



Fisheries and Oceans
Canada

Pêches et Océans
Canada

Ecosystems and
Oceans Science

Sciences des écosystèmes
et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2019/062

Central and Arctic Region

Updated stock status of commercially harvested Arctic Char (*Salvelinus alpinus*) from the Jayko and Halokvik rivers, Nunavut: A summary of harvest, catch-effort and biological information

Les N. Harris¹, Christopher L. Cahill², Tyler Jivan¹, Xinhua Zhu¹, Ross F. Tallman¹

¹Fisheries and Oceans Canada
Freshwater Institute
501 University Crescent
Winnipeg, Manitoba, R3T 2N6

²Department of Biological Sciences
University of Calgary
2500 University Dr. NW
Calgary, Alberta, T2N 1N4

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.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

[http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca](http://www.dfo-mpo.gc.ca/csas-sccs/csas-sccs@dfo-mpo.gc.ca)



© Her Majesty the Queen in Right of Canada, 2021
ISSN 1919-5044

Correct citation for this publication:

Harris, L.N., Cahill, C.L., Jivan, T., Zhu, X., and Tallman, R.F. 2021. Updated stock status of commercially harvested Arctic Char (*Salvelinus alpinus*) from the Jayko and Halokvik rivers, Nunavut: A summary of harvest, catch-effort and biological information. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/062. v + 97 p.

Aussi disponible en français :

Harris, L.N., Cahill, C.L., Jivan, T., Zhu, X., et Tallman, R.F. 2021. Mise à jour de l'état du stock d'omble chevalier (Salvelinus alpinus) pêché à des fins commerciales dans les rivières Jayko et Halokvik, au Nunavut : résumé de la récolte, des prises et de l'effort, et de l'information biologique. Secr. can. de consult. sci. du MPO. Doc. de rech. 2019/062. v + 100 p.

TABLE OF CONTENTS

ABSTRACT.....	v
INTRODUCTION	1
ARCTIC CHAR IN THE CAMBRIDGE BAY REGION OF NUNAVUT	1
BREIF OVERVIEW OF MANAGEMENT AND ASSESSMENTS FOR THE CAMBRIDGE BAY CHAR FISHERY	2
OBJECTIVES.....	4
THE JAYKO AND HALOKVIK FISHERIES	4
LIFE HISTORY, MIGRATORY PATTERNS, AND IMPLICATIONS FOR GENETIC STOCK STRUCTURE.....	6
MATERIAL AND METHODS.....	8
HARVEST MONITORING	8
Cambridge Bay Plant Sampling Program and Harvest Reporting.....	8
Nunavut General Monitoring Plan.....	9
FISHERY INDEPENDENT SAMPLING	9
DATA ANALYSIS	10
Catch-Per-Unit-Effort.....	10
Biological Data Analysis	10
RESULTS AND DISCUSSION.....	12
ABUNDANCE AND EXPLOITATION	12
COMMERCIAL HARVEST AND CATCH-EFFORT	13
BIOLOGICAL CHARACTERISTICS	15
Sex ratio and maturity	15
Weight and length	27
Age	52
Growth	56
Condition.....	68
Mortality	68
SOURCES OF UNCERTAINTY AND RESEARCH NEEDS	83
DEMOGRAPHIC INDEPENDENCE AND GENETIC DISCRETENESS OF STOCKS	83
CONSISTENT CRITERIA FOR AGEING	83
PLANT SAMPLING	83
UNKNOWN CENSUS POPULATION SIZES	83
FISHERY-DEPENDENT CPUE.....	84
HARVEST OF MIXED STOCKS	84
ACOUSTIC TELEMETRY	84
SUBJECTIVE MATURITY CLASSIFICATION.....	84
ECOSYSTEM-BASED FISHERIES MANAGEMENT.....	84
LIFE-CYCLE	85
PARASITES.....	85

FREQUENCY OF SPAWNING AND STOCK RECRUITMENT	85
SUBSISTENCE HARVEST	85
CRITICAL HABITATS	85
FECUNDITY	86
CONCLUSIONS.....	86
ACKNOWLEDGEMENTS	87
REFERENCES CITED.....	87
APPENDIX 1. QUOTA AND HARVEST NUMBERS	93
APPENDIX 2. CATCH PER UNIT EFFORT	95
APPENDIX 3. ROBSON-CHAPMAN ESTIMATES.....	96

ABSTRACT

Anadromous Arctic Char, *Salvelinus alpinus*, are the focus of commercial fisheries in several communities in Nunavut. In the Cambridge Bay region of the territory, two water bodies, the Jayko and Halokvik (locally known as 30 Mile) rivers, started as open-water gill-net commercial fisheries in the 1960s. These transitioned to conduit weir fisheries in the 1990s. Fisheries and Oceans Canada (DFO) has been collecting fishery-dependent biological data (i.e., data collected through sampling commercially harvested fish at the processing plant) from these fisheries since the 1970s. More recently, DFO collected fishery-independent biological and catch and effort data from 2010–2015 at both locations. Using data collected from these multiple programs, trends in fishery-dependent (1971–2015) and fishery-independent (2010–2015) biological and catch-effort data were summarized to inform the population status of Arctic Char from the Jayko and Halokvik rivers. Mean age, fork length, round weight, and condition each exhibited sinusoidal patterns through time and all, with the exception of mean age, have increased significantly since commercial fishing commenced. The observed trends in these biological metrics raise no concern on stock health but it is not clear if the variability among years is the result of environmental variability, varying responses to harvest over time, or changes in gear type over time. Of concern, length (L_{50}) and age (A_{50}) at 50% maturity have declined over the course of fishery-independent sampling at both the Jayko and Halokvik rivers. Both metrics were lower in the last year of sampling compared to initial values at both sites (Jayko L_{50} from 587 mm to 537 mm and Halokvik L_{50} from 554 mm to 533 mm; Jayko A_{50} from 15.2 years to 12.1 years and Halokvik A_{50} from 11.8 years to 9.1 years) from years 1 to 4 (year five was excluded due to concerns over maturity status identification that year). These results, however, were within ranges reported when historical data were used in the analysis. The overall Brody growth coefficient (k), calculated using fishery-dependent data, varied without trend and was similar among commercial water bodies, with median values of 0.20 and 0.21 across all years assessed for the Jayko and Halokvik rivers, respectively. Towards the latter years of the assessment, k appears to be quite stable at both locations. Finally, estimates of total instantaneous mortality (Z) and annual finite survival (S) calculated using fishery-dependent data have varied without trend since commercial fishing commenced at both locations. Across all years, Z has ranged from 0.27–0.84 at Jayko (mean = 0.46) and 0.23–1.26 at Halokvik (mean = 0.64). This results in annual survival rates (S , the percentage of a stock surviving annually) ranging from 0.43–0.76 at Jayko (mean across all years = 0.66) and 0.28–0.79 at Halokvik (mean across all years = 0.55). At both locations, mortality has been decreasing and survival has been increasing since 2007–2008. Updated ageing results, however, may change estimates of mortality and survival. Given all available information and the current understanding of these fisheries, there is likely a low to moderate risk of decline in these populations if harvest remains the same. The available analyses cannot support an increase or a decrease in harvest at either fishery. It is recommended that monitoring of biological parameters (in particular, age structure and estimates of mortality and survival) continue.

INTRODUCTION

ARCTIC CHAR IN THE CAMBRIDGE BAY REGION OF NUNAVUT

Subsistence and commercial fisheries exist throughout the Canadian Arctic, both of which target a variety of species across a variety of freshwater and marine habitats (Kristofferson and Berkes 2005, Roux et al. 2011, Zeller et al. 2011, Christiansen et al. 2013). Subsistence harvests of fisheries resources have played a vital role in sustaining the traditional Inuit way of life for millennia (Friesen 2002, 2004) and these subsistence lifestyles remain prominent in contemporary times (Huntington and Fox 2005, Nuttall et al. 2005). In recent decades, however, commercial fisheries have emerged throughout the Canadian North and have presented economic opportunities for several Inuit communities in the Arctic (Roux et al. 2011, Day and Harris 2013). Additionally, exploratory and emerging fisheries are being pursued throughout the Canadian Arctic as a result of the economic and employment opportunities that resulted from early commercial operations.

Arctic Char (*Salvelinus alpinus*) is the most widely distributed northern freshwater fish species (Scott and Crossman 1998, Reist et al. 2013) and has a long history of subsistence and commercial fisheries throughout its range (Roux et al. 2011). Arctic Char exhibits variability in morphology, life history and ecology. For example, there exists anadromous, freshwater-resident and land-locked migratory forms (Johnson 1980, Babaluk et al. 1997, Gomez-Uchida et al. 2009, Reist et al. 2013). This species is especially sought after throughout Nunavut (Roux et al. 2011), and is considered one of the most important renewable resources in the territory (Priest and Usher 2004). One area with a rich history of Arctic Char harvest is the Cambridge Bay region on southern Victoria Island, where Arctic Char-bearing river systems are numerous. Indeed, the Inuinaqtun name for the small community is *Ekaluktutiak* (or *Iqaluktuttiaq*) which directly translates to 'good place to fish for char'. Subsistence harvest of Arctic Char in the region dates back thousands of years to when the Pre-Dorset Inuit settled the area (Friesen 2002). Commercial fishing for anadromous char on Freshwater Creek, which enters Cambridge Bay a few kilometres northwest of the community, commenced in 1960 (Day and Harris 2013). Freshwater Creek also supported an important subsistence fishery, but fishing ceased at this location in 1962 because of concerns the fish stock was declining (Day and Harris 2013). Fishing was relocated to the Ekalluk River (*Iqaluktuuq*) which drains to the east side of Wellington Bay, approximately 50 km northwest of Cambridge Bay. The commercial fishery for Arctic Char expanded rapidly, and while a variety of sites in the region were explored, the fishery developed primarily around seven rivers. These rivers included the Lauchlan (Byron Bay), Halokvik (30 Mile), Paliryuak (Surrey) and Ekalluk rivers on southern Victoria Island near Wellington Bay, as well as the Jayko River in Albert Edward Bay (100 km northeast of Cambridge Bay) and the Ellice and Perry rivers on the mainland across Queen Maud Gulf (Figure 1). Today, only the Halokvik, Paliryuak, Ekalluk and Jayko rivers are commercially fished, due largely to the high costs of transporting harvested char back to the processing facility (Kitikmeot Foods Ltd.) in Cambridge Bay. Despite this reduction in active fishing locations, this fishery remains the largest commercial fishery for this species in Canada. Commercial fishing in the region traditionally incorporated the use of 5.5" gill nets, but in the early 1980s harvesters also began using conduit pipe weirs (Kristofferson et al. 1986). Since commercial fishing in the region first commenced, more than 2.3 kt of Arctic Char have been harvested.

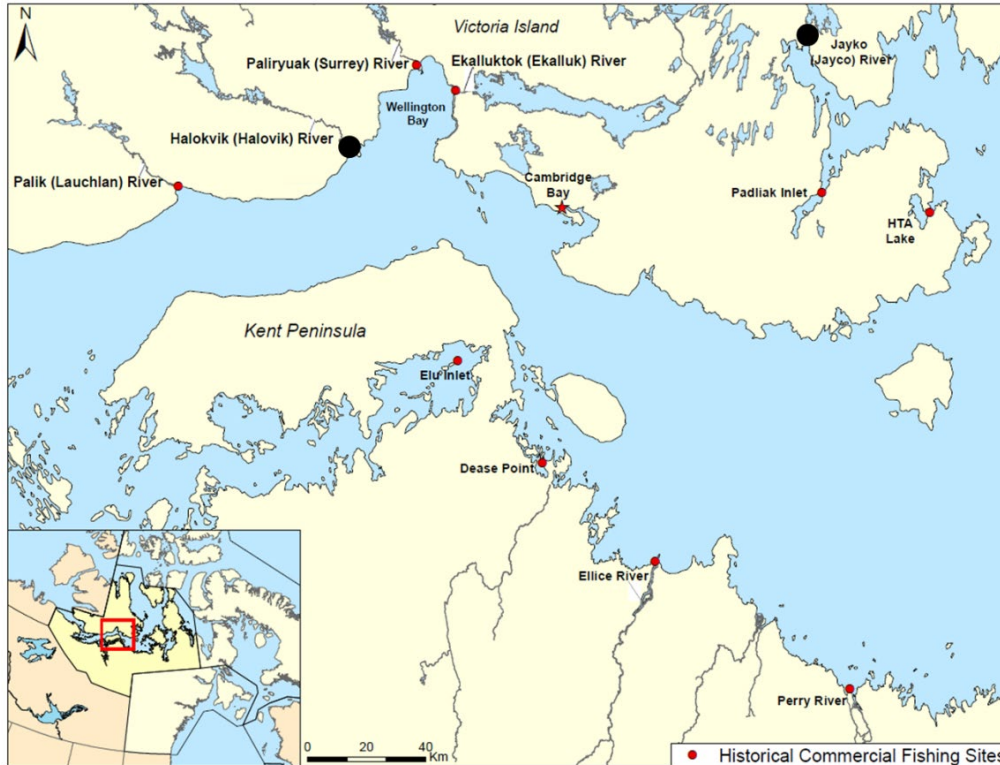


Figure 1. Cambridge Bay area of Nunavut showing historical Arctic Char commercial fishing sites (red dots). The Jayko and Halokvik rivers being assessed are shown with black circles and the community of Cambridge Bay is shown with a red star.

BREIF OVERVIEW OF MANAGEMENT AND ASSESSMENTS FOR THE CAMBRIDGE BAY CHAR FISHERY

Kristofferson and Berkes (2005) provided a comprehensive review of both traditional Inuit and conventional fisheries management practices for Cambridge Bay Arctic Char. Here, we briefly summarize some of their main points. Evidence suggests that the early Inuit of the Cambridge Bay region (formerly called the Copper Eskimo) managed local Arctic Char resources through rotational fishing practices. Harvesters would heavily harvest a specific waterbody and then cease harvesting to allow the fish population in that waterbody to recover (Johnson 1976, Berkes 1999). Traditional fisheries management practices also involved targeting aggregations of fish and the harvesting of a wide range of sizes (Kristofferson and Berkes 2005). The latter would ensure that not all of the reproductive individuals were removed from a population.

Conventional management practices emerged with the commencement of commercial fishing in the region. Initial quotas for Arctic Char were river-specific, starting at Freshwater Creek in 1960. When this fishery was closed the commercial operation moved to the Ekalluk River with a river-specific quota of 18,000 kg. This quota remained until 1967 after which an area quota of 45,000 kg was established for Wellington Bay with the intent to distribute fishing pressure to additional rivers in the area (i.e., the Paliryuak, Surrey, Halokvik and Lauchlan rivers). Unfortunately, most of the fishing pressure remained at the Ekalluk River given its closer proximity to Cambridge Bay. This resulted in the presumed overfishing of the Ekalluk River stock primarily based on a reduction in average fish weight between 1963 and 1969 (from 3.9 to 1.4 kg). As a result, the fishery was closed to allow the stock to recover before being reopened in 1973 under a river-specific quota of 18,160 kg. River specific quotas for all commercial waterbodies have been in place since then.

Initially, quotas for Arctic Char commercial harvests were established on an experimental basis (e.g., at the mouth of Freshwater Creek; Barlishen and Webber 1973). More recently, the management of Arctic Char from Cambridge Bay fisheries, including assessments on the health or status of harvested stocks, has relied on the analysis of trends in biological characteristics focussing on age, weight and, to a lesser degree, fork length and condition factor (Day and de March 2004, Day and Harris 2013). These assessments primarily relied on data collected as part of a commercial fishery plant sampling program. The earliest fishery assessments were not true stock assessments per se, but rather summaries of fish plant-sampled biological data (e.g., Carder 1983, 1988).

The Arctic Fisheries Science Advisory Committee (AFSAC) was formed in 1985 with the mandate of developing and providing scientifically sound advice for stocks of fish and marine mammals in the Northwest Territories. This committee would meet annually and the fish Subcommittee of AFSAC would review the quota recommendations for commercial Arctic Char fisheries in the Northwest Territories each year. In 1999, the Canadian Science Advisory Secretariat (CSAS) was established and became the official body for coordinating the production of peer reviewed science advice for Fisheries and Oceans Canada (DFO). Since then periodic assessments of the Cambridge Bay Arctic Char fishery have been completed. These have typically involved summarizing all available data (Day and de March 2004, Day and Harris 2013). More recently, quantitative stock assessment modelling approaches have also been explored (Zhu et al. 2014a, b) but the results of these analyses have not yet resulted in the modification of existing management strategies (e.g., the development of reference points under the DFO Precautionary Approach framework; DFO 2006). Presently, the Cambridge Bay fishery is managed following the Adaptive Co-Management Approach advocated by Kristofferson and Berkes (2005). This is exemplified by the recently approved [Integrated Fisheries Management Plan \(IFMP\) for Cambridge Bay Arctic Char](#) that involved the work of a variety of stakeholders including community elders, youth, fish processing plant representatives, the Ekaluktutiak Hunters and Trappers Organization (EHTO) and DFO.

The Cambridge Bay Arctic Char commercial fishery, including all stocks currently harvested, was last assessed in 2009 by Day and Harris (2013) primarily using harvest data collected between 1961 and 2009 and fishery-dependent biological data collected between 1971 and 2009. They concluded that all of the primary stock complexes were considered to have a low level of risk of overexploitation under current harvest regimes, with the exception of the Ellice River stock complex which had not been fished since 1999. Day and Harris (2013) concluded that the Cambridge Bay Arctic Char fishery and its supportive stocks were stable and being fished at or below their sustainable rates of harvest. However, it is important to note that fishery-dependent sampling can and often does obscure true trends in population dynamics and reliance solely on fishery-dependent data can result in overly optimistic assessments (Hilborn and Walters 1992, Walters and Martell 2004). Nonetheless, the annual monitoring of harvest has continued since 2009 as has the collection of fishery-dependent biological data collected as part of a plant sampling program. Additionally, fishery-independent biological data collection was initiated in 2010 at the Jayko River and in 2011 at the Halokvik River. No assessments of these stocks have been conducted since 2009. Following a request from the Fisheries and Aquaculture Management (FAM) sector of DFO, we provide an updated assessment of the current status of commercially harvested Arctic Char from the Jayko and Halokvik rivers. We examine trends in harvest, catch and effort data, and biological characteristics of anadromous Arctic Char from these two waterbodies to evaluate the current status of these stocks. We also discuss sources of uncertainty and make recommendations for future research programs that will increase our collective understanding of the ecology and population dynamics of char in the region and thus potentially refine management plans.

OBJECTIVES

The objective of this work is to use data collected from multiple programs to inform the population status of Arctic Char from the Jayko and Halokvik rivers. Specifically, our objectives were to:

- Summarize and assess trends in harvest, catch-effort and fishery-dependent biological data collected through the Cambridge Bay plant sampling program and the Arctic Char monitoring program supported through the Nunavut General Monitoring Plan;
- Summarize and assess trends in fishery-independent catch-effort and biological data collected during 2010–2015;
- Examine the above trends over time for interpreting stock status/health;
- Discuss sources of uncertainty and future research needs for Arctic Char in these river systems.

THE JAYKO AND HALOKVIK FISHERIES

Exhaustive reviews of the Cambridge Bay fishery are provided elsewhere (e.g., Day and Harris 2013). Here we provide general summaries for the Jayko and Halokvik river fisheries as background information.

The Jayko River drains a large series of lakes (~ 3,733 km²), the largest of which is Jayko Lake, before emptying into Albert Edward Bay approximately 100 km northeast of Cambridge Bay (Kristofferson 2002). Commercial fishing at this location occurs close to the outlet of Jayko Lake, the last lake draining this system. Commercial fishing here commenced in 1975 using gill nets under a quota of 6,800 kg (Figure 2; Appendix 1). Since then, this fishery has been harvested under several different quotas (Figure 2; Appendix 1). Jayko River was harvested by gill net until 1980 at which time a test weir was erected to test the feasibility of weirs for the commercial harvest. A combination of weirs and gill nets were used from 1980–1996 after which commercial harvest was almost always completed by weir in the fall (i.e., late August and early September). Given its geographic distance from other commercial waterbodies and differences in biological characteristics (e.g., fish size and age), the Jayko River is thought to be part of a distinct stock complex comprised of populations in the Albert Edward Bay region (Kristofferson et al. 1984). More recent genetic data (Harris et al. 2016, Moore et al. 2017) confirms the genetic distinctiveness of this stock and its demographic independence from other active commercially harvested waterbodies in the Cambridge Bay region.

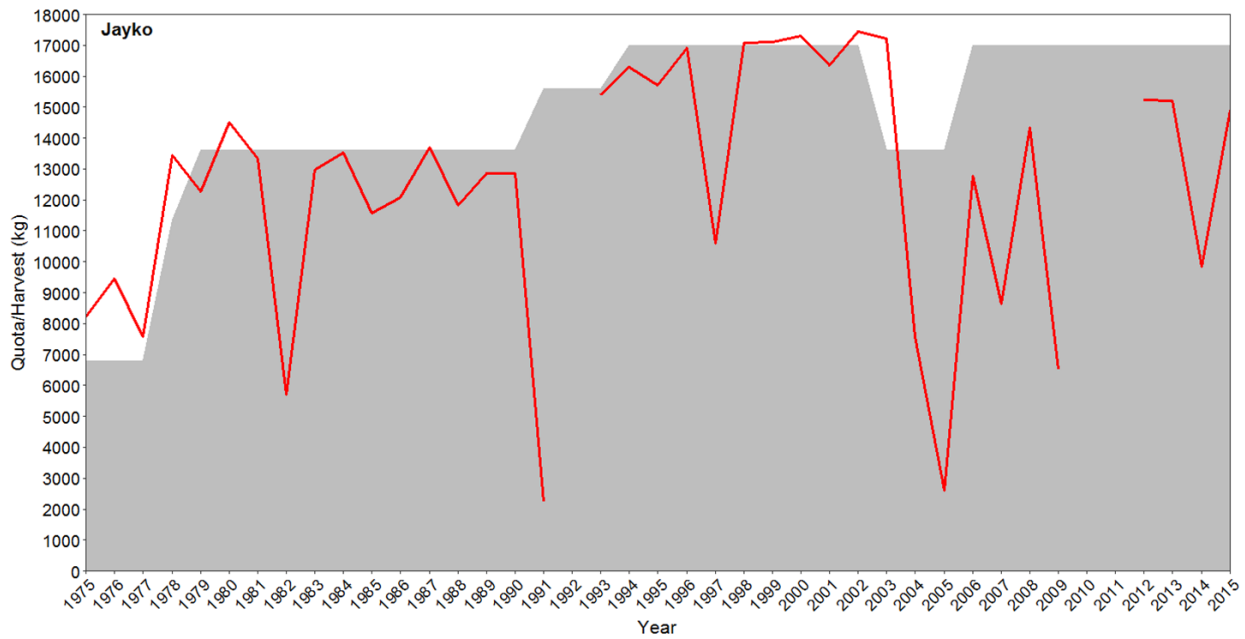


Figure 2. Commercial harvest of Arctic Char at the Jayko River fishing location since the inception of the fishery. Shown are both the annual quota (grey shaded area) and the annual harvest (red line).

The Halokvik River drains a large series of lakes (~ 2,450 km²) before entering the west side of Wellington Bay approximately 80 km from Cambridge Bay (Kristofferson 2002). This site is locally known as “30 Mile” as the river meanders approximately thirty miles (~ 48.3 km) from the last lake draining this system before entering the southwestern side of Wellington Bay. Commercial fishing commenced in 1968 under a 45,000 kg area quota established for Wellington Bay the previous year. That year, 2,614 kg of Arctic Char was harvested at this location. This location has also been fished under a variety of local yearly quotas including the Wellington Bay area quota that was initially established (Figure 3; Appendix 1). Similar to Jayko River, the Halokvik fishery started as a gill net operation in estuarine habitat near the mouth of the river. This transitioned to a weir fishery in 1994 and the site has primarily been fished using a weir since that time. Presently, fishing occurs in mid- to late-August before fishing starts at the Jayko River. Kristofferson et al. (1984) suggested that this population be considered part of a “Wellington Bay complex” that included the Ekalluk, Paliryuak, and Lauchlan rivers. Recently, Harris et al. (2016) used microsatellite DNA variation and found that commercially harvested stocks were considered part of the Wellington Bay complex were weakly differentiated at these neutral markers.

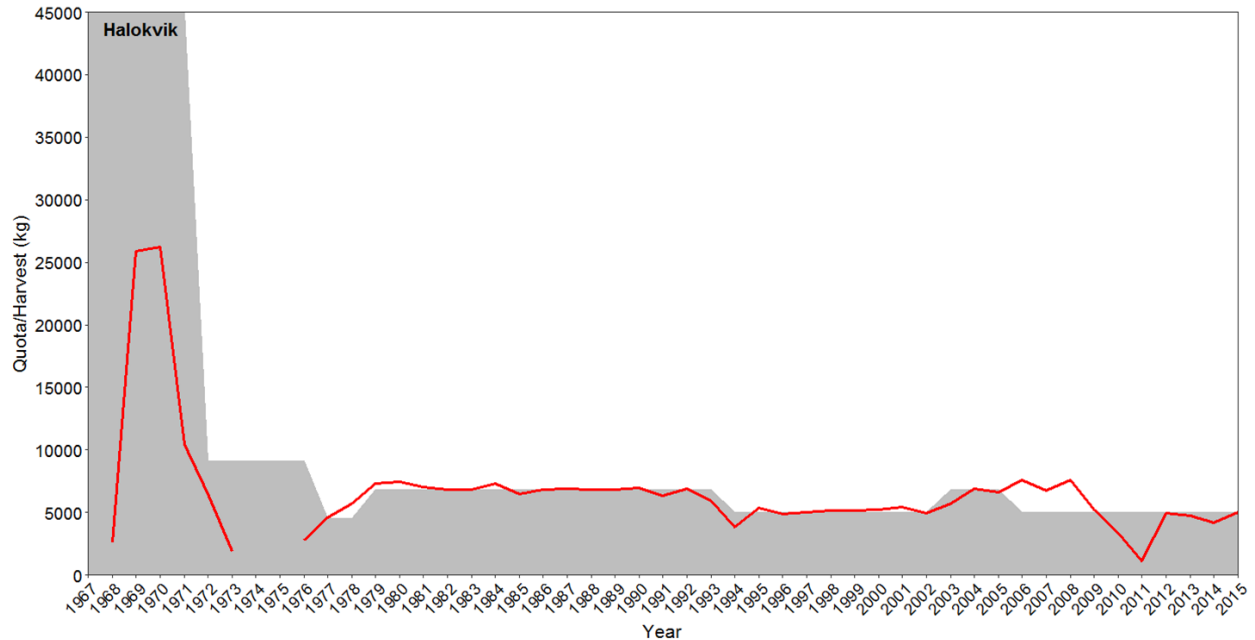


Figure 3. Commercial harvest of Arctic Char at the Halokvik River fishing location since the inception of the fishery. Shown are both the annual quota (grey shaded area) and the annual harvest (red line).

LIFE HISTORY, MIGRATORY PATTERNS, AND IMPLICATIONS FOR GENETIC STOCK STRUCTURE

As noted above, management units composed of discrete stocks (i.e., “Wellington Bay”, “Albert Edward Bay”, and mainland stock complexes) have previously been proposed based on differences in biological characteristics among these stocks and evidence from tagging projects (Kristofferson et al. 1984). More recently, acoustic tagging data and microsatellite DNA assessments have improved our understanding of stock structure in the region and have helped elucidate the extensive stock mixing that occurs at known fishing locations when commercial fishing is occurring (Harris et al. 2016, Moore et al. 2016). Here, we reiterate some of the unique aspects of the life history of Arctic Char from the Cambridge Bay region given its relevance for understanding genetic stock structure and its bearing on management strategies in the region. Harris et al. (2016) provides a thorough summary of local Arctic Char biology and much of the description provided below is taken directly from their work.

In the Cambridge Bay region spawning occurs in lakes in the fall over gravel substrate, the eggs hatch in the spring, and juveniles will rear in freshwater until around 4-5 years of age (although ages 3-9 have been documented) before they smolt (Gyselman 1994). Post-smoltification, adults and juveniles migrate from freshwater habitats (typically lakes) to estuarine and marine habitats for foraging purposes (Gyselman 1984, Johnson 1980, Moore et al. 2016). Although the exact reason is unknown, estuarine habitats appear to be exceedingly important during this summer feeding phase (Moore et al. 2016). The downstream migration is composed almost exclusively of mature individuals that will not spawn that year (current-year non-spawners [CYNS]) and juveniles (Gyselman and Broughton 1991, L.N. Harris, DFO, pers. comm.). In this region, Arctic Char that will spawn within the year are called current year spawners (CYS). They remain in freshwater throughout the summer in preparation to spawn that fall (Johnson 1980, Kristofferson 2002).

Feeding in marine and estuarine habitats lasts for approximately 40 days (Gyselman 1984, Moore et al. 2016). During this time Arctic Char have been known to travel great distances (e.g.,

≥ 100-400 km) (Gyselman 1984, Dempson and Kristofferson 1987, Gyselman 1994, Moore et al. 2016). Separate stocks are known to mix extensively while feeding in marine habitats, including at commercial and subsistence fishing locations (Dempson and Kristofferson 1987, Kristofferson 2002, Harris et al. 2016, Moore et al. 2016).

Arctic Char in the region must return to freshwater every fall to overwinter regardless of reproductive status (i.e., even if they are CYNS; Johnson 1980). Fidelity to natal habitats appears to be quite low (Gyselman 1994, but see Moore et al. 2016 for evidence of homing) and genetic evidence for Arctic Char in general suggests lower fidelity in individuals returning to freshwater solely for the purpose of overwintering (Moore et al. 2013). For example, in the Cambridge Bay region, and the central Canadian Arctic in general, it appears that a larger proportion of CYNS overwinter in non-natal habitats (i.e., “the overwintering refuge” hypothesis, Moore et al. 2017). This phenomenon was more recently demonstrated in the work by Gilbert et al. (2016) who found in the Nulahugyuk system near the community of Kugluktuk, Nunavut that the distribution of sizes and ages of char in this system is bimodal. They concluded that Arctic Char in this system typically leave at a length of 19 cm and an age of 4 years and do not return for 4 to 5 years, presumably overwintering in other systems that require less energy to migrate to. In the Cambridge Bay region specifically, we presumed that a significant proportion of all CYNS char in the region will opt to overwinter in Ferguson Lake given the likely large overwintering carrying capacity of this system and the short distance between marine and freshwater habitats (~ 3 km). Homing to natal systems in Arctic Char appears to be much higher when they are returning to freshwater the year before they spawn ((presumably because they are opting to forego a marine migration the following year, Moore et al. (2016)). Therefore, in terms of understanding patterns of dispersal, subsequent gene flow, and genetic stock structure, one must be aware of reproductive status (i.e., only dispersal in CYS Arctic Char (‘breeding dispersal’) results in contemporary gene flow). This is especially relevant for Cambridge Bay Arctic Char, given that virtually all upstream-migrating individuals are CYNS (Kristofferson 2002). Dispersal in CYNS Arctic Char (i.e., ‘overwintering dispersal’) is viewed as a bet-hedging strategy that is thought to be evolutionarily advantageous in unpredictable and stochastic environments (Moore et al. 2013).

Several important points relevant to understating genetic stock structure and the subsequent ramifications for the management of char stocks in the region are:

- discrete stocks are known to mix extensively while at sea,
- mixing of discrete stocks is likely very prevalent in overwintering habitats,
- individual Arctic Char must return to freshwater annually to overwinter regardless of reproductive status resulting in the potential for two types of dispersal (i.e., breeding and overwintering dispersal),
- in the Cambridge Bay region virtually all upstream-migrating individuals are CYNS and have no potential for gene flow in the present year,
- the majority of dispersal events would therefore be overwintering dispersal, and
- overall fidelity appears to be quite low in this species.

Only three genetic assessments to date have focused specifically on resolving stock structure in Cambridge Bay Arctic Char, although Moore et al. (2014) do provide a comprehensive review of anadromous Arctic Char migratory behavior and genetic population structure for Arctic Char in general. Furthermore, historical tagging initiatives in the region have provided valuable insights into migration within and dispersal among stocks in the region (see Kristofferson et al. 1984, Dempson and Kristofferson 1987). The first molecular assessment among char stocks in the

region assayed enzyme variation and suggested that CYS home with a high degree of fidelity resulting in the establishment of discrete stocks both between and within river systems and that multiple stocks likely overwinter within individual river systems (Kristofferson et al. 2002). The work of Kristofferson et al. (2002), however, should be viewed with caution given that this assessment and conclusions therein were based solely on differences in allele frequencies for only one enzyme (Malic enzyme) among CYS samples. There was no variability (or limited variability) among samples when assessed at five additional enzymes (all of which were excluded from the study). Furthermore, only two of ten pairwise comparisons of CYS samples were significant which confirms a relative lack of differentiation among char stocks in the Cambridge Bay region.

More recently, Harris et al. (2016) used microsatellite DNA data to describe genetic variation within and genetic structure among samples collected in a fashion intended to mirror commercial harvest in the region. Although their sampling design may have hindered their ability to assess genetic stock structure among Cambridge Bay stocks directly, they concluded that:

1. There was regional genetic structure across the entire study area,
2. Commercial fishery sampling locations in the Cambridge Bay region were weakly differentiated (average $F_{ST} < 0.01$),
3. Differentiation (F_{ST}) was never significant between temporally collected samples and rarely significant among sampling locations within the Wellington Bay complex (specifically the Ekalluk, Surrey, and Halokvik rivers), and
4. The Jayko River sampling location was typically differentiated from the Wellington Bay sampling locations as were mainland (Nauyuk Lake and Hornaday River) and western Victoria Island (Kujjua River and Qunnguauq Lake) sampling locations.

Finally, next-generation sequencing methods currently being employed have suggested that Arctic Char home to their natal river to spawn but may overwinter in rivers with the shortest migratory route to minimize the costs of migration in non-breeding years (Moore et al. 2017). Samples from juveniles that have not yet left their natal systems (see Moore et al. 2013) or from CYS fish at their spawning locations are required to more precisely understand genetic stock structuring and the ecological and biological complexities of this species in the region.

MATERIAL AND METHODS

HARVEST MONITORING

Cambridge Bay Plant Sampling Program and Harvest Reporting

The collection of fishery-dependent biological data, which have formed the backbone for assessments of commercially harvested Arctic Char stocks in the Cambridge Bay region, has primarily been facilitated through a commercial plant sampling program. This annual sampling program, in which commercially harvested char are sampled at the Cambridge Bay fish plant (Kitikmeot Foods Ltd.), has been operating in varying capacities since 1971. The early history of this program is described by Kristofferson and Carder (1980) and numerous data reports provide summaries of data collected through this program (Carder 1981, 1983, Carder and Low 1985, Carder and Stewart 1989). The plant sampling program involves the sampling of commercially harvested char for fork length (± 1 mm), dressed weight (head on, viscera and gills removed; ± 50 g), and aging structures for the six primary Cambridge Bay stocks (Ekalluk, Lauchlan, Halokvik, Paliryuak, Ellice, and Jayko rivers). Typically 200 Arctic Char per commercial waterbody are sampled on a yearly basis. More recently, the plant sampling

program has also facilitated the collection of genetic samples and tissue samples for stable isotope, fatty acid, and contaminant analyses. Additionally, Kitikmeot Foods Ltd. reports daily to DFO with harvest details related to each delivery of commercially harvested char (float plane deliveries of fish tubs in this case) including weights. This allows for real time harvest reporting and daily quota monitoring by DFO. Conversion factors are applied to the reported harvest to translate dressed weight into round weight as per the commercial quota. In this assessment, we summarize all available plant sampling data and harvest data for the Jayko and Halokvik rivers. For harvest and weight data we use the conversion factors 1.2 (2004 and earlier) and 1.25 (for 2005 and later) to convert dressed weight to round weight.

Nunavut General Monitoring Plan

Fishery-dependent catch-per-unit-effort (CPUE) information is one of the most fundamental statistics in fisheries stock assessment. If the catchability remains constant over time, trends in CPUE can be used as a proxy for estimating abundance and biomass of the harvested population. Assuming constant catchability through time is a strong assumption of all subsequent analyses in this report (Hilborn and Walters 1992). In 2012, a long-term river-based monitoring program aimed at collecting fishery-dependent CPUE and harvest data was established for actively harvested commercial fisheries in the Cambridge Bay region. Led by the Ekaluktutiak Hunters and Trappers Organization (EHTO) with support of Kitikmeot Foods Ltd. and DFO, the program has been maintained for five consecutive years through a funding contribution from the Nunavut General Monitoring Plan (NGMP). Over time, the monitoring program will be transitioned into a commercial fisher-led data collection program. The monitoring program is designed to estimate annual CPUE of commercial harvest through the use of logbooks. Additionally, the reporting of by-catch and discards in the fishery contributes to an improved understanding of species interactions.

FISHERY INDEPENDENT SAMPLING

The collection of biological data through the plant sampling program has proven to be a cost-effective method (\$7.00 per sample) for ensuring biological data are collected annually from commercially harvested Arctic Char. The limitation of using these data, however, is that older and larger individuals are usually over-represented because of selectivity in the fishery resulting in a lack of biological information that accurately represents the population as a whole. Additionally, given the fish plant sampling regime (i.e., Arctic Char are dressed before they arrive at the processing plant for sampling), little information is available on sex and maturity for commercially harvested char. Furthermore, the collection of catch and effort data only started recently in the Cambridge Bay region. As a result, a fishery-independent sampling program was initiated in 2010 with the intent to start addressing some of these data and knowledge gaps.

The fishery-independent biological data presented in this assessment are based on biological sampling between 2010 and 2015. The Jayko River was sampled during 2010–2015 (2013 was excluded because a blizzard prevented travel to the site). The Halokvik River was sampled during 2011–2015. For all years, sampling commenced towards the end of August or the beginning of September. The Halokvik River was sampled in estuarine habitat at the mouth of the Halokvik River where fish congregate prior to commencing upstream migrations to spawning and overwintering areas in this system. The Jayko River was sampled in the river subsequent to the commencement of the upstream migration of char to spawning and overwintering areas. To collect a representative sample of the population at each location, multi-mesh gill nets were fished that consisted of the following stretched mesh sizes: 38.1 mm (1.5"), 63.5 mm (2.5"), 88.9 mm (3.5"), 114.3 mm (4.5"), and 139.7 mm (5.5"). Each panel of the multi-mesh gill net was 9.14 m (30') in length resulting in research nets that were 45.72 m (150') in length.

Arctic Char collected as part of the fishery-independent sampling program were sampled for fork length (± 1 mm), round weight (± 1 g), sex, maturity, gonad weight (± 1 g), and sagittal otoliths were collected for age estimation. All Arctic Char ages were subsequently estimated using sectioned or whole otoliths. The capture net and mesh size were recorded for each fish and catch and effort data (i.e., hours fished and number of fish captured) were recorded throughout the duration of fishing.

DATA ANALYSIS

Catch-Per-Unit-Effort

For commercial harvest, CPUE was calculated separately for each year of the NGMP program (2012–2016) at both commercial water bodies as the number of Arctic Char captured/24 hrs of weir fishing. To our knowledge, the calculation of CPUE for a commercial weir fishery for Arctic Char has never been done. Given that the weir may often be fishing for some time before it is filled to the point of being emptied for the first time, we disregarded the first data point from each year of fishery-dependent CPUE data collection. For fishery-independent data, CPUE was calculated as the number of Arctic Char landed per 45.72 m of stretched multi-mesh gill net per 24 hours of fishing. T-tests or non-parametric alternatives were used to test for differences in means between the first and last years of data collection within each fishery. Box plots were used to display median CPUE per year of sampling for both gill-net and weir generated data.

Biological Data Analysis

For all parameters, normality was tested with Shapiro-Wilkes tests. Sex ratios were calculated for each year in each fishery. Non-parametric binomial tests were used to determine if sex ratios differed significantly from 0.5 (i.e., 1:1) within each year of sampling at each site. Significant differences in sex ratios among years within each waterbody were tested using non-parametric Chi-square tests. Fisher exact tests were then used to determine if sex ratios differed significantly between the first and last year of sampling. The same procedure was used to test for differences in the frequency of maturity stages (immature, mature, or resting) among years.

Trends (trend analyses) in age, length, and weight (and analyses employing these data) were compared among years within each waterbody using both fishery-dependent and -independent data. Both fishery-dependent and -independent biological data were evaluated for each year of sampling to identify responses to harvest through time. For fishery-independent data, mean weight, length, and age were compared between sexes for each year at each waterbody using two sample t-tests or non-parametric alternatives ($\alpha = 0.05$). The same tests were used to determine if there were differences in the means of the biological parameters between the first and last years of sampling (or harvest). Fishery-dependant and -independent data were summarized visually using frequency distributions and box plots. Splines with 95% confidence intervals (CIs) were fit to these data where applicable to help visualize the results. Furthermore, general linear models were used to assess potential trends in mean length, weight, and age through time for fishery-dependant data. The frequency distributions of all biological parameters were also compared among years (specifically the first and last years or decades) using two-sample Kolmogorov-Smirnov Goodness of Fit tests.

Fulton's relative condition factor (K) (Ricker 1975) was calculated as:

$$K = \frac{W \times 10^5}{L^3}$$

where W and L are round weight (g) and fork length (mm) respectively. Condition was summarized as the annual mean determined from individual specimens and was compared

across years for each fishery. Condition factor was only displayed visually for fishery-dependant and –independent data as described above.

Weight-length relationships for Arctic Char were described using a linear regression model for both data sets. The weight-length relationship,

$$W_i = aL_i^b$$

was transformed into its logarithmic form expressed as:

$$\log(W_i) = \log(a) + b * \log(L_i) + \varepsilon_i$$

where W is the round weight (g), L is the fork length (mm), a is the y-intercept, b is the slope of the regression, and ε_i is a normally distributed error term for the i th fish. The parameters a and b were calculated by least-squares regression separately for each sampling year (fishery-independent data) or by decade (fishery-dependent data).

Arctic Char length at age by year (fishery-independent) or decade (fishery-dependent) was modeled using the von Bertalanffy growth function (Beverton and Holt 1957) expressed by the equation:

$$L_t = L_\infty(1 - e^{-k(t-t_0)}) + \varepsilon_i$$

where L_t is the expected or average length at time t , L_∞ is the asymptotic average length, k is the Brody growth rate coefficient, t_0 is the theoretical length at age 0, and ε_i is a normally distributed error term for the i th fish. (Ricker 1975). Statistical differences in growth between sexes within years for each fishery and between first and last sampling years for each fishery were determined using analysis of the residual sum of the squares following Haddon (2001).

To compare potential differences in maturity indices (sexes combined) across sampling years for the fishery-independent data, the length and age at 50% maturity (L_{50} and A_{50} respectively) was determined using logistic regression. The proportion mature within a given length or age class was modeled as:

$$x = \frac{\log\left(\frac{p}{1-p}\right) - \alpha}{\beta_1}$$

where p is the proportion mature (0.00–1.00) in length class (x) or age class (x). For determining x for 50% maturity, (i.e., $p = 0.05$) the above formula reduces to:

$$x = -\frac{\alpha}{\beta_1}$$

For L_{50} and A_{50} for both stocks, we compared the results for the fishery-independent data to years where historical data on maturity were also available.

Finally, catch curve data were used to estimate the total annual survival rate (S), and thus the annual finite mortality (A) and instantaneous (Z) total mortality rates. We employed the methods of Chapman and Robson (1960) which is based on the assumption that the descending limb of the curve showing catches at each age follows a geometric probability distribution. Briefly, the natural log of age class frequency was plotted against age for each year. Least squares regression was then used to fit a curve to the descending limb of the catch curve (from the modal year class plus one year to the oldest year class where $n > 1$). Instantaneous mortality rate (Z), annual survival rate (S), and annual mortality rate (A) were then calculated as follows from Ricker (1975):

$$Z = \text{positive slope of regression}$$

$$S = e^{-z}$$

$$A = 1 - S$$

The Chapman-Robson estimate of the annual survival rate (\hat{S}) is:

$$\hat{S} = \frac{T}{n + T - 1}$$

where n is the total number of fish observed on the descending limb of the curve, T is the total recorded age of fish on the descending limb of the catch curve. The parameters S and A were calculated as described above for each year of sampling for both fishery-dependant and -independent data.

RESULTS AND DISCUSSION

ABUNDANCE AND EXPLOITATION

Despite its value in fisheries stock assessment and management, direct counts of commercially harvested Arctic Char populations are rare. These data are of crucial importance for determining exploitation rates on Arctic Char populations and understanding Arctic Char responses to harvest via quantitative stock assessment models. River systems in the Cambridge Bay region represent some of the only known examples where such data are available in the Canadian Arctic.

Using a commercial weir for scientific purposes, enumerations were performed at both the Jayko and Halokvik rivers. In 1980 and 1981, 33,388 (partial count only) and 138,795 Arctic Char were counted respectively at the Jayko River (McGowan 1990). Little information on abundance in this system is available since that time. The population of Arctic Char from the Halokvik River system was also enumerated via weir in 1981 at which time 21,214 Arctic Char were counted (McGowan 1990). A more recent enumeration was completed in 2014 (DFO, unpublished data) and, although it is assumed that a portion of the run was missed because the weir could not be operated in high water conditions, ~ 15,000 Arctic Char were counted. In 2013 and 2014, 948 and 1548 Arctic Char were tagged, respectively, and subsequent recapture data were used to generate population estimates for this system (DFO, unpublished data). The mark-recapture population estimates (using a modification of the Petersen method) derived for this fishery were 35,546 (95% C.I. 30,513-49,254) and 48,377 (95% C.I. 37,398-74,601) for 2014 and 2015, respectively (Harris et al. 2020). These numbers, however, should be interpreted with caution as data analyses are ongoing and additional methods (e.g., Baileys triple catch method) are being explored.

Using the enumeration data described above, Day and Harris (2013) crudely estimated exploitation rates for the Jayko and Halokvik rivers. Briefly, they estimated total biomass (the number of fish enumerated multiplied by the average weight of enumerated fish for which weight information was collected) against the biomass of Arctic Char harvested to determine an approximate rate of exploitation. Using the enumeration data, exploitation rates were estimated to be 4.2% and 11.1% of the total available biomass for the Jayko and Halokvik rivers, respectively. Here, we update these estimates by including the average individual weight of fish harvested in 1981. As a result, the estimated exploitation rates in 1981 were 2.80% and 9.27% for the Jayko and Halokvik rivers, respectively. Finally, the same calculations, using the average weight of all fish available to us and the current quotas (17,000 and 5,000 kg), suggest that exploitation rates in the Jayko and Halokvik rivers have been 3.38% and 5.44%, respectively, in years when the full quotas are realized. However, the above calculations should be interpreted

with caution as they assume the population size has remained constant since the enumerations in the early 1980s.

In general, very little is known regarding population abundance of Arctic Char in systems where they occur. McGowan (1990) and McGowan and Low (1992) detail the most substantial enumeration efforts from the Cambridge Bay area for five river systems including those in the current assessment. Given the logistical challenges and expenses associated with operating a weir for enumeration purposes, accurate or reliable counts of Arctic Char in a system are typically available for a single year only (but see McGowan and Low 1992). Data that are available suggest that population abundance is highly variable among river systems and likely among years within river systems (McGowan 1990, McGowan 1992). For example, over three consecutive enumerations (1982, 1988, and 1992) the abundance of Arctic Char in Freshwater Creek near the community of Cambridge Bay ranged from ~ 10,000 char to > 39,000 char. This system is roughly the same the size as the Halokvik system, so recent mark-recapture estimates may not be that unreasonable. More work on the factors that impact abundance needs to be completed to understand what drives differences in Arctic Char abundance among systems. Local resource users have not raised any concerns regarding potential declines in abundance in either stock and the consensus is that catch rates have remained consistent throughout the years (B. Greenley, Chair, Ekaluktutiak Hunter's and Trapper's Organization, Cambridge Bay, NU).

COMMERCIAL HARVEST AND CATCH-EFFORT

Since the last assessment (Day and Harris 2013), harvest at the Jayko River from 2010–2015 ranged from 9,851 kg (2014) to 15,231 kg (2012) and harvest at the Halokvik River ranged from 1,124 kg (2011) to 5,010 kg (2015) (Figures 2 and 3, Appendix 1). Average harvest over that same time period was 13,792 kg and 3,883 kg per year for the Jayko and Halokvik rivers, respectively. Quotas are generally filled or nearly filled on an annual basis. Exceptions to this occurred at Jayko River where no fishing took place in 2010 and 2011 due to concerns over parasites.

Both fishery-dependent and -independent CPUE data are available for commercial Arctic Char stocks in the Cambridge Bay region. The former, to our knowledge, is the first available CPUE fishery-dependent data for a commercial Arctic Char fishery in the Canadian Arctic. Given both the Jayko and Halokvik fisheries are weir fisheries, fishery dependant CPUE was calculated as the number of char harvested per 24 hr of weir fishing. Fishery-dependant CPUE differed between the two rivers and among years within rivers (Figure 4, Appendix 2). Mean CPUE at Jayko River ranged from 311.5 Arctic Char per 24 hours of weir fishing in 2014 to 789.2 Arctic Char per 24 hours of weir fishing in 2013 (Figure 4, Appendix 2). Across all years, CPUE at Jayko averaged 533.3 Arctic Char per 24 hours. The mean number of Arctic Char caught per 24 hours did not differ significantly between the first and last year of sampling ($t = -1.71$, d.f. = 18.19, $p = 0.10$). Commercial CPUE at Halokvik was lower and more variable than that at Jayko. At Halokvik, mean CPUE ranged from 150.1 Arctic Char per 24 hours of weir fishing in 2012 to 462.3 Arctic Char per 24 hours of weir fishing in 2014 (Figure 4, Appendix 2). With the exception of 2014, where catch rates were abnormally high (note only two data points were available for this year), CPUE appears to be relatively constant across sampling years at this site. Across all years, CPUE at Halokvik averaged 215.5 Arctic Char per 24 hours. The average number of Arctic Char caught per 24 hours at Halokvik also did not differ significantly between the first and last year of sampling ($t = -1.70$, d.f. = 12.52, $p = 0.11$).

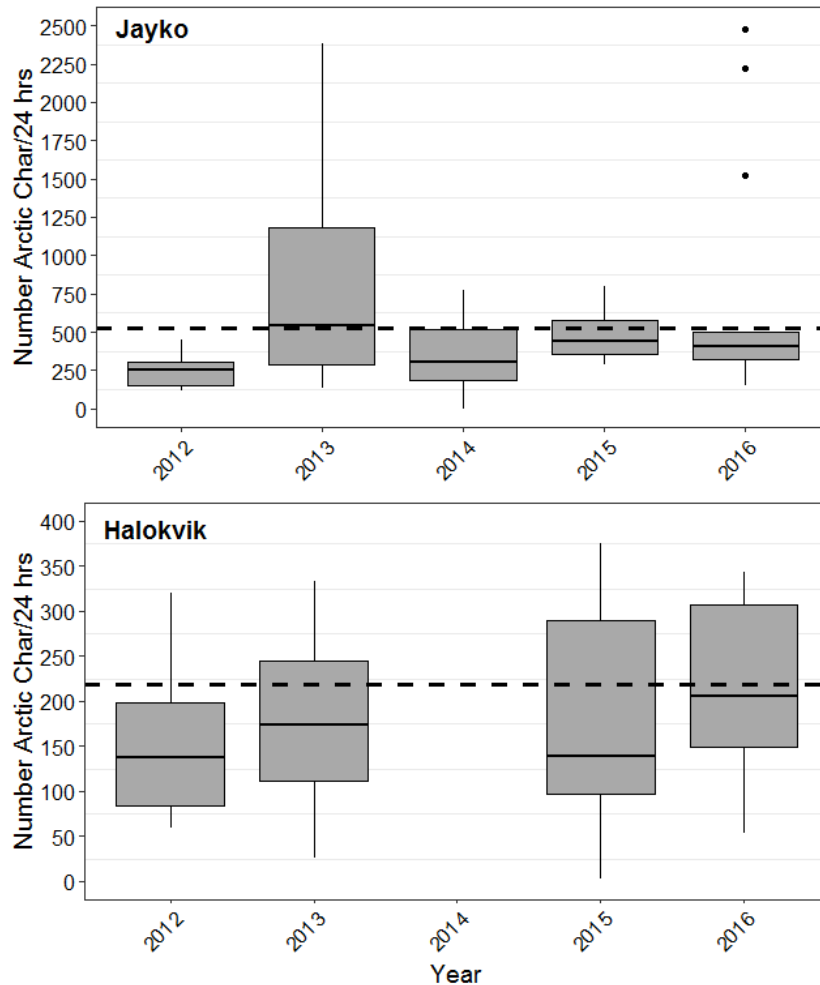


Figure 4. Box plots (showing the 25th and 75th percentile or inter-quartile range (IQR, grey box), the median (black line within the box) and 1.5 x the IQR ('whiskers' of the plot)) of mean fishery-dependent catch-per-unit-effort (CPUE, number of Arctic Char /24 h of weir fishing) at the Jayko and Halokvik rivers from 2012 to 2016. The black dotted line shows the mean CPUE across all years for each river.

Fishery-independent average CPUE, calculated as the number of fish landed per 24 hours of fishing (all mesh sizes combined), ranged from 11.29 (2012) to 69.86 (2010) at Jayko and 8.86 (2012) to 25.93 (2015) at Halokvik (Figure 5, Appendix 2). Across all years, fishery independent CPUE at Jayko averaged 26.5 Arctic Char per 24 hours and CPUE at Halokvik averaged 16.6 Arctic Char per 24 hours. CPUE was significantly different ($p < 0.05$) between the first and last sampling years for both fisheries. CPUE decreased between 2010 and 2015 at the Jayko River with considerable interannual variability. CPUE increased between 2011 and 2015 at the Halokvik River showing a steady increase in CPUE over the last four sampling years.

Effort and CPUE are key indices used to understand fishing mortality and the density of the exploited stock. There is no long-term monitoring system implemented to record and track changes in CPUE for commercially harvested Arctic Char anywhere in Nunavut. This impedes the effective design of management strategies essential for ensuring the long-term sustainability of this resource (Quinn and Deriso 1999). The catch and effort data collected as part of the NGMP for commercially harvested Arctic Char is currently the longest known time-series in the territory for such data. This is promising and should continue over the long run as a long term series of CPUE data. Additionally, this monitoring will compliment fishery-independent biological

data collected through stock assessment surveys and will be valuable in future quantitative modelling exercises that require catch-effort data and in guiding future conservation and management strategies. The Cambridge Bay region is an ideal location for collecting this information given the long history of the fishery and DFO involvement in the fishery as well as the ongoing support and assistance provided by Kitikmeot Foods Ltd. and the Ekaluktutiak HTO, and local resource users.

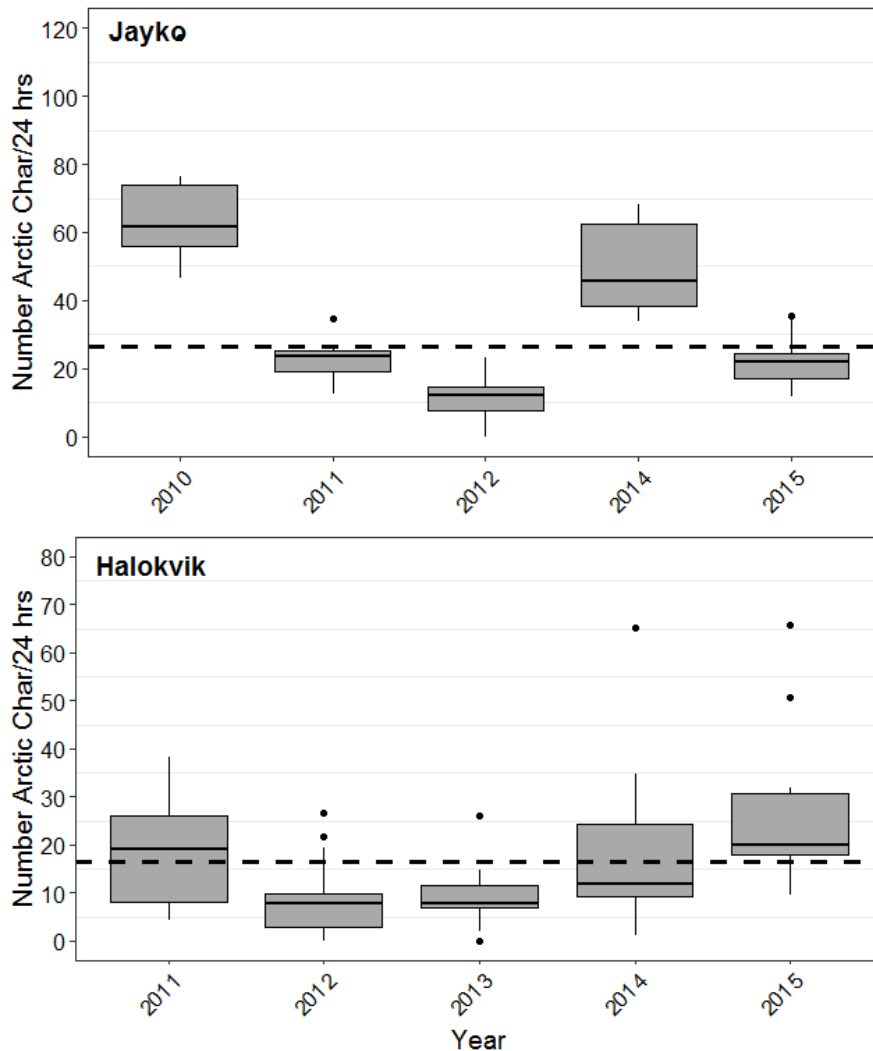


Figure 5. Box plots (showing the 25th and 75th percentile or inter-quartile range (IQR, grey box), the median (black line within the box) and 1.5 x the IQR ('whiskers' of the plot)) of mean fishery-independent catch-per-unit-effort (CPUE, number of Arctic Char /per 150 ft. of multi-mesh gill net/24 h) at the Jayko and Halokvik rivers from 2012 to 2015. The black dotted line shows the mean CPUE across all years for each river.

BIOLOGICAL CHARACTERISTICS

Sex ratio and maturity

Sex and maturity information are only available for the fishery-independent data. Over the duration of the research program, the sex ratio (M:F) remained relatively constant and no statistical differences were found across all years for both the Jayko ($\chi^2 = 2.67$, d.f. = 4,

p = 0.61) and Halokvik ($\chi^2 = 2.36$, d.f. = 4, p = 0.67) rivers. Sex ratios varied between river systems, ranging from 0.98 (2014) to 1.27 (2012) at Jayko and from 0.88 (2015) to 1.18 (2013) at Halokvik (Table 1). Sex ratios were not significantly different (p > 0.05) from a binomial distribution in any year of sampling at either Jayko or Halokvik. Sex ratios did not differ significantly (p > 0.05) between the first and last sampling year in either river system. However, the overall sex ratio did differ between the two rivers (p > 0.05).

The majority of Arctic Char sampled in fishery-independent surveys for both river systems were classified as 'immature' or 'resting' (Table 1). Fish classified as 'mature' were virtually non-existent in our samples from both river systems (Table 1). The maturity ratios differed between rivers ($\chi^2 = 52.34$, d.f. = 2, p < 0.05) and between the first and last sampling year for each river (p < 0.05). There appeared to be more immature fish at Jayko and more resting fish at Halokvik. This may be due to differences in sampling design between the rivers. Fishery-independent sampling at Jayko takes place in a section of the Jayko River between Jayko Lake and marine habitats whereas all sampling at Halokvik takes place in estuarine habitats. Thus, there is a much higher probability of catching immature fish in freshwater habitats in the Jayko River.

Table 1. Timing of sampling, sample sizes (N), and sex and maturity information for Arctic Char caught in the fishery-independent research sampling for the Jayko River and Halokvik River, 2010–2015. Data from all mesh sizes in the multi-mesh gill nets are pooled.

Year	Start Date	End Date	N	N Female (F)	N Male (M)	Sex Ratio M:F	N Immature	N Mature	N Resting
Jayko River									
2010	3 Sept.	6 Sept.	210	95	115	1.21	146	0	64
2011	2 Sept.	5 Sept.	206	101	105	1.04	132	1	73
2012	31 Aug.	2 Sept.	211	93	118	1.27	106	9	96
2014	31 Aug.	2 Sept.	216	109	107	0.98	121	2	93
2015	29 Aug.	1 Sept.	200	90	110	1.22	86	2	112
Totals	29 Aug.	6 Sept.	1043	488	555	1.14	591	14	438
Halokvik River									
2011	26 Aug.	30 Aug.	192	99	93	0.94	110	0	82
2012	22 Aug.	26 Aug.	205	106	99	0.93	102	3	100
2013	22 Aug.	26 Aug.	168	77	91	1.18	88	0	80
2014	21 Aug.	24 Aug.	192	100	92	0.92	66	0	126
2015	21 Aug.	25 Aug.	197	105	92	0.88	35	0	162
Totals	21 Aug.	30 Aug.	954	487	467	0.96	401	3	550

In the current assessment, length (L_{50}) and age (A_{50}) at 50% maturity were used as indices for reproductive potential. These measures were calculated (sexes combined) for both river systems. Jayko River Arctic Char appear to mature at older and larger sizes than Halokvik River Arctic Char (Figures 6 and 7). Using the contemporary fishery-independent data (2010–2015), across all samples combined, the overall L_{50} at Jayko was 553.7 mm while overall L_{50} was 539.7 mm at Halokvik (Figure 6). Among years, Jayko L_{50} ranged between 477.3 mm in 2015 and 587.1 mm in 2010 (Figure 8). At Halokvik, L_{50} ranged between 463.3 mm in 2015 and 588.8 mm in 2012 (Figure 9). These values were comparable to L_{50} values calculated using earlier data for the Jayko (1980 and 2005, Figure 10) and Halokvik (1972 and 2006, Figure 11) rivers. Across all samples combined, the overall A_{50} at Jayko was 12.5 years whereas the overall A_{50} at Halokvik was 10.4 years (Figure 7). Among years, Jayko A_{50} ranged between 9.4 years in 2015 and 15.2 years in 2010 (Figure 12). The A_{50} at Halokvik ranged between 7.9 years in 2015 and 11.8 years in 2010 and 2011 (Figure 13). With the exception of 2005, the contemporary values of A_{50} calculated using the most recent fishery independent data for the Jayko fishery were all lower than historical values (Figure 14). Similarly, all contemporary values of A_{50} calculated using the most recent fishery-independent data for the Halokvik River fishery were below values calculated using historical data (Figure 15). These results, however, should be interpreted with caution given that throughout the history of the fishery-independent sampling program, Arctic Char have been aged by different readers potentially resulting in conflicting values for these maturity indices. However, at both river systems it is clear that L_{50} and A_{50} decreased over the fishery independent sampling period. Indeed, all but L_{50} significantly decreased over this time ($p < 0.05$). These results, however, should be interpreted with caution as distinguishing between resting and immature fish is often difficult and the results above could be an artifact of inter-researcher differences in maturity classification. Nonetheless, it is disconcerting that these parameters are declining as this pattern was observed during Lake Trout (*S. namaycush*) population collapses in the Laurentian Great Lakes (Walters et al. 1980). There are, however, a variety of aspects of maturity that are still not fully understood for Cambridge Bay Arctic Char and subtle or more substantive changes in the length or age at 50% maturity could be due to a number of factors (e.g., marked changes in biomass, plastic changes to maturation schedules). These values are both higher than the only other calculations of L_{50} and A_{50} for Arctic Char (Isuituq River on Baffin Island, Harris and Tallman 2010).

The reproductive potential of a population is determined by a variety of factors including maturation, sex ratio, and fecundity (Trippel 1999). Most sexually reproducing organisms, particularly fish, should exhibit sex-ratios close to 1:1 (i.e., 1:1 is the equilibrium sex ratio) (Grayson et al. 2014). At a 1:1 sex ratio, reproductive fitness within populations should be maximized and deviations from this ratio have been attributed to compensatory responses to exploitation (Silliman and Gutsell 1958). The overall sex ratios for Jayko (M:F = 1.14) and Halokvik (M:F = 0.96) are close to 1:1 (Table 1). In the current assessment these did not differ significantly from a binomial distribution. This fact coupled with the temporal stability of the sex ratios in both river systems provides some indication of stock stability (Morgan 2008). Fecundity data of Arctic Char from commercially exploited populations on southern Victoria Island is lacking. Therefore, we recommend that future research initiatives focus on finding and capturing mature individuals for fecundity analyses to improve understanding of reproductive potential and recruitment in Cambridge Bay Arctic Char.

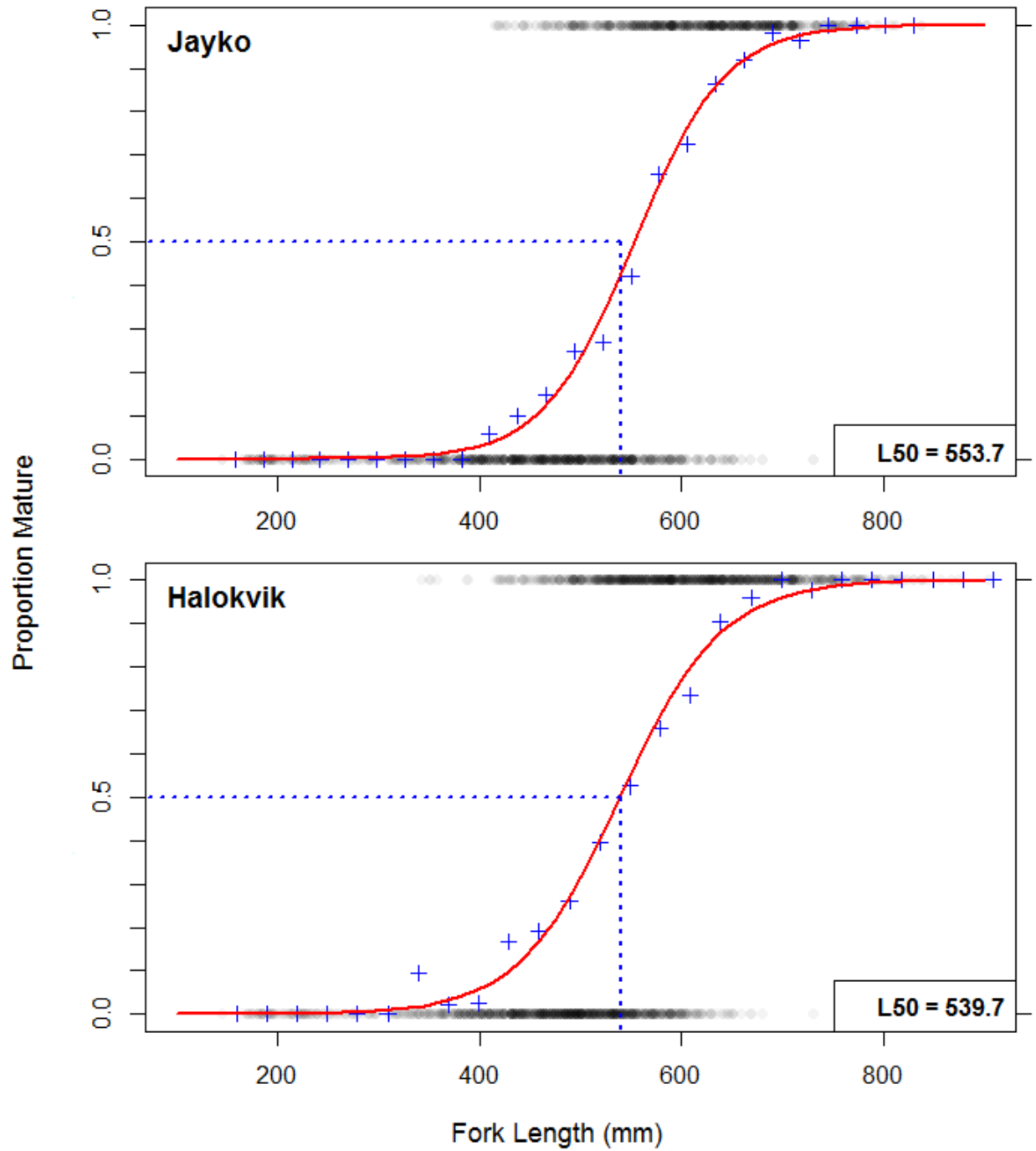


Figure 6. Length at 50% maturity (L_{50}) for Arctic Char (sexes combined) captured at the Jayko and Halokvik rivers, NU, using multi-mesh gill nets during fishery-independent sampling. Shown are the results for all available fishery-independent data including (bottom left corner) the estimate of L_{50} for each river.

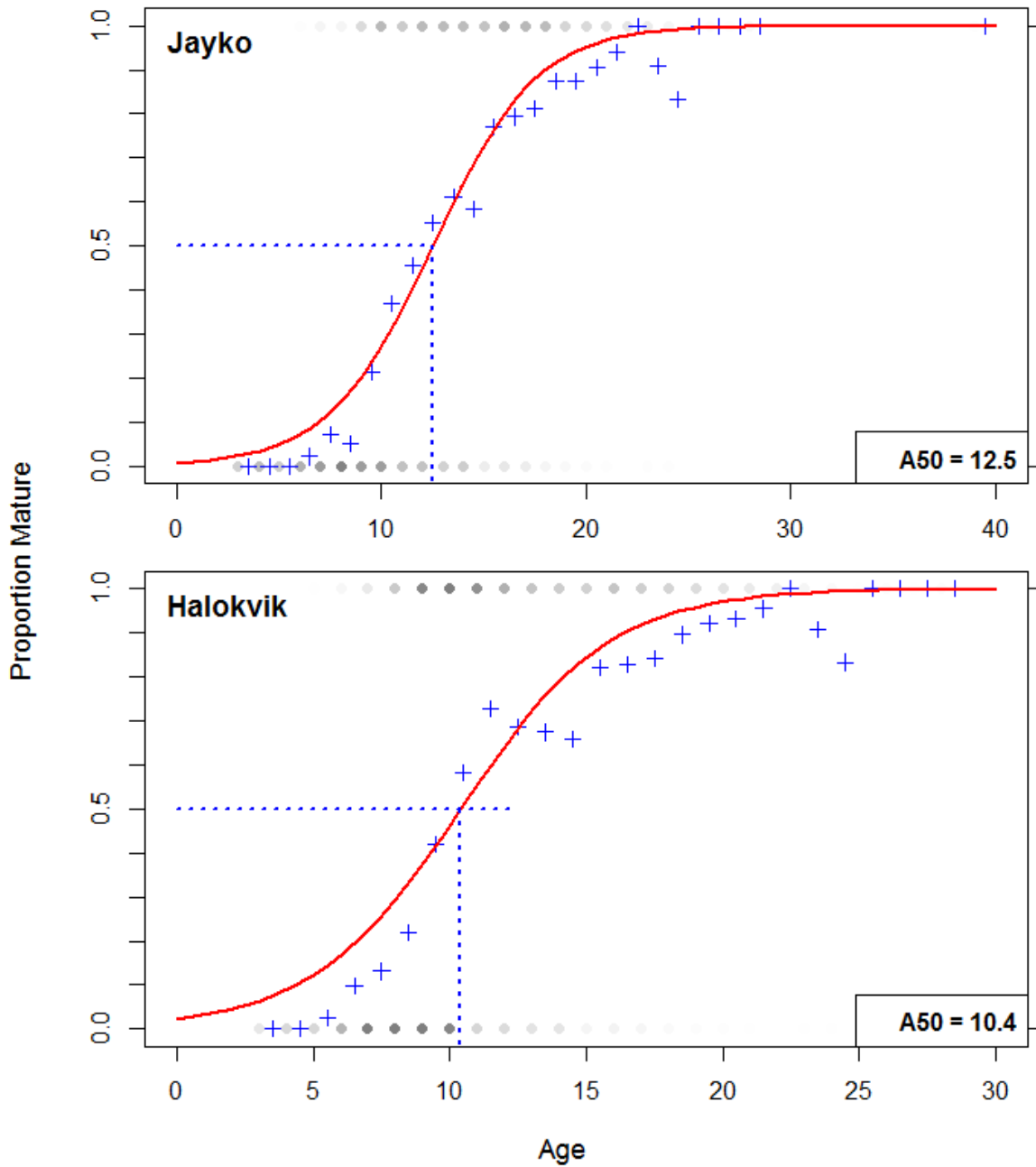


Figure 7. Age at 50% maturity (A_{50}) for Arctic Char (sexes combined) captured at the Jayko and Halokvik rivers, NU, using multi-mesh gill nets during fishery-independent sampling. Shown are the results for all available fishery-independent data including (bottom left corner) the estimate of A_{50} for each river.

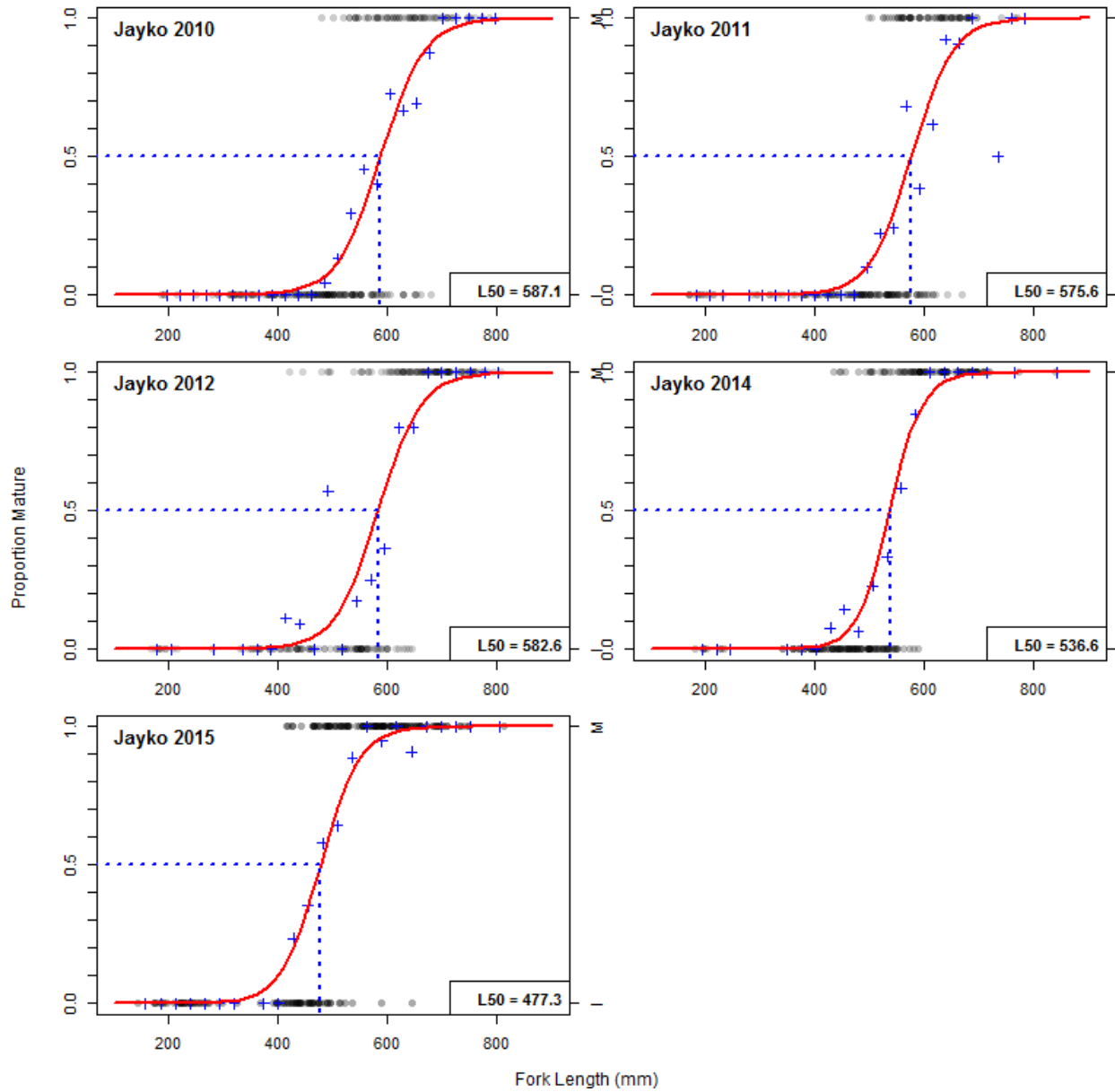


Figure 8. Length at 50% maturity (L_{50}) for Arctic Char (sexes combined) captured at the Jayko River, NU, using multi-mesh gill nets during fishery-independent sampling, 2010–2015. Shown are the results for each year of sampling including (bottom left corner) the estimate of L_{50} for each year.

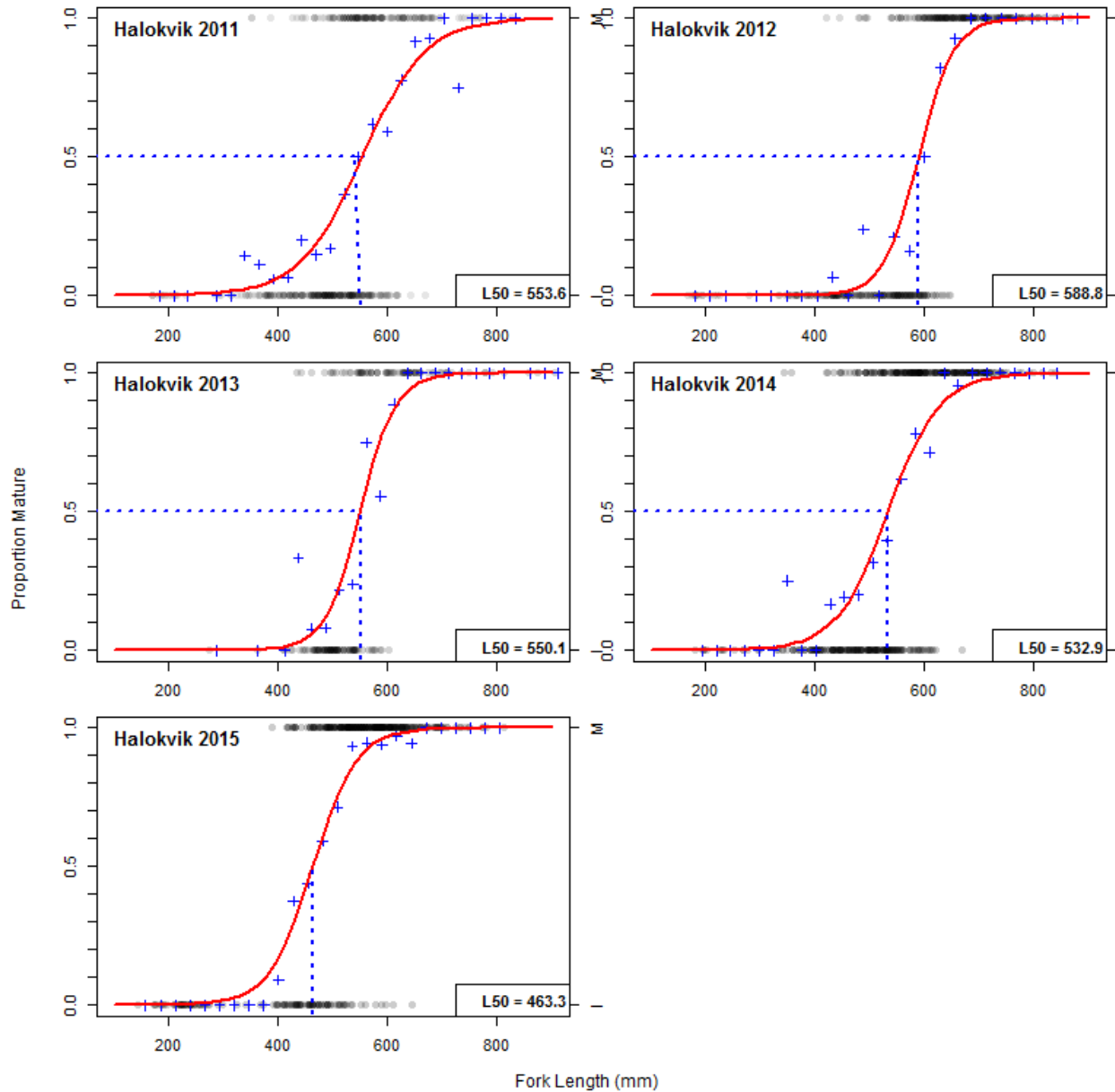


Figure 9. Length at 50% maturity (L_{50}) for Arctic Char (sexes combined) captured at the Halokvik River, NU, using multi-mesh gill nets during fishery-independent sampling, 2010–2015. Shown are the results for each year of sampling including (bottom left corner) the estimate of L_{50} for each year.

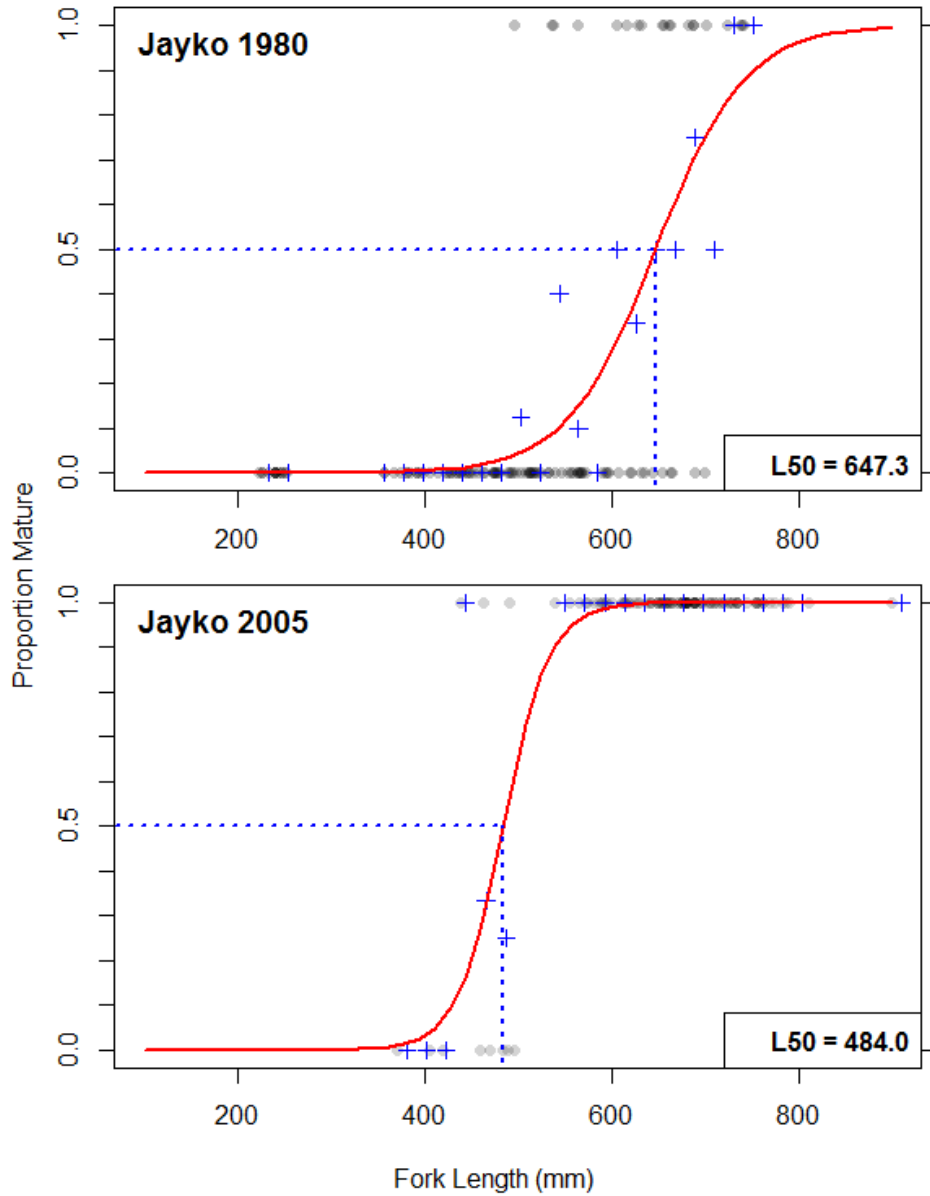


Figure 10. Length at 50% maturity (L50) for Arctic Char (sexes combined) captured at the Jayko River, NU, historical data from 1980 and 2005. Shown are the results for each year of sampling for which historical data on maturity status were available including (bottom left corner) the estimate of L50 for each year.

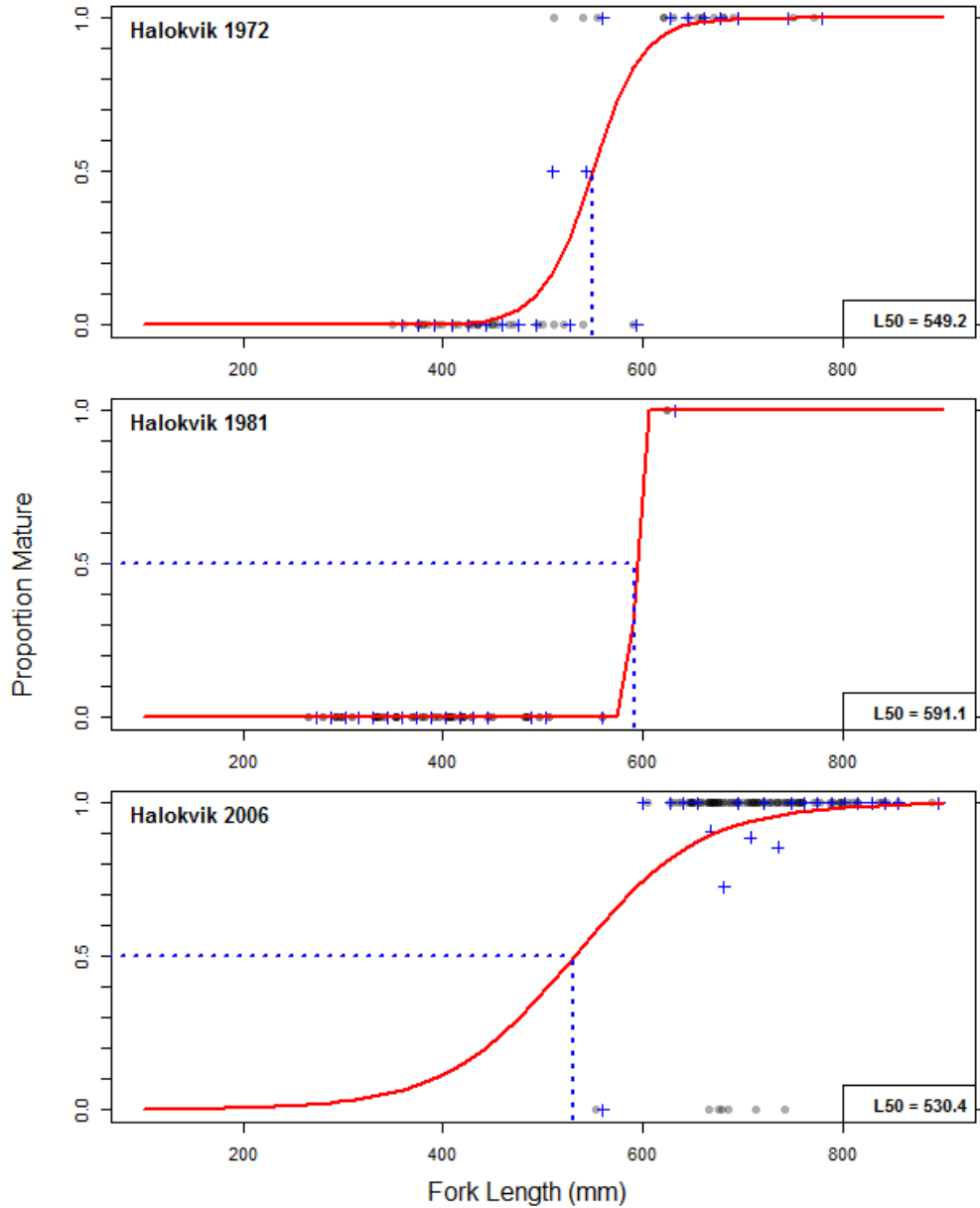


Figure 11. Length at 50% maturity (L_{50}) for Arctic Char (sexes combined) captured at the Halokvik River, NU, historical data from 1972, 1981 and 2006. Shown are the results for each year of sampling for which historical data on maturity status were available including (bottom left corner) the estimate of L_{50} for each year.

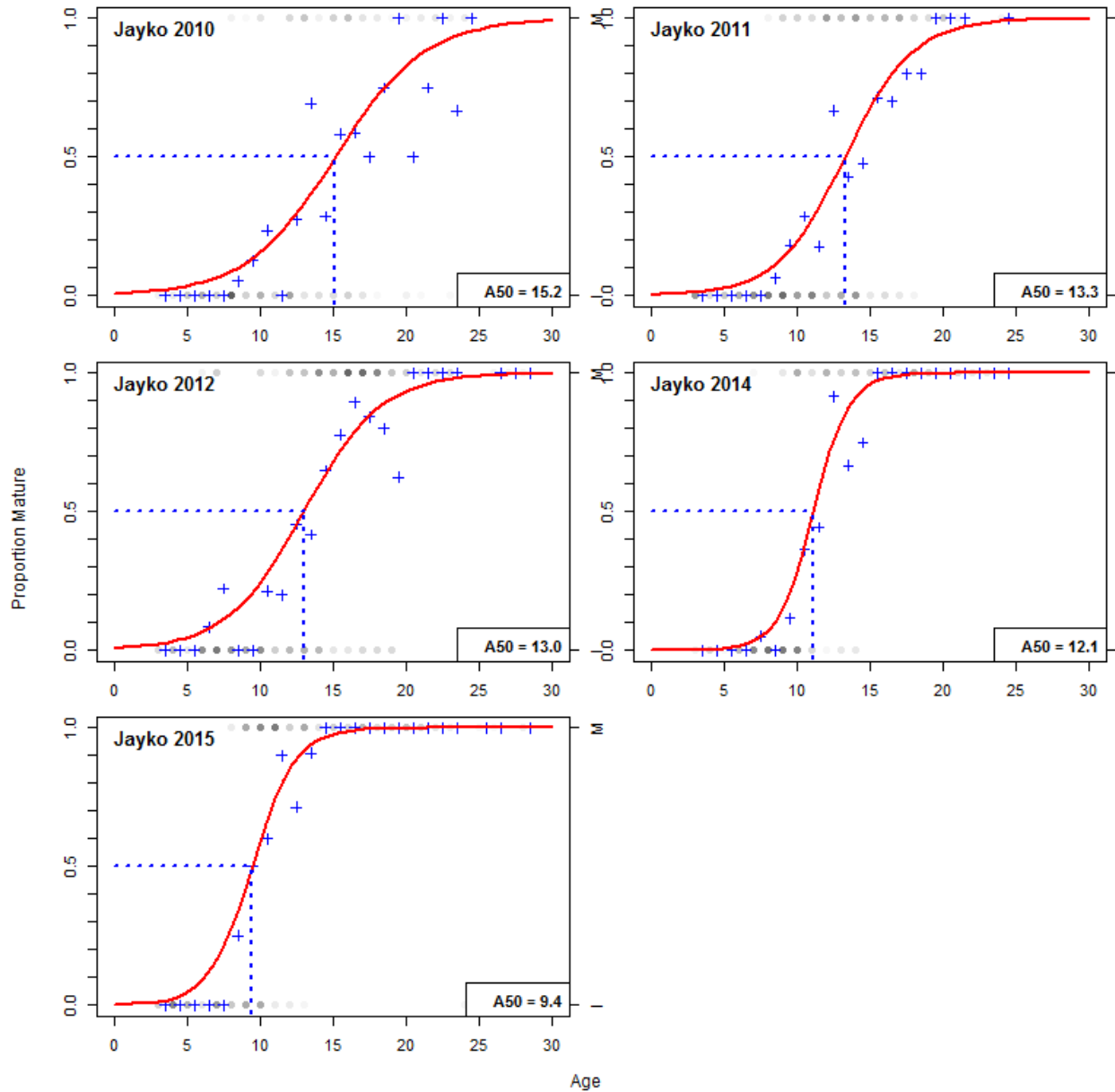


Figure 12. Age at 50% maturity (A_{50}) for Arctic Char (sexes combined) captured at the Jayko River, NU, using multi-mesh gill nets during fishery-independent sampling, 2010–2015. Shown are the results for each year of sampling including (bottom left corner) the estimate of A_{50} for each year.

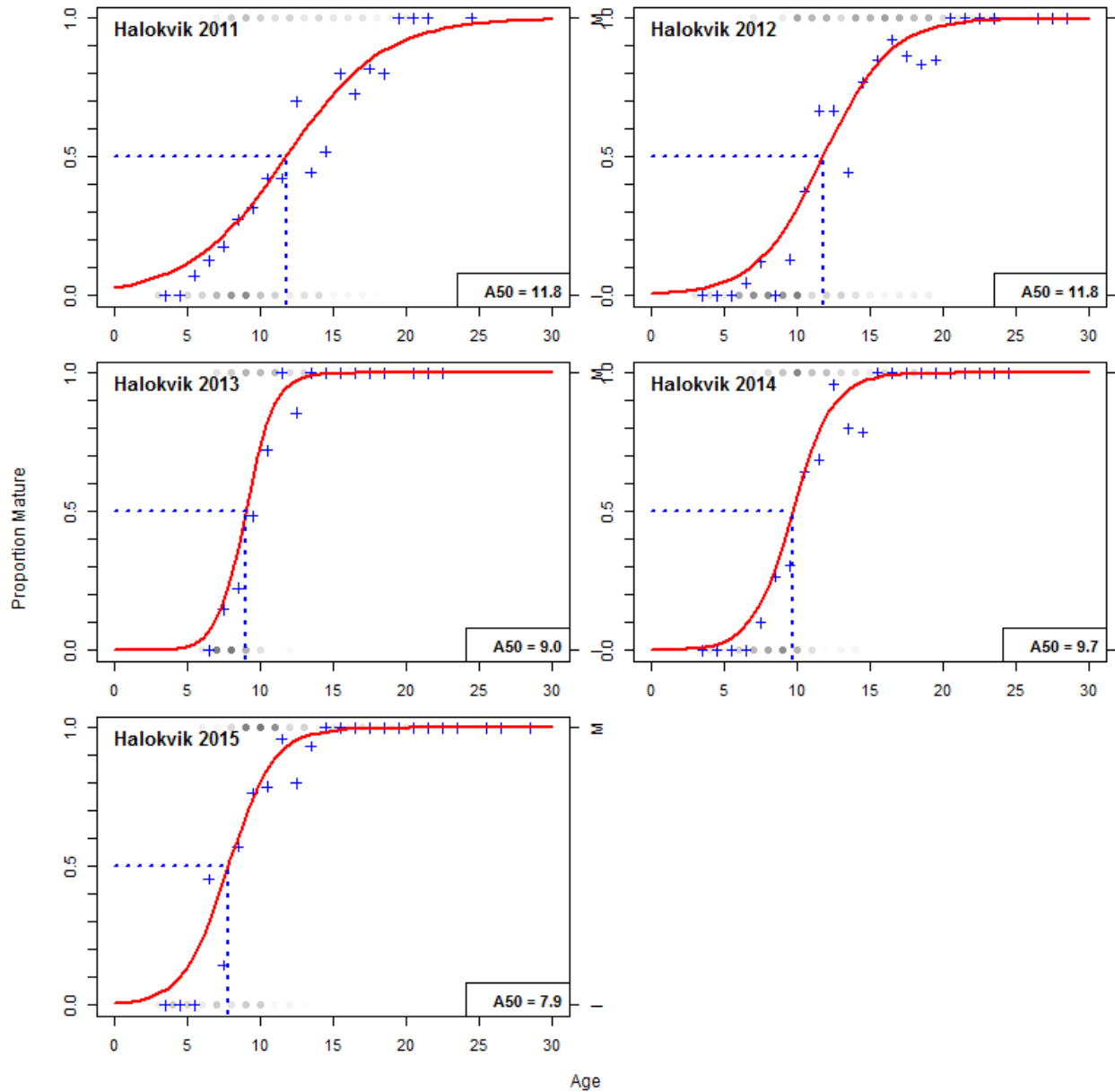


Figure 13. Age at 50% maturity (A_{50}) for Arctic Char (sexes combined) captured at the Halokvik River, NU, using multi-mesh gill nets during fishery-independent sampling, 2011–2015. Shown are the results for each year of sampling including (bottom left corner) the estimate of A_{50} for each year.

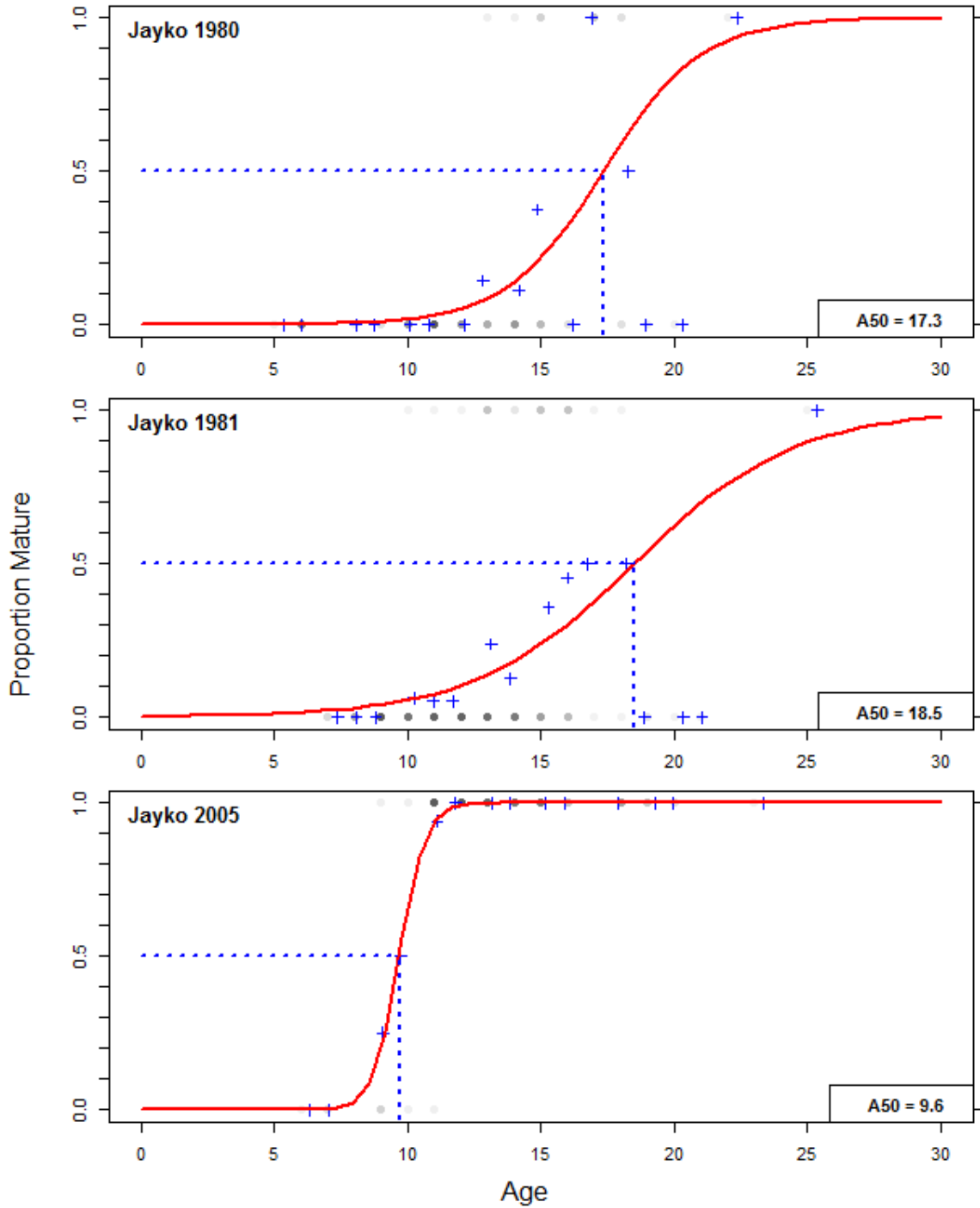


Figure 14. Age at 50% maturity (A_{50}) for Arctic Char (sexes combined) captured at the Jayko River, NU, historical data from 1980, 1981 and 2005. Shown are the results for each year of sampling for which historical data on maturity status were available including (bottom left corner) the estimate of A_{50} for each year.

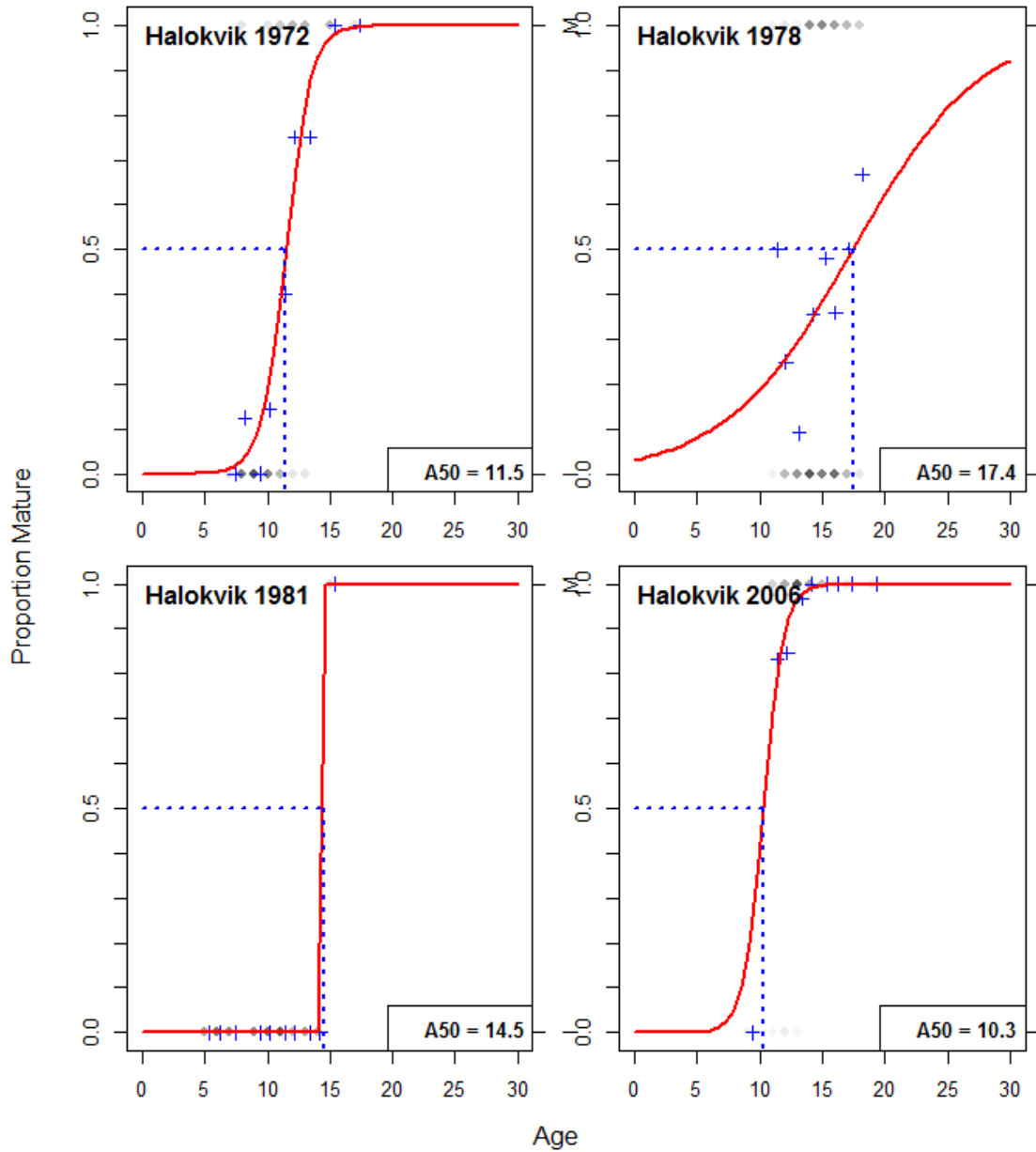


Figure 15. Age at 50% maturity (A_{50}) for Arctic Char (sexes combined) captured at the Halokvik River, NU, historical data from 1972, 1978, 1981 and 2006. Shown are the results for each year of sampling for which historical data on maturity status were available including (bottom left corner) the estimate of A_{50} for each year.

Weight and length

Across all decades of sampling, individual weight of Jayko River Arctic Char collected as part of the fishery-dependent sampling program ranged from 813 to 9,375 g with a mean of 3,733 g. (Table 2). On average, individual weights of Halokvik River Arctic Char collected as part of the fishery-dependant sampling program were significantly larger ($t = -28.20$, d.f. = 13,974, $p < 0.01$), ranging from 140 to 11,298 g with an average of 4,327 g (Table 2). Mean round weight was highly variable among years following a sinusoidal pattern with noticeable peaks evident throughout the time-series (Figure 16). Within each stock linear models showed an

increasing trend in weight through time ($p < 0.01$, Figure 16). This is especially apparent at the Halokvik River. The increase in weight in the latter years could potentially be related to the shift from fishing with gill net to weirs (~1994) at both rivers. Gill nets would have selectively harvested larger individuals. Additionally, around that time, the Halokvik fishery switched from harvesting in July to harvesting at the end of August. This would result in the harvest of Arctic Char that are in better condition after having spent the summer feeding at sea. At both rivers, average weights differed significantly between the first and last decades of sampling (Jayko: $t = -18.07$, $d.f. = 1251.2$, $p < 0.01$; Halokvik: $t = -32.419$, $d.f. = 1447.6$, $p < 0.01$).

Arctic Char sampled as part of a fishery-independent sampling program at the Jayko River ranged in weight from 45 to 7750 g (average across all years = 1847 g), whereas at the Halokvik River round weight ranged from 75 to 7650 g (average across all years = 2341 g, Figure 17, Table 4). Combined over all sampling years, there were no differences in weight between sexes in either the Jayko ($t = 1.64$, $d.f. = 973.29$, $p = 0.10$) or Halokvik ($t = 0.28$, $d.f. = 945.15$, $p = 0.78$) stocks. The average weights between the first and last sampling year at each location were significantly different (Jayko: $t = 2.24$, $d.f. = 407.19$, $p = 0.026$; Halokvik: $t = -2.97$, $d.f. = 385.88$, $p < 0.01$, Table 4).

Weight frequency distributions for fishery-dependant data were essentially unimodal in shape for both the Jayko and Halokvik stocks and distributions were qualitatively similar among decades within each stock (Figures 18 and 19). The weight of Arctic Char harvested from Jayko was primarily dispersed among weight intervals between 2000 and 6000 g (Figure 18) whereas Halokvik often attained weights larger than 6000 g (Figure 19). The weight frequency distributions were significantly different between the first and last decades of sampling for both stocks with the distributions skewed towards larger sizes in the latter years (Jayko: $D = 0.37$, $p\text{-value} < 0.01$; Halokvik: $D = 0.561$, $p\text{-value} < 0.01$). Weight frequency distributions for both Jayko and Halokvik Arctic Char sampled during fishery-independent programs appear somewhat left-skewed suggesting, as might be expected, that smaller fish are captured during fishery-independent sampling (Figures 20 and 21). Males and females appear to be evenly distributed among weight classes when assessing the fishery-independent data and there were no differences in weight between sexes at either Jayko ($t = 1.64$, $d.f. = 973.29$, $p = 0.10$) or Halokvik ($t = 0.28$, $d.f. = 945.15$, $p = 0.60$). The weight frequency distributions differed significantly between the first and last years of fishery-independent sampling at each location (Jayko: $D = 0.15$, $p = 0.019$; Halokvik: $D = 0.23$, $p < 0.01$).

Table 2. Summary of fishery-dependent biological data (fork length, round weight, age and condition) from commercially harvested Arctic Char from the Jayko (A) and Halokvik (B) rivers collected as part of the Cambridge Bay plant sampling program. Data are summarized by decade. N = total number of fish sampled for the decade.

Year	N	Mean Fork Length (Range)	Mean Weight (Range)	Mean Age (Range)	Mean Condition Factor (Range)
Jayko River					
1970s	927	676 (435–835)	3412 (813–7875)	16.26 (10–32)	1.07 (0.54–1.92)
1980s	2388	657 (443–845)	3480 (875–7312)	15.64 (8–26)	1.21 (0.64–2.51)
1990s	1849	659 (465–870)	3941 (1188–9375)	14.40 (7–28)	1.34 (0.69–2.29)
2000s	1505	667 (478–900)	3801 (1164–9360)	13.46 (7–24)	1.25 (0.72–2.02)
2010s	600	715 (540–850)	4417 (1878–8274)	17.19 (9–32)	1.30 (0.87–2.22)
Average	1454	667 (435–900)	3733 (813–9375)	15.07 (7–32)	1.23 (0.54–2.29)
Halokvik River					
1970s	1182	656 (225–925)	3064 (140–8156)	14.05 (7–20)	1.01 (0.54–1.70)
1980s	1626	706 (410–861)	4010 (100–8188)	15.24 (8–22)	1.13 (0.57–2.18)
1990s	2069	702 (445–965)	4547 (1250–11298)	13.11 (7–23)	1.30 (0.70–2.83)
2000s	1688	727 (454–895)	4894 (1248–8850)	13.73–7–28)	1.2 (0.64–2.95)
2010s	750	734 (500–890)	5124 (1573–6123)	14.29–7–24)	1.27 (0.64–2.15)
Average	1463	704 (225–965)	4327 (140–11298)	13.97 (7–28)	1.20 (0.54–2.95)

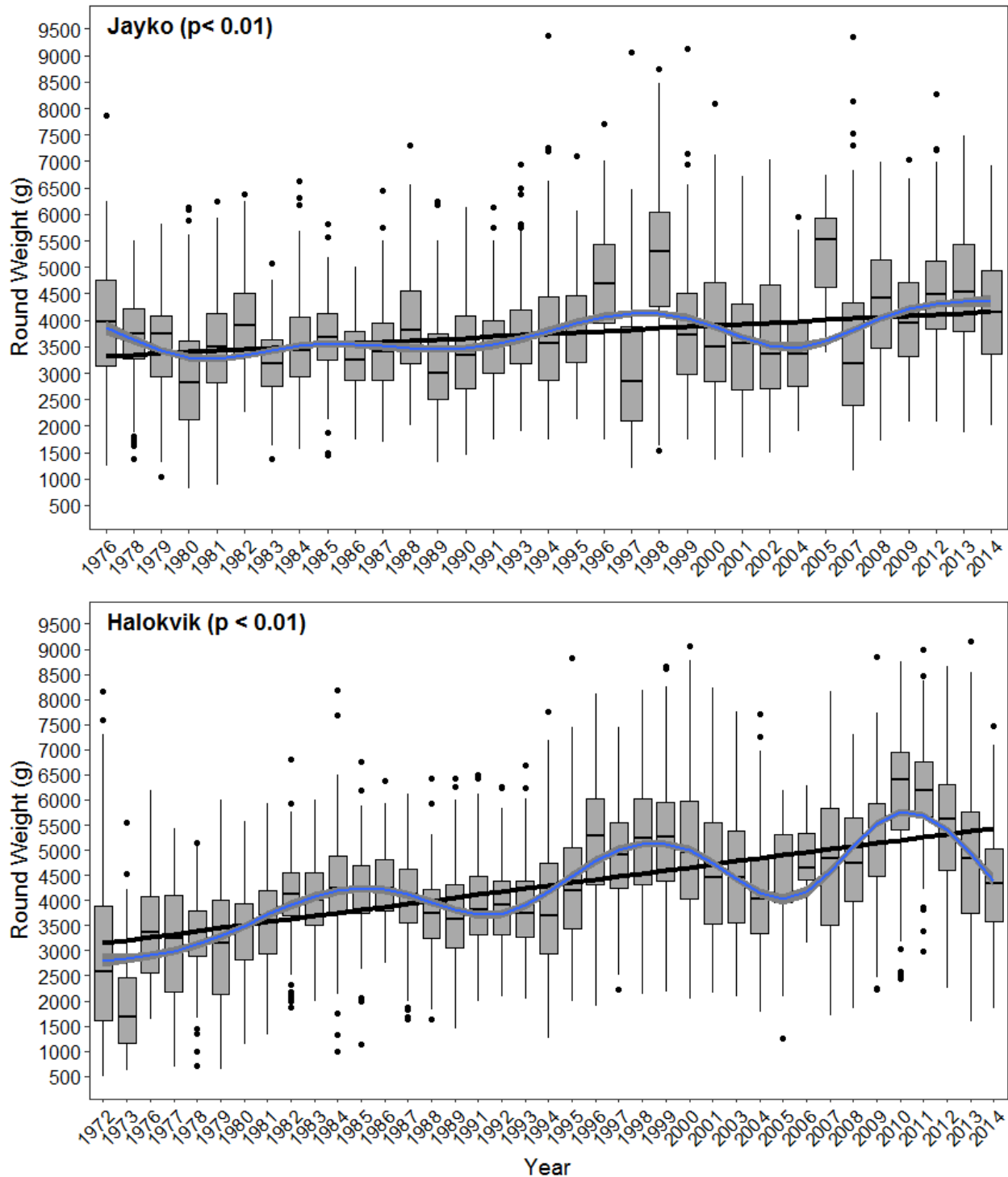


Figure 16. Box plots (showing the 25th and 75th percentile or inter-quartile range (IQR, grey box), the median (black line within the box) and 1.5 x the IQR ('whiskers' of the plot)) of round weight (g) collected from fishery-dependent sampling of Arctic Char from the Jayko and Halokvik rivers. A trend line (shown in black) was fit to the data and the significance of this relationship is shown in the top left corner. A spline (blue line) was also fit to help visualize patterns in the data.

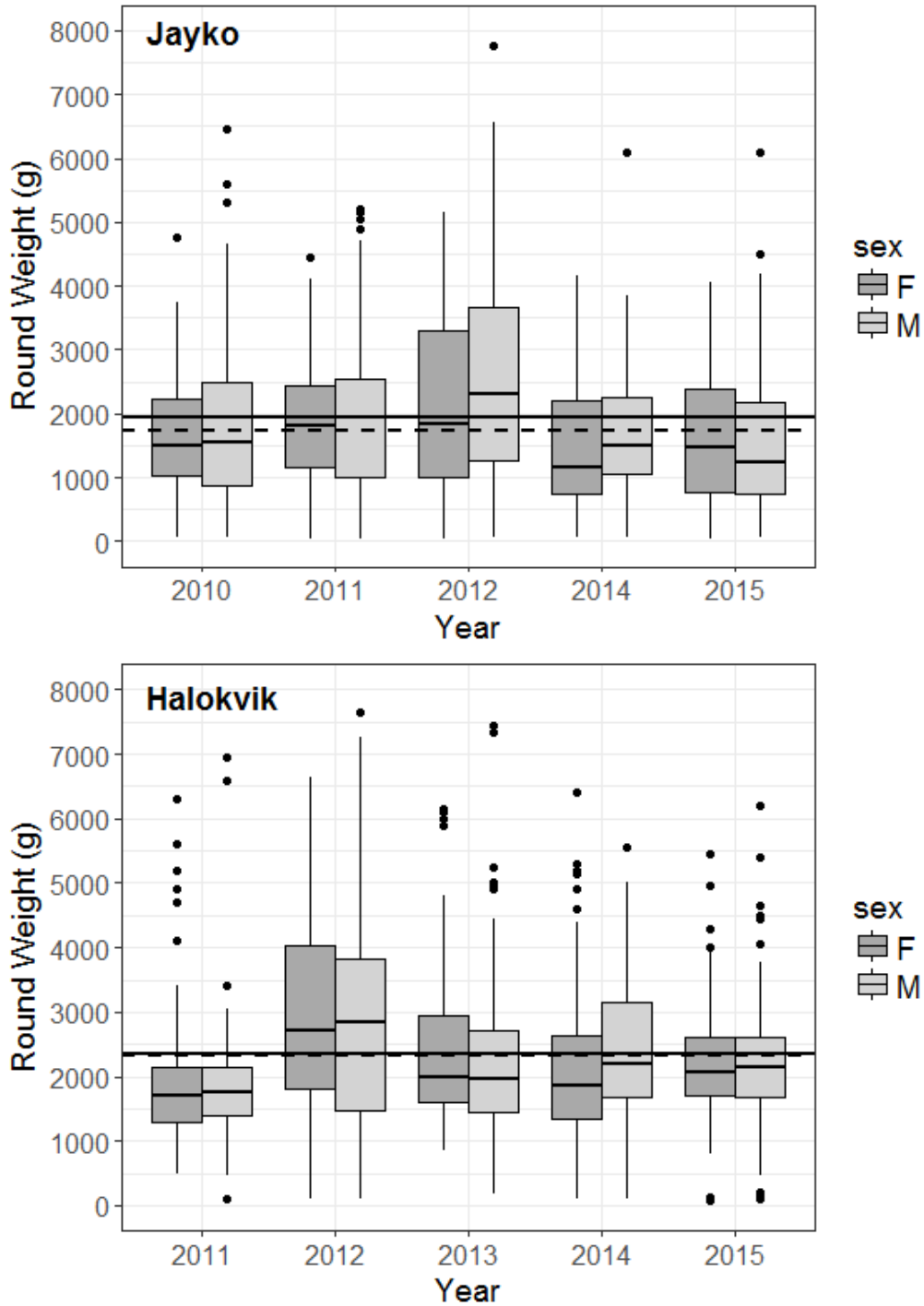


Figure 17. Box plots (showing the 25th and 75th percentile or inter-quartile range (IQR, grey box), the median (black line within the box) and $1.5 \times$ the IQR ('whiskers' of the plot)) of round weight (g) collected from fishery-independent sampling of Arctic Char from the Jayko and Halokvik rivers, 2010–2015. The mean round weight across all years is shown for males (solid black line) and females (dotted black line).

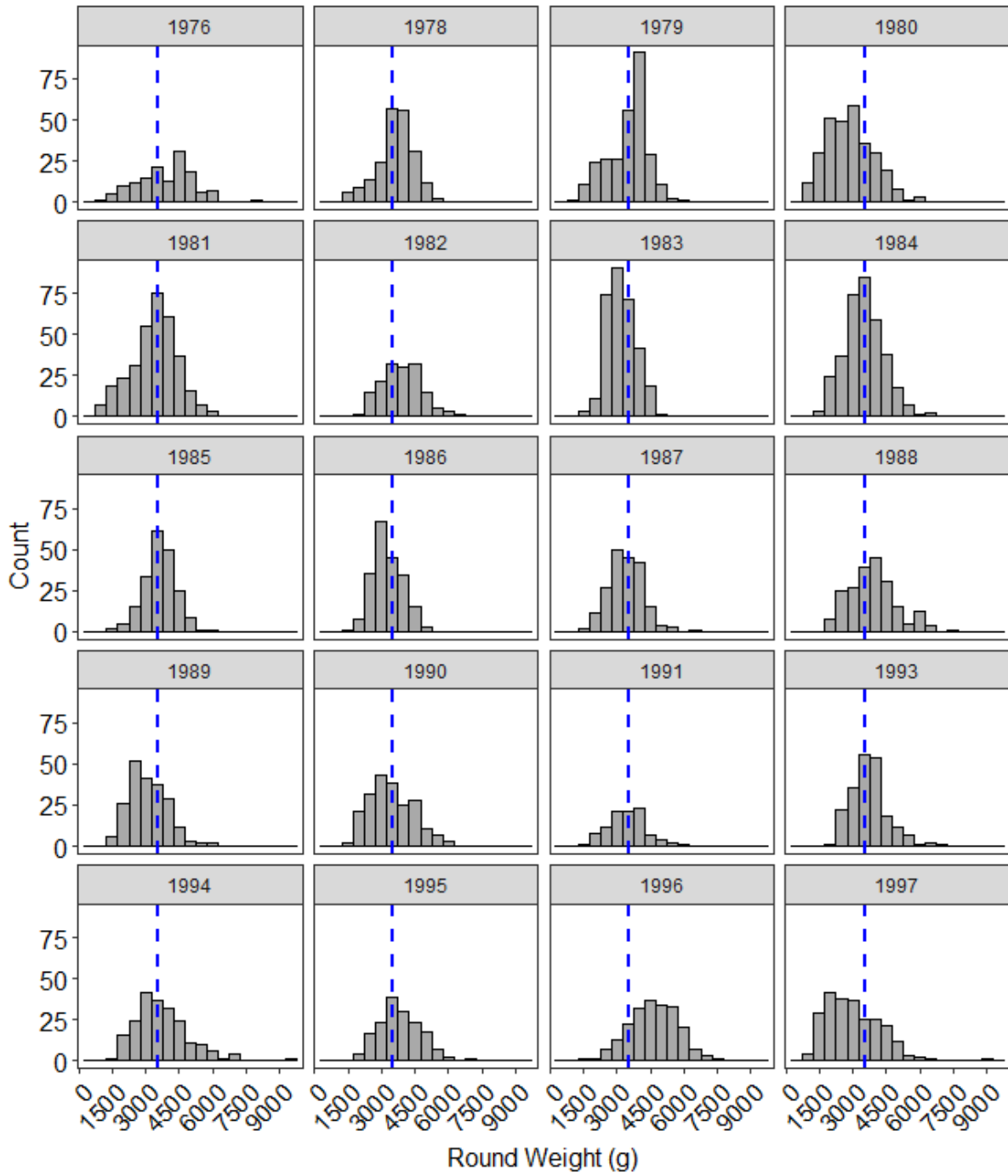


Figure 18. Frequency distributions of round weight (g) collected from fishery-dependent sampling of Arctic Char from the Jayko River, NU. Mean round weight across all years is shown as a blue dotted line.

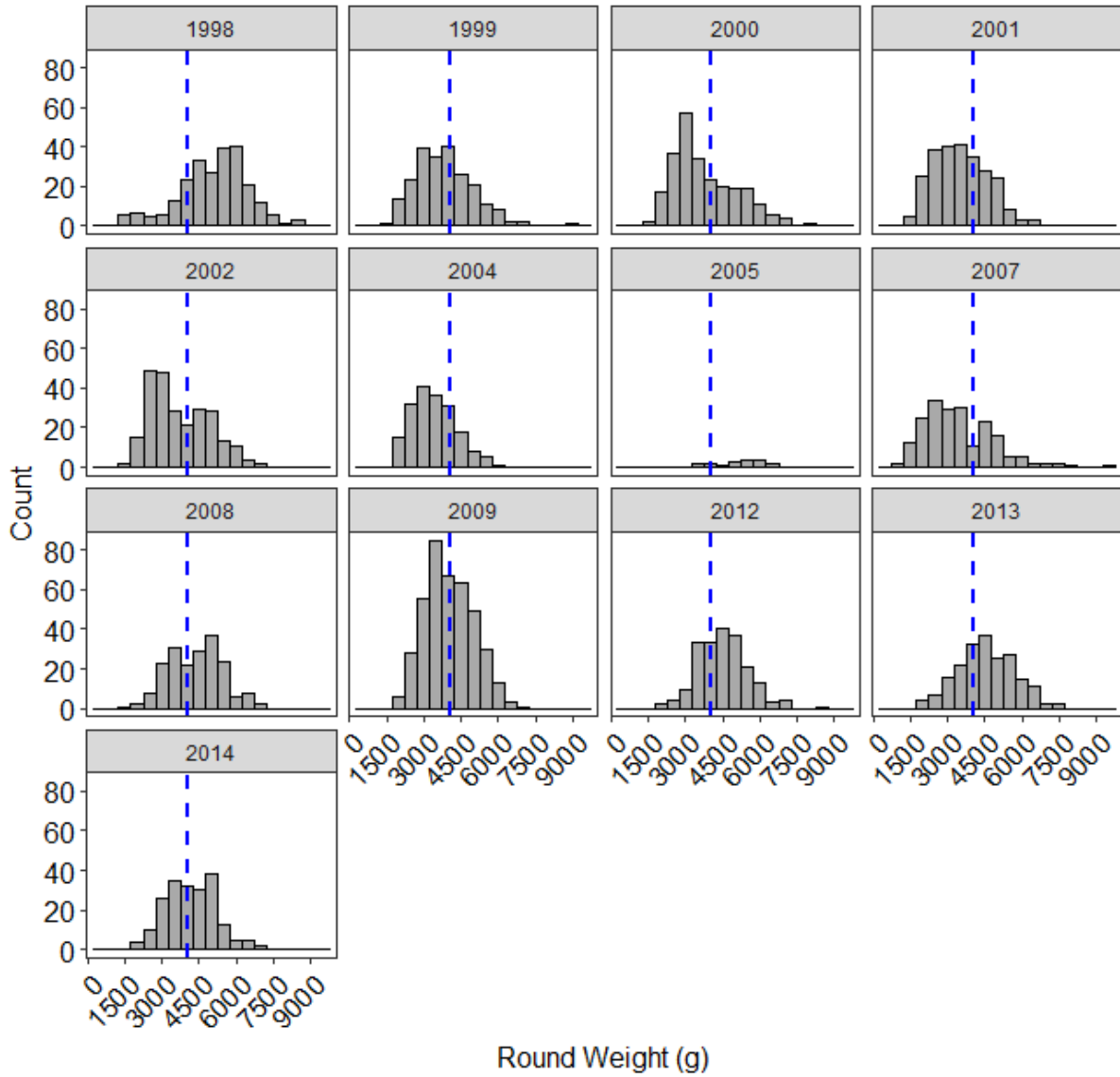


Figure 18 Continued. Frequency distributions of round weight (g) collected from fishery-dependent sampling of Arctic Char from the Jayko River, NU. Mean round weight across all years is shown as a blue dotted line.

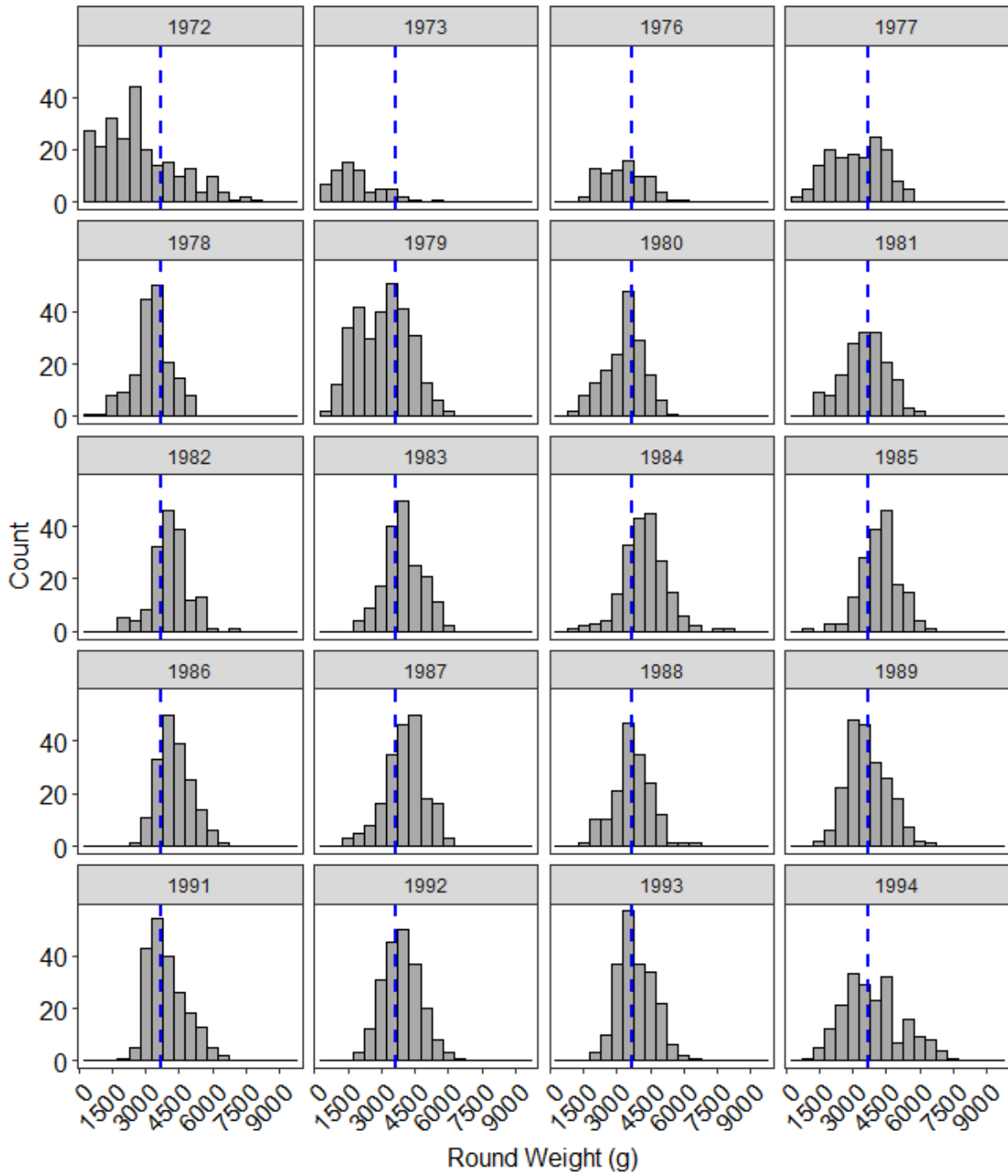


Figure 19. Frequency distributions of round weight (g) collected from fishery-dependent sampling of Arctic Char from the Halokvik River, NU. Mean round weight across all years is shown as a blue dotted line.

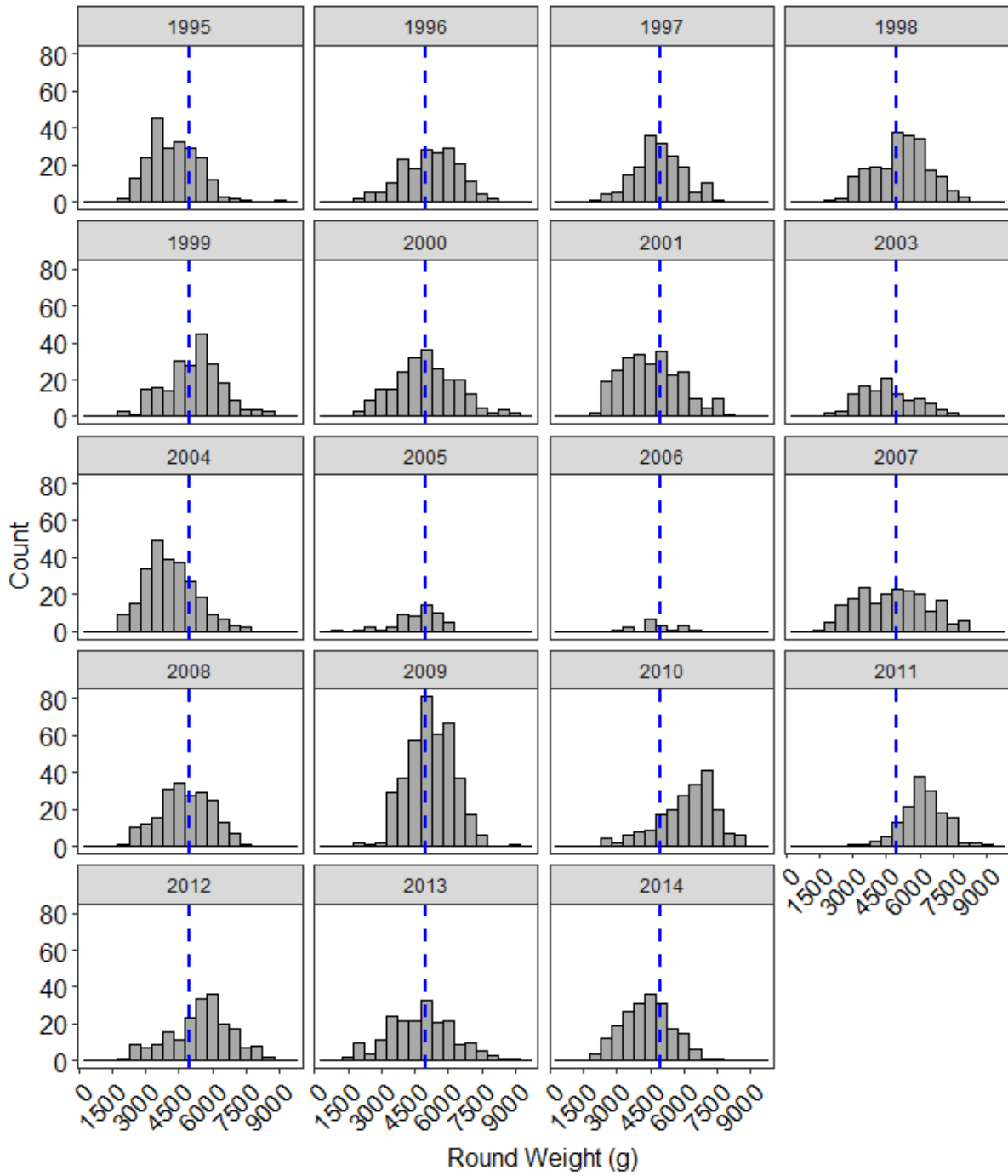


Figure 19 Continued. Frequency distributions of round weight (g) collected from fishery-dependent sampling of Arctic Char from the Halokvik River, NU. Mean round weight across all years is shown as a blue dotted line.

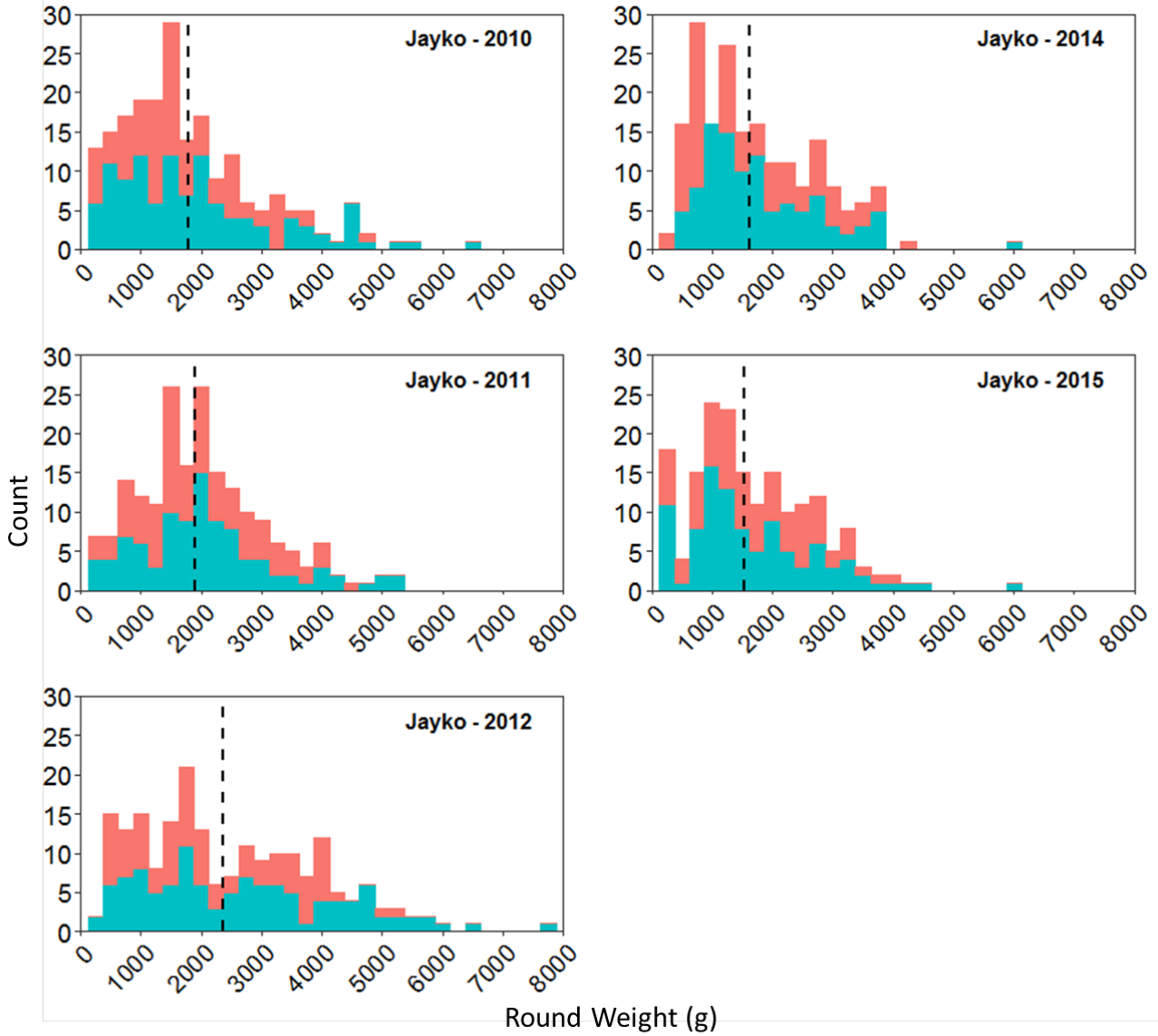


Figure 20. Frequency distributions of round weight (g) collected from fishery-independent sampling of Arctic Char from the Jayko River, NU, 2010–2015. Females are shown in red and males are shown in blue. The mean round weight for each year (sexes combined) is shown as a black dotted line.

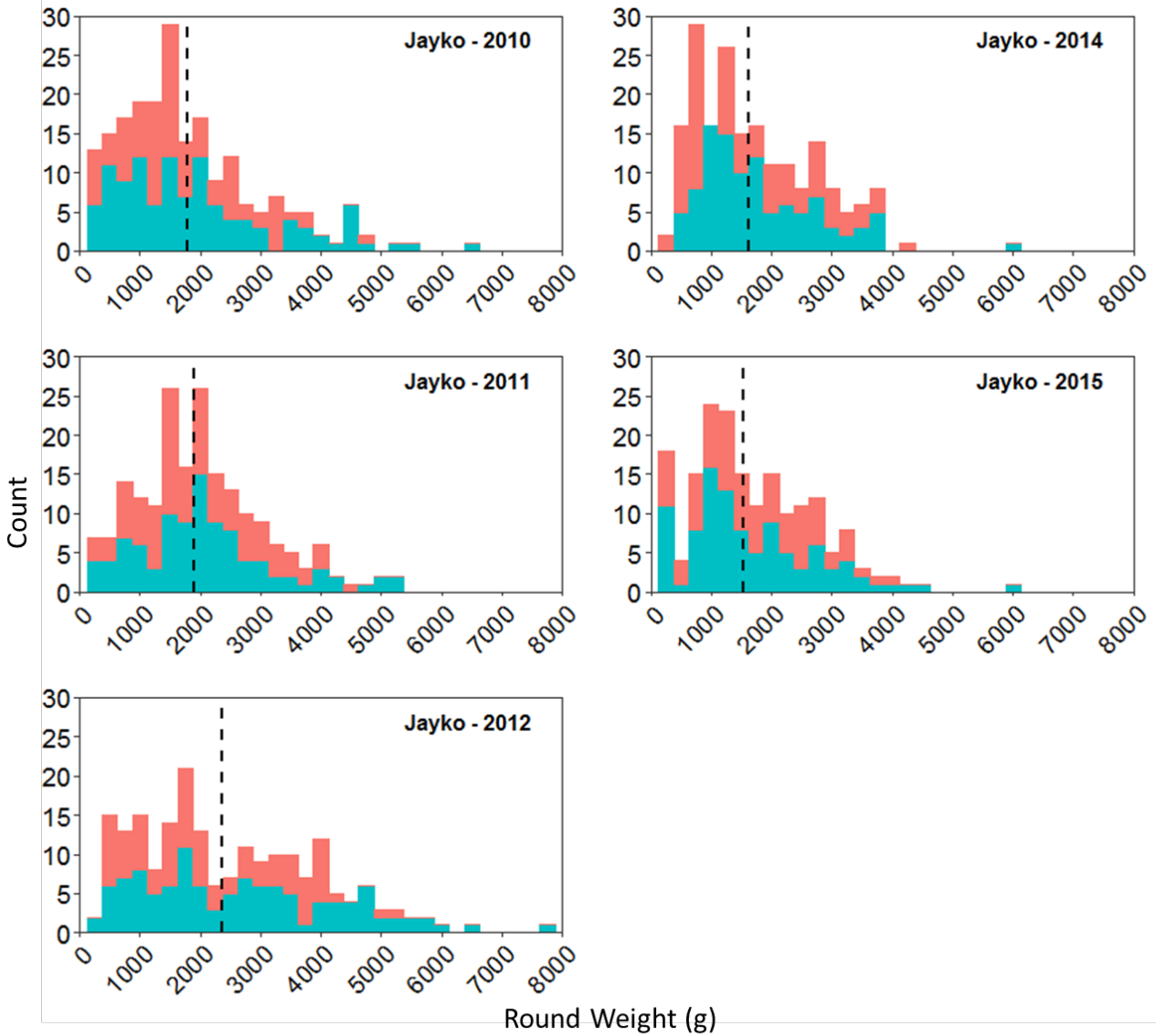


Figure 21. Frequency distributions of round weight (g) collected from fishery-independent sampling of Arctic Char from the Halokvik River, NU, 2011–2015. Females are shown in red and males are shown in blue. The mean round weight for each year (sexes combined) is shown as a black dotted line.

Table 3. Linear regression parameters: *a* (*y*-intercept), *b* (slope) and *R*² (coefficient of determination) for length-weight relationships of Jayko and Halokvik river Arctic Char collected from the commercial harvest (i.e., plant sampling, Top) or through fishery-independent research surveys (bottom). Na for Jayko River was due to blizzard in 2013 preventing access to the site. Na for Halokvik River was because sampling did not begin until 2011.

Year/Decade	Jayko River				Halokvik River			
	<i>a</i>	<i>B</i>	<i>R</i> ²	<i>p</i>	<i>a</i>	<i>B</i>	<i>R</i> ²	<i>p</i>
Fishery-Dependent								
1970s	-10.87	2.91	0.84	< 0.001	-12.91	3.21	0.92	< 0.001
1980s	-9.16	2.66	0.71	< 0.001	-8.62	2.58	0.76	< 0.001
1990s	-10.77	2.93	0.87	< 0.001	-8.79	2.62	0.72	< 0.001
2000s	-10.00	2.80	0.84	< 0.001	-9.56	2.74	0.85	< 0.001
2010s	-10.00	2.80	0.71	< 0.001	-9.14	2.67	0.85	< 0.001
Fishery-Independent								
2010	-11.44	3.00	0.98	< 0.001	Na	Na	Na	Na
2011	-12.21	3.13	0.98	< 0.001	-11.21	3.00	0.96	< 0.001
2012	-12.30	3.14	0.99	< 0.001	-11.60	3.05	0.97	< 0.001
2013	Na	Na	Na	Na	-11.17	2.98	0.96	< 0.001
2014	-11.47	3.00	0.98	< 0.001	-13.02	3.25	0.97	< 0.001
2015	-11.45	3.00	0.98	< 0.001	-12.01	3.12	0.95	< 0.001

In general, Arctic Char in the Cambridge Bay region grow to larger sizes than char in other areas of the Canadian Arctic where they are exploited (Harwood 2009, Harris and Tallman 2010). Mean round weight in both fisheries exhibited a sinusoidal pattern across the duration of the assessment (Figure 16) with evidence of a significant ($p < 0.01$) increase in round weight in the latter years. Long-term declines in mean weight have been linked to heavy exploitation in Newfoundland (Dempson et al. 2008). Furthermore, declines in weight have previously been used in these systems as a measure of stock over-exploitation (e.g., Ekalluk River in the late 1960s, Kristofferson and Berkes 2005) and previous assessments for these fisheries included fish weight as a key parameter of stock health (Day and Harris 2013). More work is needed to resolve the potential cause(s) of the increase in average round weight towards the latter years and to determine the driving causes behind the sinusoidal patterns observed in Cambridge Bay. For example, increased duration of the marine ice-free period may allow char to feed longer at sea and attain better condition. Variability in sea ice conditions may lead to sinusoidal patterns in weight and condition (Harwood et al. 2013).

Across all decades of sampling, individual fork length of Jayko River Arctic Char collected as part of the fishery-dependant sampling program ranged from 435 to 900 mm while averaging 667 mm (Table 2). On average individual length of Halokvik River Arctic Char collected as part of the fishery-dependant sampling program was significantly larger ($t = -32.23$, d.f. = 14,339, $p < 0.01$), ranging from 225 to 965 mm with an average of 704 mm (Table 2). Mean fork length was variable among years within each waterbody and clearly exhibited sinusoidal patterns in both waterbodies although the timing of peaks differed (Figure 22). Similar to weight, there was a clear increasing trend in fork length through time at both locations ($p < 0.01$, Figure 22). Once again, this is especially apparent in the Halokvik River stock, however, as mentioned previously these increases might be the result of the gear transition from weirs to gill nets at both waterbodies. In both stocks, average fork length differed significantly between the first and last

decades of sampling (Jayko: $t = -12.06$, d.f. = 1485.90, $p < 0.01$; Halokvik: $t = -20.01$, d.f. = 1824.10, $p < 0.01$).

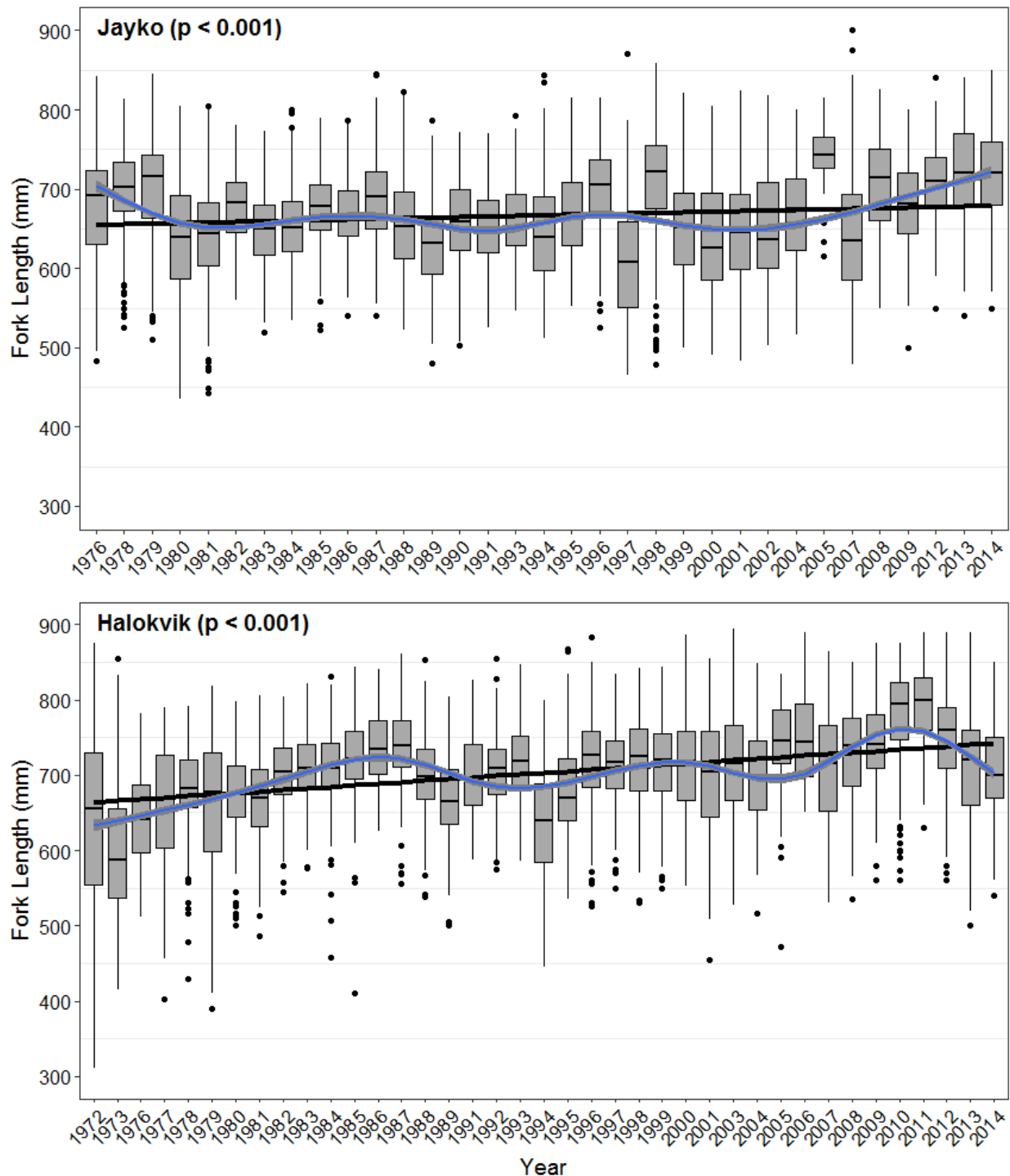


Figure 22. Box plots (showing the 25th and 75th percentile or inter-quartile range (IQR, grey box), the median (black line within the box) and 1.5 x the IQR ('whiskers' of the plot)) of fork length (mm) collected from fishery-dependent sampling of Arctic Char from the Jayko and Halokvik rivers. A trend line (shown in black) was fit to the data and the significance of this relationship is shown in the top left corner. A spline (blue line) was also fit to help visualize patterns in the data.

Mean fork length in fishery-independent sampling did not vary substantially among years in either sex within each stock (Figure 23, Table 4). At Jayko, fork length from fishery-independent sampling of Arctic Char ranged from 144 to 833 mm, averaging 519.20 mm across all samples (Table 4). Overall, males were slightly larger at Jayko (Table 4). At Halokvik, fork length from fishery-independent sampling of Arctic Char ranged from 209 to 905 mm, averaging 554.70 mm across all samples (Table 4). We detected no difference in fork length between sexes at this location ($t = 0.33$, $d.f. = 944.26$, $p = 0.74$) although overall mean fork length was different between waterbodies with Halokvik Arctic Char being larger ($t = -6.54$, $d.f. = 1956.50$, $p < 0.01$). Fork length between the first and last sampling years was not significantly different at Jayko ($t = 1.75$, $d.f. = 385.01$, $p = 0.0809$), whereas at Halokvik they were ($t = -3.21$, $d.f. = 382.67$, $p < 0.01$).

Fishery-dependant length frequency distributions illustrated that the size of harvested fish at both locations was unimodal in shape and relatively stable (Figures 24 and 25). Modal values differed among years for both rivers but were primarily centered around 560–750 mm at Jayko and 700–750 mm at Halokvik. The fork length frequency distributions between the first and last decades of fishery-dependent sampling at each location were significantly different (Jayko: $D = 0.25$, $p < 0.01$; Halokvik: $D = 0.38$, $p < 0.01$) with the distribution skewed towards larger sizes in the latter years (Table 4). Length frequency distributions from fishery-independent sampling were also primarily unimodal (except Jayko 2015) with modal lengths relatively stable across years (Figures 26 and 27). The modal values for length centered around 500-600 mm at both sites although there is considerable variation in the shape of the distribution (Figures 26 and 27). Males and females were evenly distributed among fork length classes. When assessing the fishery-independent data, the first and last years of sampling at each location were significantly different (Jayko: $D = 0.15$, $p = 0.019$; Halokvik: $D = 0.28$, $p < 0.01$).

Overall, mean length and weight have increased since the last assessment (Day and Harris 2013) at Jayko but decreased at Halokvik. Sinusoidal patterns in mean length and weight are evident throughout the history of each stock. The increases and decreases in mean length and weight throughout the harvest time series may relate more to environmental variation (e.g., ice-free periods, see Harwood et al. 2013) than to variation in exploitation. It is recommended that these parameters continue to be monitored through the plant sampling program and that environmental variables also be measured as a means to understanding what is driving the observed patterns in fish length and weight. Changes in demographic parameters, regardless of the cause, should be given full consideration when assessing the sustainability of a harvest level.

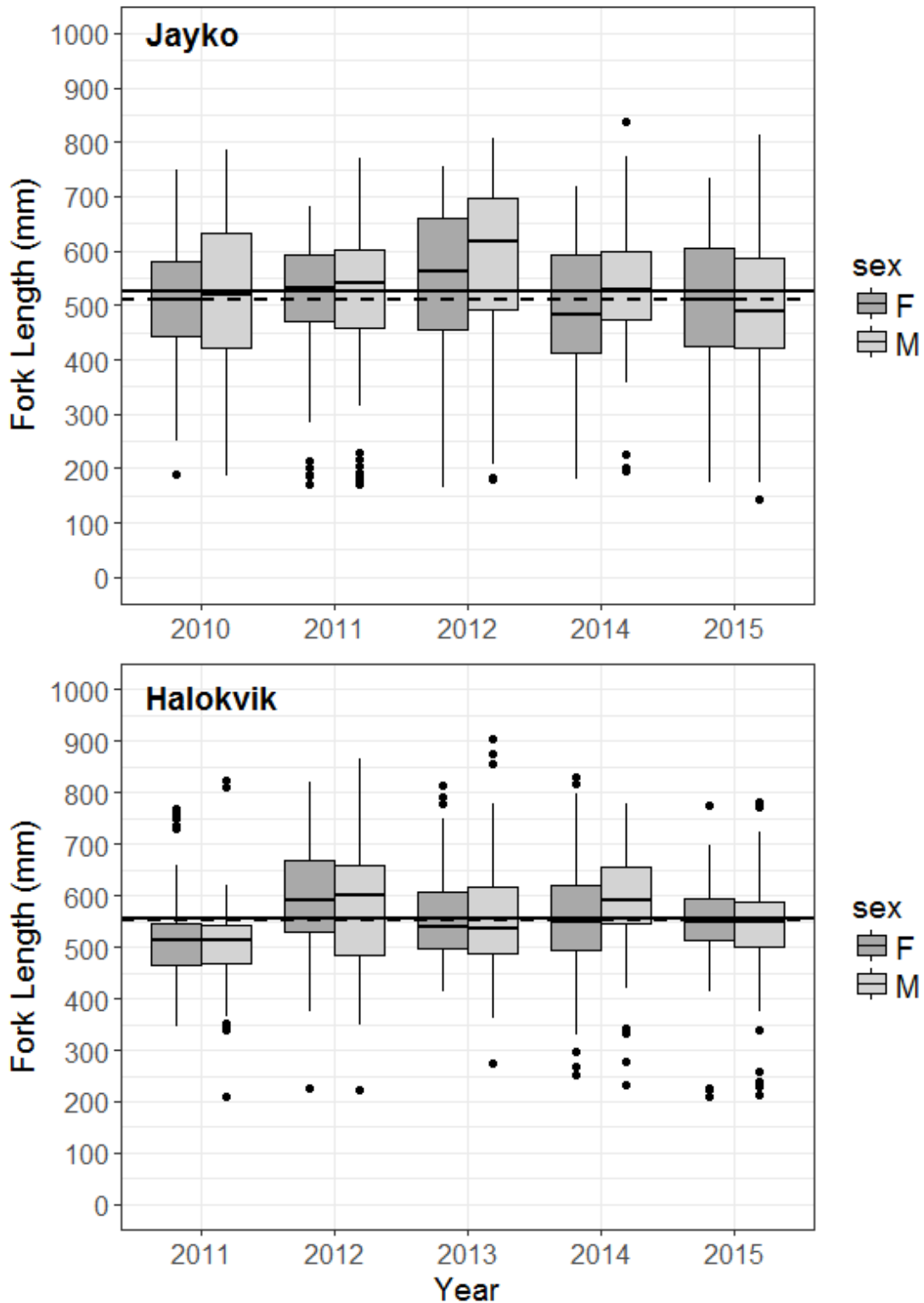


Figure 23. Box plots (showing the 25th and 75th percentile or inter-quartile range (IQR, grey box), the median (black line within the box) and 1.5 x the IQR ('whiskers' of the plot)) of fork length (mm) collected from fishery-independent sampling of Arctic Char from the Jayko and Halokvik rivers, 2010–2015. The mean fork length across all years is shown for males (solid black line) and females (dotted black line).

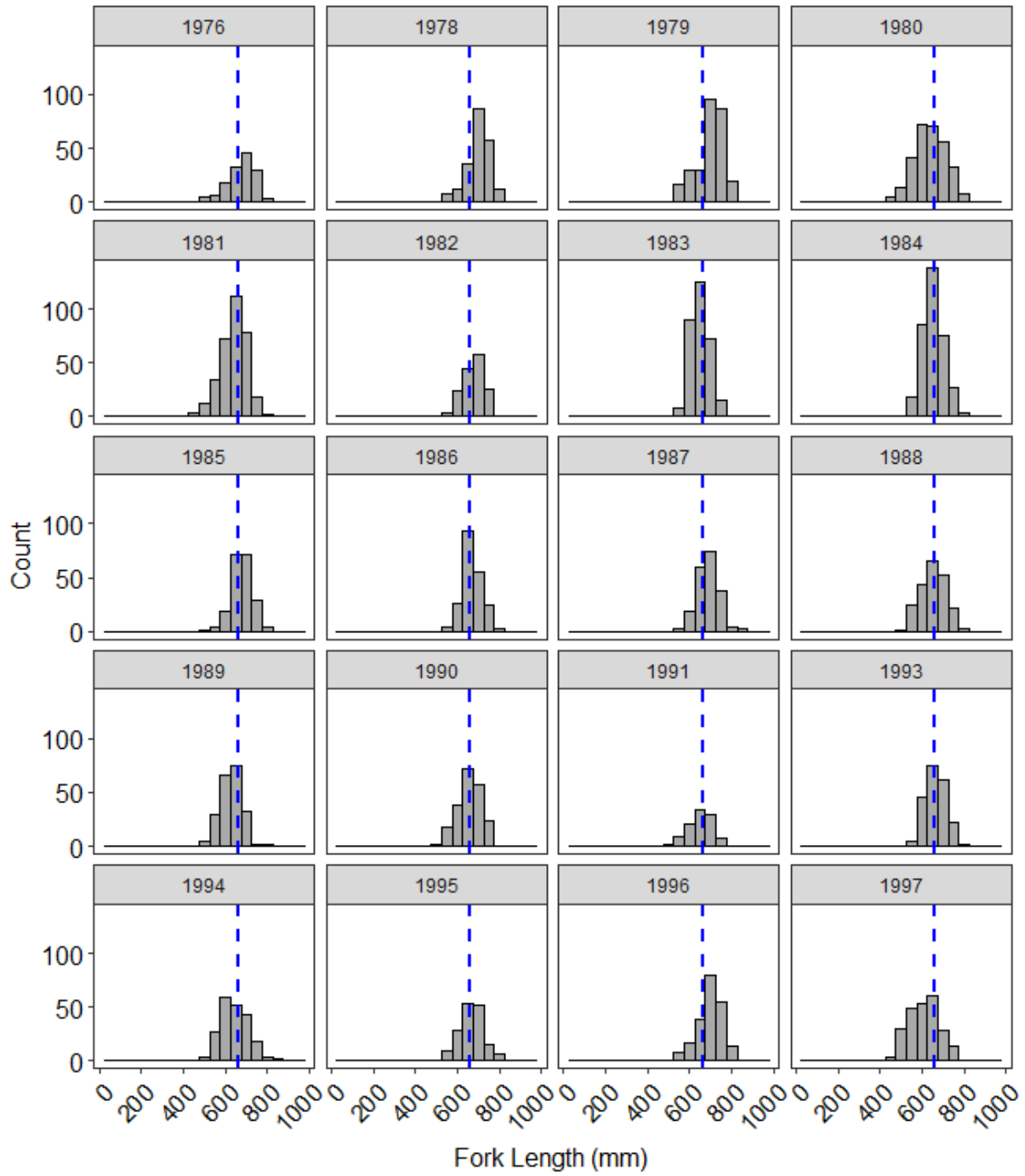


Figure 24. Frequency distributions of fork length (mm) collected from fishery-dependent sampling of Arctic Char from the Jayko River, NU. Mean fork length across all years is shown as a blue dotted line.

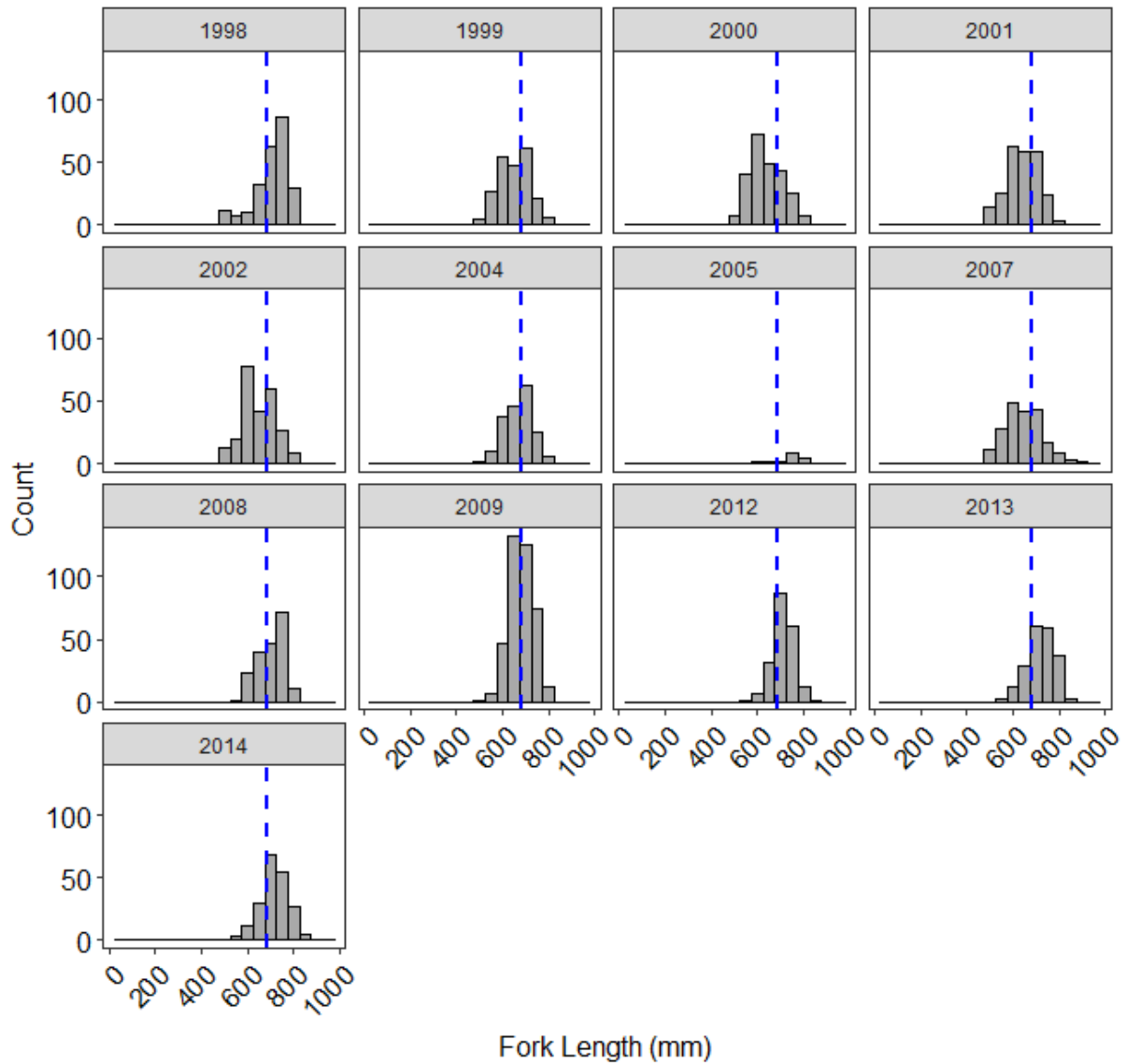


Figure 24 Continued. Frequency distributions of fork length (mm) collected from fishery-dependent sampling of Arctic Char from the Jayko River, NU. Mean fork length across all years is shown as a blue dotted line.

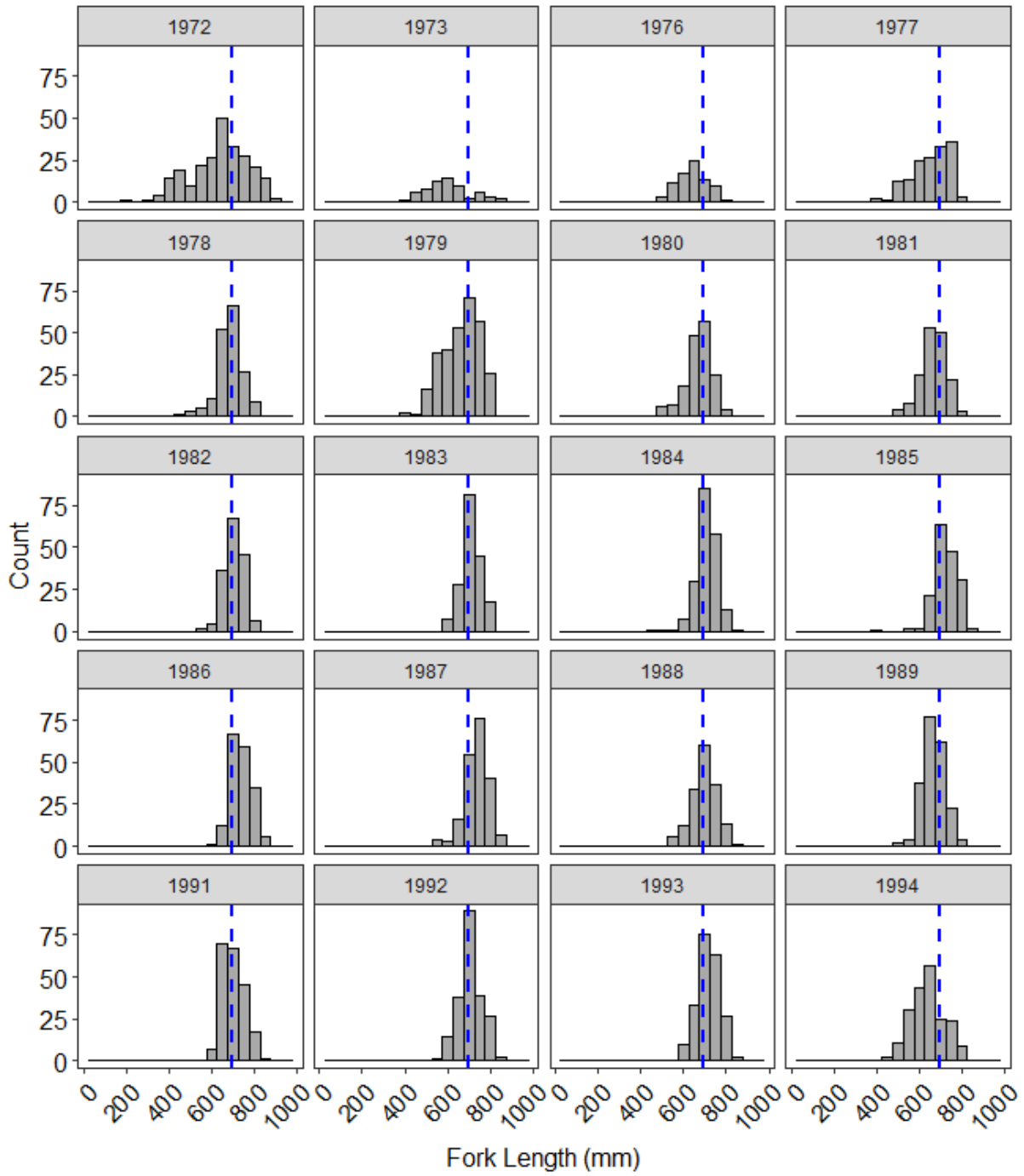


Figure 25. Frequency distributions of fork length (mm) collected from fishery-dependent sampling of Arctic Char from the Halokvik River, NU. Mean fork length across all years is shown as a blue dotted line.

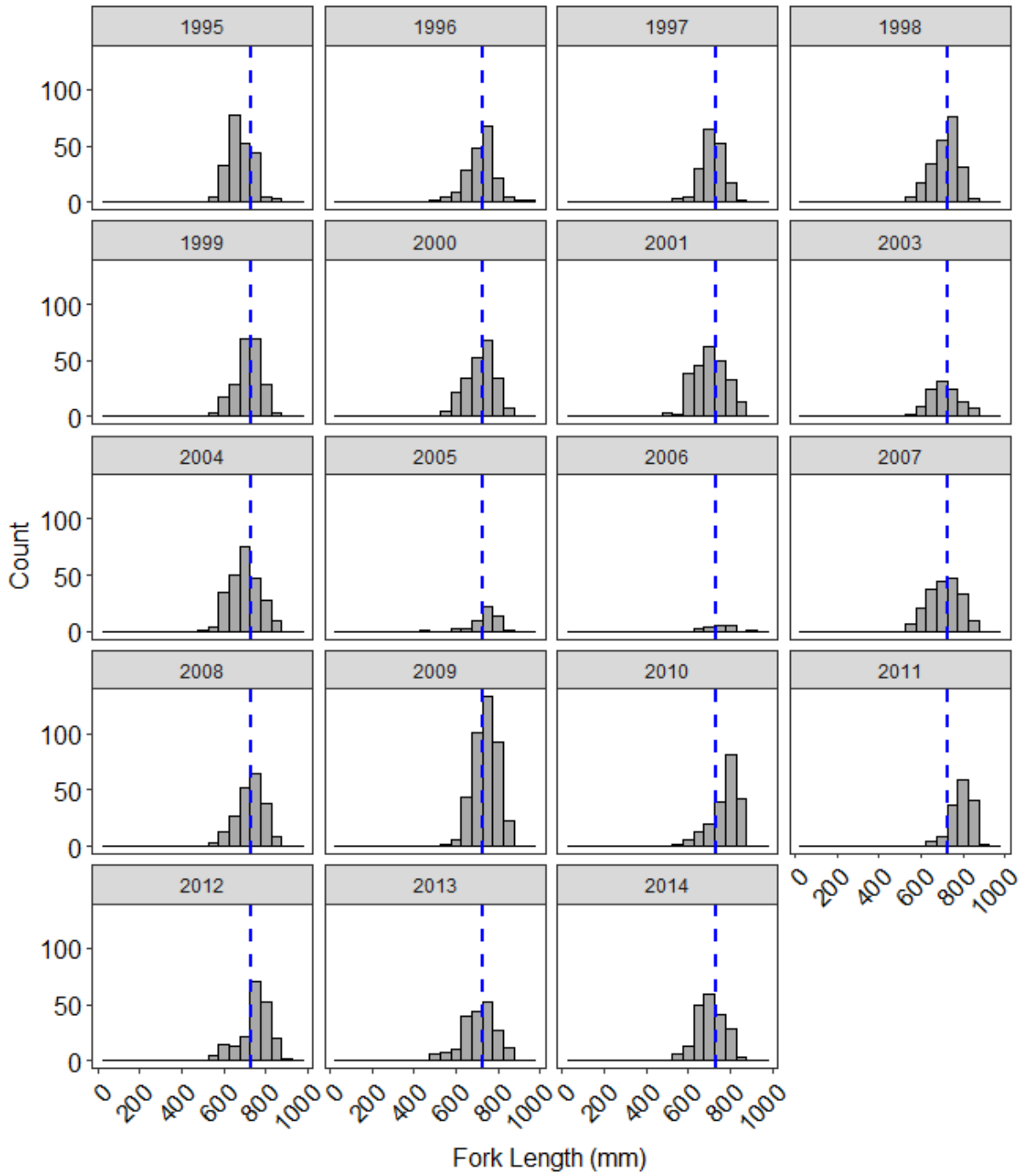


Figure 25 Continued. Frequency distributions of fork length (mm) collected from fishery-dependent sampling of Arctic Char from the Halokvik River, NU. Mean fork length across all years is shown as a blue dotted line.

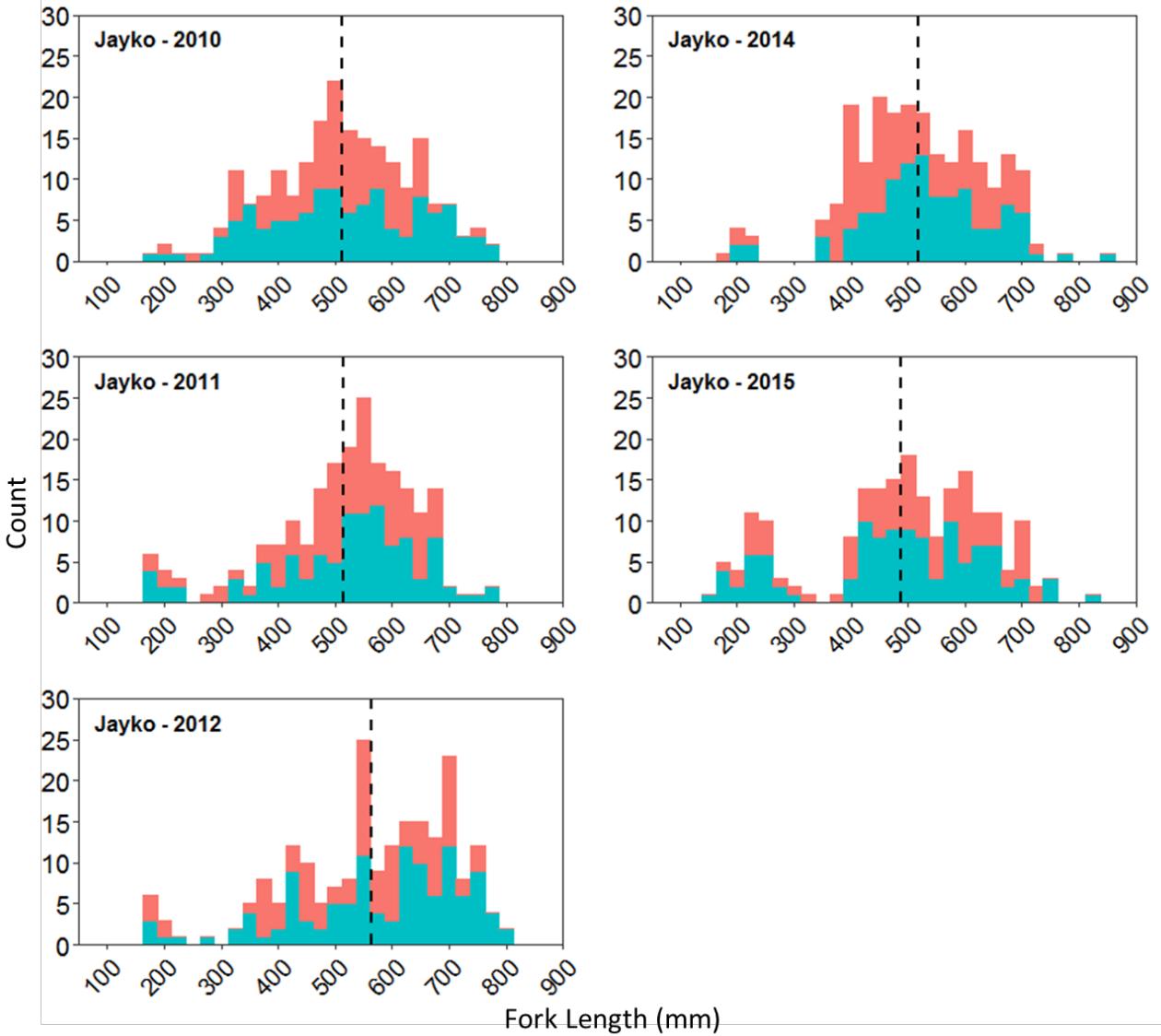


Figure 26. Frequency distributions of fork length (mm) collected from fishery-independent sampling of Arctic Char from the Jayko River, NU, 2010–2015. Females are shown in red and males are shown in blue. The mean round weight for each year (sexes combined) is shown as a black dotted line.

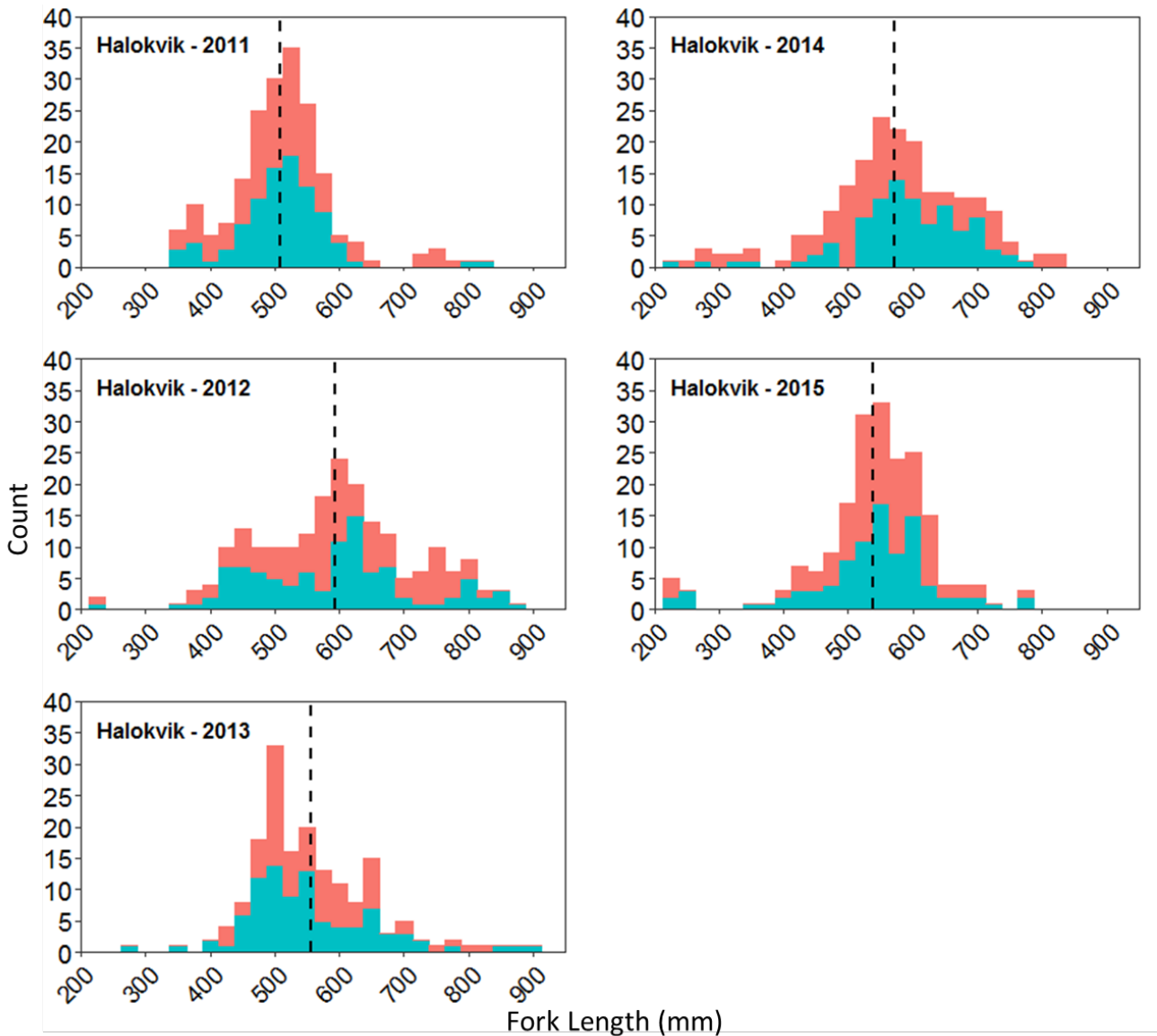


Figure 27. Frequency distributions of fork length (mm) collected from fishery-independent sampling of Arctic Char from the Halokvik River, NU, 2011–2015. Females are shown in red and males are shown in blue. The mean round weight for each year (sexes combined) is shown as a black dotted line.

The relationship between fork length and round weight for the two stocks are shown in Figures 28 and 29 (fishery-dependant data by decade) and Figures 30 and 31 (fishery-independent data by sampling year). The parameters for these linear regressions are shown in Table 3. In general, the length-weight relationships did not differ substantially among decades (fishery-dependent data) or among sampling years (fishery-independent data). The slope of the regression line (b) was typically less than 3 for fishery-dependent regressions whereas b was almost always greater than 3 for fishery-independent regressions. The slopes of the weight-length relationships ranged from 2.58 (Halokvik 1980s) to 3.21 (Halokvik 1970s) for fishery-dependent data and from 2.98 (Halokvik 2013) to 3.25 (Halokvik 2014) for fishery-independent data (Table 3).

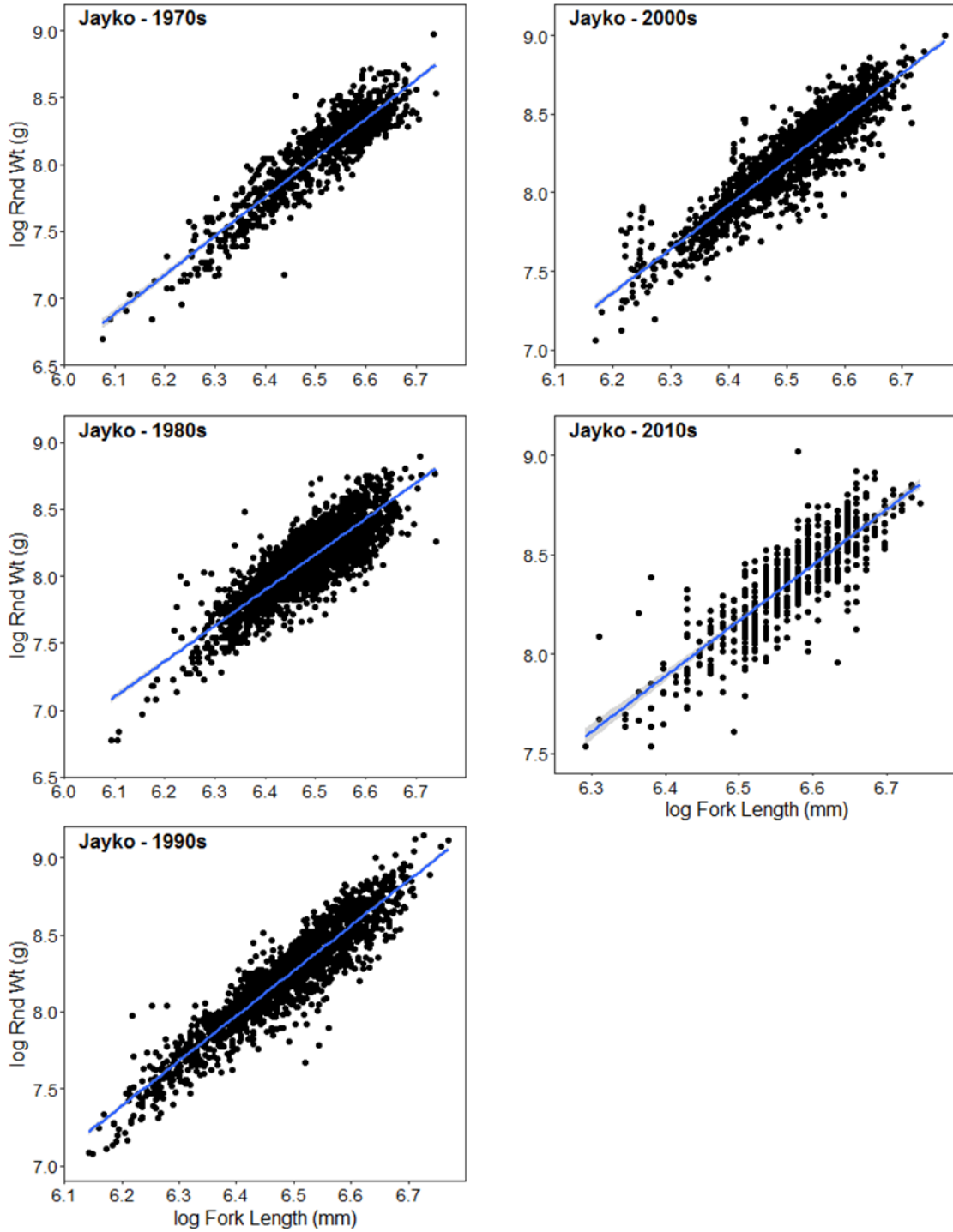


Figure 28. Weight-length relationships of commercially harvested Jayko River, NU Arctic Char collected as part of the fishery-dependent sampling program. Data are combined for each decade of the fishery-dependent sampling program. Parameters of the weight length relationships are shown in Table 4.

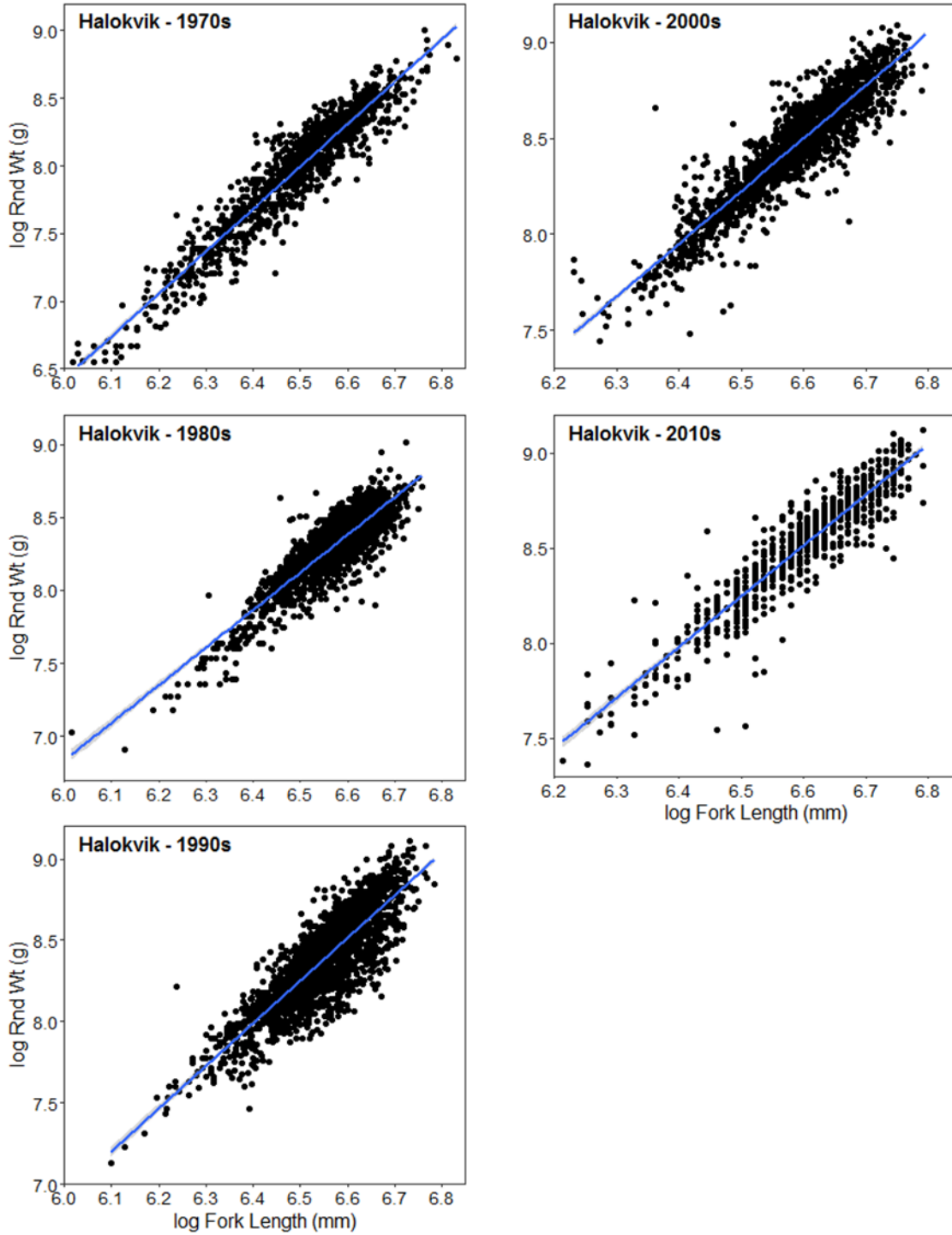


Figure 29. Weight-length relationships of commercially harvested Halokvik River, NU Arctic Char collected as part of the fishery-dependent sampling program. Data are combined for each decade of the fishery-dependent sampling program. Parameters of the weight length relationships are shown in Table 4.

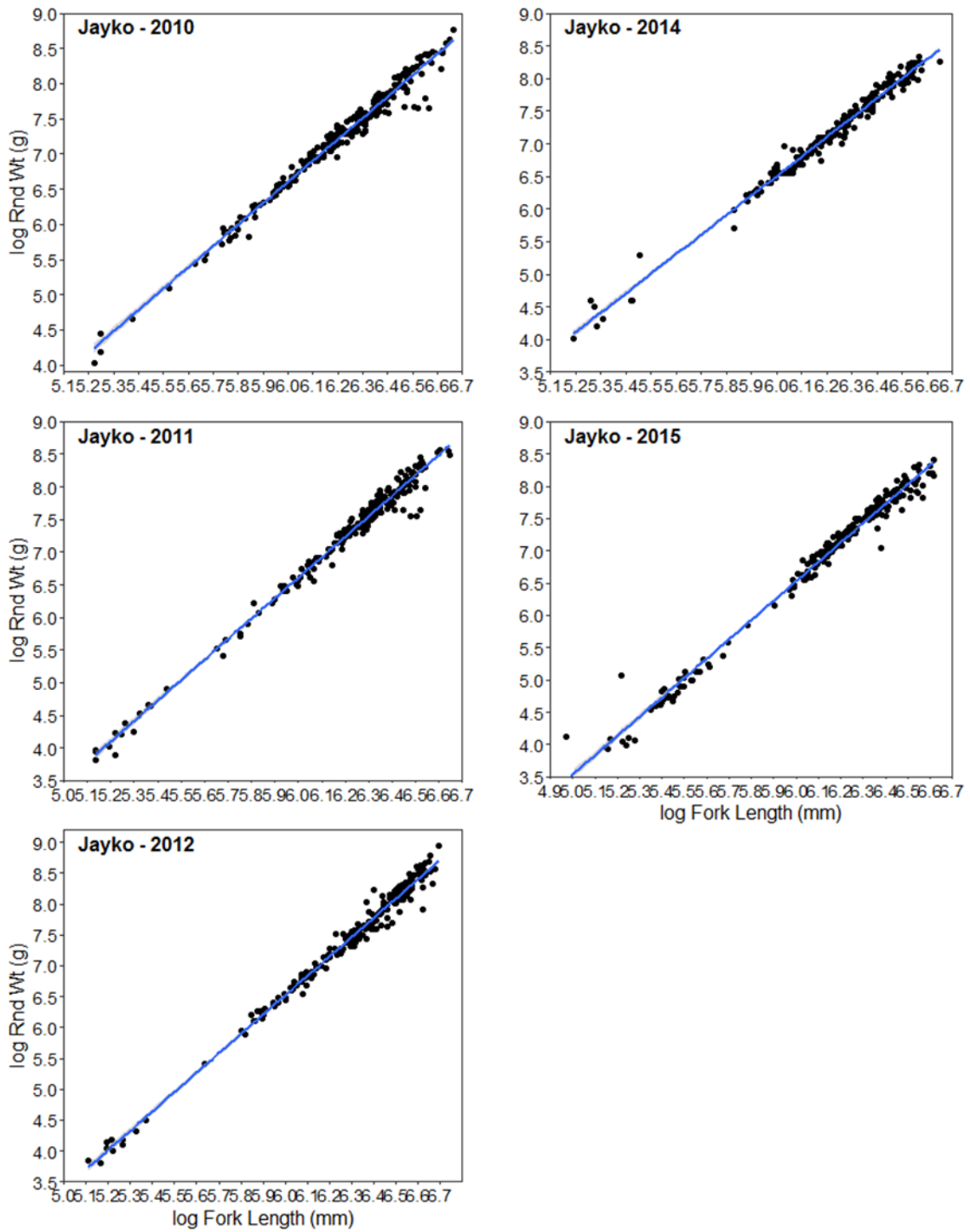


Figure 30. Weight-length relationships of Jayko River, NU Arctic Char collected as part of the fishery-independent sampling program, 2010–2015. Parameters of the weight length relationships are shown in Table 4.

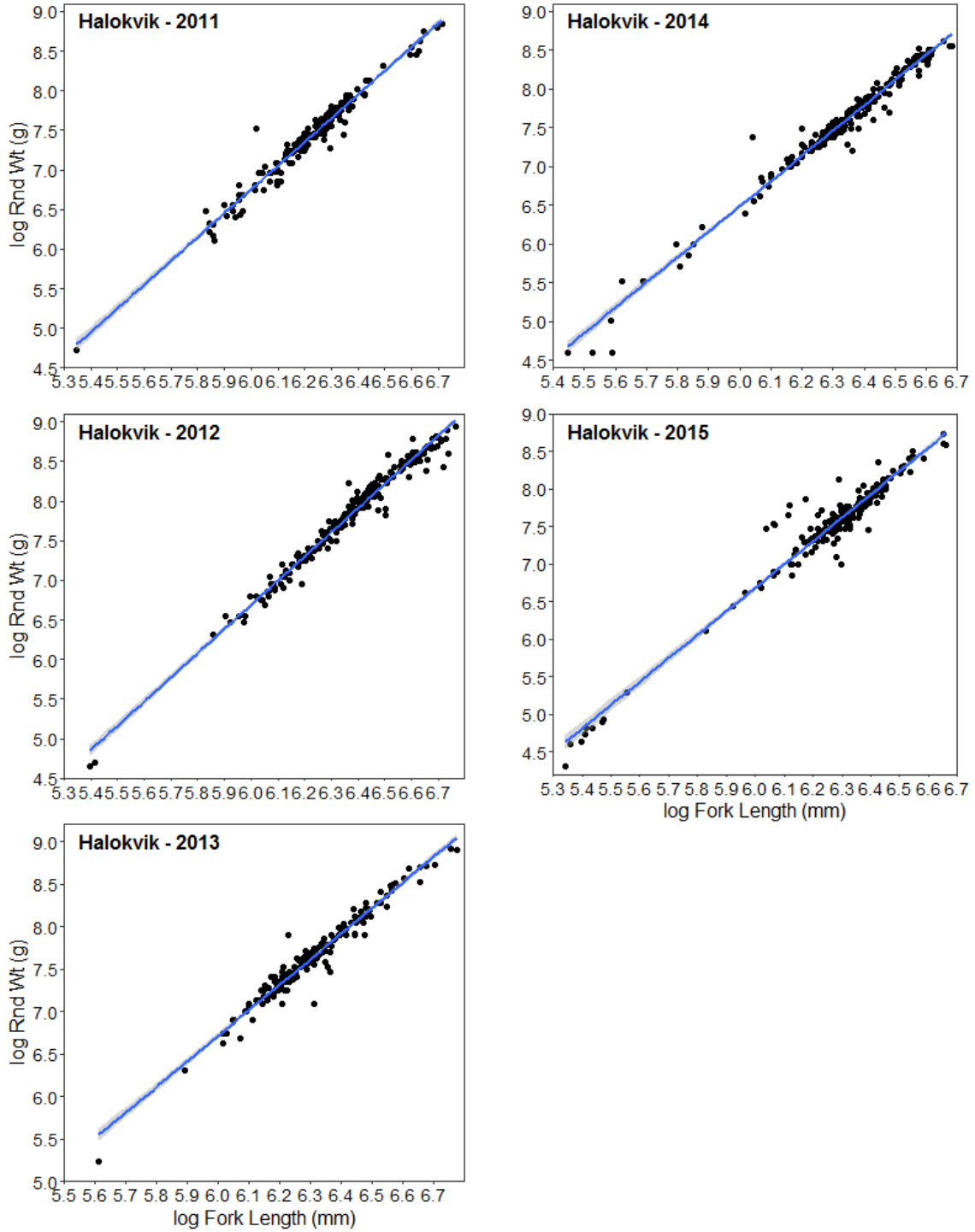


Figure 31. Weight-length relationships of Halokvik River, NU Arctic Char collected as part of the fishery-independent sampling program, 2011–2015. Parameters of the weight length relationships are shown in Table 4.

Age

Across all decades of fishery-dependent sampling, the age of commercially harvested Arctic Char from the Jayko River ranged from 7 to 32 (average across all decades = 15.07) and at Halokvik age ranged from 7 to 28 (average across all decades = 13.97) with the latter being significantly younger overall ($t = 19.77$, d.f. = 9945.2, p -value < 0.01, Table 2). Fishery-dependent data clearly show inter-annual variation in mean age over time for both rivers and clear sinusoidal patterns were resolved for both (Figure 32). Across all years, average age has decreased slightly since fishery-dependent sampling began ($p < 0.01$). Since the last assessment average age at Jayko has increased whereas average age at Halokvik has decreased. Mean age between the first and last decades of sampling was significantly different at Jayko ($t = -5.06$, d.f. = 1115.50, $p < 0.01$) but not at Halokvik ($t = 1.40$, d.f. = 1217.0, $p = 0.16$). Mean ages from the fishery-independent data were stable among sampling years at each site (Figure 33) ranging from 3 to 39 at Jayko (average = 11.75 across all sampling years) and 3 to 26 at Halokvik (average = 9.93 across all sampling years, Table 4). Overall, sexes were not different in age within either of the stocks (Jayko: $t = -0.67$, d.f. = 958.44, $p = 0.50$; Halokvik: $t = -2.57$, d.f. = 899.84, $p = 0.104$) whereas ages were significantly different between stocks ($t = 9.80$, d.f. = 1687.90, $p < 0.01$). Average age between the first and last years of sampling was significantly different at Halokvik ($t = -2.25$, d.f. = 371.48, $p = 0.025$) but not Jayko ($t = 0.73$, d.f. = 382.57, $p = 0.46$) with larger fish harvested later on in the sampling period.

Table 4. Mean (and ranges) of round weight (A), fork length (B), age (C) and condition (D) by sex from Jayko and Halokvik rivers Arctic Char collected in fishery-independent research sampling, 2010–2015. Data from all mesh sizes in the multi-mesh gill nets are pooled. Na for Jayko River was due to blizzard in 2013 preventing access to the site. Na for Halokvik River was because sampling did not begin until 2011.

Year	Jayko River		Halokvik River	
	F	M	F	M
(A) Round Weight (g)				
2010	1668 (66–4750)	1893 (56–6450)	Na	Na
2011	1854 (49–4450)	1955 (45–5200)	1900 (475–6300)	1955 (45–5200)
2012	2100 (45–5150)	2571 (57–7750)	2985 (109–6650)	2904 (105–7650)
2013	Na	Na	2395 (850–6150)	2347 (187–7450)
2014	1521 (55–4150)	1738 (75–6100)	2167 (100–6400)	2475 (100–5550)
2015	1567 (51–4050)	1568 (51–4050)	2176 (75–5450)	2164 (100–6200)
Average	1737 (45–5150)	1944 (45–7750)	2329 (75–6650)	2353 (100–7650)
(B) Fork Length (mm)				
2010	504 (190–750)	517 (185–785)	Na	Na
2011	512 (170–682)	519 (170–770)	511 (345–770)	518 (170–770)
2012	544 (166–756)	579 (180–808)	598 (225–821)	590 (221–867)
2013	Na	Na	538 (414–814)	555 (274–905)
2014	501 (180–718)	533 (195–838)	557 (251–830)	590 (232–778)
2015	496 (174–733)	480 (144–813)	542 (209–775)	536 (213–782)
Average	511 (166–756)	526 (144–838)	554 (209–830)	556 (210–905)

Table 4 Continued. Mean (and ranges) of round weight (A), fork length (B), age (C) and condition (D) by sex from Jayko and Halokvik rivers Arctic Char collected in fishery-independent research sampling, 2010–2015. Data from all mesh sizes in the multi-mesh gill nets are pooled. Na for Jayko River was due to blizzard in 2013 preventing access to the site. Na for Halokvik River was because sampling did not begin until 2011.

Year	Jayko River		Halokvik River	
	F	M	F	M
(C) Age				
2010	11.93 (3–24)	11.72 (3–39)	Na	Na
2011	11.16 (3–24)	11.22 (3–21)	9.2 (5–20)	11.2 (3–21)
2012	13.18 (3–27)	12.83 (3–28)	11.71 (3–26)	10.81 (5–21)
2013	Na	Na	9.86 (7–22)	9.24 (6–21)
2014	11.29 (3–24)	11.41 (3–23)	10.2 (4–21)	10.0 (6–17)
2015	12.13 (3–28)	10.86 (3–28)	9.73 (4–22)	9.40 (4–17)
Average	11.89 (3–28)	11.63 (3–39)	10.18 (3–26)	9.67 (4–21)
(D) Condition Factor (k)				
2010	1.15 (0.90–1.39)	1.14 (0.59–1.37)	Na	Na
2011	1.18 (0.69–1.54)	1.16 (0.64–1.49)	1.30 (0.91–1.58)	1.16 (0.88–1.78)
2012	1.10 (0.82–1.72)	1.10 (0.65–1.54)	1.26 (0.84–1.92)	1.25 (0.80–1.55)
2013	Na	Na	1.29 (0.71–2.07)	1.25 (0.90–1.49)
2014	1.08 (0.76–1.56)	1.01 (0.77–1.46)	1.09 (0.52–1.51)	1.10 (0.78–2.14)
2015	1.03 (0.78–1.27)	1.07 (0.60–2.54)	1.28 (0.79–2.56)	1.28 (0.69–2.36)
Average	1.10 (0.69–1.72)	1.10 (0.59–2.55)	1.24 (0.52–2.56)	1.24 (0.69–2.66)

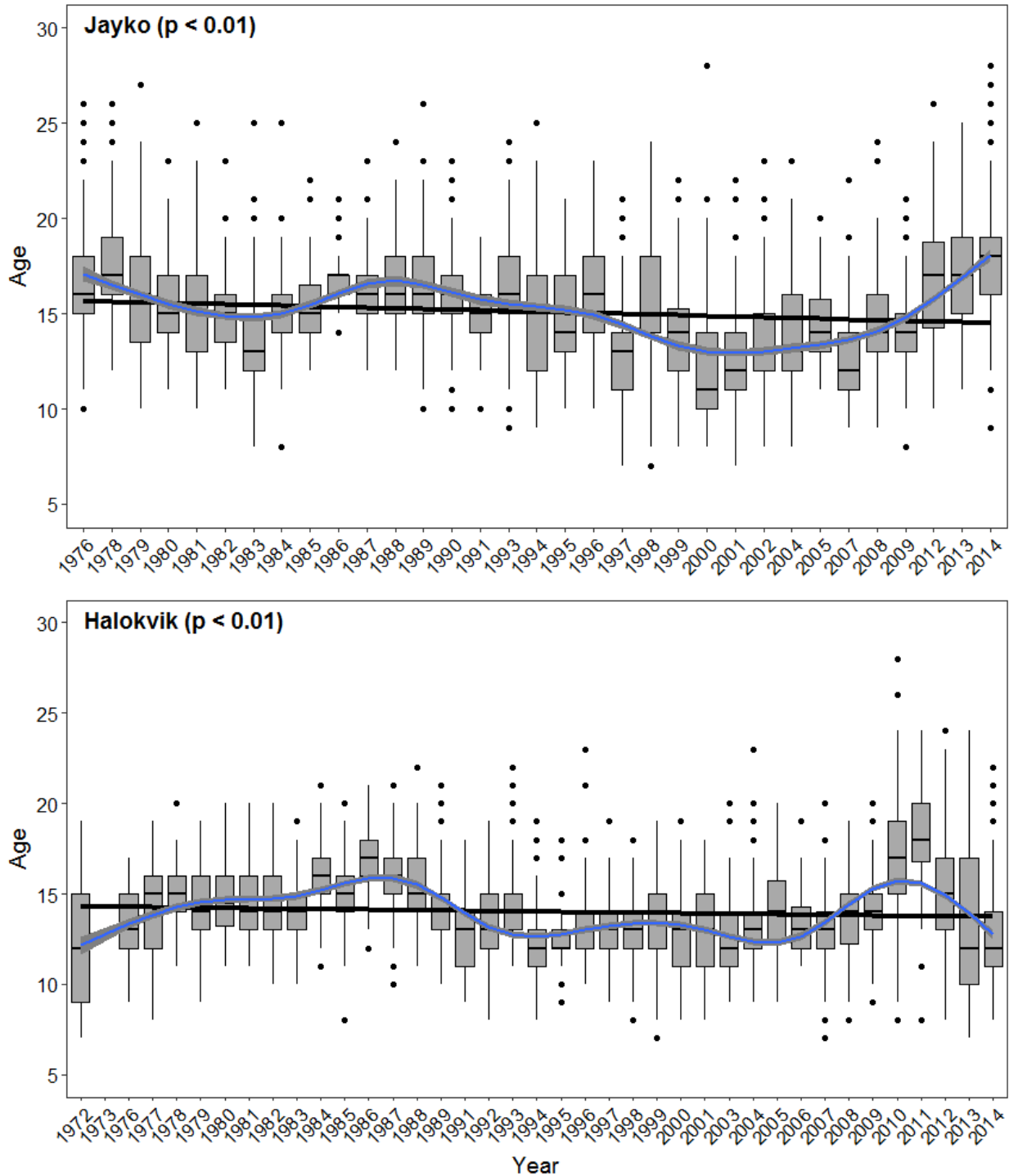


Figure 32. Box plots showing the 25th and 75th percentile or inter-quartile range (IQR, grey box), the median (black line within the box) and 1.5 x the IQR ('whiskers' of the plot) of age collected from fishery-dependent sampling of Arctic Char from the Jayko and Halokvik rivers. A trend line (shown in black) was fit to the data and the significance of this relationship is shown in the top left corner. A spline (blue line) was also fit to help visualize patterns the data.

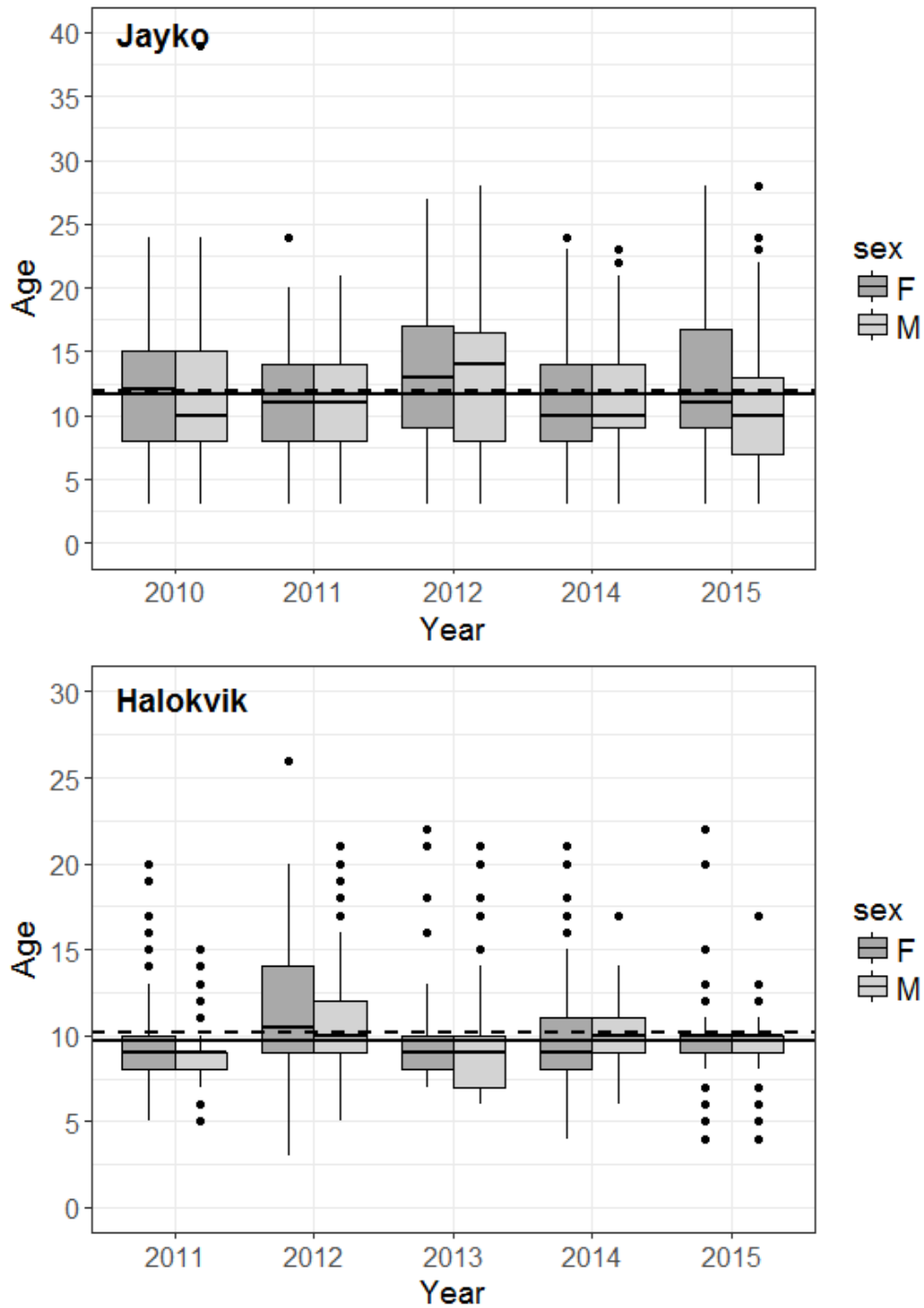


Figure 33. Box plots (showing the 25th and 75th percentile or inter-quartile range (IQR, grey box), the median (black line within the box) and $1.5 \times$ the IQR ('whiskers' of the plot)) of age collected from fishery-independent sampling of Arctic Char from the Jayko and Halokvik rivers, 2010–2015. The mean age across all years is shown for males (solid black line) and females (dotted black line).

Age frequency distributions of fishery-dependent data for both the Jayko and Halokvik fisheries are shown in Figures 34 and 35, respectively. For the most part, age-frequency distributions were unimodal with a few yearly exceptions and appear relatively stable. That is, there appears to be no clear shift in either direction of the age structure of the catch over time (Figures 34 and 35). There was strong representation of the older age classes (> 15) throughout all years of the assessment. Fish greater than 24 years of age were captured in every decade. The modal age varied between 14–17 years at Jayko and 13–15 years at Halokvik. The age frequency distributions at both fisheries differed significantly between the first and last decades of sampling (Jayko: $D = 0.17$, $p < 0.01$; Halokvik: $D = 0.17$, $p < 0.01$). Age frequency distributions from the fishery-independent data were much more variable in shape although the modes for each fishery were stable across the sampling period (Figures 36 and 37). Sexes were also evenly distributed among age classes. The age-frequency distributions differed significantly between the first and last decades of sampling at Halokvik ($D = 0.26$, $p < 0.01$) but not at Jayko ($D = 0.13$, $p = 0.08$).

Arctic Char from the Jayko and Halokvik rivers grow older than Arctic Char in other regions of the Canadian Arctic (Harris and Tallman 2010). Fish over 25 years of age were not uncommon in this assessment and we document some of the oldest known anadromous char to date (e.g., char > 30 yrs of age). Fishery-dependent age frequency data illustrated that the size distribution of harvested fish at both sites was unimodal in shape and relatively stable. Modal values differed among years for both fisheries but were primarily centered around 13–16 years of age. Decadal age frequency distributions from commercially harvested Arctic Char, were normally distributed and showed no evidence of truncations. Truncated age and length distributions are often associated with the negative impacts of commercial harvest and over-exploitation (Johnson 1989, Gallagher and Dick 2010). In this assessment ages and lengths do not appear to be truncated in any decade of commercial harvest. This suggests that Arctic Char in the Jayko and Halokvik rivers have been resilient to varying harvest regimes throughout the history of each fishery including recent harvest levels.

Growth

Length-at-age was modelled for each stock using the von Bertalanffy growth function using both fishery-dependent and fishery-independent data. Population growth rates for fishery-dependent data are shown in Figures 38 and 39 for the Jayko and Halokvik rivers, respectively. Qualitatively, growth of Jayko River and Halokvik River Arctic Char was similar among decades within each stock (Figures 38 and 39). The von Bertalanffy parameters for fishery-dependent data are shown in Table 5. Overall, the Brody growth coefficient (k) varied little among decades within each fishery ranging from 0.14–0.25 at Jayko and from 0.10–0.19 at Halokvik (Table 5). Growth curves for fishery-independent data are shown in Figures 40 and 41. On average, k was slightly larger for males ($k = 0.17$) compared to females (0.15) at Jayko and overall k did not vary considerably among sampling years. At Halokvik, k was much more variable within and between sexes across sampling years (Table 6).

Understanding growth in commercially harvested species is crucial for understanding the effects of exploitation and stock productivity (Conover and Schultz 1997). In general, as stocks become more exploited, growth rates are expected to increase and age at length at maturity is expected to be smaller/younger as a compensatory response to harvest which is often associated with relaxation of intraspecific competition (Policansky 1993). In the current assessment, growth rates appear to have remained stable over time.

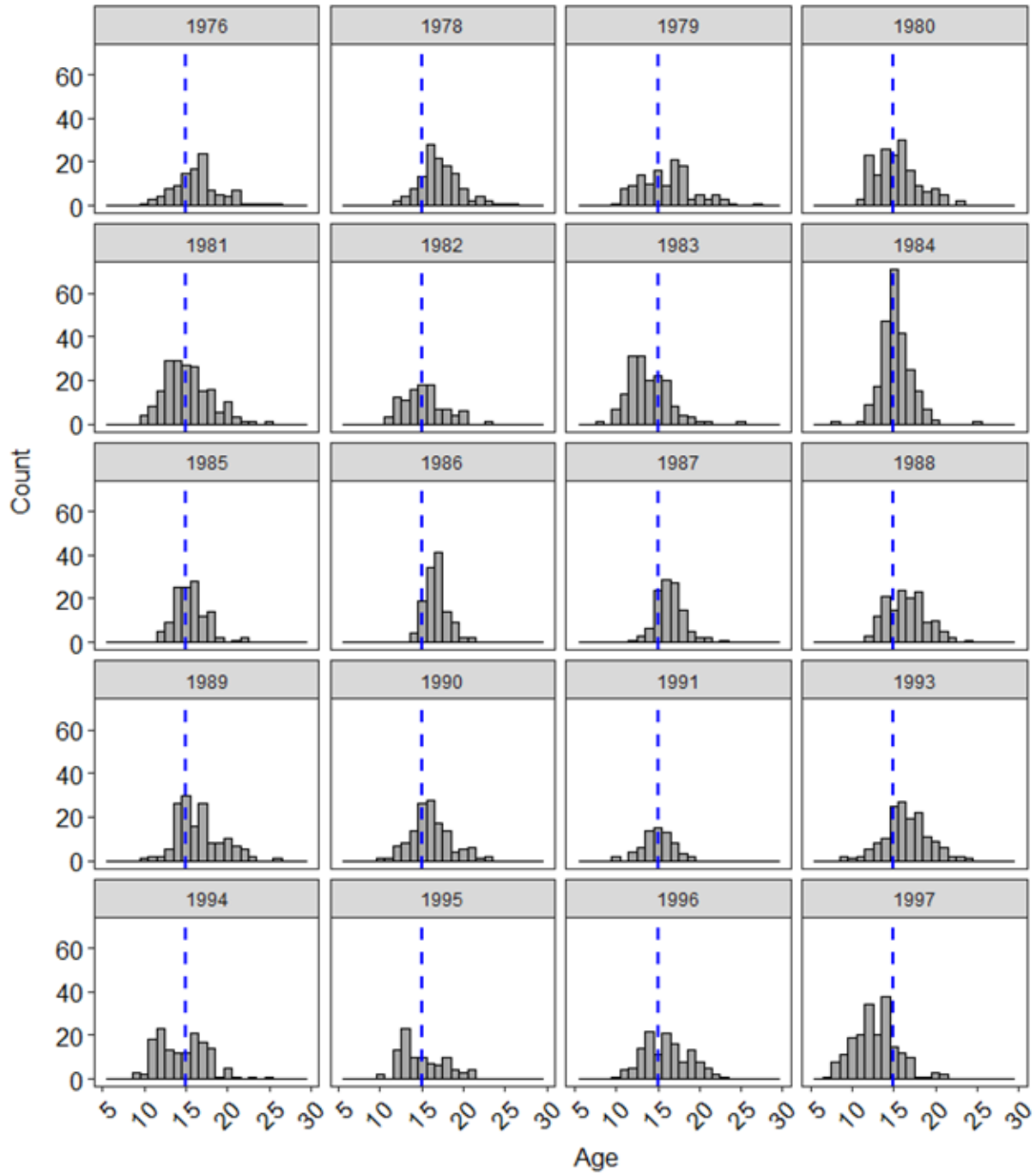


Figure 34. Frequency distributions of age collected from fishery-dependent sampling of Arctic Char from the Jayko River, NU. Mean fork length across all years is shown as a blue dotted line.

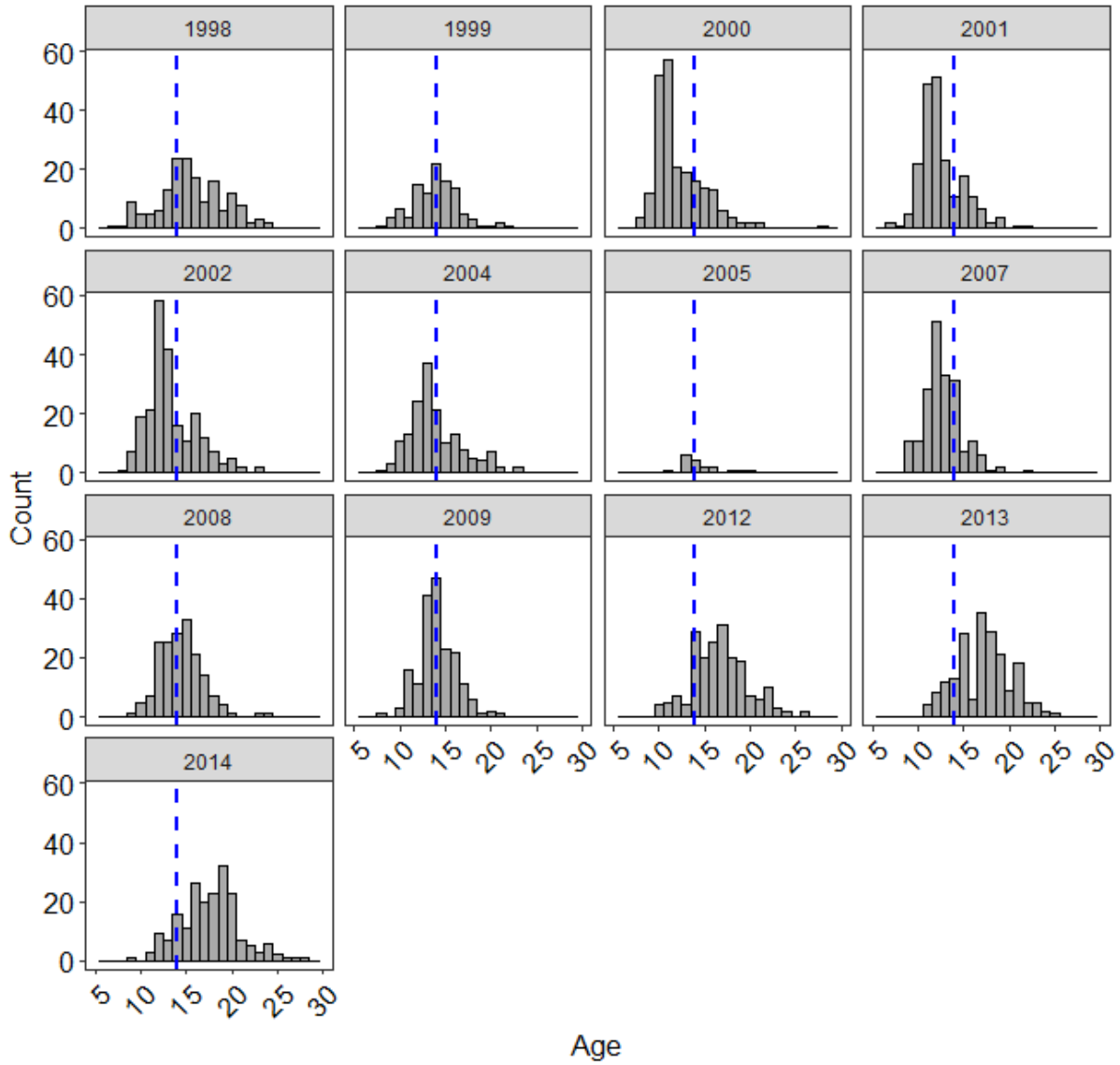


Figure 34 Continued. Frequency distributions of age collected from fishery-dependent sampling of Arctic Char from the Jayko River, NU. Mean fork length across all years is shown as a blue dotted line.

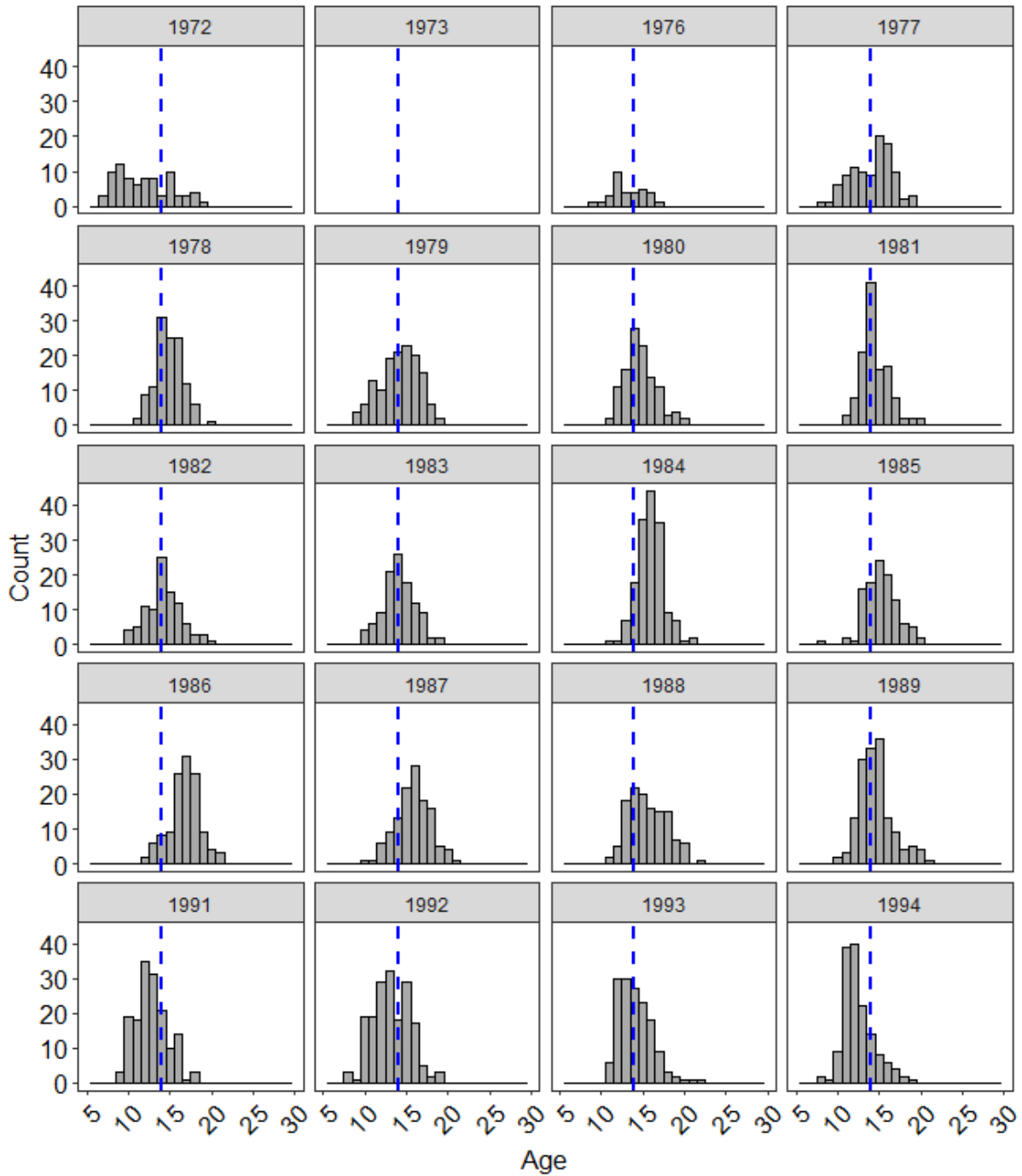


Figure 35. Frequency distributions of age collected from fishery-dependent sampling of Arctic Char from the Halokvik River, NU. Mean fork length across all years is shown as a blue dotted line.

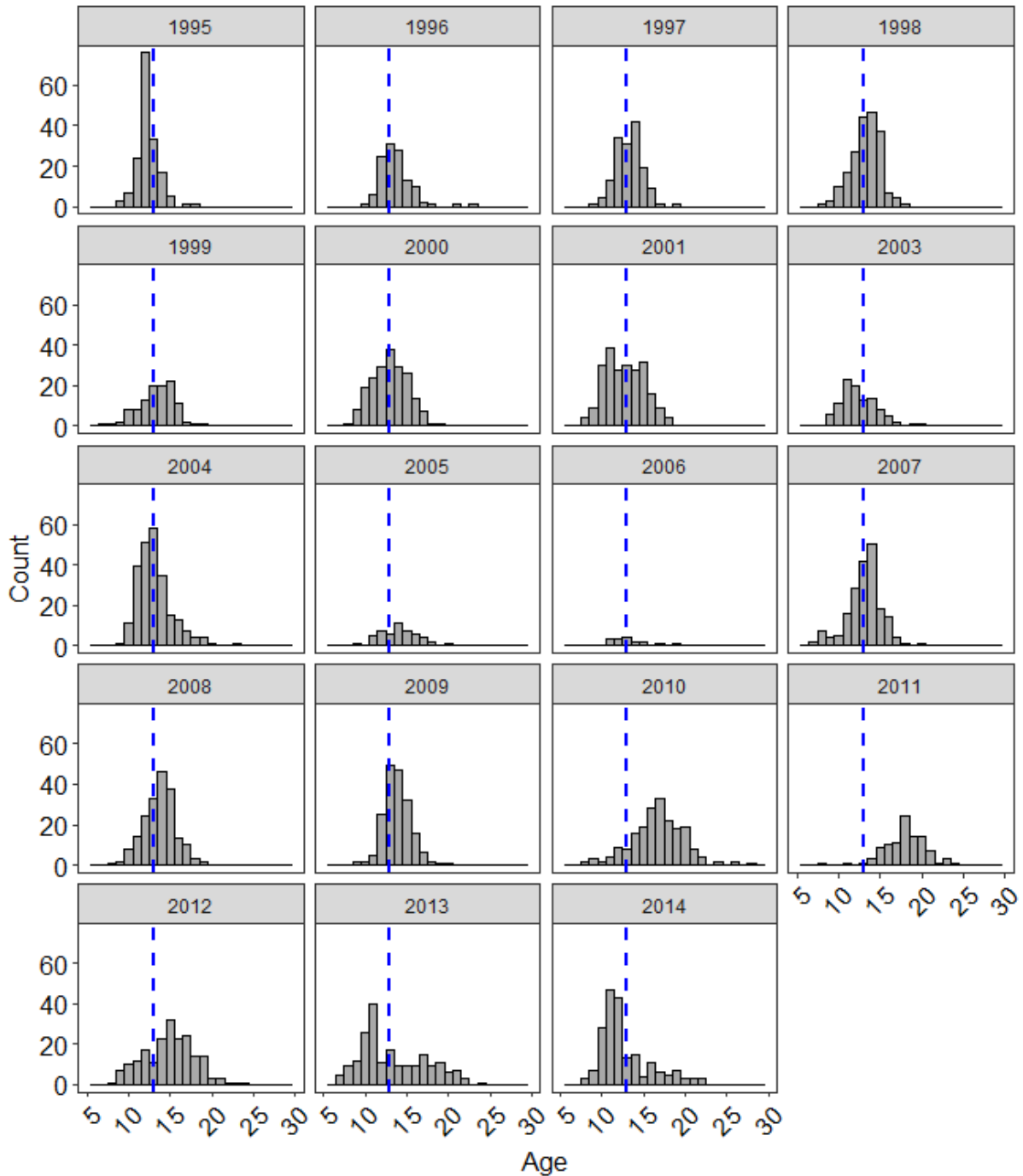


Figure 35 Continued. Frequency distributions of age collected from fishery-dependent sampling of Arctic Char from the Halokvik River, NU. Mean fork length across all years is shown as a blue dotted line.

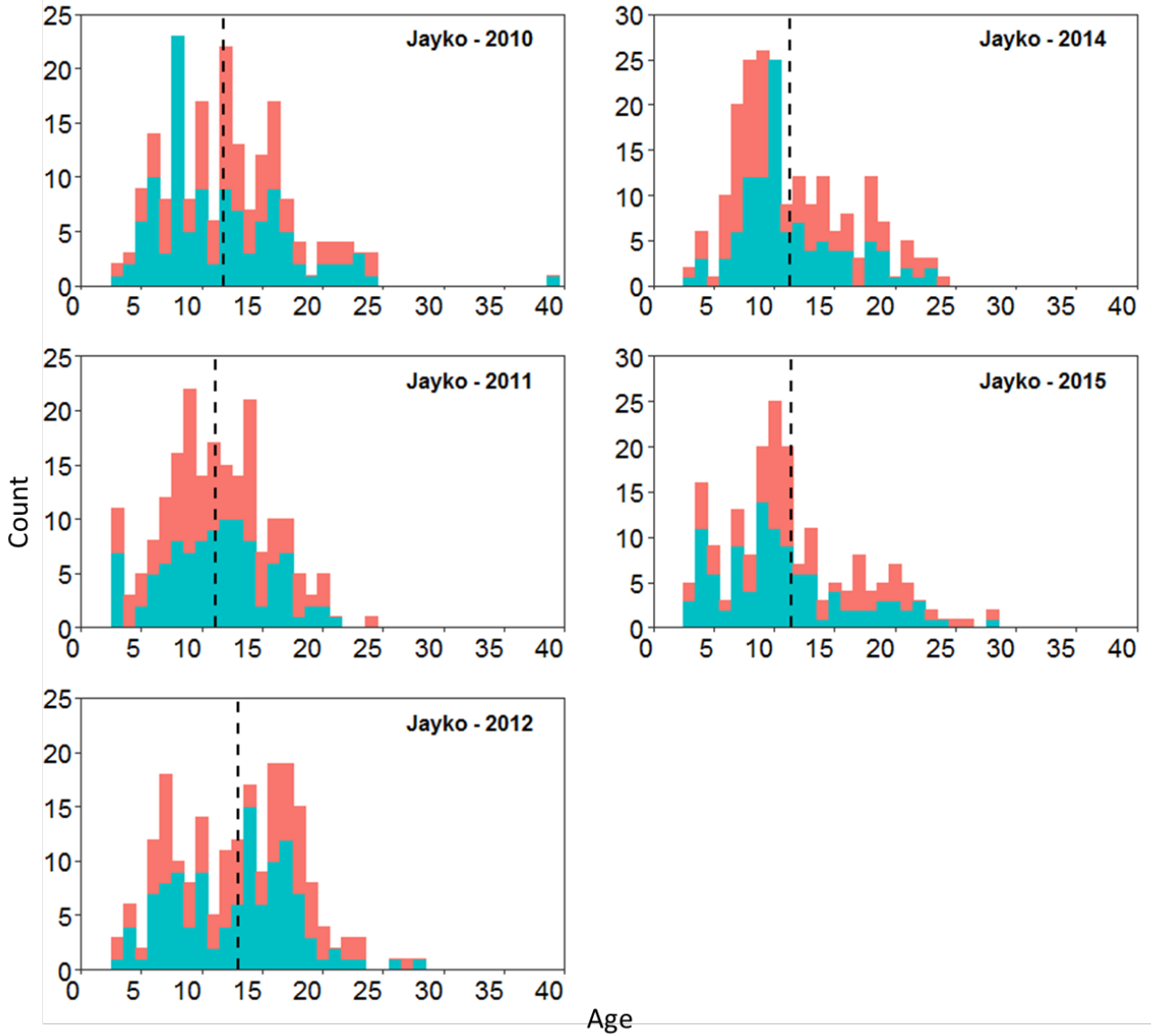


Figure 36. Frequency distributions of age collected from fishery-independent sampling of Arctic Char from the Jayko River, NU, 2010–2015. Females are shown in red and males are shown in blue. The mean round weight for each year (sexes combined) is shown as a black dotted line.

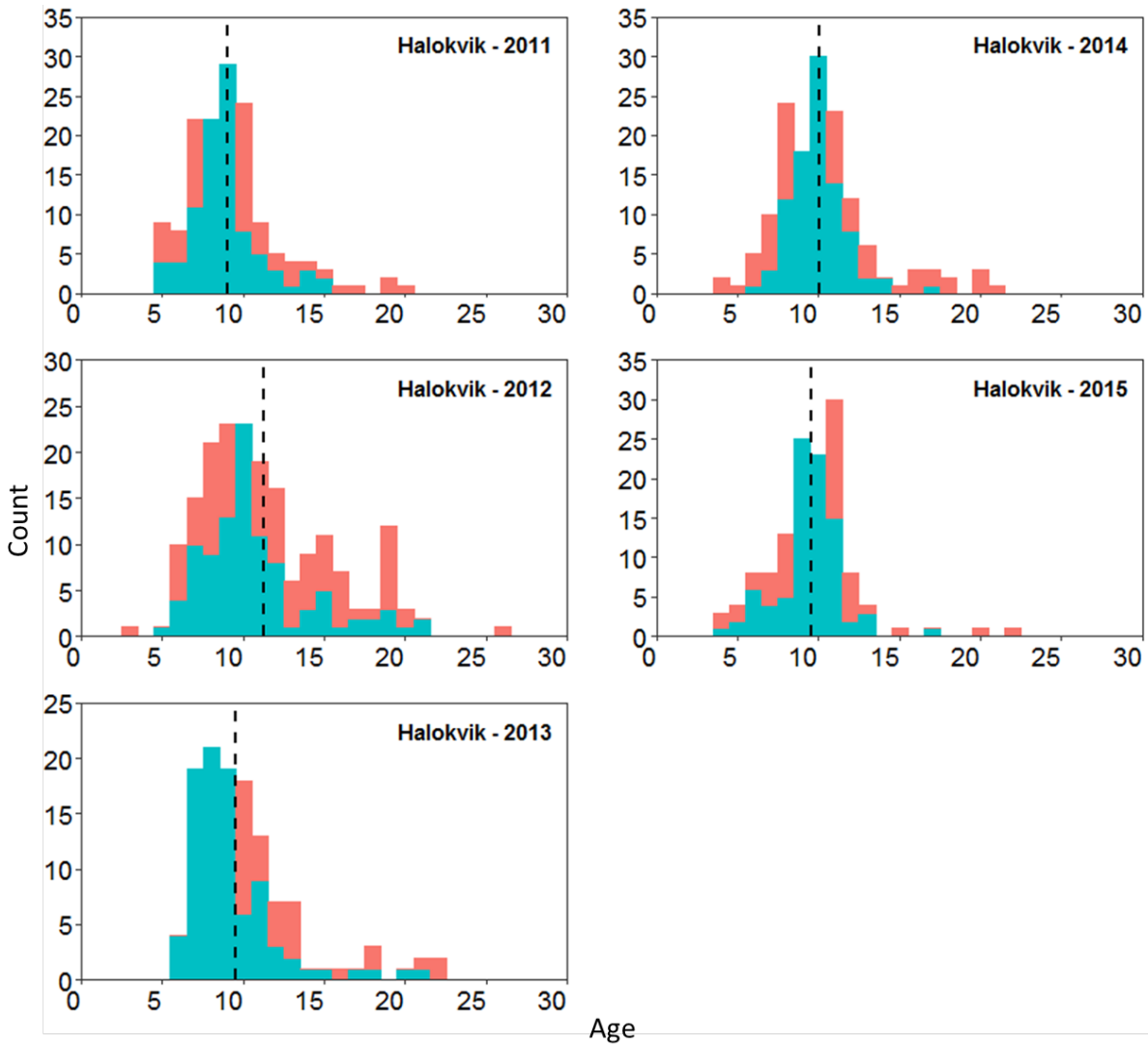


Figure 37. Frequency distributions of age collected from fishery-independent sampling of Arctic Char from the Halokvik River, NU, 2011–2015. Females are shown in red and males are shown in blue. The mean round weight for each year (sexes combined) is shown as a black dotted line.

Table 5. von Bertalanffy growth equation parameters (L_{∞} = is the asymptotic average length; k = Brody growth coefficient; t_0 = modeling artifact that represents the time or age at which average length was zero) for Jayko and Halokvik river Arctic Char collected from the commercial harvest. Data have been combined by decade.

Year	Jayko River			Halokvik River		
	L_{∞}	K	t_0	L_{∞}	k	t_0
1970s	786 (735–832)	0.16 (0.09–2.34)	2.76 (-1.70–5.19)	786 (754–832)	0.19 (0.15–0.23)	4.13 (3.18–4.86)
1980s	716 (693–774)	0.15 (0.08–0.23)	-1.26 (-8.64–2.30)	809 (770–900)	0.14 (0.08–20)	0.39 (-4.75–3.11)
1990s	761 (734–789)	0.14 (0.10–0.17)	-0.05 (-2.23–1.39)	909 (837–1080)	0.10 (0.05–0.15)	-2.32 (-6.65–0.40)
2000s	769 (750–801)	0.18 (0.4–0.22)	2.21 (0.50–0.33)	872 (844–914)	0.14 (0.11–0.17)	0.37 (-1.35–1.60)
2010s	742 (731–762)	0.25 (0.16–0.36)	-0.16 (-1.58–5.43)	831 (816–851)	0.18 (0.15–0.21)	1.62 (0.51–2.51)

Table 6. von Bertalanffy growth equation parameters (L_{∞} = is the asymptotic average length; k = Brody growth coefficient; t_0 = modeling artifact that represents the time or age at which average length was zero) for each sex for Jayko and Halokvik river Arctic Char collected from fishery-independent research surveys.

Year	Female			Male		
	L_{∞}	k	t_0	L_{∞}	k	t_0
Jayko River						
2010	649 (601–727)	0.15 (0.09–0.21)	0.64 (-174–1.99)	718 (640–771)	0.14 (0.11–0.19)	1.12 (-0.21–2.23)
2011	644 (618–677)	0.20 (0.16–0.24)	1.31 (0.70–1.85)	704 (658–766)	0.15 (0.11–0.19)	0.79 (-0.5–1.40)
2012	714 (665–800)	0.14 (0.09–0.19)	0.99 (-0.41–2.05)	740 (712–783)	0.18 (0.14–0.21)	2.10 (1.31–2.58)
2014	696 (654–746)	0.14 (0.12–0.20)	0.88 (-0.24–1.93)	713 (672–763)	0.16 (0.12–0.20)	1.38 (0.21–2.31)
2015	714 (672–774)	0.13 (0.10–0.16)	0.84 (-0.08–1.59)	649 (614–694)	0.20 (0.15–0.25)	1.87 (1.21–2.39)
Halokvik River						
2011	1197 (796–2373)	0.04 (0.01–0.11)	-4.10 (-8.15–0.09)	816 (645–1386)	0.10 (0.03–0.21)	-1.57 (-5.94–1.41)
2012	846 (790–950)	0.11 (0.08–0.15)	0.25 (-1.46–1.39)	930 (850–1089)	0.12 (0.08–0.15)	1.55 (0.23–2.54)
2013	809 (705–1285)	0.11 (0.030.20)	-1.67 (-9.66–1.74)	1202 (922–2499)	0.06 (0.01–0.12)	-1.28 (-5.83–1.12)
2014	878 (806–987)	0.12 (0.09–0.16)	1.44 (1.18–2.40)	723 (674–802)	0.37 (0.24–0.51)	4.92 (3.96–5.49)
2015	724 (664–819)	0.19 (0.13–0.25)	1.98 (0.74–2.77)	692 (615–884)	0.22 (0.11–0.39)	2.17 (0.14–3.31)

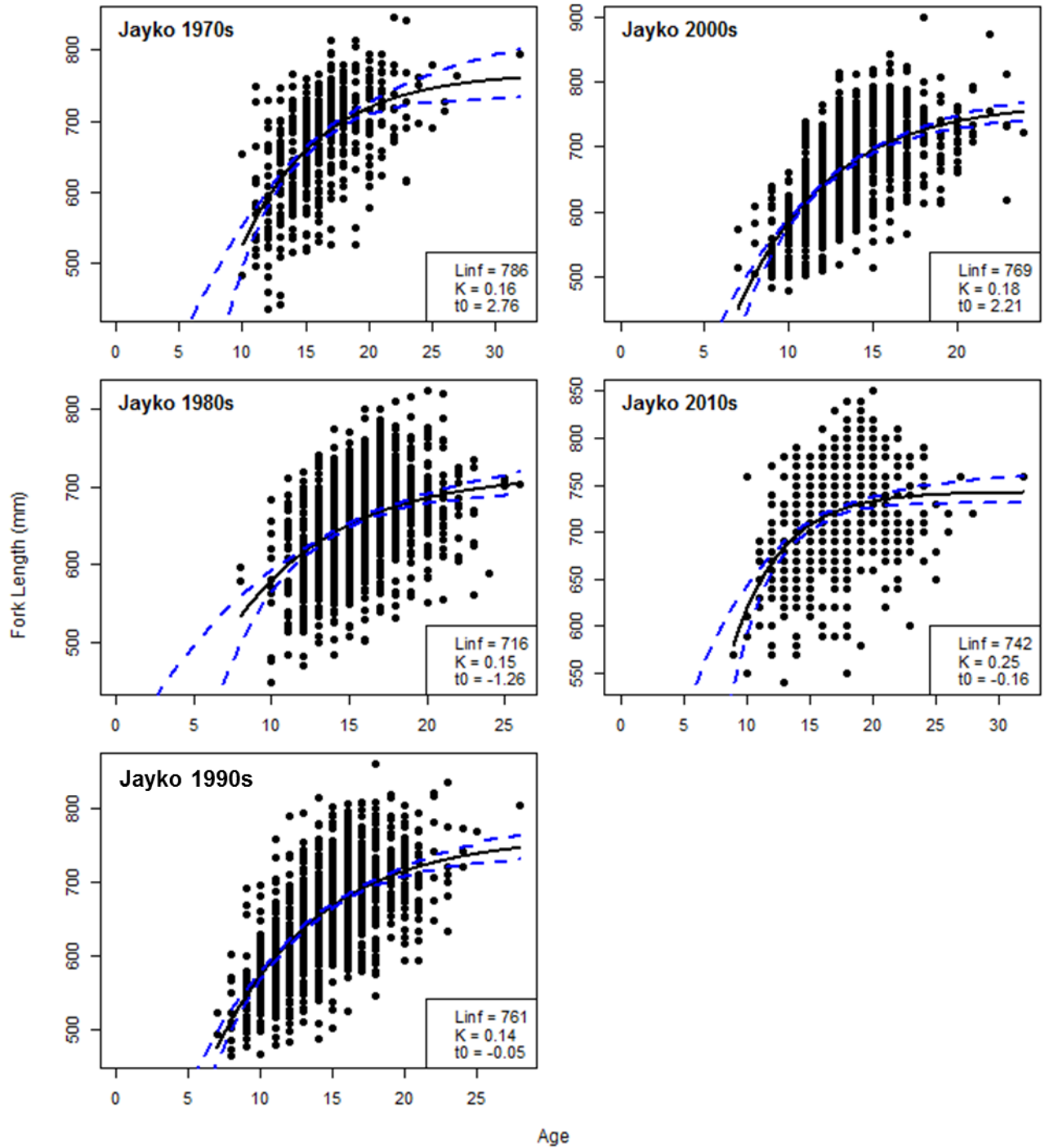


Figure 38. von Bertalanffy growth curves fitted to lengths at age for Jayko River, NU Arctic Char collected as part of the fishery-dependent sampling program. Data are combined for each decade of the fishery-dependent sampling program. von Bertalanffy growth parameters are shown in the bottom left corner of each plot and in Table 5.

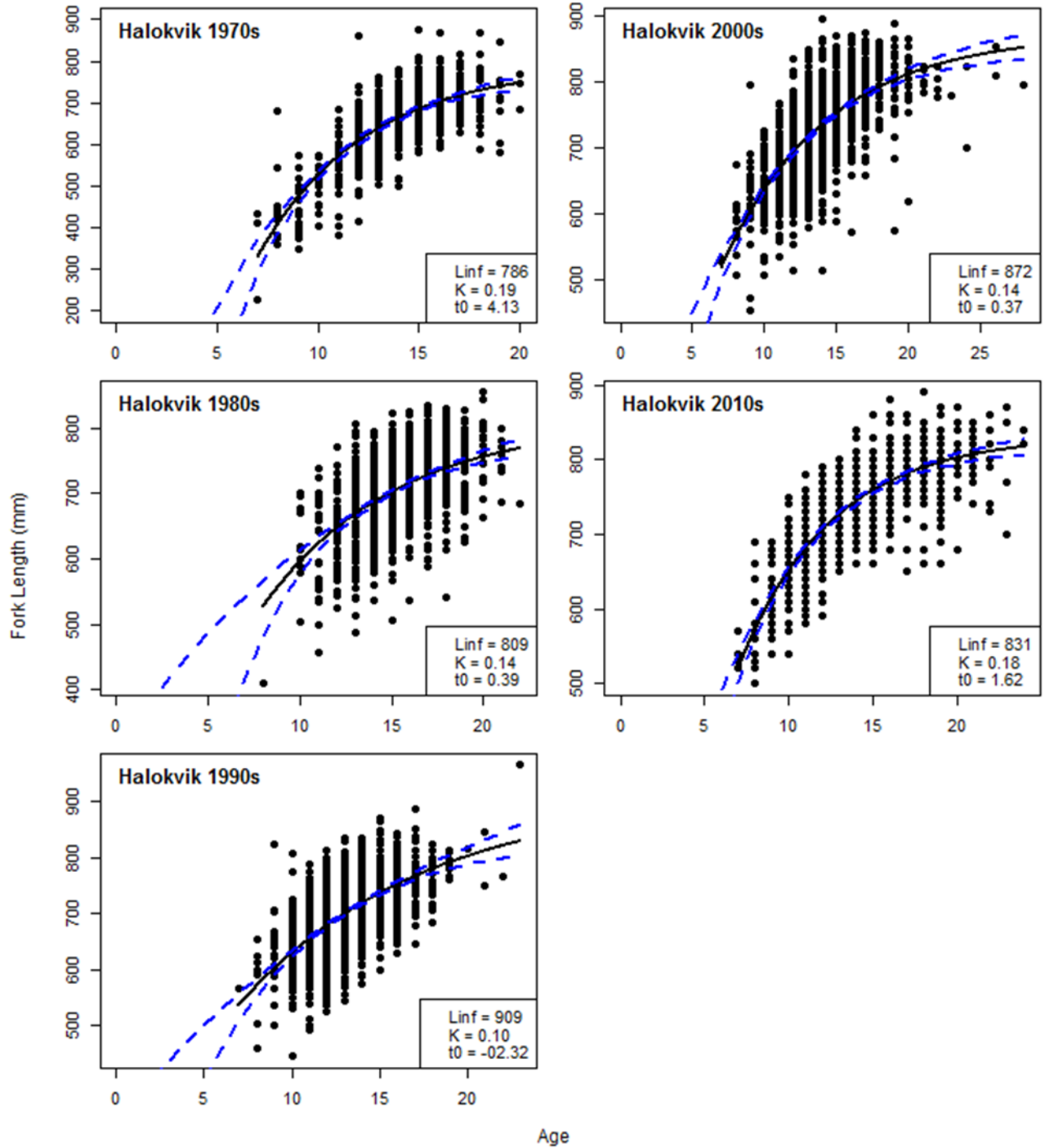


Figure 39. von Bertalanffy growth curves fitted to lengths at age for Halokvik River, NU Arctic Char collected as part of the fishery-dependent sampling program. Data are combined for each decade of the fishery-dependent sampling program. von Bertalanffy growth parameters are shown in the bottom left corner of each plot and in Table 5.

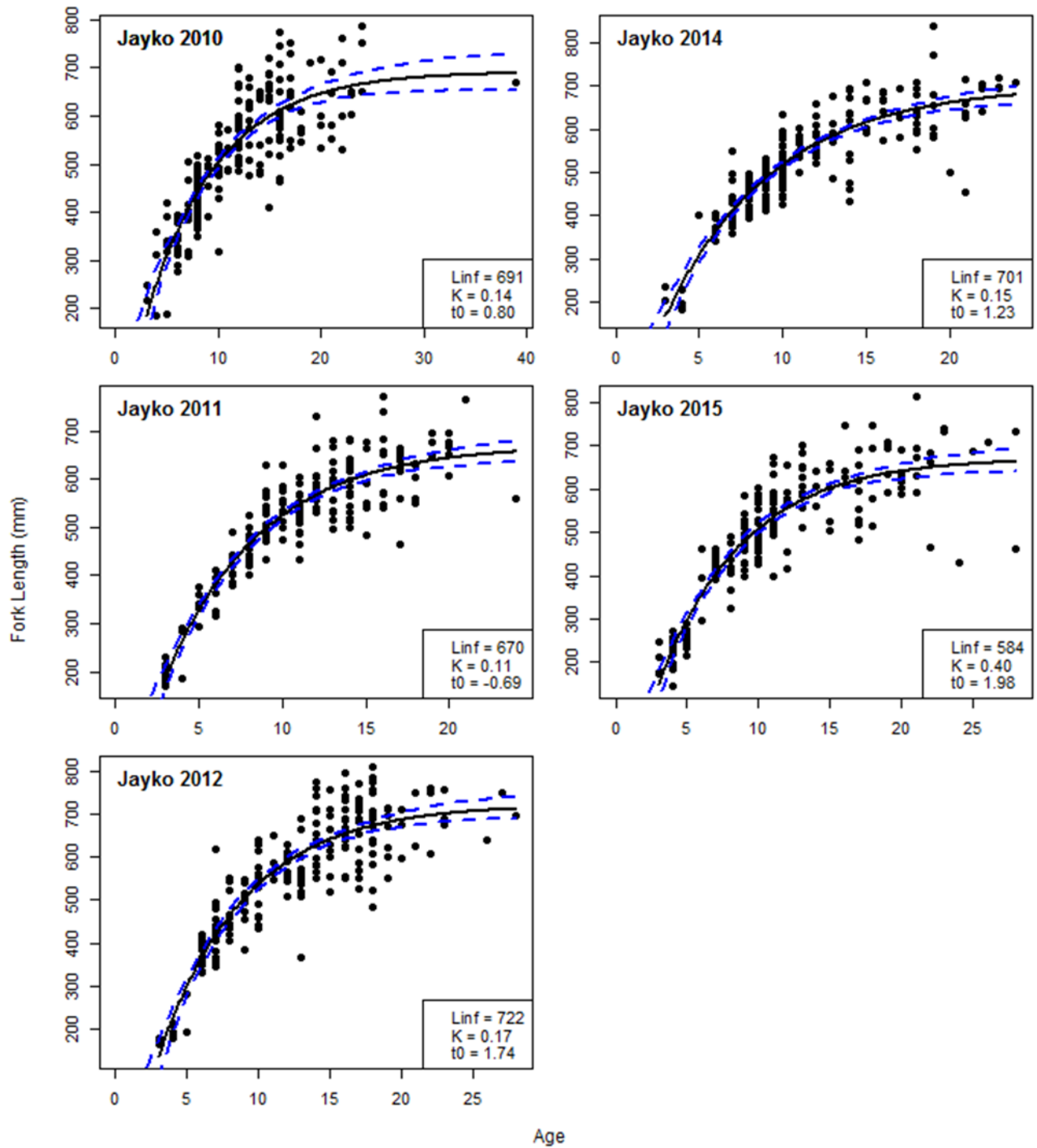


Figure 40. von Bertalanffy growth curves fitted to lengths at age for Jayko River, NU Arctic Char collected as part of the fishery-independent sampling program, 2010–2015. von Bertalanffy growth parameters are shown in the bottom left corner of each plot and Table 6.

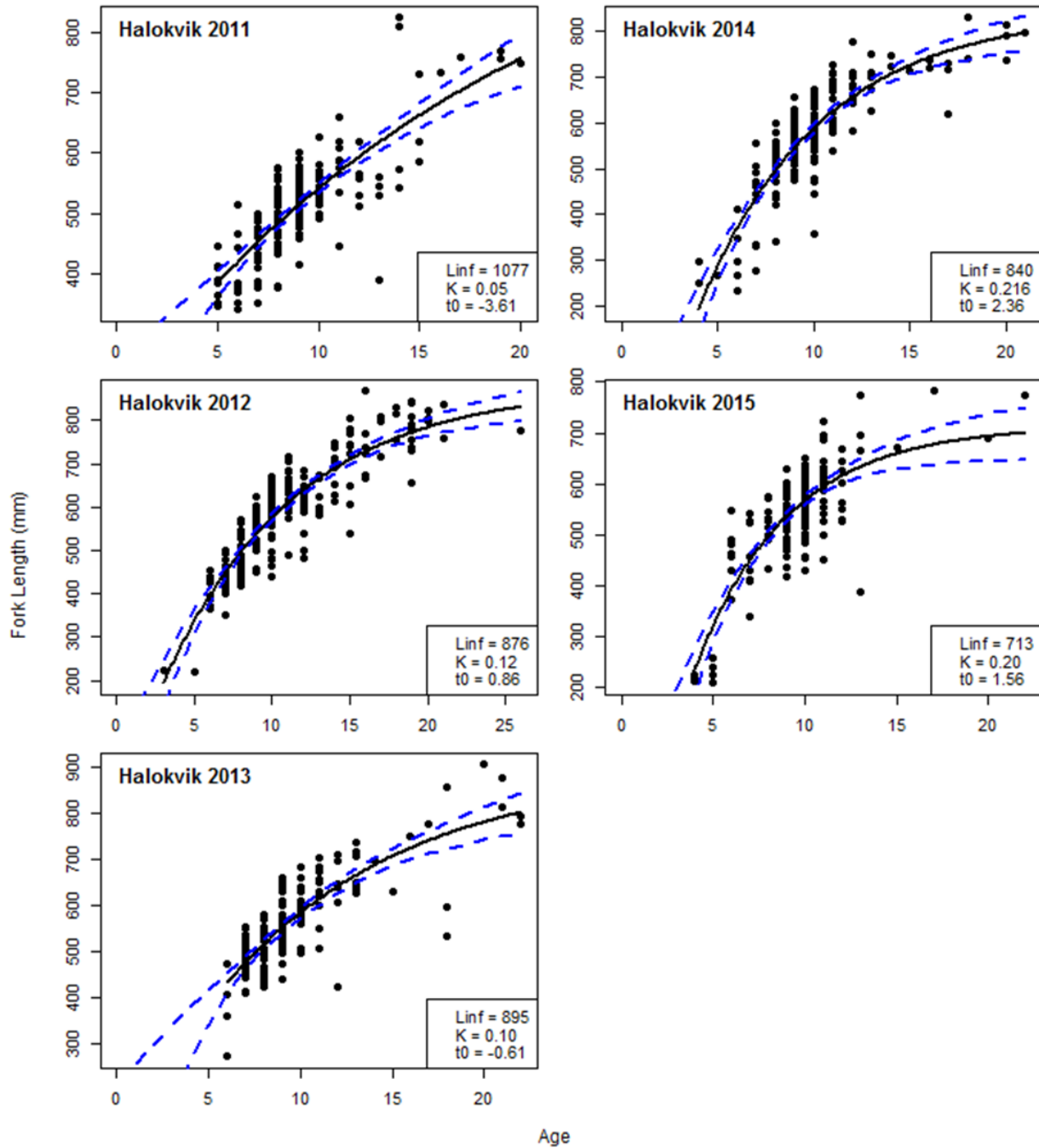


Figure 41. von Bertalanffy growth curves fitted to lengths at age for Halokvik River, NU Arctic Char collected as part of the fishery-independent sampling program, 2011–2015. von Bertalanffy growth parameters are shown in the bottom left corner of each plot and Table 6.

Condition

At both commercial fishing locations condition factor was relatively high. Across all decades of fishery-dependent sampling, condition of commercially harvested Arctic Char from the Jayko stock ranged from 0.54 to 2.29 (average = 1.23) and at Halokvik condition factor ranged from 0.54 to 2.95 (average = 1.20, Table 2). Jayko River Arctic Char were in better condition overall ($t = 10.44$, d.f. = 14,534, $p < 0.01$). Given the overall patterns in weight and length data, it is not surprising that relative condition factor also exhibits a sinusoidal pattern (Figure 42). Mean condition also increased significantly through time at both locations ($p < 0.01$, Figure 42). Mean condition between the first and last decades of fishery-dependent sampling was significantly different at both commercial waterbodies (Jayko: $t = -13.73$, d.f. = 1160.80, $p < 0.01$; Halokvik: $t = -35.67$, d.f. = 1567.70, $p < 0.01$). Overall condition for males and females was virtually identical overall years of fishery-independent sampling (Figure 43). Throughout the course of fishery independent sampling mean condition decreased slightly over time (Figure. 43). Mean condition between the first and last years of fishery-independent sampling were significantly different (Jayko: $D = 0.33$ $p < 0.01$; Halokvik: $D = 0.29$, $p < 0.01$). Frequency distributions of condition factor incorporating fishery-dependent data were unimodal for both fisheries and the modal values appeared to increase throughout the history of each fishery (Figures 44 and 45). In the latter years of sampling the modal value centered around 1.25 at both fishing locations and appeared to stabilize around that value (Figures 44 and 45). The frequency distributions of condition factor were significantly different between the first and last decade of sampling for both fisheries (Jayko: $D = 0.33$ $p < 0.01$; Halokvik: $D = 0.65$, $p < 0.01$). The condition distribution is skewed towards higher condition in the latter years. Frequency distributions of condition from the fishery-independent data appear stable across the sampling period (Figures 46 and 47). Sexes were also evenly distributed among condition classes. Condition factor Jayko and Halokvik river Arctic Char appeared to improve throughout the history of the fishery.

Mortality

Full recruitment of Arctic Char to the commercial harvest varied among years and waterbodies but for both stocks, in general, Arctic Char were fully recruited to the fishery at around 15 years of age. Instantaneous mortality rates (Z) calculated following the methods of Chapman and Robson (1960) using fishery-dependent data ranged from 0.27–0.84 at Jayko (mean = 0.46 across all decades, Figure 48, Appendix 3). Instantaneous mortality at Halokvik was higher ranging from 0.23–0.1.26 (mean = 0.64 across all years, Figure 49, Appendix 3). This results in annual survival rates (S , the percentage of a stock surviving annually) ranging from 0.43–0.76 at Jayko (mean across all years = 0.66) and 0.28–0.79 at Halokvik (mean across all years = 0.55). At both locations, mortality and survival has been highly variable throughout the years but total mortality has been decreasing and survival has been increasing since 2007–2008 for both stocks. Finally, instantaneous mortality rates calculated using fishery-independent data were much lower and more stable than those calculated using fishery-dependent data (Figures 50 and 51, Appendix 3). This is likely the result of a wider range of ages being sampled in the former. At Jayko, instantaneous mortality ranged from 0.17–0.23 (average = 0.19 across all years of sampling) and at Halokvik instantaneous mortality ranged from 0.23–0.67 (average = 0.37 across all years of sampling) (Appendix 3). No trends in mortality (annual or instantaneous) or survival could be resolved from these data but overall it does appear that annual survival is relatively high in these systems based on the fishery-independent biological data.

Fishing affects the productivity of fish stocks by increasing mortality. As a result, estimates of mortality can provide useful reference points for assessing the impacts of fishing on commercially exploited populations over time. Mortality rates have never been calculated for Cambridge Bay Arctic Char and those calculated here should provide useful benchmarks for

future comparisons and for further understanding Arctic Char responses to exploitation in the region. However, mortality estimates from commercially exploited anadromous stocks of Arctic Char are rare. Ranges and overall estimates of instantaneous mortality calculated here for commercially harvested Arctic Char using fishery-dependent data are within ranges that have been calculated in other exploited stocks (Harris and Tallman 2010, Harwood et al. 2013). For example, in the Isuituq River on Baffin Island, NU, Harris and Tallman (2010) resolved instantaneous mortality estimates ranging between 0.27 and 0.68 (average 0.43 over 6 years of sampling). In the Hornaday River system, although not a commercial stock but it is fished heavily for subsistence purposes, Harwood et al. (2013) estimated annual mortality over a 30 year period. In their study, annual mortality ranged from approximately 0.35–0.55. In the present assessment, mortality and survival at both sites was highly variable and some of the highest know estimates of mortality for this species reported to date were resolved in this assessment. For example, several estimates calculated using fishery dependent data exceeded 0.75 in both water bodies and several estimates exceed 1.0 at the Halokvik River. Updated ageing results, however, may result in updated estimates of mortality and survival. Finally, instantaneous mortality rates calculated using fishery-independent data were much lower and more stable than those calculated using fishery-dependent data. No trends in instantaneous mortality (annual or instantaneous) or survival could be resolved from these data. Overall, mortality appears to be high compared to the best available instantaneous natural mortality estimate from the unfished Murchison River.

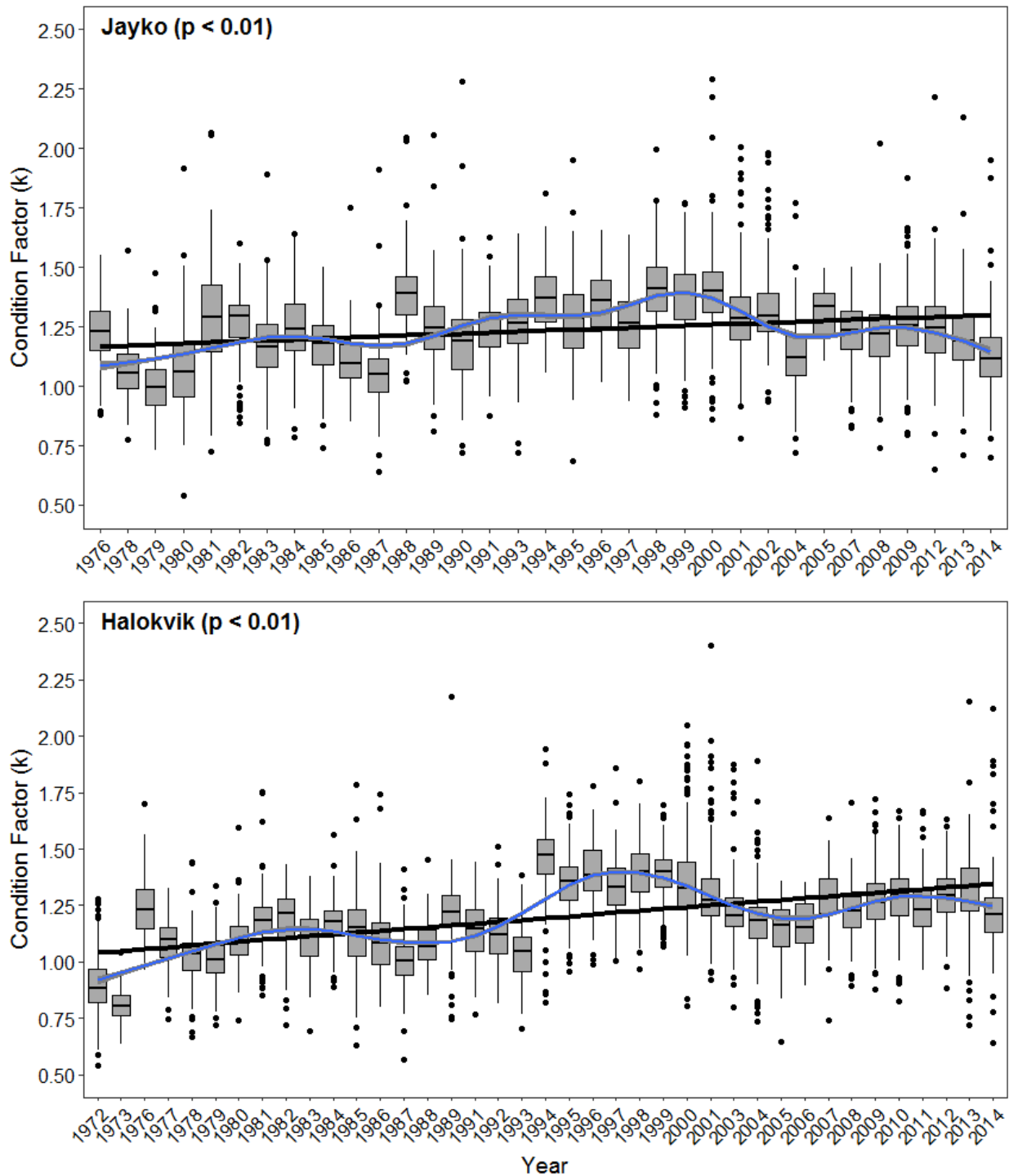


Figure 42. Box plots (showing the 25th and 75th percentile or inter-quartile range (IQR, grey box), the median (black line within the box) and 1.5 x the IQR ('whiskers' of the plot)) of age collected from fishery-dependent sampling of Arctic Char from the Jayko and Halokvik rivers. A trend line (shown in black) was fit to the data and the significance of this relationship is shown in the top left corner. A spline (blue line) was also fit to help visualize the data.

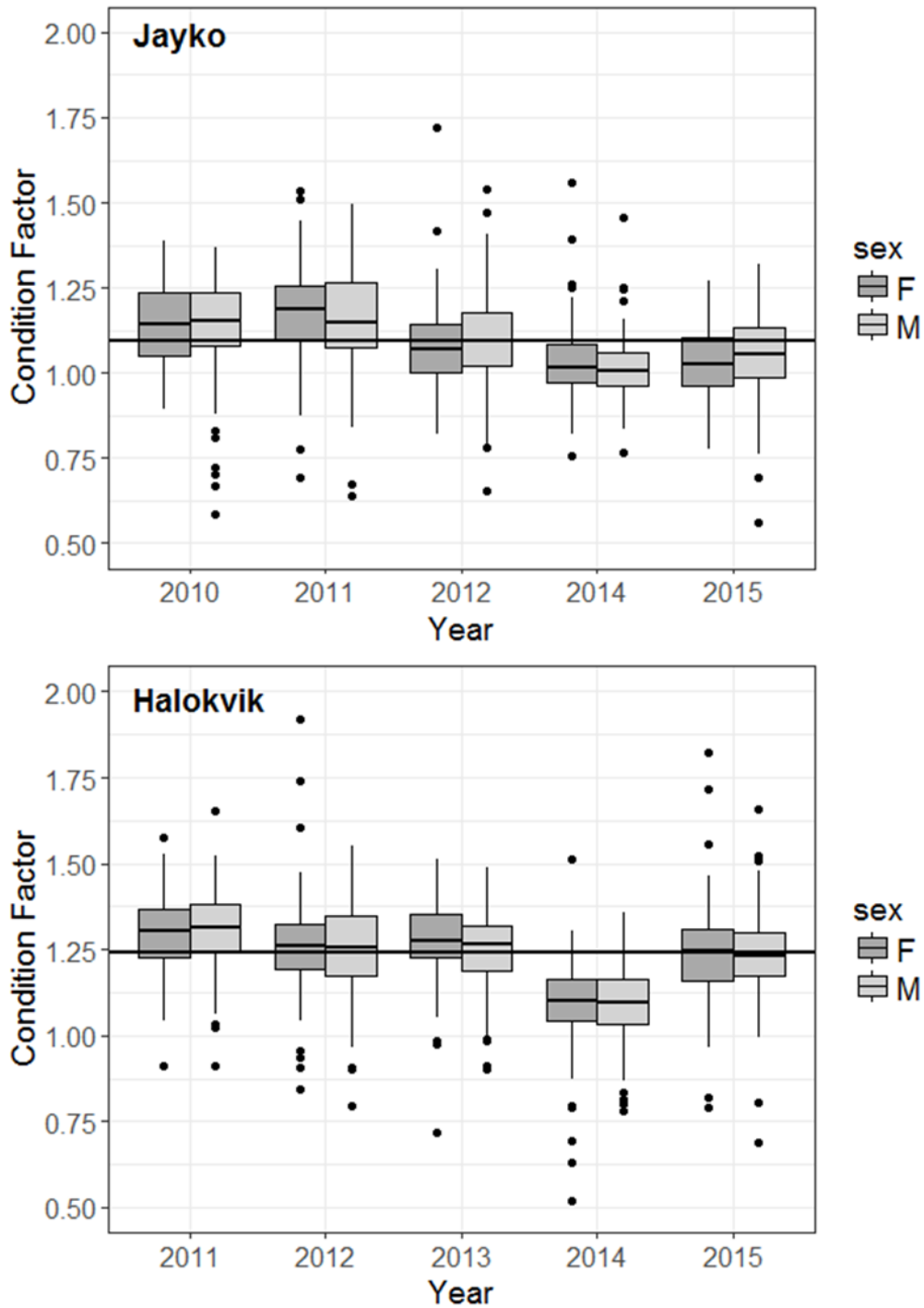


Figure 43. Box plots (showing the 25th and 75th percentile or inter-quartile range (IQR, grey box), the median (black line within the box) and 1.5 x the IQR ('whiskers' of the plot)) of condition factor (k) collected from fishery-independent sampling of Arctic Char from the Jayko and Halokvik rivers, 2010–2015. The mean condition factor across all years is shown for males (solid black line) and females (dotted black line).

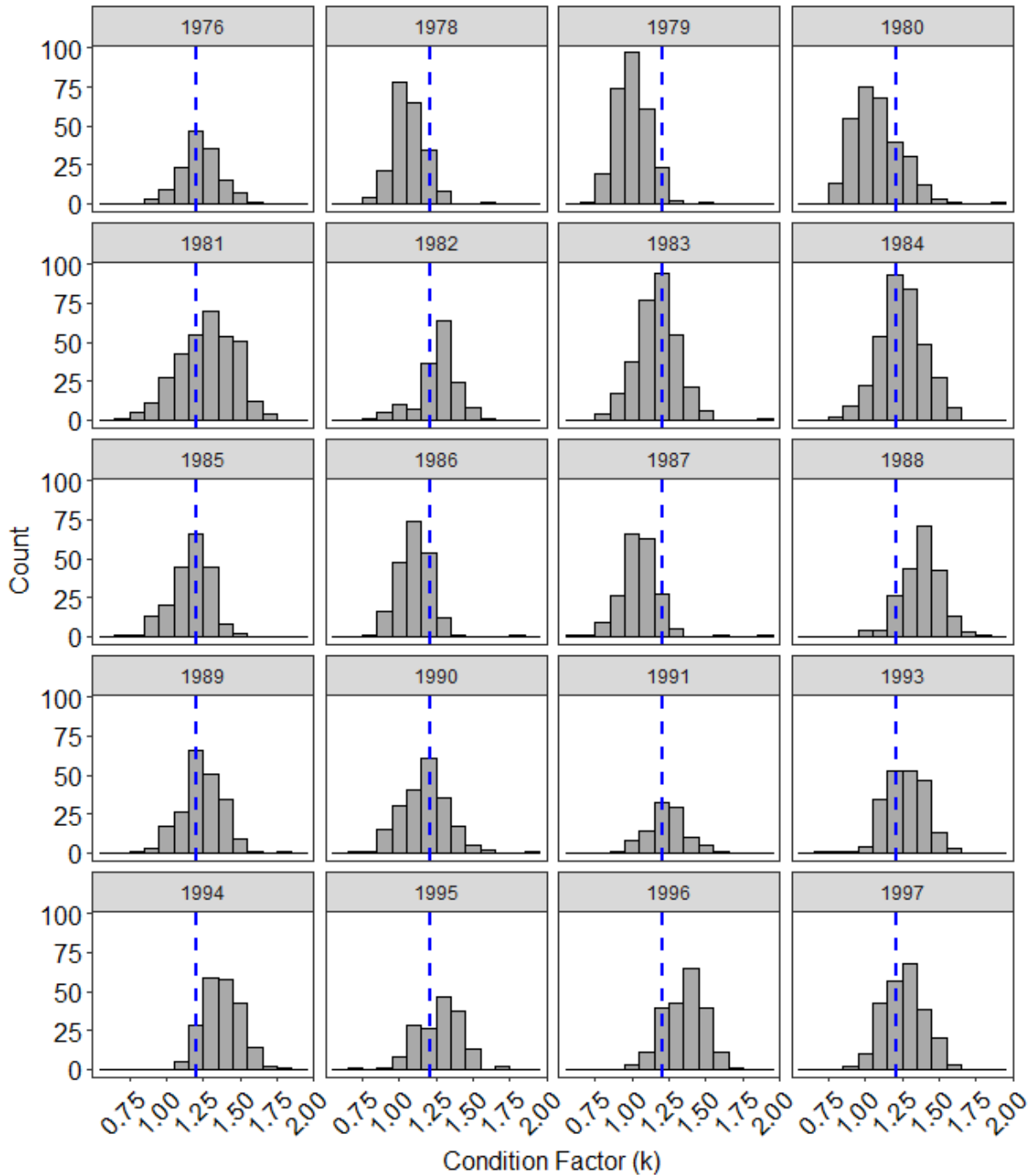


Figure 44. Frequency distributions of condition factor (k) calculated from data collected from fishery-dependent sampling of Arctic Char from the Jayko River, NU. Mean fork length across all years is shown as a blue dotted line.

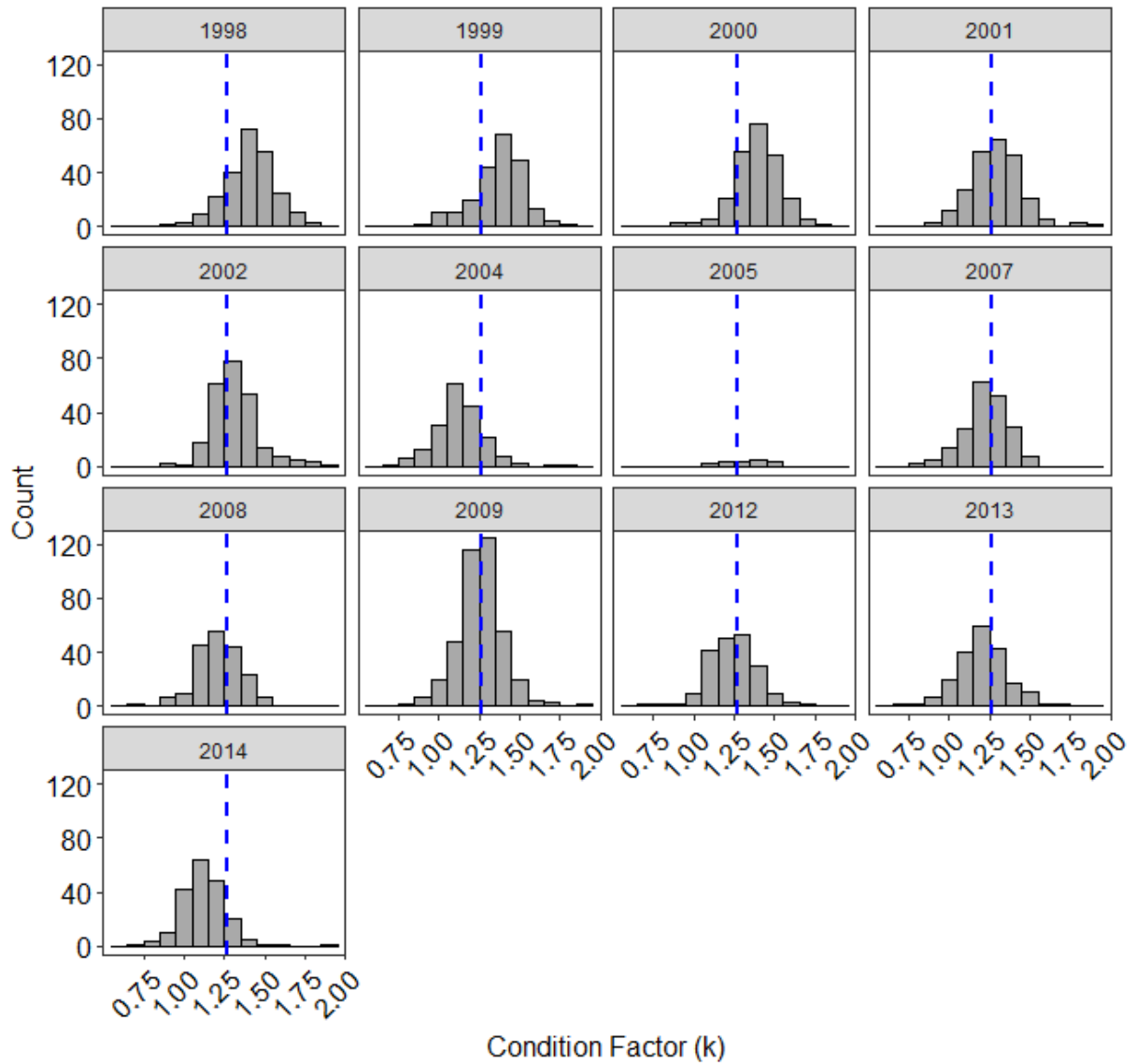


Figure 44. Continued. Frequency distributions of condition factor (k) calculated from data collected from fishery-dependent sampling of Arctic Char from the Jayko River, NU. Mean fork length across all years is shown as a blue dotted line.

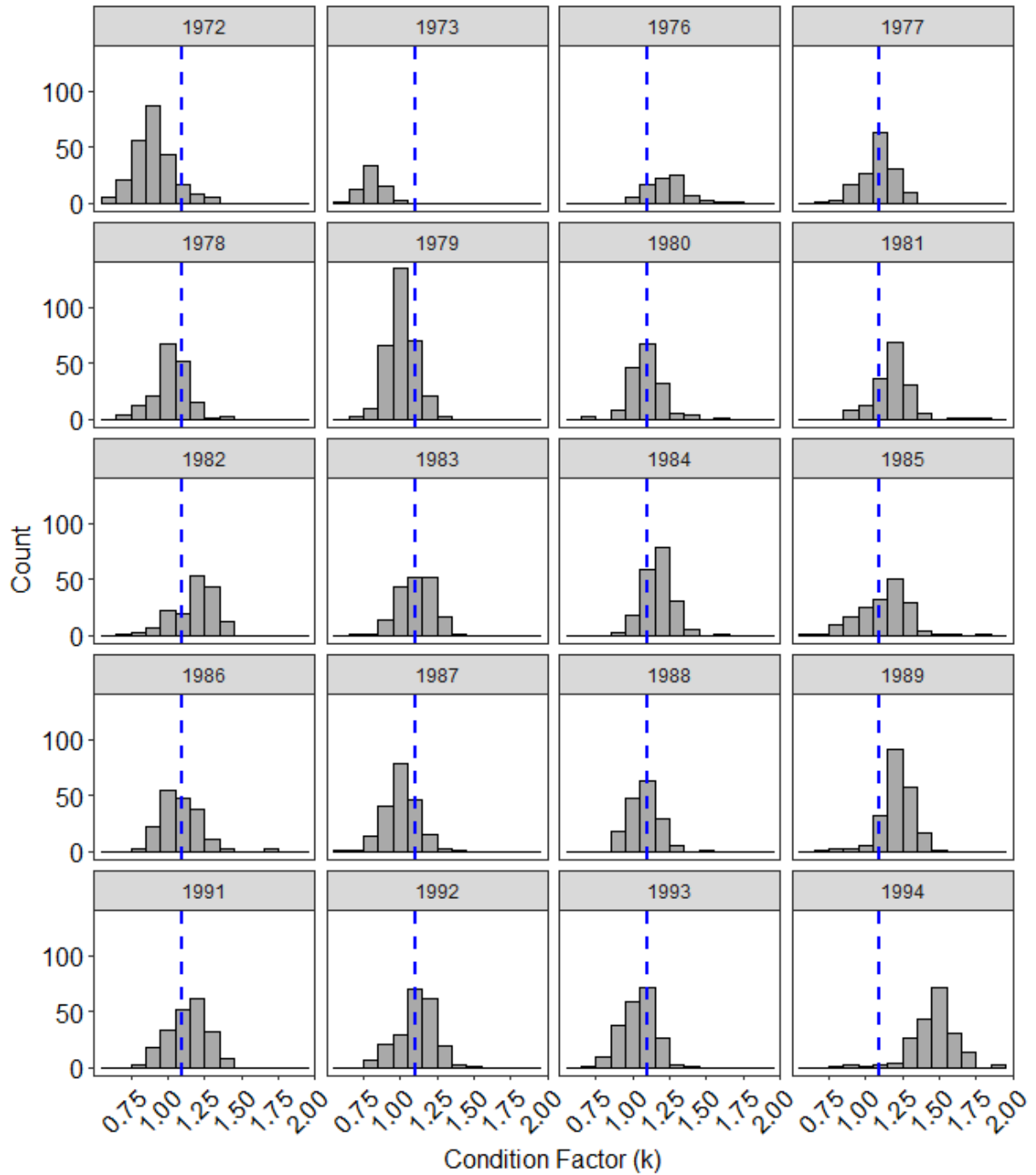


Figure 45. Frequency distributions of condition factor (k) calculated from data collected from fishery-dependent sampling of Arctic Char from the Halokvik River, NU. Mean fork length across all years is shown as a blue dotted line.

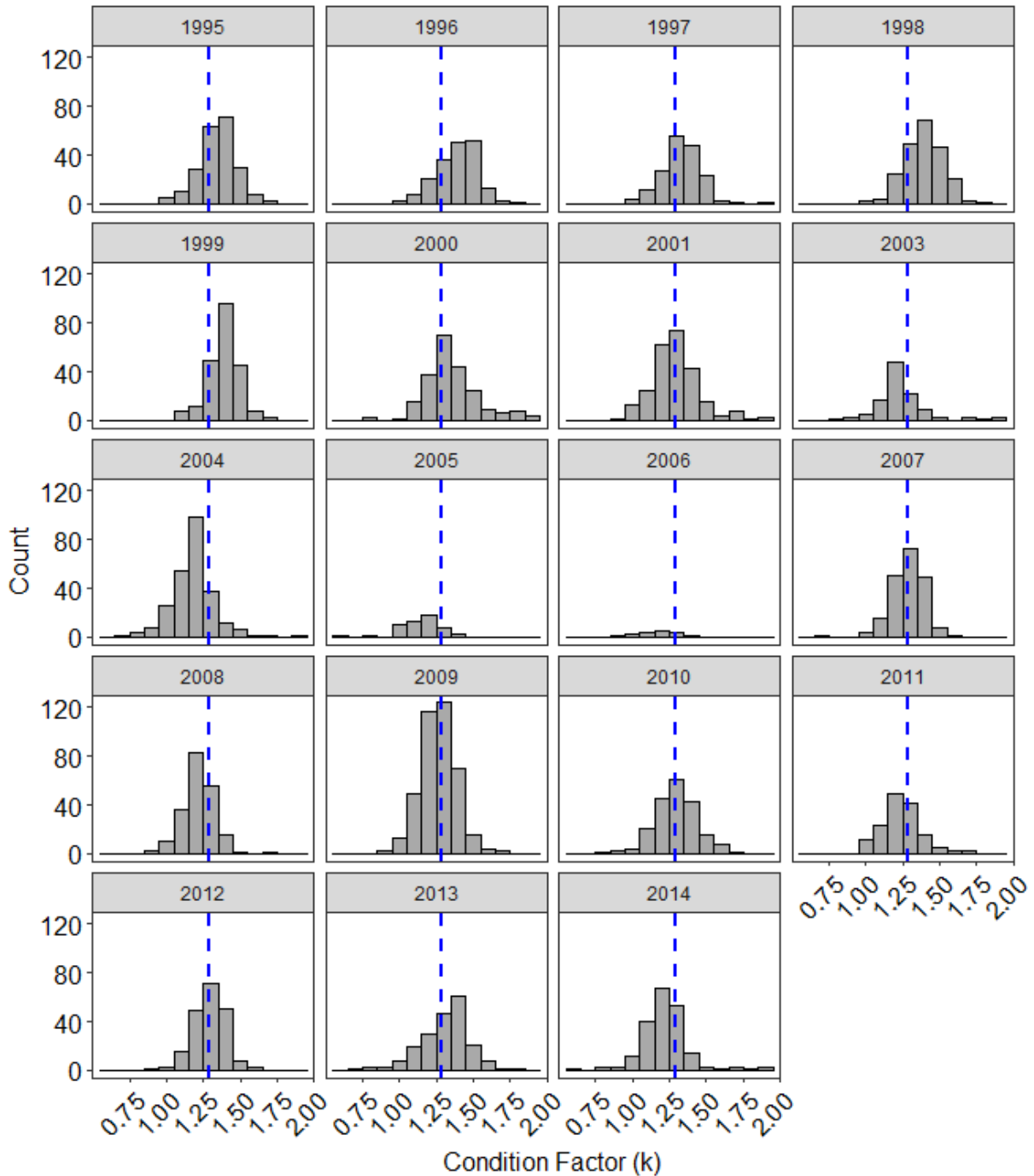


Figure 45 Continued. Frequency distributions of condition factor (k) calculated from data collected from fishery-dependent sampling of Arctic Char from the Halokvik River, NU. Mean fork length across all years is shown as a blue dotted line.

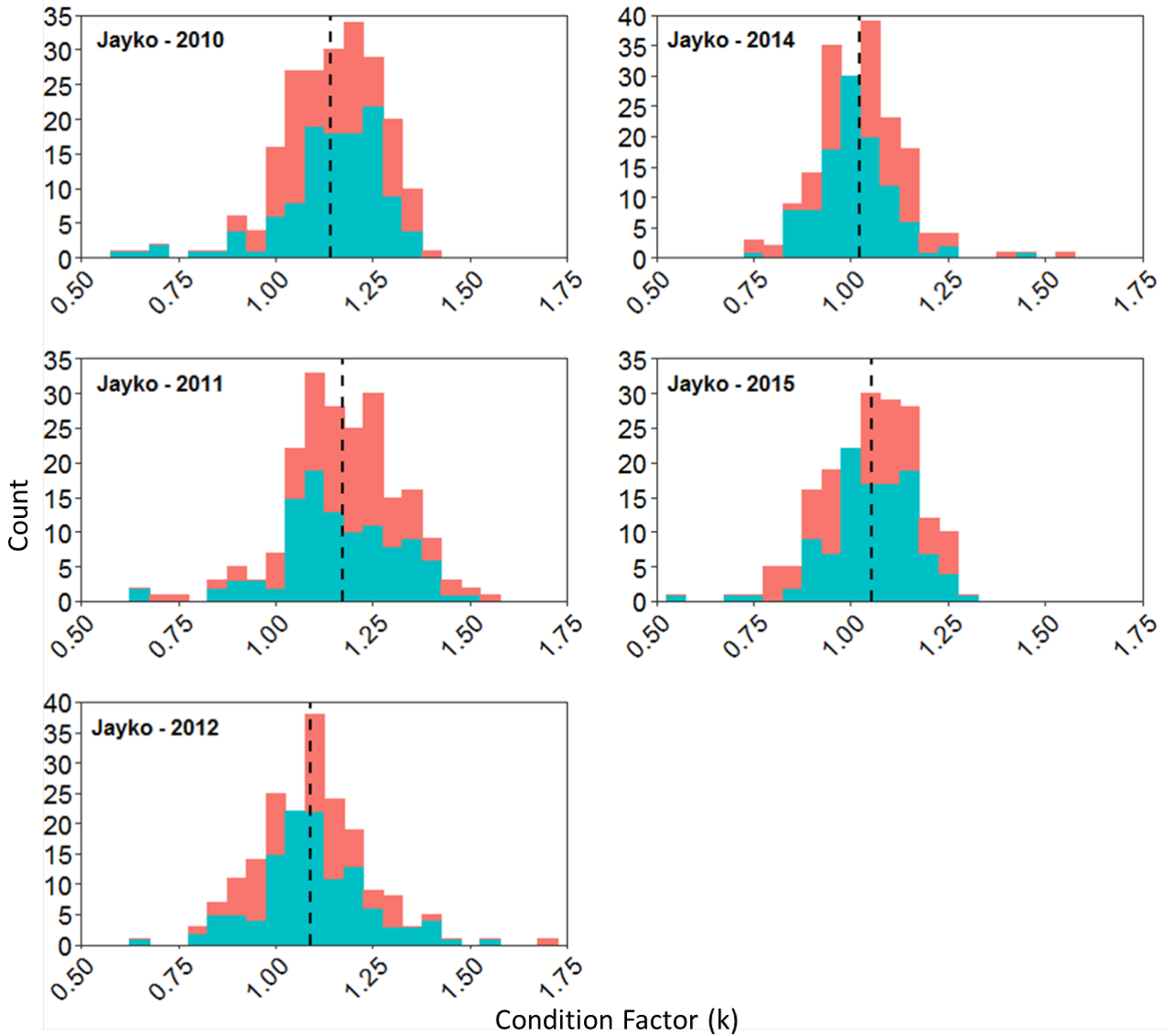


Figure 46. Frequency distributions of condition factor (k) collected from fishery-independent sampling of Arctic Char from the Jayko River, NU, 2010–2015. Females are shown in red and males are shown in blue. The mean round weight for each year (sexes combined) is shown as a black dotted line.

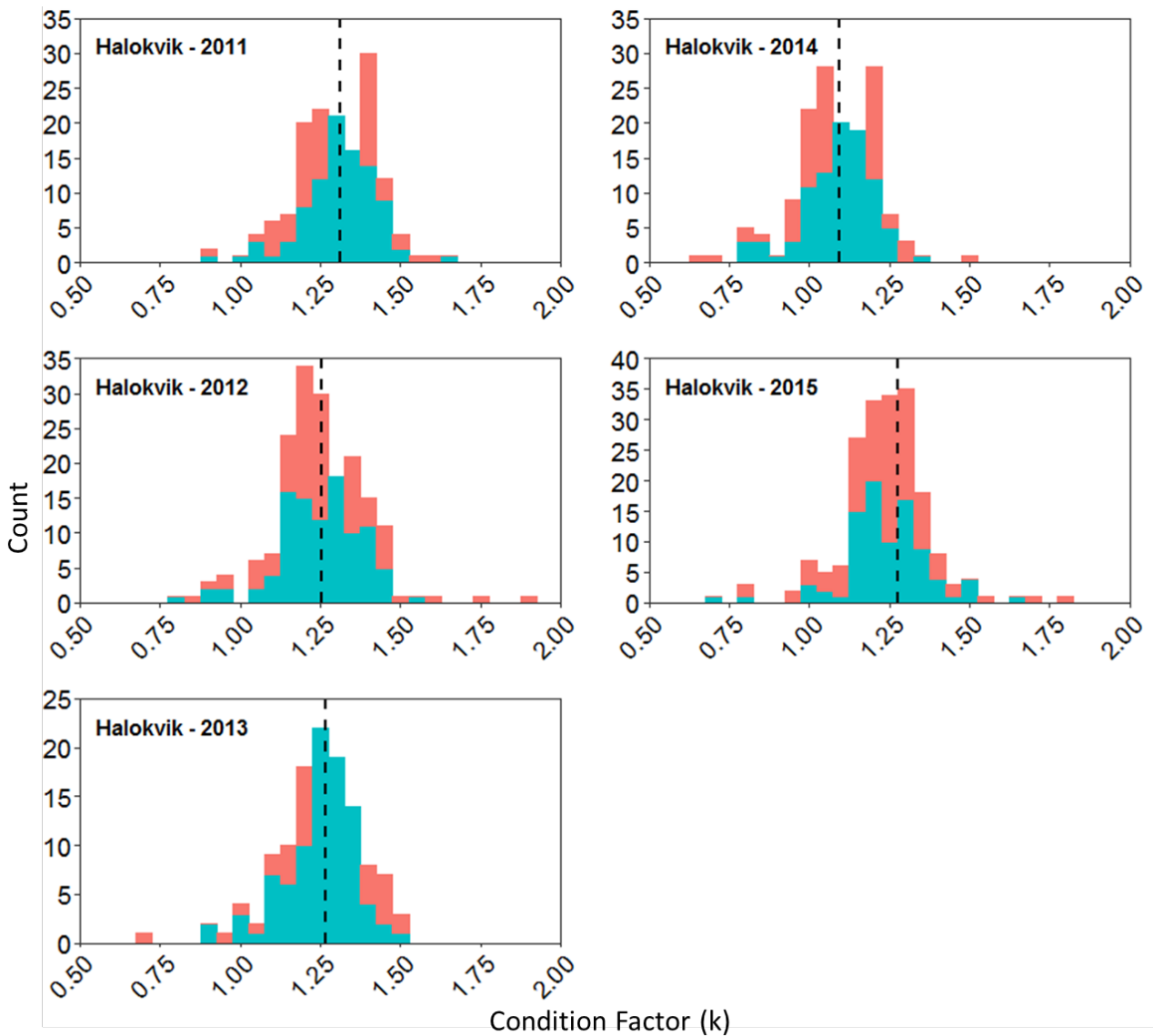


Figure 47. Frequency distributions of condition factor (k) collected from fishery-independent sampling of Arctic Char from the Halokvik River, NU, 2011–2015. Females are shown in red and males are shown in blue. The mean round weight for each year (sexes combined) is shown as a black dotted line.

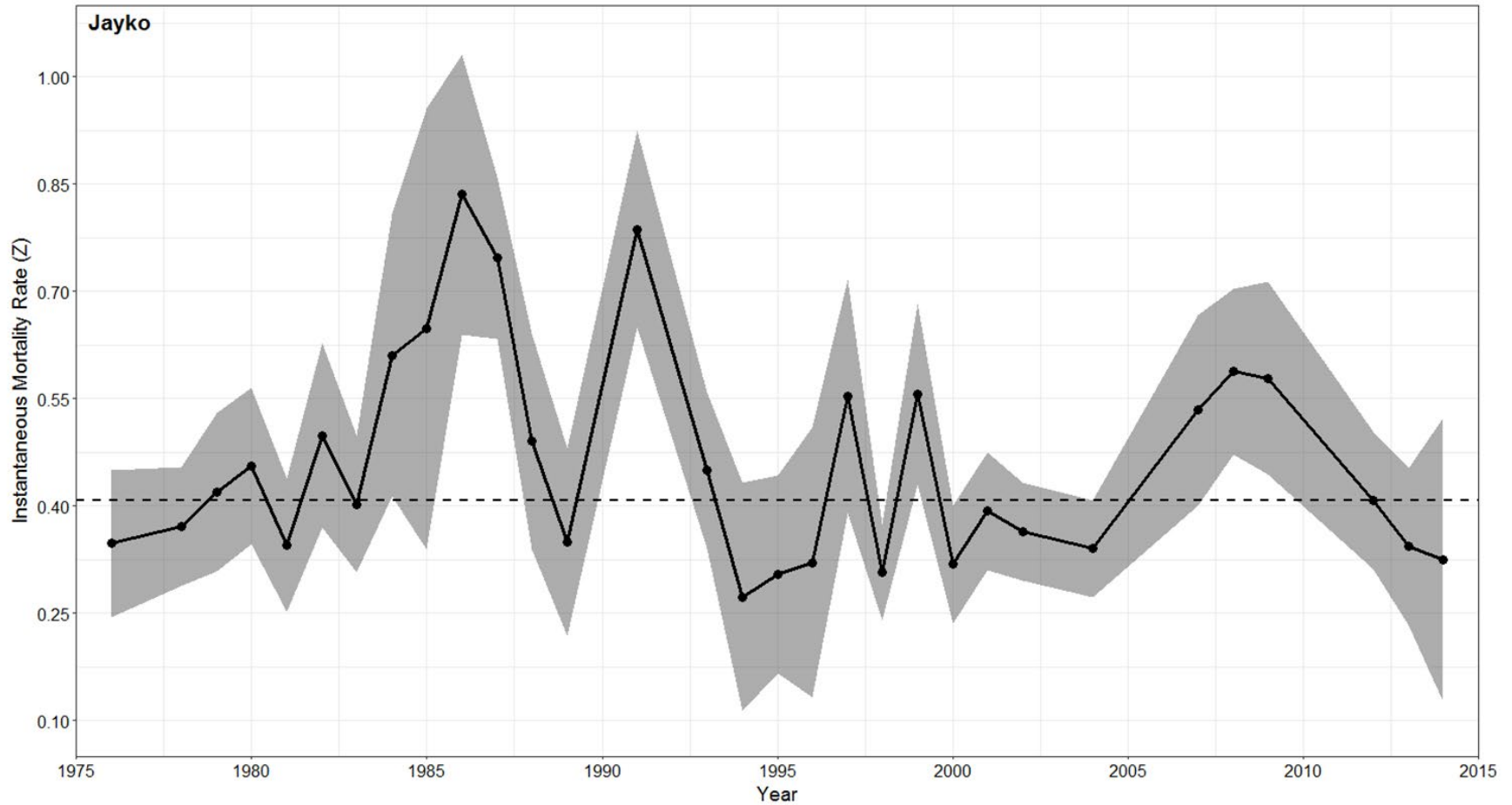


Figure 48. Estimates of instantaneous mortality (Z) for commercially harvested Arctic Char from the Jayko River, NU assessed using fishery-dependent data. Shown is the estimate for each year of sampling (black dot) and the corresponding 95% confidence intervals (grey shading).

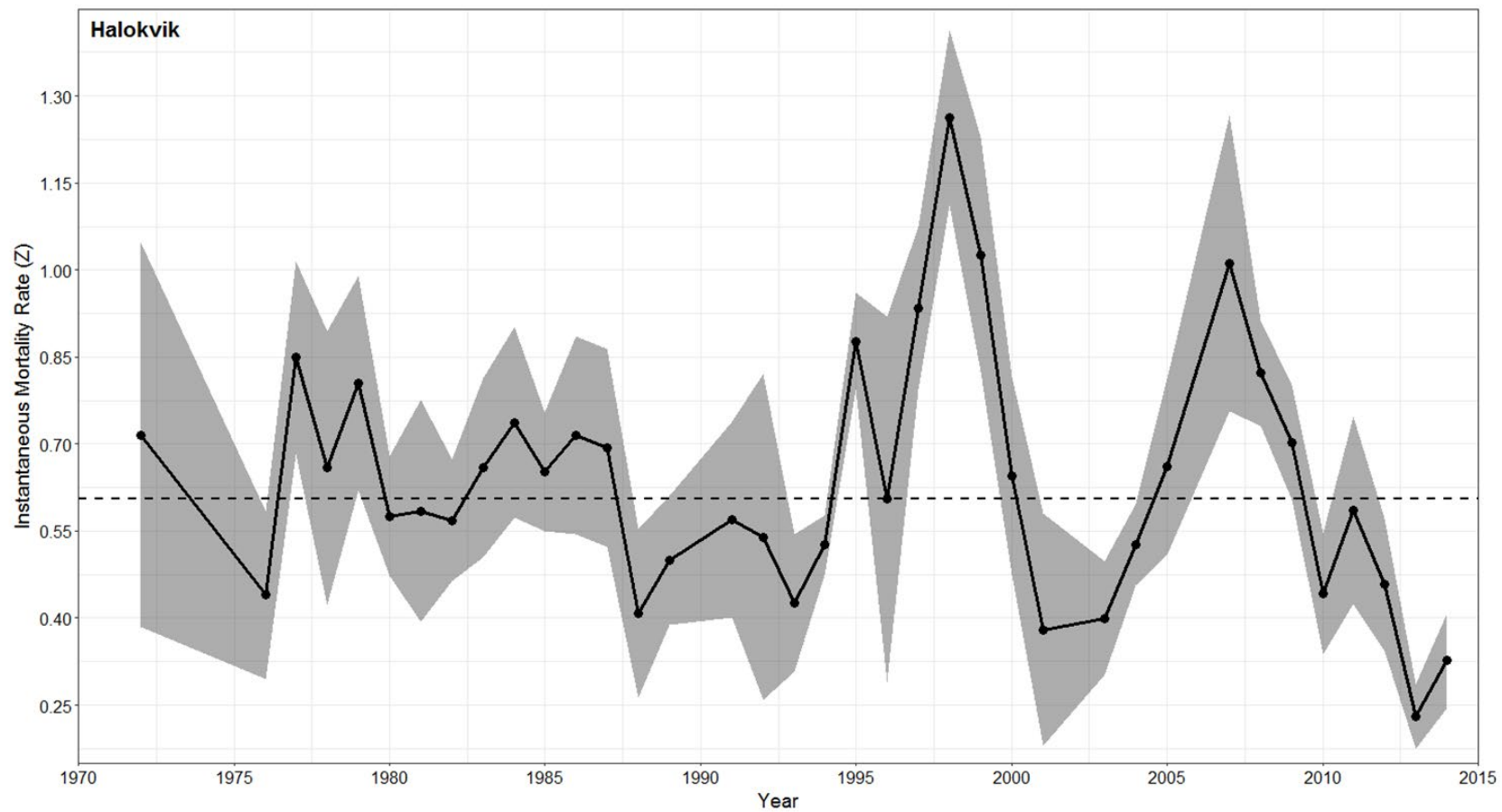


Figure 49. Estimates of instantaneous mortality (Z) for commercially harvested Arctic Char from the Halokvik River, NU assessed using fishery-dependent data. Shown is the estimate for each year of sampling (black dot) and the corresponding 95% confidence intervals (grey shading).

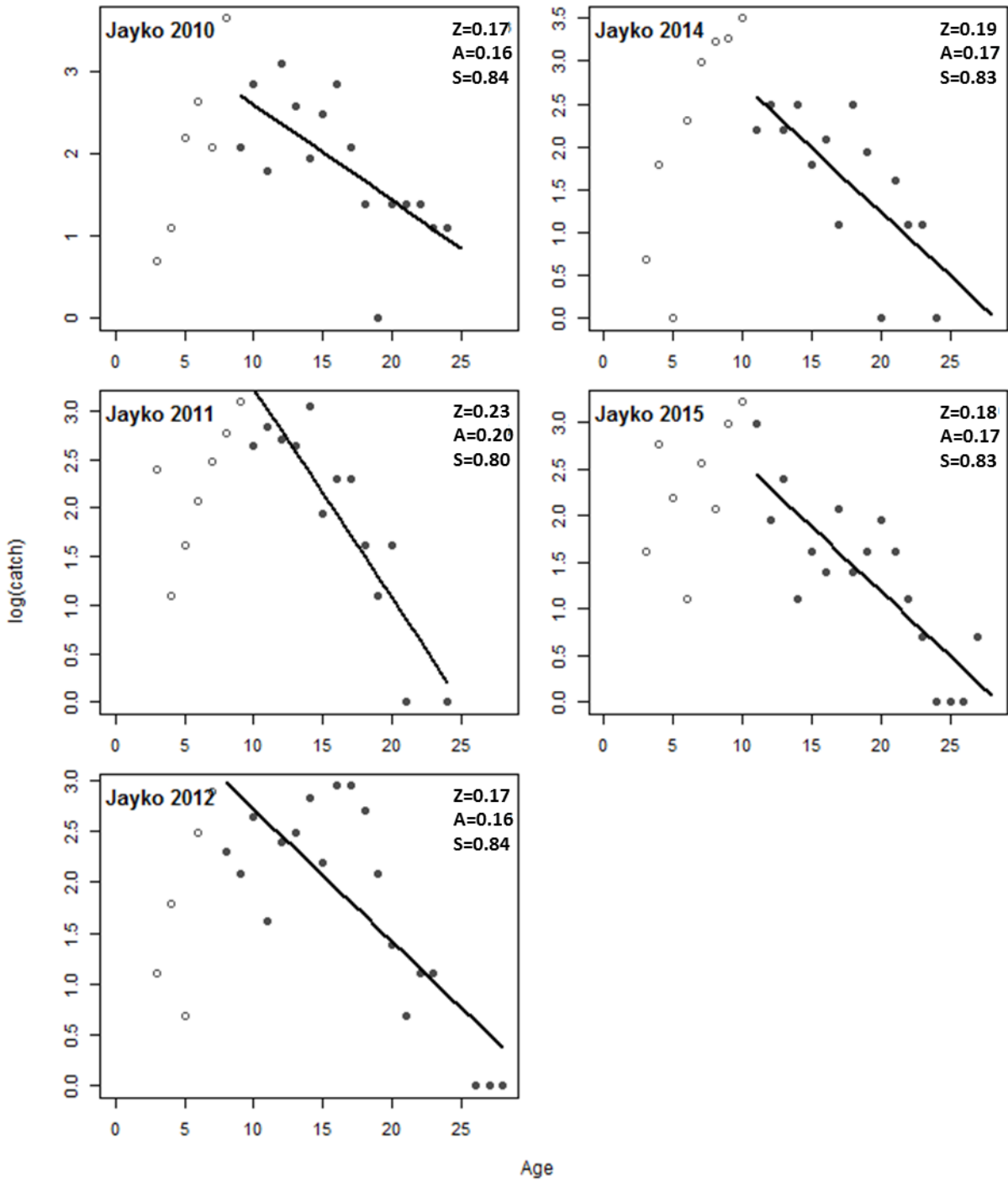


Figure 50. Age frequency catch curves for Jayko River, NU Arctic Char collected as part of the fishery-independent sampling program, 2010–2015. Catch curve parameters (calculated using the Chapman-Robson method) instantaneous mortality (Z), annual mortality (A), and annual survival (S) are shown in the top right corner of each plot.

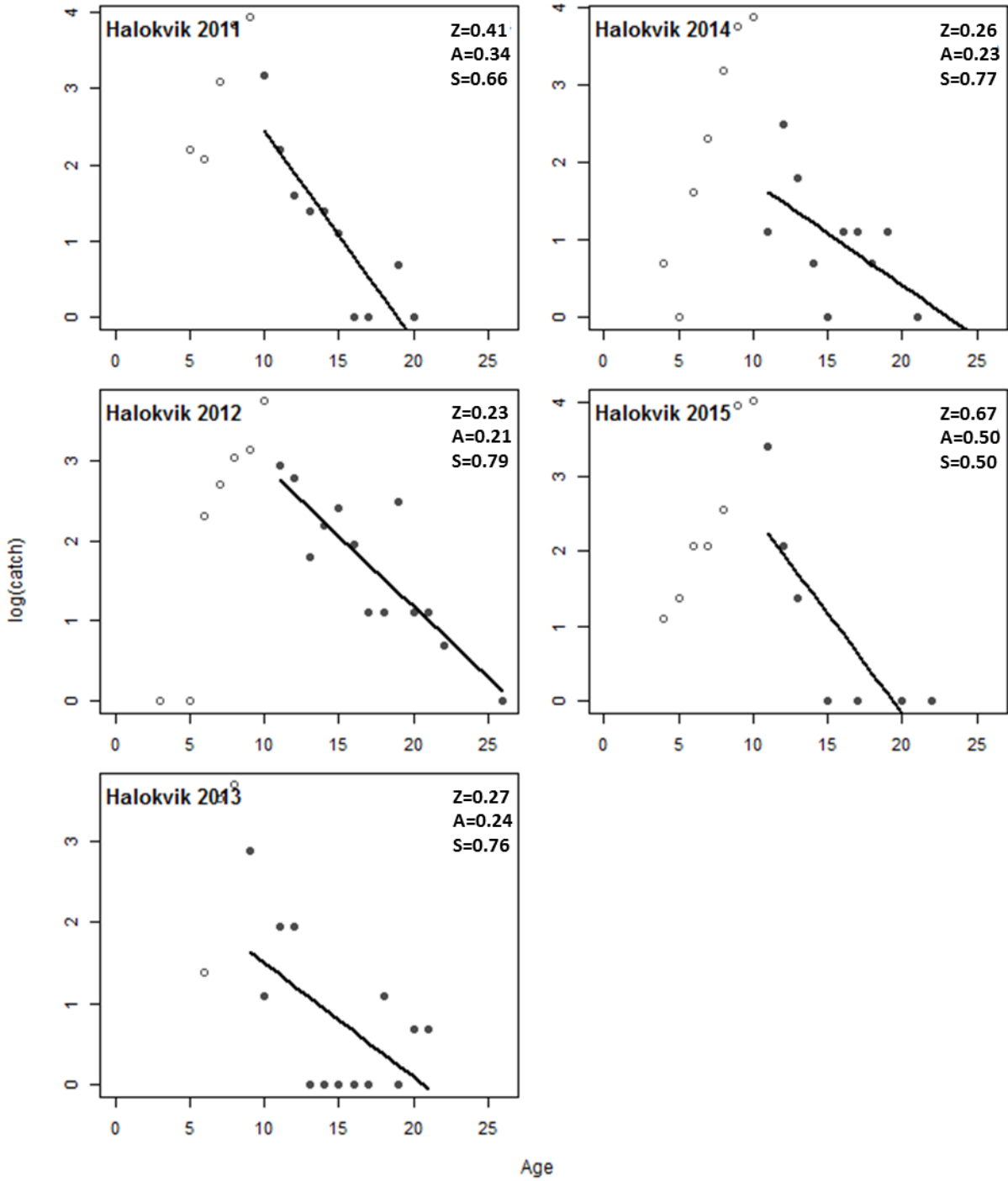


Figure 51. Age frequency catch curves for Halokvik River, NU Arctic Char collected as part of the fishery-independent sampling program, 2011–2015. Catch curve parameters (calculated using the Chapman-Robson method) instantaneous mortality (Z) and annual mortality (A) are shown in the top right corner of each plot.

SOURCES OF UNCERTAINTY AND RESEARCH NEEDS

DEMOGRAPHIC INDEPENDENCE AND GENETIC DISCRETENESS OF STOCKS

The management of anadromous char from the Halokvik system is based on the notion that char in this system represents a discrete stock. This assumption, however, has not been tested directly because samples from spawning individuals (or juveniles from natal sites) have not yet been available. Although recent microsatellite work (Harris et al. 2016) and ongoing next-generation sequencing initiatives (Moore et al. 2017) have shed some light on genetic stock structure among Arctic Char in the region, samples used in these studies came directly from the commercial harvest or from sampling designs intended to mirror the commercial harvest. Although several important management implications were gleaned from this work, assessing genetic stock structure among samples collected at coastal fishing locations does not truly represent stock structure in the region. Thus, it is recommended that spawning individuals or juveniles that have not left their natal system be sampled and assessed. This would be beneficial for resolving genetic stock structure, furthering our understanding of the demographic independence of commercially exploited stocks, and the degree of mixed-stock harvest in the region.

CONSISTENT CRITERIA FOR AGEING

Arctic Char throughout the history of the fishery-dependent plant sampling program have been aged by different readers. Initially all otoliths were aged whole and then methods were refined and otoliths from older individuals were sectioned for ageing. There is a possibility that older Arctic Char may have been under-aged in earlier years of sampling as has been noticed in other Arctic Char stocks in the region. If this is the case, the proportion of older age classes in the population would have been underestimated which would cause mortality estimates to be over-estimated. An age-comparison study is underway to address this concern. Having better age data will ensure more reliable estimates of mortality and will permit the use of different and improved stock assessment models.

PLANT SAMPLING

The Cambridge Bay plant sampling program is the most successful of its kind for permitting the collection of weight, length, and age data from commercially harvested Arctic Char. These data have formed the backbone of previous assessments and will be extremely valuable for future assessments especially with the addition of fishery-dependent CPUE data. This program is a cost effective way for collecting these data (\$7 per sample in 2015) and should continue for as long as the fishery is still active.

UNKNOWN CENSUS POPULATION SIZES

Little is known regarding the actual sizes of stocks harvested in the Cambridge Bay Arctic Char fishery. Such information is vital for establishing and refining quotas and for understanding Arctic Char responses to exploitation. Unfortunately, enumerating upstream runs of Arctic Char is expensive and only provides single-year point estimates (snap shots) of abundance unless programs are run for multiple years. Furthermore, although mark-recapture techniques have recently been employed, many underlying assumptions (e.g., closed systems, incomplete mixing of tagged and untagged fish, etc.) could be violated in the models that have been fit. Thus, the results generated from these methods come with high uncertainty and therefore should be interpreted with caution. Continuing to collect fishery-dependent and fishery-independent data, including effort data for both types, will prove valuable for exploring quantitative models that will allow for the estimation of abundance or biomass. It may be

prudent to update point estimates of the abundances of commercial Arctic Char stocks in the Cambridge Bay region. However, such estimates are highly variable from year to year for a variety of reasons (dispersal, recruitment successes or failures, etc.).

FISHERY-DEPENDENT CPUE

Catch and effort data are fundamental in stock assessment and allow for the calculation of CPUE which can be used as an index of stock abundance. Assuming fishing methods and gear remain consistent, increases or decreases in CPUE overtime can be used to make inferences on the health of a stock given current and historical levels of harvesting. However, inference based on fishery-dependent CPUE is misleading if catchability does not remain constant and this assumption appears to have been violated in nearly every commercial fishery stock assessment (Hilborn and Walters 1992, Quinn and Deriso 1999). Fishery-dependent CPUE data are virtually absent from all commercial Arctic Char stocks in Nunavut with the exception of those harvested in the Cambridge Bay region. For these latter stocks, it is only recently that CPUE data have become available as a result of a monitoring program funded by the Nunavut General Monitoring Plan. Despite obvious problems with fishery-dependent CPUE, it still remains an important tool for parameterizing quantitative models, and should be continued.

HARVEST OF MIXED STOCKS

It is likely that the Halokvik River stock is also harvested in subsistence and commercial mixed-stock fisheries (e.g., in Ferguson Lake during over-wintering and the area locally known as Gravel Pit described above) and this may be especially true in years when Arctic Char are not spawning. This also leads to situations where total harvest of this stock is not known. Collecting genetic baseline samples from juvenile Char or spawning individuals would be required to perform mixed-stock fisheries analyses to address this unknown. Samples from all known contributing stocks would be required for accurate mixed-stock fishery analysis.

ACOUSTIC TELEMETRY

Recent acoustic telemetry work has provided valuable insights into the movement of Arctic Char among commercial waterbodies and the degree of mixing of different stocks while being targeted in fisheries in marine environments. Our telemetry data set is the largest of its kind for Arctic Char. Continuing this work will provide a long-term data set of movement, dispersal, and mixing among stocks to address many unknowns that still exist regarding the biology and ecology of this species. Furthermore, continuing this work will help resolve unknowns pertaining to the “over-wintering” hypothesis and the degree of mixing among different commercial stocks in over-wintering habitats.

SUBJECTIVE MATURITY CLASSIFICATION

Classifying maturity status is somewhat subjective especially when distinguishing between ‘immature’ and ‘resting’ fish. Research should be undertaken to resolve this concern given the importance of understanding potential changes in age and length at maturity as it pertains to commercial exploitation of these stocks. Other methods/ways to identify maturity status (e.g., histological methods) should also be explored in attempts remedy this concern.

ECOSYSTEM-BASED FISHERIES MANAGEMENT

Research focusing on better understanding of the ecosystem in general and trophic relationships is needed to support adaptive ecosystem-based management approaches to the conservation of fisheries resources. Such information will be valuable for understanding the

environmental, biological, and ecological drivers of char productivity and for resolving spatial variation in resource availability. Equally important, the data will be useful for assessing the impacts of char fisheries on the surrounding ecosystem.

LIFE-CYCLE

Freshwater resident individuals (i.e., those that do not migrate to marine waters for feeding after smolting) have been identified in other areas of the Canadian Arctic but have yet to be confirmed in the Cambridge Bay region. Residents typically spawn with their anadromous counterparts and therefore impact recruitment where they exist. Work should be undertaken to confirm if resident Arctic Char exist in the Cambridge Bay region and expand our knowledge of Arctic Char life history in general.

PARASITES

Previously, there were concerns regarding heavy parasitism in Jayko River Arctic Char such that commercial fishing ceased at this location for several years. Samples for parasitological analyses should be analyzed to confirm if Jayko River Arctic Char are more heavily parasitized in comparison to other commercially fished waterbodies.

FREQUENCY OF SPAWNING AND STOCK RECRUITMENT

Arctic Char at northern latitudes are presumed not to spawn yearly, yet the frequency of spawning and number of life time spawning events remain unknown. Furthermore, there is virtually no information on the fecundity of Cambridge Bay Arctic Char. Both of these unknowns hinder our understanding of Arctic Char recruitment which has implications for stock assessment modelling. Potential identification of chemical markers through otolith micro-chemical analyses may be promising for furthering our understanding of spawning events and lifetime reproductive output. Analyses of otolith strontium may also prove useful for resolving the frequency of skipped migrations in these systems. Furthermore, the collection of ripe ovaries should be undertaken to further our understanding of fecundity and the reproductive biology of Arctic Char in the region.

SUBSISTENCE HARVEST

The total harvest of Jayko and Halokvik river Arctic Char is unknown due to the absence of data on subsistence harvests at these locations. Zhu et al. (2014b) suggested that the subsistence harvest of Arctic Char in Cambridge Bay is upwards of 50% of the annual commercial harvest. This is likely an over-estimate of the true subsistence harvest at these locations given the distances from the community. However, it is imperative to understand the total removals from a stock, including subsistence harvest, for the models used in this assessment. Work aimed at collecting information on subsistence and recreational harvests of Arctic Char should be initiated. Furthermore, there is a large subsistence harvest of Arctic Char at the area locally known as Gravel Pit and it is unknown what proportions of Jayko and Halokvik Arctic Char, if any, are harvested at this location.

CRITICAL HABITATS

Knowledge of critical habitats is essential for the conservation of exploited fish stocks. Identifying these habitats is crucial for the long term persistence of stocks and is of the utmost importance for populations facing potential anthropogenic habitat disturbances (e.g., oil, gas, and mining exploration and development). Although recent acoustic telemetry work has provided valuable insights into the timing of migrations, straying, and marine habitat use and

feeding areas, knowledge regarding habitats important for spawning, rearing, and overwintering is still absent for these stocks. Research to identify critical habitats for Cambridge Bay Arctic Char will be valuable for guiding future conservation strategies and potential habitat recovery and/or protection procedures. Freshwater acoustic telemetry work would be a key step in resolving these unknowns. Furthermore, identifying critical habitats will allow for the collection of true “baseline” genetic samples (described above) that would provide better resolution of genetic population structure among Arctic Char in the region and permit the application of mixed-stock fishery analyses for resolving contributions to mixed-stock harvests.

FECUNDITY

Fecundity is a fundamental property of reproductive potential, yet there is virtually no information on fecundity of Arctic Char from the Cambridge Bay region. Thus, there are still many unknowns pertaining to reproductive output which is vital for understanding recruitment within and among stocks. It is recommended that current-year spawning individuals be sampled and ovaries collected for subsequent fecundity analyses. This should be done for several commercial fisheries so that variation in fecundity among stocks can also be addressed.

CONCLUSIONS

Trends in the fishery-dependent biological and catch-effort data time-series do not provide sufficient information to assess whether these stocks are being overharvested. Most trends are sinusoidal in nature and have increased through time. More work, however, is needed to assess whether these sinusoidal trends, including the overall increases in most biological parameters over time, are the result of temporal environmental variability or commercial harvest over time. With the exception of 2014 at the Halokvik River, fishery-dependent CPUE has remained relatively constant since data collection began in 2012.

Trend analyses based on fishery-independent data provide little indication that Jayko and Halokvik river Arctic Char have been adversely impacted by recent harvests in these systems. The majority of biological characteristics of these stocks have not been altered significantly as a result of fishing in this system. Harvests, independent of CPUE, however, were quite variable among years within each system. It should also be noted that fishery-independent times-series are relatively short (five years) and the continued collection of these types of data in future will be valuable for further assessing Arctic Char responses to harvest.

Age and length at maturity have decreased substantially at both locations since fishery-independent sampling began which may be a response to over-harvest. There are, however, some concerns over the subjectivity of maturity classification that need to be addressed before firm conclusions are drawn. Furthermore, the values reported for fishery-independent data are within ranges of values calculated using historical data that were available.

Estimates of mortality (Z) from fishery-dependent data were highly variable through time for both stocks, averaging 0.46 at Jayko and 0.64 at Halokvik across all years of harvest. Although we report some of the highest known estimates of mortality for this species, mortality has been decreasing at both sites since around 2007. Overall, no trends in mortality (annual or instantaneous) or survival could be resolved from these data but our fishery-dependent estimates appear to be high compared to best available estimates from known unfished stocks. Estimates of mortality from fishery-independent sampling were much lower overall (at Jayko average $Z = 0.19$ across all years of sampling, at Halokvik average $Z = 0.37$ across all years of sampling).

A depletion-based stock reduction analysis (DB-SRA) that was completed in conjunction with this assessment suggested that biomass at both river systems has undergone a short period of over-exploitation since commercial fishing first commenced (Zhu et al. 2021). The Halokvik River appears to have stabilized while the Jayko River is still on a downward trajectory in biomass. Based on the DB-SRA model, maximum sustainable yield (MSY) was estimated to be 10,394.16 kg and 4,358.84 kg at the Jayko and Halokvik rivers, respectively. This suggests that both rivers are currently being fished at levels above MSY, although not substantially at Halokvik. Based on the DB-SRA model, the Jayko and Halokvik stocks are currently experiencing exploitation rates of around 10%. This may be high but it is currently unknown what the maximum exploitation rates are for anadromous Arctic Char in the region.

Considering the generally stable or increasing trends observed in most of the fishery-dependent and fishery-independent demographic and CPUE data together with the declines in A50 and L50, and the results of the DB-SRA model, the available analyses do not support either an increase or a decrease in harvest in either fishery. To support future stock assessments and the application of additional assessment methods, ongoing monitoring of biological parameters (particularly ageing and estimates of mortality and survival) should continue.

ACKNOWLEDGEMENTS

First and foremost, we would like to extend many thanks to the Ekaluktutiak Hunter's and Trapper's Organization for their traditional knowledge and ongoing support of our Arctic Char research in the Cambridge Bay region. Koana specifically to Brenda Sitatak, Alice Maghagak, Beverly Maksagak, Dianne Mala, Jimmy Haniliak, Bobby and Howard Greenley, Peter Evalik, George Angohiatok, and James Panioyak. We also extend a great deal of gratitude to Kitikmeot Foods Ltd. for their assistance with the plant sampling program. Specifically, we are indebted to Denise Lebleu, Stephane Lacasse, Annie Anavolik, and Alice Keyok. We would also like to thank the many residents of Cambridge Bay who have been a part of our field programs over the years. Specifically, we would like to thank Bobby Maghagak, Richard and Mary Ekpakohak, Kevin Kanayok, Darcy Kanayok, Devon Oniak, Jimmy and Ruby Haniliak, Johnny Pedersen, Colin Amegainik, Randy Klengenber, Brandon Klengenber, and Jamie Panioyak. Mitch Leclaire, Chris McDermid, and especially Brendan Malley have been instrumental in our research programs. Many thanks to Jean-Sébastien Moore for field assistance and for the many fruitful collaborations that have occurred since 2013. We also thank the commercial fishers for their ongoing support of our stock assessment work and for sharing their knowledge of Arctic Char and the Cambridge Bay commercial fishery; we are especially grateful to Jack Ekpakohak. We are also grateful for the funding support from Nunavut Implementation Funds, the Nunavut Wildlife Management Board, the Nunavut General Monitoring Plan, and the Ocean Tracking Network which has been vital for facilitating Cambridge Bay char research. Finally, we would like to thank all participants who took part in this assessment and contributed to the advice reached at the meeting. We especially would like to thank Brian Dempson for his ongoing participation in Nunavut Arctic Char assessments and for relaying his extensive knowledge of char biology.

REFERENCES CITED

Babaluk, J.A., Halden, N.M., Reist, J.D., Kristofferson, A.H., Campbell, J.L., and Teesdale, W.J. 1997. Evidence for non-anadromous behaviour of Arctic charr (*Salvelinus alpinus*) from Lake Hazen, Ellesmere Island, Northwest Territories, Canada, based on scanning proton microprobe analysis of otolith strontium distribution. *Arctic* 50(3): 224–233.

-
- Barlshen, W.J., and Webber, T.N. 1973. A history of the development of commercial fishing in the Cambridge Bay area of the Northwest Territories. Report for the Federal-Territorial Task Force report on Fisheries Development in the Northwest Territories. 37 p.
- Berkes, F. 1999. Sacred Ecology. Traditional Ecological Knowledge and Resource Management. Taylor & Francis, Philadelphia and London. 209 p.
- Beverton, R.J H., and Holt, S.J. 1957. On the Dynamics of Exploited Fish Populations. Fishery Investigations Series II Volume XIX, Ministry of Agriculture, Fisheries and Food. Great Britain. 533 p.
- Carder, G.W. 1981. [Data from the commercial fishery for Arctic Charr *Salvelinus alpinus* \(Linnaeus\), in the Cambridge Bay area, Northwest Territories, 1979-80.](#) Can. Data Rep. Fish. Aquat. Sci. 284: v + 22 p.
- Carder, G.W. 1983. [Data from the commercial fishery for Arctic Charr *Salvelinus alpinus* \(Linnaeus\), in the Cambridge Bay and Rankin Inlet areas, Northwest Territories, 1981-82.](#) Can. Data Rep. Fish. Aquat. Sci. 391: v + 24 p.
- Carder, G.W. 1988. [Data from the commercial fishery for Arctic Charr *Salvelinus alpinus* \(Linnaeus\), in the Northwest Territories, 1985-86.](#) Can. Data Rep. Fish. Aquat. Sci. 681: v + 35 p.
- Carder, G.W., and Low, G. 1985. [Data from the commercial fishery for Arctic Charr, *Salvelinus alpinus* \(Linnaeus\), in the Cambridge Bay and Rankin Inlet areas, Northwest Territories, 1983-84.](#) Can. Data Rep. Fish. Aquat. Sci. 519: v + 26 p.
- Carder, G.W., and Stewart, D.B. 1989. [Data from the commercial fishery for Arctic Charr, *Salvelinus alpinus* \(L.\), in the central and Keewatin regions of the Northwest Territories, 1987-88.](#) Can. Data Rep. Fish. Aquat. Sci. 766: vi + 47.
- Chapman, D.G., and Robson, D.S. 1960. The analysis of a catch curve. Biometrics 16: 354–368.
- Christiansen J.S., and Reist, J.D. 2013. Chapter 6: Fishes. *In Arctic Biodiversity Assessment: Status and trends in Arctic biodiversity.* Edited by H. Meltofte. Conservation of Arctic Flora and Fauna, Akureyri, Iceland. pp. 193–245.
- Conover, D.O., and Schultz, E.T. 1997. Natural selection and the evolution of growth rate in the early life history: what are the trade-offs? *In Early Life History and Recruitment in Fish Populations.* Edited by R.C. Chambers and E.A. Trippel. Chapman & Hall, London. pp. 305–332.
- Day, A.C., and de March, B. 2004. [Status of Cambridge Bay Anadromous Arctic Char Stocks.](#) DFO Can. Sci. Advis. Sec. Res. Doc. 2004/052.
- Day, A.C., and Harris, L.N. 2013. [Information to support an updated stock status of commercially harvested Arctic Char \(*Salvelinus alpinus*\) in the Cambridge Bay region of Nunavut, 1960-2009.](#) DFO Can. Sci. Adv. Sec. Res. Doc. 2013/068. v + 30 p.
- Dempson, J.B., and Kristofferson, A.H. 1987. Spatial and temporal aspects of the ocean migration of anadromous Arctic Char. Am. Fish. Soc. Symp. 1: 340–357.
- Dempson, J.B., Shears, M., Furey, G., and Bloomm, M. 2008. Resilience and stability of north Labrador Arctic charr, *Salvelinus alpinus*, subject to exploitation and environmental variability. Env. Biol. Fishes 82: 57–67.
- DFO 2006. [A Harvest Strategy Compliant with the Precautionary Approach.](#) DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2006/023.
-

-
- Friesen, T.M. 2002. Analogues at Iqaluktuuq: The social context of archaeological inference in Nunavut, Arctic Canada. *World Archaeol.* 34(2): 330–345.
- Friesen, T.M. 2004. Contemporaneity of Dorset and Thule cultures in the North American Arctic: New radiocarbon dates from Victoria Island, Nunavut. *Current Anthropol.* 45(5): 685–691.
- Gallagher, C.P., and Dick, T.A. 2010. Historical and Current Population Characteristics and Subsistence Harvest of Arctic Char from the Sylvia Grinnell River, Nunavut, Canada. *N. Am. J. Fish. Manag.* 30: 126–141.
- Gilbert, M.J.H., Donadt, C., Swanson, H.K., and Tierney, K.B. 2016. Low annual fidelity and early upstream migration of anadromous Arctic char in a variable environment. *Trans. Am. Fish. Soc.* 145(5): 931–942.
- Gomez-Uchida, D., Knight, T.W., and Ruzzante, D. 2009. Interaction of landscape and life history attributes on genetic diversity, neutral divergence and gene flow in a pristine community of salmonids. *Mol. Ecol.* 18(23): 4854–4869.
- Grayson, K.L., Mitchell, N.J., Monks, J.M., Keall, S.N., and Wilson, J.N. 2014. Sex ratio bias and extinction risk in an isolated population of Tuatara (*Sphenodon punctatus*). *PLoS ONE* 9(4): e94214.
- Gyselman, E.C. 1984. The seasonal movements of anadromous Arctic charr at Nauyuk Lake, Northwest Territories, Canada. *In* *Biology of the Arctic charr*, Proceedings of the International Symposium on Arctic Charr, Winnipeg, Manitoba. Edited by L. Johnson and B. Burns. University of Manitoba Press, Winnipeg, Man. pp. 575–578.
- Gyselman, E.C. 1994. Fidelity of anadromous Arctic char (*Salvelinus alpinus*) to Nauyuk Lake, N.W.T., Canada. *Can. J. Fish. Aquat. Sci.* 51: 1927–1934.
- Gyselman, E.C., and Broughton, K.E. 1991. [Data on the anadromous Arctic charr \(*Salvelinus alpinus*\) of Nauyuk Lake, Northwest Territories, 1974-1988](#). *Can. Data Rep. Fish. Aquat. Sci.* 815: v + 125 p.
- Haddon, M. 2001. *Modeling and quantitative methods in fisheries*. Chapman and Hall, Boca Raton, Florida. 405 p.
- Harwood, L.A. 2009. [Status of anadromous Arctic charr \(*Salvelinus alpinus*\) of the Hornaday River, Northwest Territories, as assessed through harvest-based sampling of the subsistence fishery, August-September 1990-2007](#). *Can. Manuscr. Rep. Fish. Aquat. Sci.* 2890: viii + 33 p.
- Harwood, L.A., Sandstrom, S.J., Papst, M.H., and Melling, H. 2013. Kuujjua River Arctic char: monitoring stock trends using catches from an under-ice subsistence fishery, Victoria Island, Northwest Territories, Canada, 1991–2009. *Arctic* 66: 291–300.
- Harris, L.N., and Tallman, R.F. 2010. [Information to support the assessment of Arctic Char, *Salvelinus alpinus*, from the Isuituq River system, Nunavut](#). DFO Can. Sci. Advis. Sec. Res. Doc. 2010/063. vi + 37 p.
- Harris, L.N., Moore, J.-S., Bajno, R., and Tallman, R.F. 2016. Genetic Stock Structure of Anadromous Arctic Char in Canada’s Central Arctic: Potential Implications for the Management of Canada’s Largest Arctic Char Commercial Fishery. *North Am. J. Fish. Manag.* 36: 1473–1488.

-
- Harris, L.N., Malley, B.K., McDermid, C.G., Gallagher, C.P., Tallman, R.F., and Moore, J-S. 2020. [Weir enumerations and capture-mark-recapture estimates of population size for Arctic Char \(*Salvelinus alpinus*\) from the Halokvik River, Nunavut](#). Can. Manuscr. Rep. Fish. Aquat. Sci. 3199: vi + 24 p.
- Hilborn, R., and Walters, C.J. 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty. Chapman and Hall, New York. 570 p.
- Huntington, H.P., and Fox, S. 2005. The changing Arctic: Indigenous perspectives. In Arctic climate impact assessment, ACIA. Cambridge University Press, Cambridge. pp. 61–98.
- Johnson, L. 1976. Ecology of arctic populations of lake trout, *Salvelinus namaycush*, Lake Whitefish, *Coregonus clupeaformis*, Arctic Char, *S. alpinus*, and associated species in unexploited lakes of the Canadian Northwest Territories. J. Fish. Res. Board Can. 33: 2459–88.
- Johnson, L. 1980. The Arctic Charr. In Charrs: salmonid fishes of the genus *Salvelinus*. Edited by E.K. Balon. W. Junk Publishers, The Hague. pp. 15–98.
- Johnson, L. 1989. The anadromous Arctic charr, *Salvelinus alpinus* of NauyukLake, N.W.T., Canada. Physiol. Ecol. Japan. 1(Suppl.): 201–228.
- Kristofferson, A.H. 2002. Identification of Arctic char stocks in the Cambridge Bay area, Nunavut Territory, and evidence of stock mixing during overwintering. Thesis (Ph.D.) University of Manitoba, Winnipeg, MB. 255 p.
- Kristofferson, A.H., and Berkes, F. 2005. Adaptive co-management of Arctic Char in Nunavut Territory. In Breaking ice: Renewable Resource and Ocean Management in the Canadian North. Edited by F. Berkes, R. Huebert, H. Fast, M. Manseau, and A. Diduck. University of Calgary Press, Calgary, AB. pp. 249–268.
- Kristofferson, A.H., and Carder, G.W. 1980. [Data from the commercial fishery for Arctic char *Salvelinus alpinus* \(Linnaeus\), in the Cambridge Bay area, Northwest Territories, 1971-78](#). Can. Data Rep. Fish. Aquat. Sci. 184: v + 25
- Kristofferson, A.H., McGowan, D.K., and Carder, G.W. 1984. Management of the commercial fishery for anadromous Arctic charr in the Cambridge Bay area, West Territories, Canada. In: Biology of the Arctic Charr. Edited by L. Johnson and B.L. Burns. University of Manitoba Press, Winnipeg, MB. pp. 447–461.
- Kristofferson, A.H., McGowan, D.K., and Ward, W.J. 1986. [Fish weirs for the commercial harvest of searun Arctic charr in the Northwest Territories](#). Can. Ind. Rep. Fish. Aquat. Sci. 174: iv + 31 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: iv + 27 p.
- McGowan, D.K., and G. Low. 1992. [Enumeration and biological data on Arctic charr from Freshwater Creek, Cambridge Bay area, Northwest Territories, 1982, 1988 and 1991](#). Can. Data Rep. Fish. Aquat. Sci. 878: iv + 23 p.
- Moore, J.-S., Harris, L.N., Tallman, R.F., and Taylor, E.B. 2013. The interplay between dispersal and gene flow in anadromous Arctic char (*Salvelinus alpinus*): implications for potential for local adaptation. Can. J. Fish. Aquat. Sci. 70: 1327–1338.

-
- Moore, J.-S., Harris, L.N., and Tallman, R.F. 2014. [A review of anadromous Arctic char \(*Salvelinus alpinus*\) migratory behavior: implications for genetic population structure and fisheries management](#). Can. Manuscr. Rep. Fish. Aquat. Sci. 2014/3051: vi + 27 p.
- Moore, J.-S., Harris, L.N., Kessel, S., Bernatchez, L., Tallman, R.F., and Fisk, A.T. 2016. Preference for near-shore and estuarine habitats in anadromous Arctic char (*Salvelinus alpinus*) from the Canadian high Arctic (Victoria Island, NU) revealed by acoustic telemetry. Can. J. Fish. Aquat. Sci. 73(9): 1434–1445.
- Moore, J.-S., Harris, L.N., Le Luyer, J., Sutherland, B.J.G., Rougemont, Q., Tallman, R.F., Fisk, A.T., and Bernatchez, L. 2017. Genomics and telemetry suggest a role for migration harshness in determining overwintering habitat choice, but not gene flow, in anadromous Arctic Char. Mol. Ecol. 26: 6784–6800.
- Morgan, J. 2008. Integrating Reproductive Biology into Scientific Advice for Fisheries Management. J. NW Atlantic Fish. Sci. 41: 37–51.
- Nuttall, M., Berkes, F., Forbes, B., Kofinas, G., Vlassova, T., and Wenzel, G. 2005. Hunting, herding, fishing, and gathering: indigenous peoples and renewable resource in the Arctic.. *In Arctic Climate Impact Assessment*. Edited by C. Symon, L. Arris, and B. Heal. Cambridge University Press, Cambridge, UK. pp. 649–690.
- Priest, H., and Usher, P.J. 2004. Nunavut wildlife harvest study. Nunavut Wildlife Management Board, Iqaluit, Nunavut, Canada. 822 p.
- Policansky, D. 1993. Fishing as a cause of evolution in fishes. *In The Exploitation of Evolving Resources*. Edited by T.K. Stokes, J.M. McGlade, and R. Law. Springer-Verlag, Berlin, Germany. pp. 2–18.
- Quinn, T.J., and Deriso, R.B. 1999. Quantitative fish dynamics. Oxford University Press, New York, NY. 560 p.
- Reist, J.D., Power, M., and Dempson, J.B. 2013. Arctic charr (*Salvelinus alpinus*): a case study of the importance of understanding biodiversity and taxonomic issues in northern fishes. Biodiversity 14(1): 45–56.
- Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Board Can. Bull. 191 : 382 p.
- Roux, M.J., Tallman, R.F., and Lewis, C.W. 2011. Small-scale Arctic charr *Salvelinus alpinus* fisheries in Canada's Nunavut: management challenges and options. J. Fish Biol. 79(6): 1625–1647.
- Scott, W.B., and Crossman, E.J. 1998. Freshwater fishes of Canada. Fish. Res. Board Can. Bull. 184: 966 p.
- Silliman, R.P., and Gutsell, J.S. 1958. Experimental exploitation of fish populations. U.S. Fish Wildlife Serv. Fishery Bull. 58: 215–252.
- Trippel, E.A. 1999. Estimation of stock reproductive potential: history and challenges for Canadian Atlantic gadoid stock assessments. J. North. Atlant. Fish. Sci. 25: 61–81.
- Walters, C.J., and Martell, S.J.D. 2004. Fisheries Ecology and Management, Princeton University Press, Princeton, NJ. 448 p.
- Walters, C.J., Steer, G., and Spangler, G.R. 1980. Responses of Lake Trout (*Salvelinus namaycush*) to harvesting, stocking, and lamprey reduction. Can. J. Fish. Aquat. Sci. 37(11): 2133–2145.
-

-
- Zeller, D., Booth, S., Pakhomov, E., Swartz, W., and Pauly, D. 2011. Arctic fisheries catches in Russia, USA, and Canada: baselines for neglected ecosystems. *Polar Biol.* 34: 955–973.
- Zhu, X., Day, A.C., Carmichael, T.J., and Tallman, R.F. 2014a. [Temporal variation in a population biomass index for Cambridge Bay Arctic Char, *Salvelinus alpinus* \(L.\), in relation to large-scale climate changes](#). DFO Can. Sci. Advis. Sec. Res. Doc. 2014/095. v + 28 p.
- Zhu, X., Day, A.C., Carmichael, T.J., and Tallman, R.F. 2014b. [Hierarchical Bayesian modeling for Cambridge Bay Arctic Char, *Salvelinus alpinus* \(L.\), incorporated with precautionary reference points](#). DFO Can. Sci. Advis. Sec. Res. Doc. 2014/096. v + 35 p.
- Zhu, X., Harris, L., Cahill, C., Tallman, R.F. 2021. Assessing population dynamics of Arctic Char, *Salvelinus alpinus*, from the Halokvik and Jayko Rivers, Cambridge Bay, Nunavut, Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/016. vi + 34 p.

APPENDIX 1. QUOTA AND HARVEST NUMBERS

Table A1.1. Quota and harvest (kg; round weight) history for the Jayko and Halokvik rivers of the Cambridge Bay commercial Arctic Char (*Salvelinus alpinus*) fishery. NQ = No Quota, NF = Not Fished.

Year	Halokvik		Jayko		Source ^a
	Quota (kg)	Harvest (kg)	Quota (kg)	Harvest (kg)	
1967	45,000 ^b	NF	NQ	NF	Kristofferson and Carder 1980
1968	45,000 ^b	2,614	NQ	NF	Kristofferson and Carder 1980
1969	45,000 ^b	25,855	NQ	NF	Kristofferson and Carder 1980
1970	45,000 ^b	26,203	NQ	NF	Kristofferson and Carder 1980
1971	45,000 ^b	10,433	NQ	NF	Kristofferson and Carder 1980
1972	9,100	6,477	NQ	NF	Kristofferson and Carder 1980
1973	9,100	1,918	NQ	NF	Kristofferson and Carder 1980
1974	Closed	NF	NQ	NF	Kristofferson and Carder 1980
1975	Closed	NF	6,800	8,231	Kristofferson and Carder 1980
1976	9,100	2,780	6,800	9,437	Kristofferson and Carder 1980
1977	4,500	4,624	6,800	7,563	Kristofferson and Carder 1980
1978	4,500	5,734	11,340	13,442	Kristofferson and Carder 1980
1979	6,800	7,316	13,600	12,260	Carder 1981
1980	6,800	7,481	13,600	14,501	Carder 1981
1981	6,800	7,009	13,600	13,320	Carder 1983
1982	6,800	6,848	13,600	5,711	Carder 1983
1983	6,800	6,825	13,600	12,966	Carder and Low 1985
1984	6,800	7,306	13,600	13,515	Carder and Low 1985
1985	6,800	6,448	13,600	11,584	Carder 1988
1986	6,800	6,830	13,600	12,076	Carder 1988
1987	6,800	6,875	13,600	13,686	Carder and Stewart 1989
1988	6,800	6,808	13,600	11,820	Carder and Stewart 1989
1989	6,800	6,857	13,600	12,866	Carder 1991
1990	6,800	6,971	13,600	12,865	Carder 1991
1991	6,800	6,354	15,600	2,226	Carder 1993
1992	6,800	6,872	15,600	NF	Carder 1993
1993	6,800	5,939	15,600	15,411	Carder 1995
1994	5,000	3,859	17,000	16,287	Carder 1995
1995	5,000	5,336	17,000	15,695	FMHIS
1996	5,000	4,909	17,000	16,914	FMHIS
1997	5,000	4,995	17,000	10,585	Day and de March 2004
1998	5,000	5,143	17,000	17,070	Day and de March 2004
1999	5,000	5,120	17,000	17,094	Day and de March 2004
2000	5,000	5,205	17,000	17,312	Day and de March 2004
2001	5,000	5,426	17,000	16,349	FMHIS
2002	5,000	4,968	17,000	17,434	FMHIS

Year	Halokvik		Jayko		Source ^a
	Quota (kg)	Harvest (kg)	Quota (kg)	Harvest (kg)	
2003	6,800	5,718	13,600	17,215	FMHIS
2004	6,800	6,914	13,600	7,573	FMHIS
2005	6,800	6,617	13,600	2,613	FMHIS
2006	5,000	7,603	17,000	12,781	FMHIS
2007	5,000	6,786	17,000	8,633	FMHIS
2008	5,000	7,587	17,000	14,327	FMHIS
2009	5,000	5,219	17,000	6,514	FMHIS
2010	5,000	3,317	17,000	NF	FMHIS
2011	5,000	1,124	17,000	NF	FMHIS
2012	5,000	4,920	17,000	15,231	FMHIS
2013	5,000	4,768	17,000	15,195	FMHIS
2014	5,000	4,160	17,000	9,851	FMHIS
2015	5,000	5,010	17,000	14,893	FMHIS

^a harvest and quota from 1960–1994 were compiled from the various data reports. Harvest and quota from 1995 to 2009 (with the exception of 1997–2000) are from the Fisheries Management Harvest Information System (FMHIS) using a 1.25 (pre-2005) or 1.2 (2005 and on) round to dressed weight conversion.

^b Wellington Bay area quota.

APPENDIX 2. CATCH PER UNIT EFFORT

Table A2.1. Mean catch-per-unit-effort (CPUE) and total number of hours fished of Arctic Char sampled from the commercial harvest (plant) for the Jayko and Halokvik rivers. Commercial CPUE is represented as the number of Arctic Char caught per 24 hrs of weir fishing.

Year	Jayko		Halokvik	
	Mean (Range) CPUE	Total Hour Fished	Mean (Range) CPUE	Total Hour Fished
2012	336.20 (111.60–1236.00)	246.3	150.10 (58.97–320.70)	227.00
2013	789.20 (137.70–2382.00)	158	162.20 (25.71–333.60)	189.20
2014	311.50 (1.85–769.50)	301.7	462.3 (411.00–533.00)	59.00
2015	552.70 (283.80–800.50)	116.5	186.20 (3.33–405.50)	186.60
2016	722.5 (148.50–2477.00)	208	249.60 (53.14–472.00)	160.50
Average	533.30 (137.69–1533.00)	206.1	215.50 (110.23–412.96)	164.46

Table A2.2. Mean catch-per-unit-effort (CPUE) and total number of hours fished each year for Arctic Char sampled through the fishery-independent research surveys at both the Jayko and Halokvik rivers. Fishery independent CPUE is calculated as the number of Arctic Char landed per 150 ft. of stretched multi-mesh gill net per 24 hours of fishing. Na for Jayko River in 2013 means no data was available due to blizzard conditions preventing travel to that river. Na for Halokvik River was because sampling did not begin until 2011.

Year	Jayko		Halokvik	
	Mean (Range) CPUE	Total Hour Fished	Mean (Range) CPUE	Total Hour Fished
2010	69.86 (46.50–117.40)	74.53	Na	Na
2011	22.47 (12.71–34.80)	223.08	19.39 (4.24–38.28)	204.18
2012	11.29 (0.00–23.31)	286.42	8.86 (0.00–26.75)	302.83
2013	Na	Na	9.42 (0.00–26.00)	449.08
2014	49.63 (33.94–68.31)	112.17	18.37 (0.99–65.04)	310.92
2015	21.85 (11.59–35.63)	270.95	25.93 (9.44–65.65)	241.27
Average	26.5 (20.94–55.71)	193.43	16.62 (2.93–44.34)	301.66

APPENDIX 3. ROBSON-CHAPMAN ESTIMATES

Table A3.1. Robson-Chapman estimates of instantaneous mortality (Z), annual mortality (A) and annual survival (S) for Jayko and Halokvik river Arctic Char collected from the commercial harvest. Data have been calculated for all years for which there were available data. Na designates years when insufficient data was available to conduct these analyses.

Year	Jayko			Halokvik		
	Z	A	S	Z	A	S
1972	Na	Na	Na	0.72	0.51	0.49
1976	0.35	0.29	0.71	0.44	0.36	0.64
1977	Na	Na	Na	0.85	0.57	0.43
1978	0.37	0.31	0.69	0.66	0.48	0.52
1979	0.42	0.34	0.66	0.81	0.55	0.45
1980	0.46	0.37	0.63	0.58	0.44	0.56
1981	0.34	0.29	0.71	0.58	0.44	0.56
1982	0.50	0.39	0.61	0.57	0.43	0.57
1983	0.40	0.33	0.67	0.66	0.48	0.52
1984	0.61	0.46	0.54	0.74	0.52	0.48
1985	0.65	0.48	0.52	0.65	0.48	0.52
1986	0.84	0.57	0.43	0.71	0.51	0.49
1987	0.75	0.53	0.47	0.69	0.50	0.50
1988	0.49	0.39	0.61	0.41	0.33	0.67
1989	0.35	0.29	0.71	0.50	0.39	0.61
1991	0.79	0.54	0.46	0.57	0.43	0.57
1992	Na	Na	Na	0.54	0.42	0.58
1993	0.45	0.36	0.64	0.43	0.35	0.65
1994	0.27	0.24	0.76	0.53	0.41	0.59
1995	0.30	0.26	0.74	0.88	0.58	0.42
1996	0.32	0.27	0.73	0.60	0.45	0.55
1997	0.55	0.42	0.58	0.93	0.61	0.39
1998	0.31	0.26	0.74	1.26	0.72	0.28
1999	0.56	0.43	0.57	1.03	0.64	0.36
2000	0.32	0.27	0.73	0.65	0.48	0.52
2001	0.39	0.32	0.68	0.38	0.32	0.68
2003	0.36	0.31	0.69	0.40	0.33	0.67
2004	0.34	0.29	0.71	0.53	0.41	0.59
2005	Na	Na	Na	0.66	0.48	0.52
2007	0.53	0.41	0.59	1.01	0.64	0.36

Year	Jayko			Halokvik		
	Z	A	S	Z	A	S
2008	0.59	0.44	0.56	0.82	0.56	0.44
2009	0.58	0.44	0.56	0.70	0.50	0.50
2010	Na	Na	Na	0.44	0.36	0.64
2011	Na	Na	Na	0.59	0.44	0.56
2012	0.41	0.34	0.66	0.46	0.37	0.63
2013	0.34	0.29	0.71	0.23	0.21	0.79
2014	0.32	0.28	0.72	0.33	0.28	0.72
Average	0.46	0.36	0.64	0.64	0.46	0.54

Table A3.2. Robson-Chapman estimates of instantaneous mortality (Z), annual mortality (A) and annual survival (S) for Jayko and Halokvik rivers Arctic Char collected from fishery-independent research surveys. Na for Jayko River was due to blizzard in 2013 preventing access to the site. Na for Halokvik River was because sampling did not begin until 2011.

Year	Jayko			Halokvik		
	Z	S	A	Z	S	A
2010	0.17	0.84	0.16	Na	Na	Na
2011	0.23	0.80	0.20	0.41	0.66	0.34
2012	0.17	0.84	0.16	0.23	0.79	0.21
2013	Na	Na	Na	0.27	0.76	0.24
2014	0.19	0.83	0.17	0.26	0.77	0.23
2015	0.18	0.83	0.17	0.67	0.50	0.50
Average	0.19	0.83	0.18	0.37	0.70	0.30