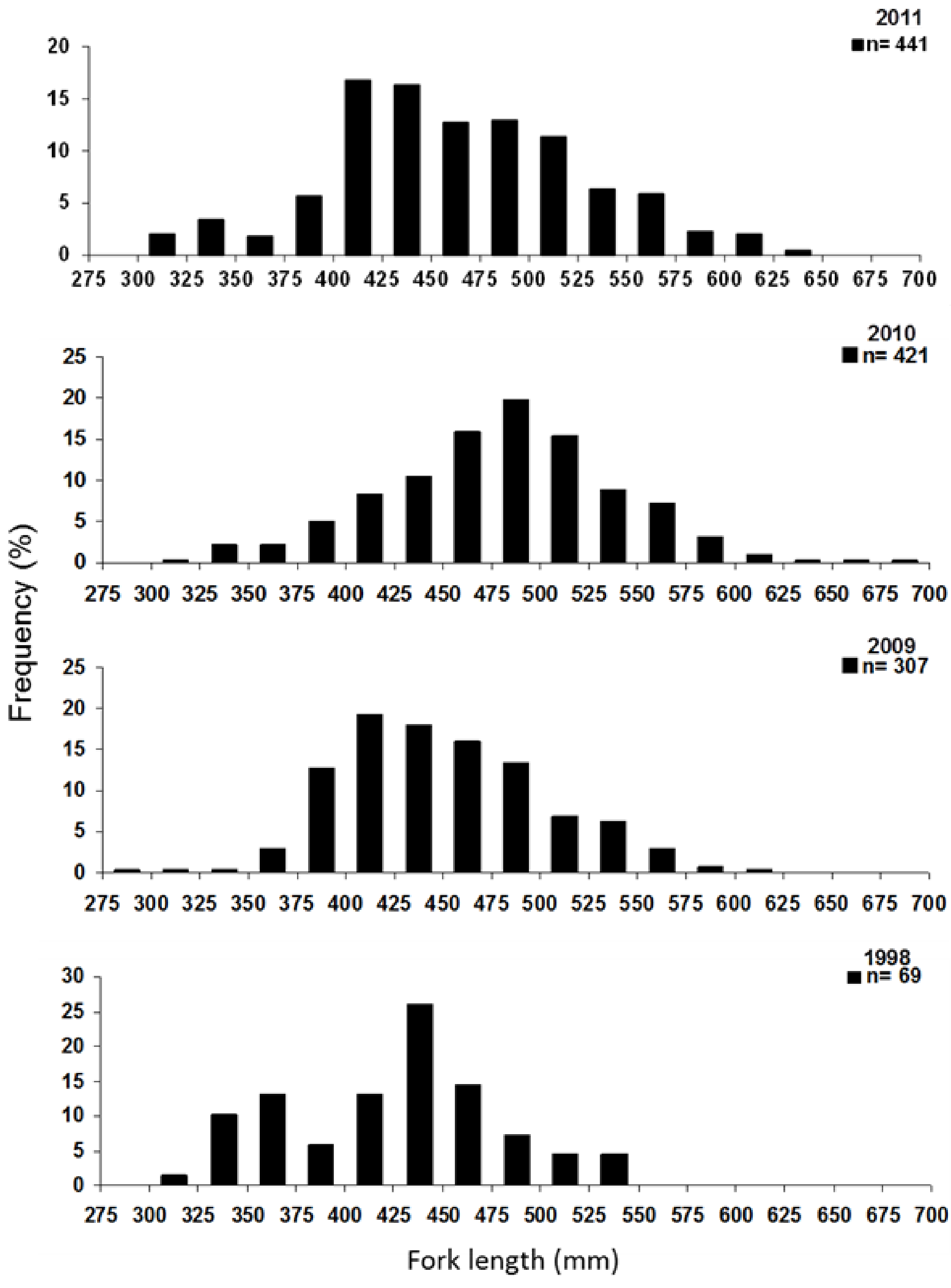

Figure 10. Fork length frequency distribution of the total sample of Dolly Varden from the Big Fish River seined at the spawning/ overwintering area between 2011 and 1972.

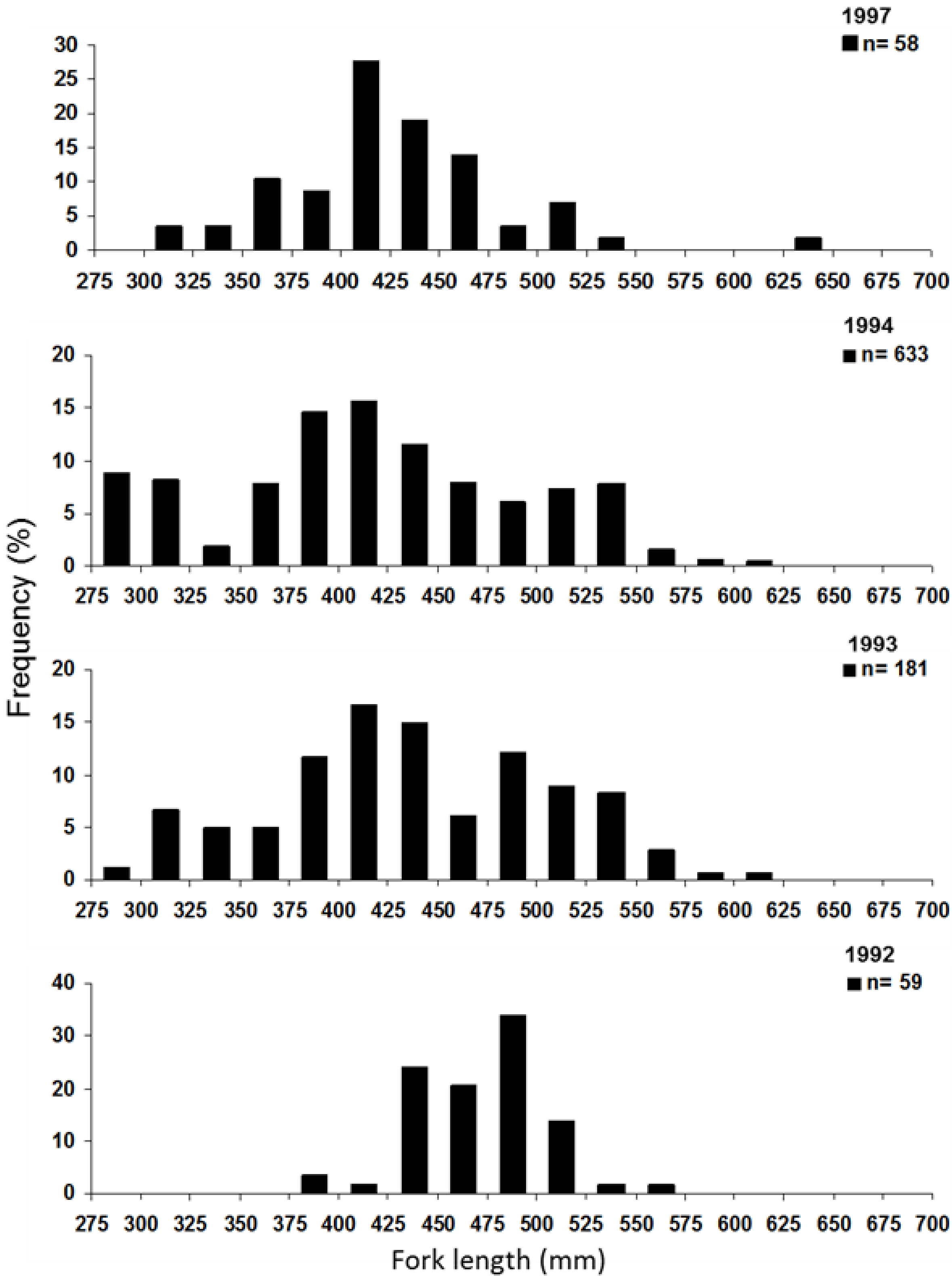

Figure 10. Continued.

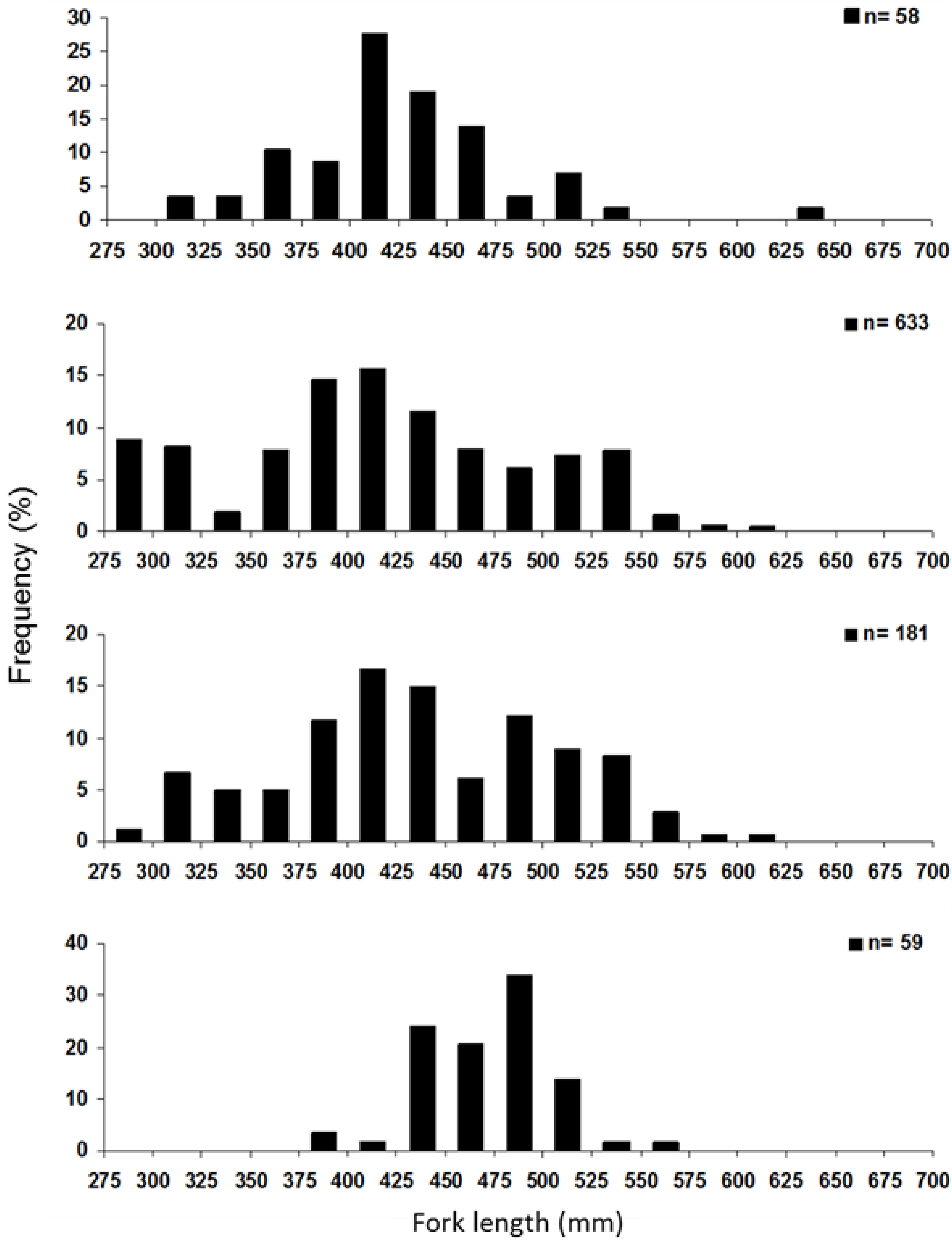

Figure 10. Continued.

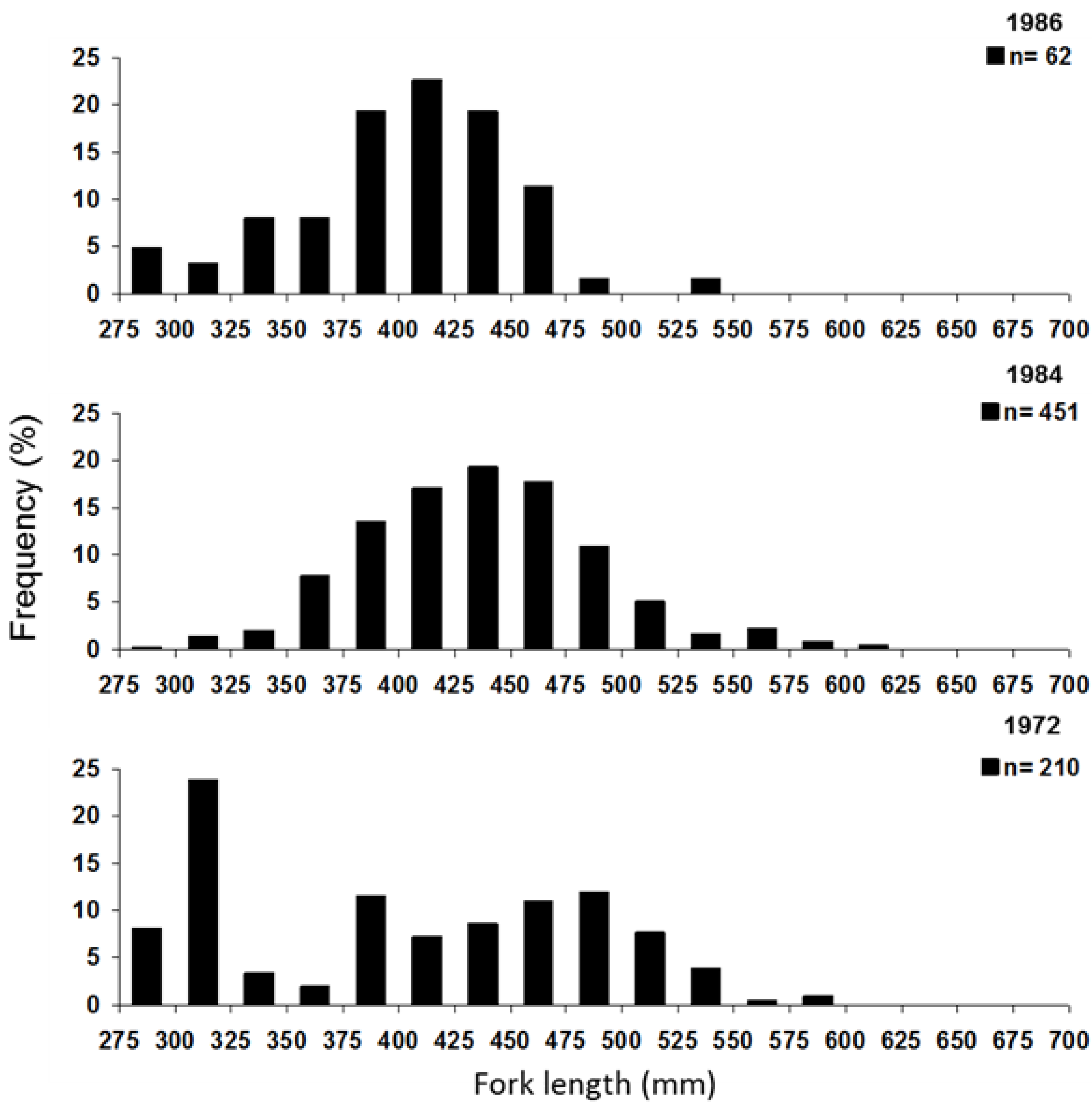

Figure 10. Continued.

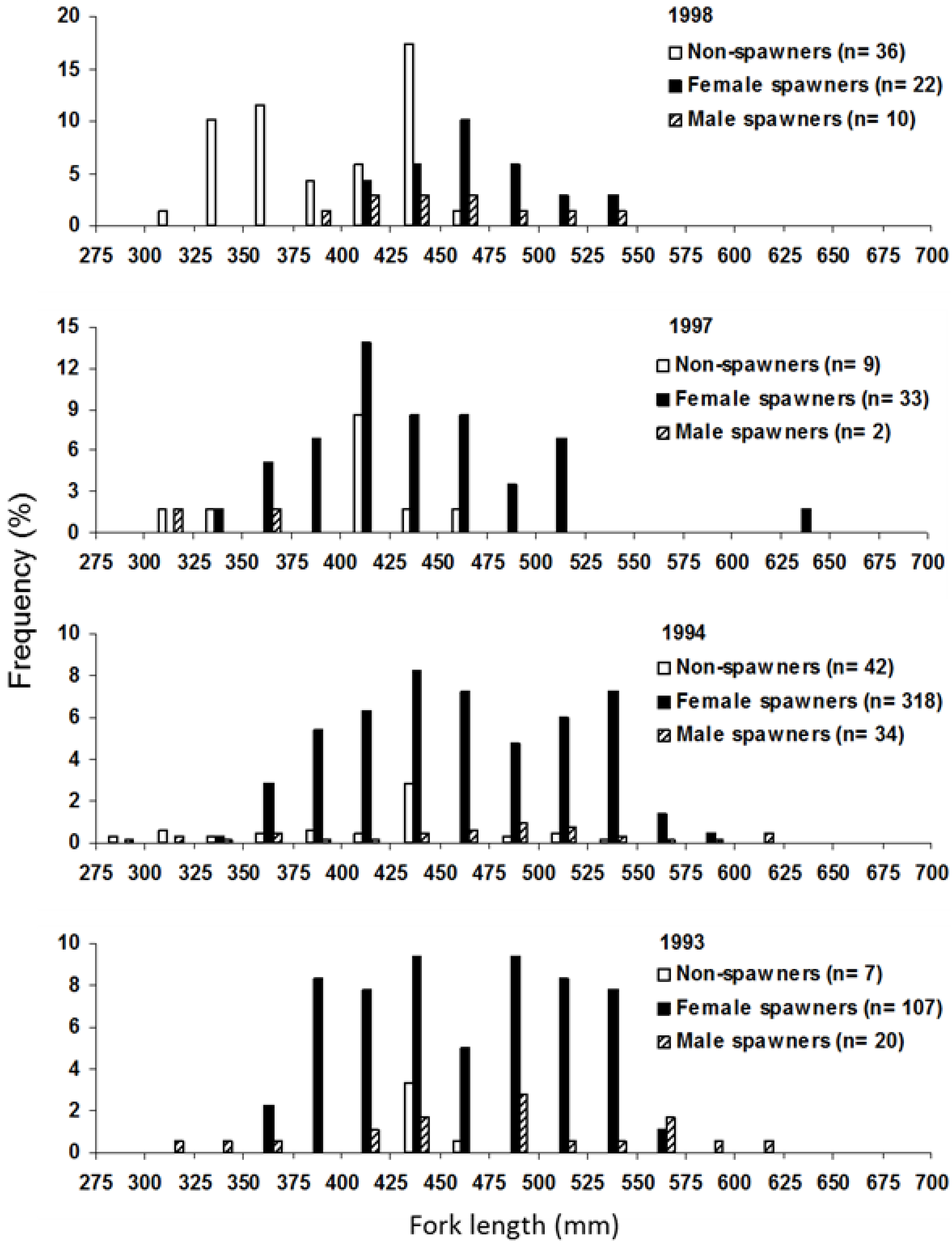

Figure 11. Fork length frequency distribution of Dolly Varden from the Big Fish River identified as non-spawners, female spawners and male spawners seined at the spawning and overwintering area between 1972 and 1998.

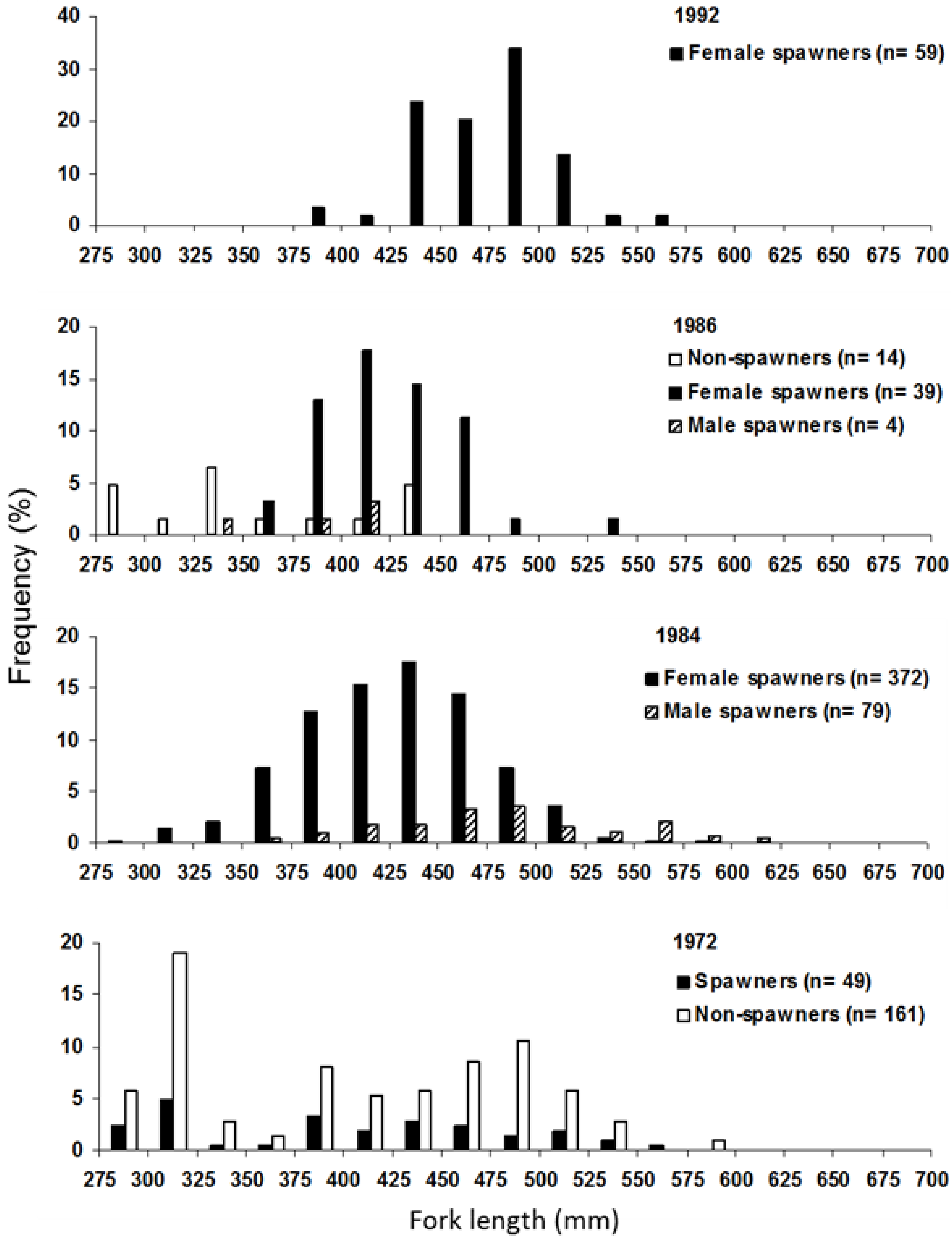

Figure 11. Continued.

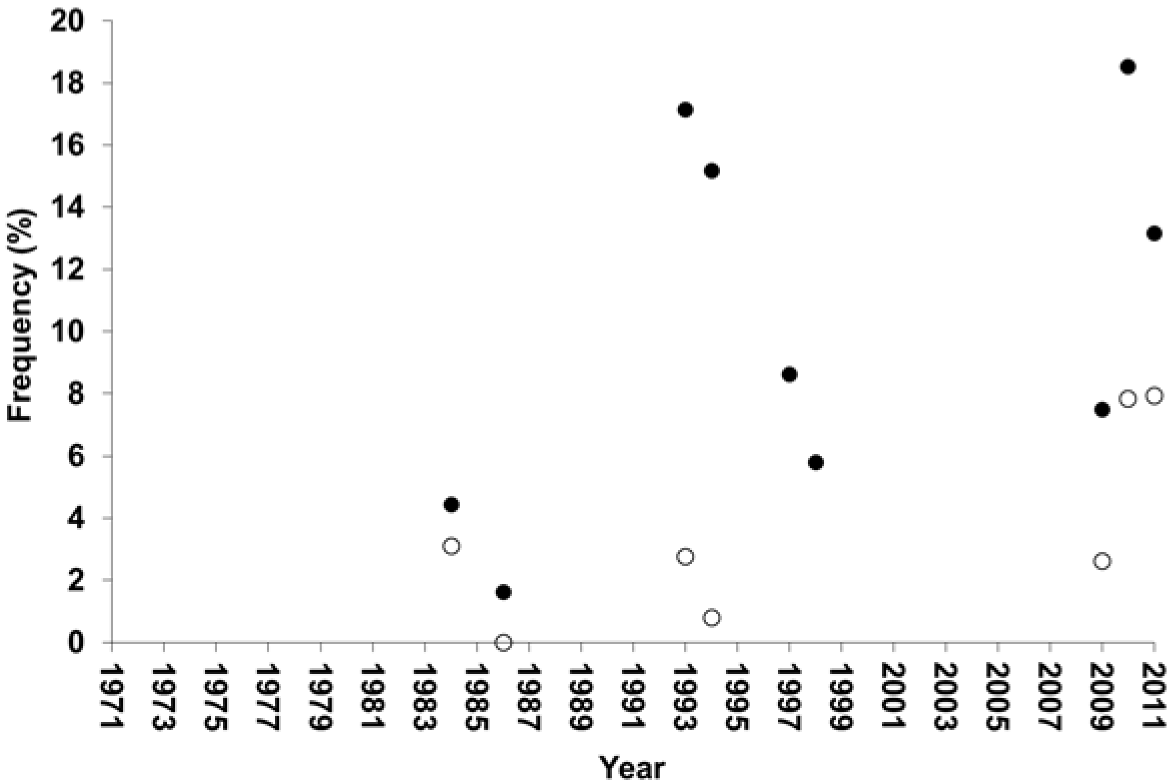

Figure 12. Percent frequency of female (●) and male (○) spawning Dolly Varden from the Big Fish River ≥500 mm (females) and ≥550 mm (males) captured by seine at the spawning and overwintering area periodically between 1972 and 2011. Note that the data for males in 1997 and 1998 are omitted because males were selectively removed from the dead-sample at the sampling site.

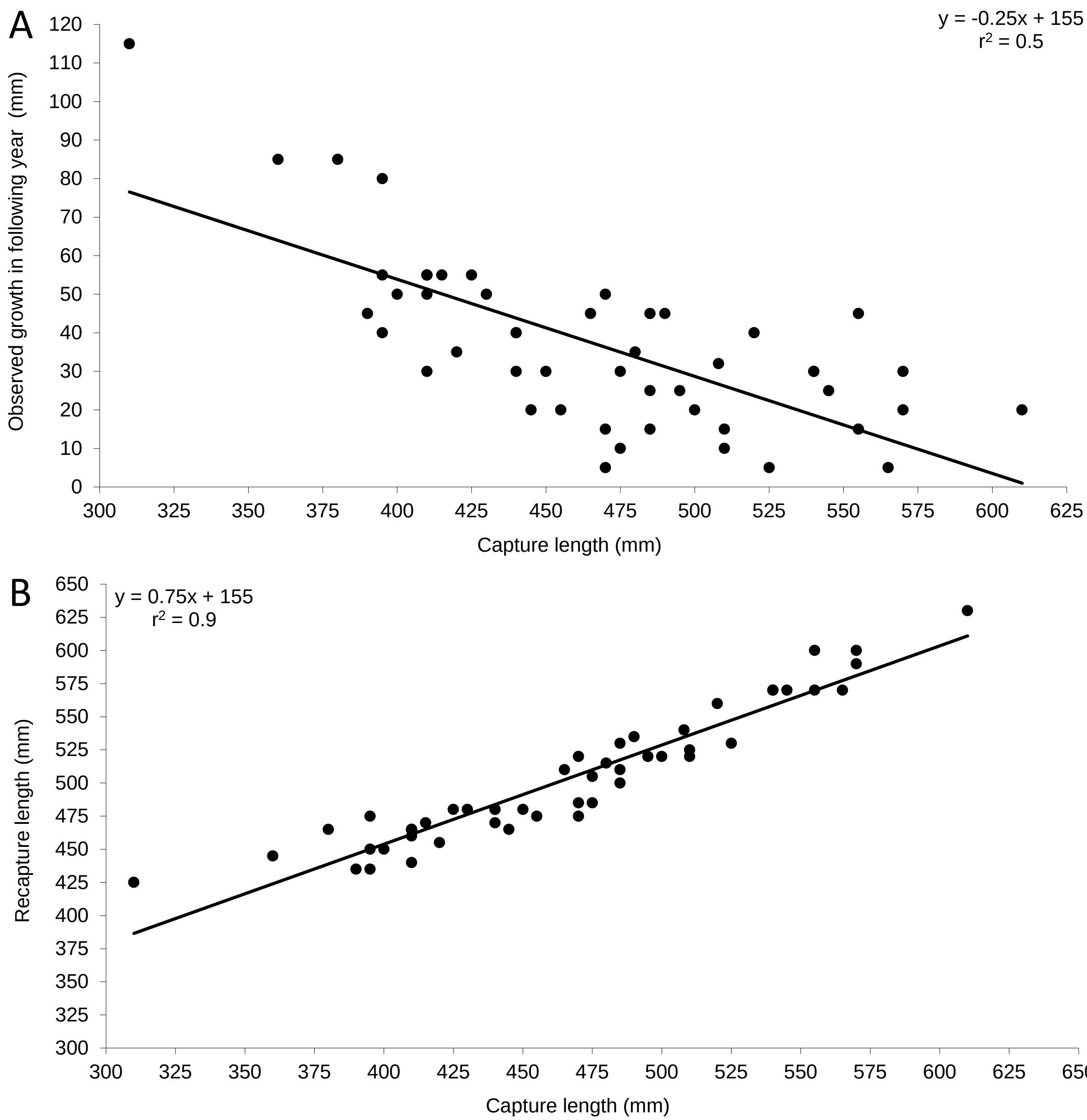

Figure13. (A) Observed annual growth and (B) length at capture and recapture of Dolly Varden from the Big Fish River based on mark and recapture studies between 2009 and 2011.

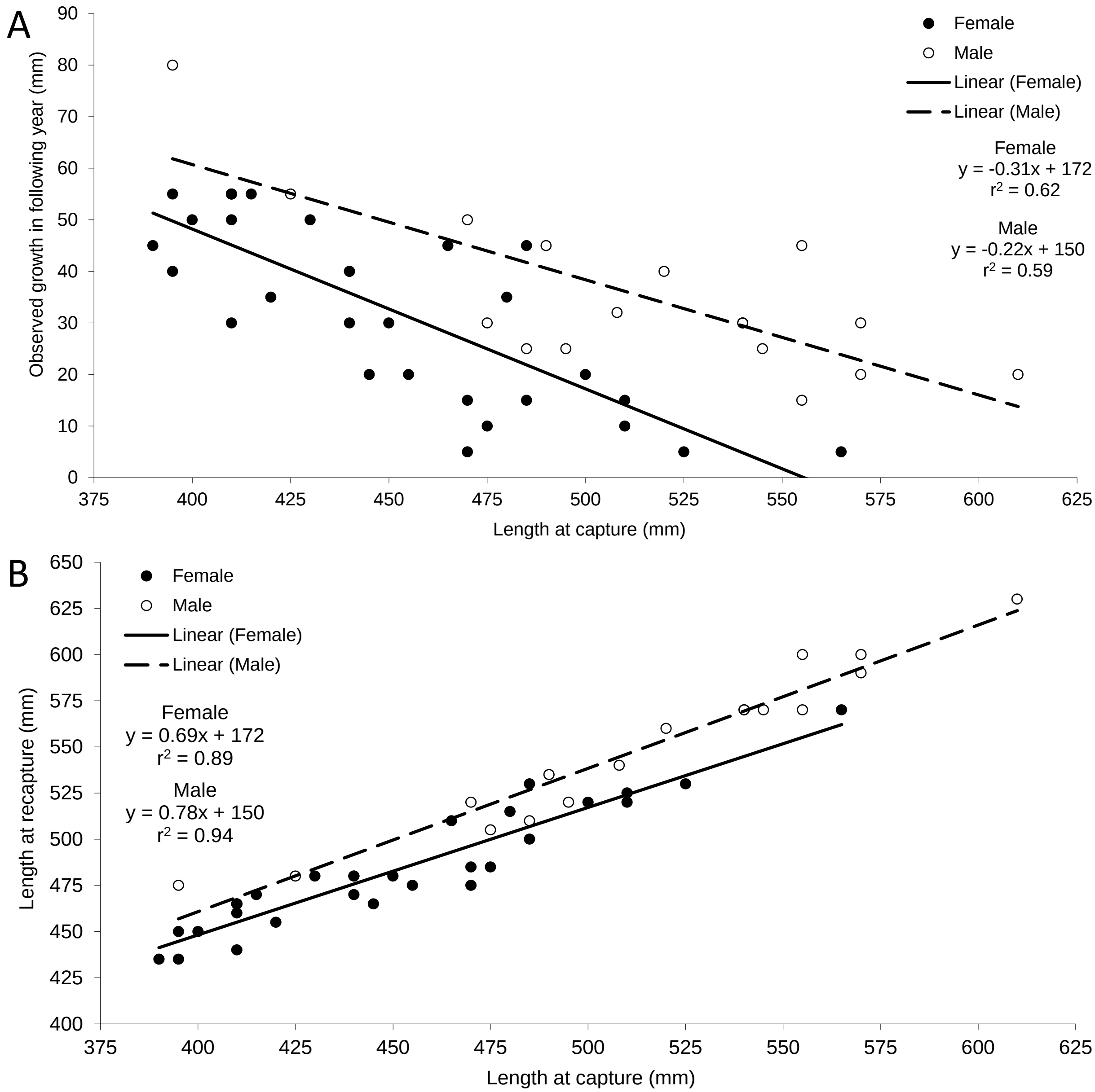

Figure 14. (A) Observed annual growth and (B) length at capture and recapture of sexually immature and mature male and female Dolly Varden from the Big Fish River based on mark and recapture studies between 2009 and 2011.

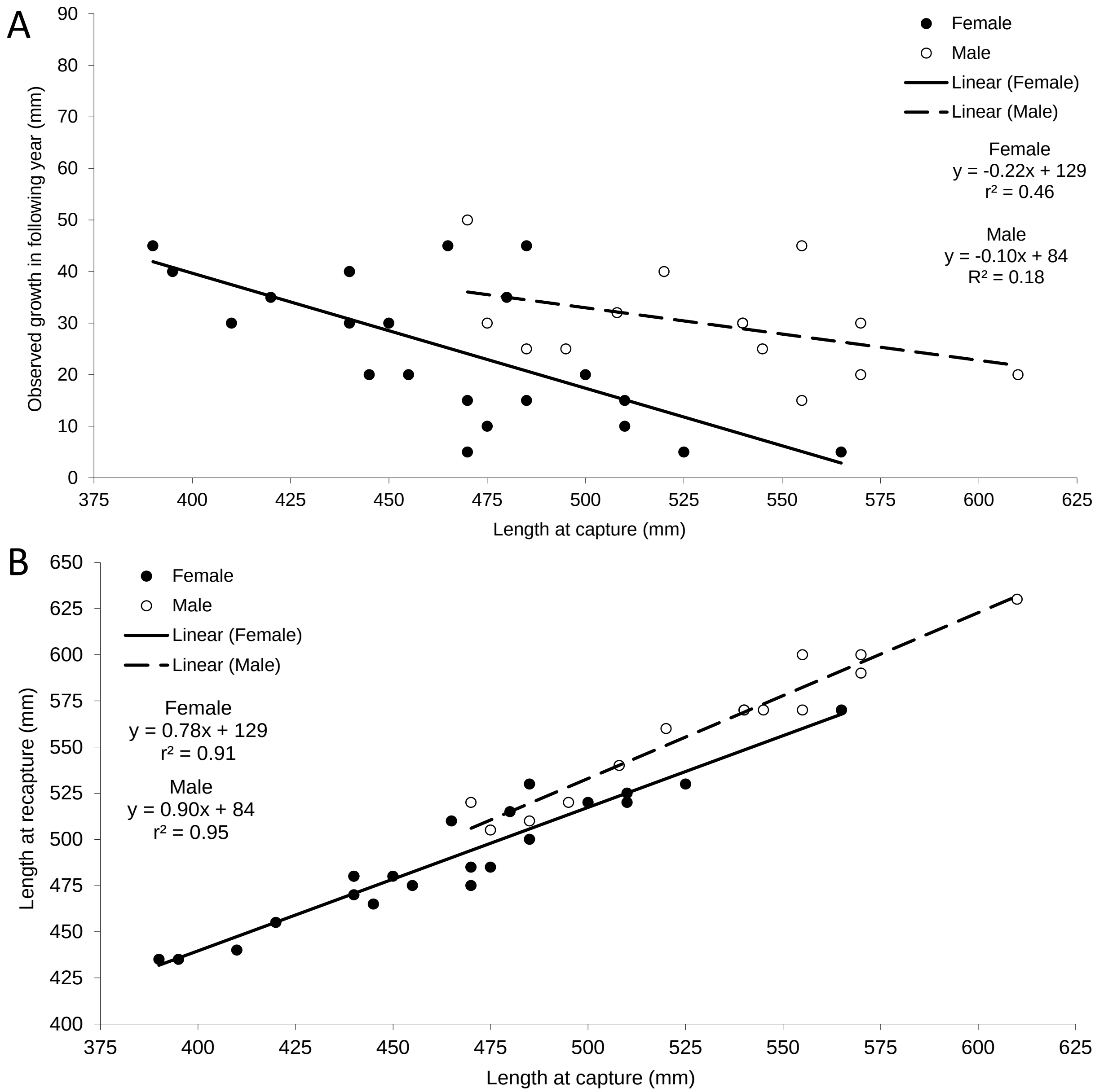

Figure 15. (A) Observed annual growth and (B) length at capture and recapture of sexually mature male and female Dolly Varden from the Big Fish River based on mark and recapture studies between 2009 and 2011.

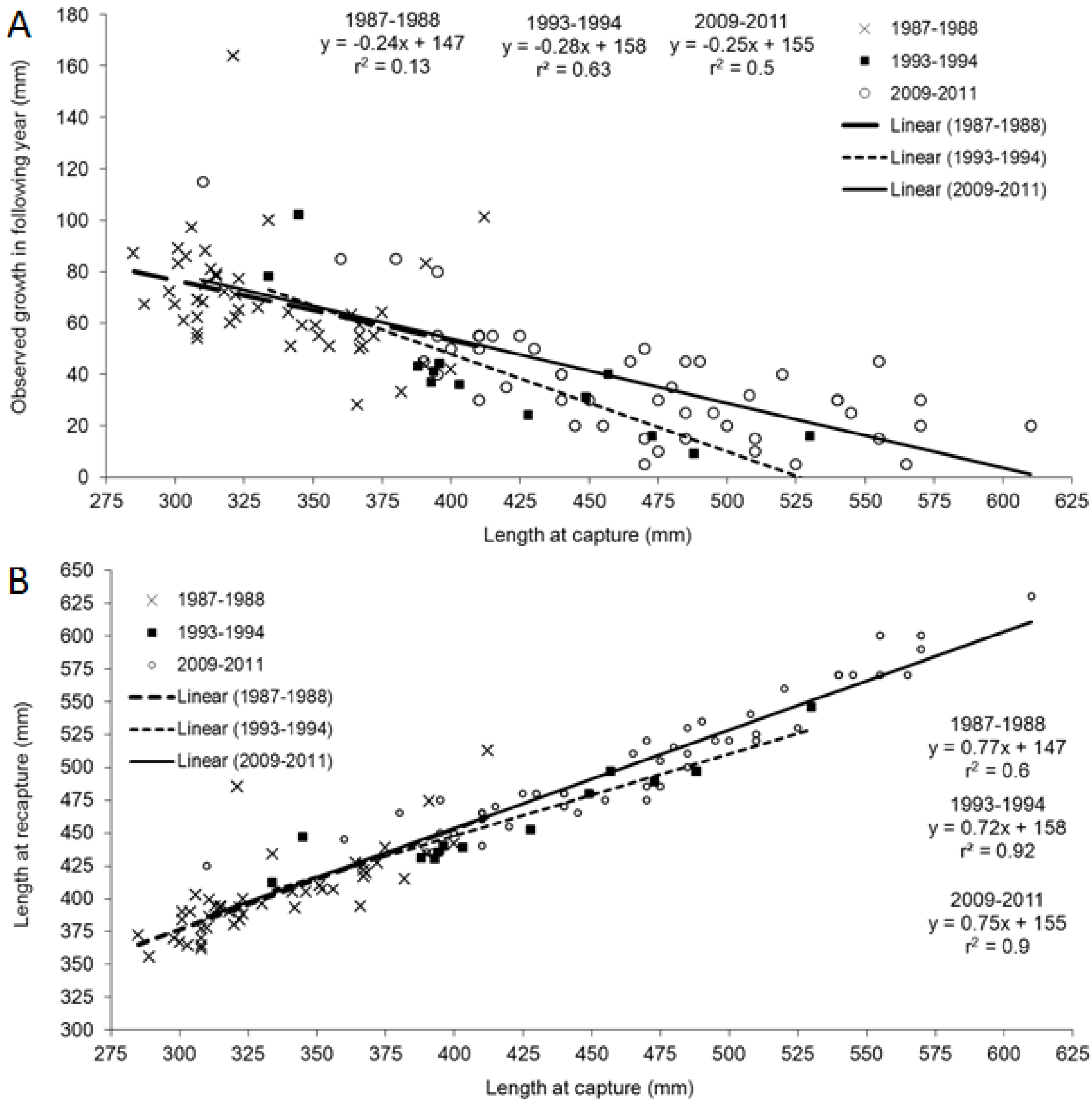

Figure 16. (A) Observed annual growth and B) length at capture and recapture of Dolly Varden from the Big Fish River between 1987-1988, 1993-1994 and 2009-2011 (total samples).

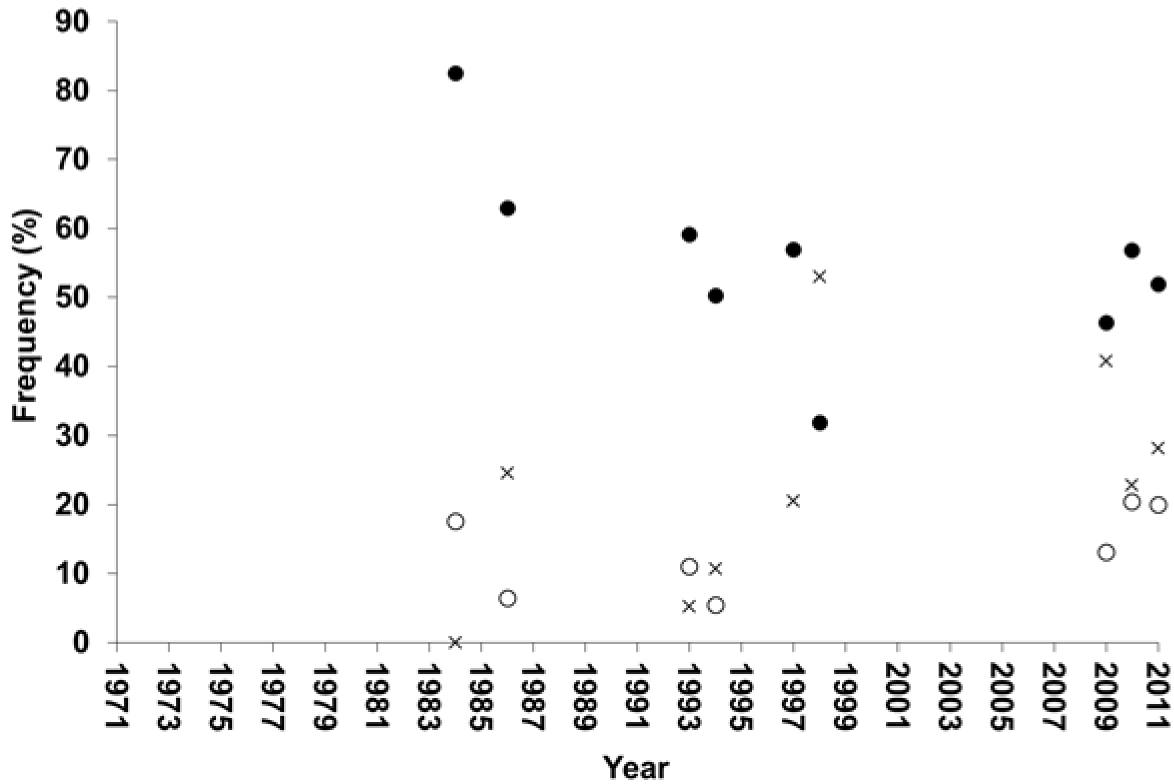

Figure 17. Percent frequency of Dolly Varden identified as non-spawners (X), female spawners (●), and male spawners (○) from the Big Fish River captured by seine at the spawning and overwintering area periodically between 1972 and 2011. Note that the data for males in 1997 and 1998 are omitted because males were selectively removed from the dead-sample at the sampling site.