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Canadian Science Advisory Secretariat
Central and Arctic Region   **Science Response 2020/049**

ASSESSMENT OF A PROPOSED QUOTA INCREASE FOR THE COMMERCIAL ARCTIC CHAR FISHERY IN THE LAUCHLAN RIVER (CAMBRIDGE BAY, NUNAVUT)

Context

During the 1990s, the Arctic Fisheries Scientific Advisory Committee (AFSAC) reviewed annual harvests and quotas for the Lauchlan River Arctic Char (*Salvelinus alpinus alpinus*) fishery (Cosens et al. 1998). AFSAC recommended a quota reduction from 9,100 kg to 2,400 kg in 1995, which was equal to an estimated exploitation rate of 7 % based on the 1983 weir counts (32,000 kg, McGowan 1990). AFSAC recommended that the lower quota remain in effect for a four or five-year period so that the effect of this level of harvest on the fishery could be determined. In 2004, Kitikmeot Foods applied for an exploratory license to fish anadromous Arctic Char in Lauchlan River/Byron Bay during August; they requested a quota of 5,000 kg. In 2004, DFO Science evaluated the request and recommended that the quota level of 2,400 kg for Lauchlan River be maintained, and that sampling be done on the harvest from this location so that the status of the stock could be assessed. In 2009, Kitikmeot Foods Ltd, with support from the Ekaluktutiak Hunters and Trappers Organization, requested an increase in quota from 2,400 kg to 9,100 kg. DFO Fisheries and Aquaculture Management sought advice from DFO Science on the sustainability of such an increase in harvest at the Lauchlan River.

This Science Response Report results from the Science Response Process of May 10, 2011, on the Assessment of a proposed quota increase for the Commercial Arctic Char Fishery in the Lauchlan River (Cambridge Bay, Nunavut).

Background

Lauchlan River (68°56'N 108°30'W, Figure 1) is included in the commercial fishing waters in the Northwest Territories (NWT) Fishery Regulations (Schedule V) and was first fished for commercial purpose under quota in 1970.

Annual quota and harvest data are summarized in Table 1 and Figure 2. No subsistence harvest data or index of abundance (e.g., Catch-per-Unit-Effort, CPUE) are available for any Cambridge Bay fisheries, including the Lauchlan River, except for a 1983 experimental weir enumeration. Anadromous Arctic Char exhibit annual downstream migrations to the sea to feed and return to freshwater each year to overwinter. Spawning occurs in freshwater and current year spawners often remain in freshwater throughout the summer rather than migrating to sea. Studies in the Cambridge Bay area have found that discrete stocks of Arctic Char exist not only among Cambridge Bay river systems but also within river systems (Kristofferson 2002). Therefore, annual samples from the Lauchlan River may be composed of individuals from several stocks. Vulnerability to over-harvesting can be different among stocks depending on their contribution to the total catch. It is challenging to determine the relative contributions of different stocks to the Cambridge Bay Arctic Char mixed-stock fisheries and to estimate stock-specific levels of exploitation.
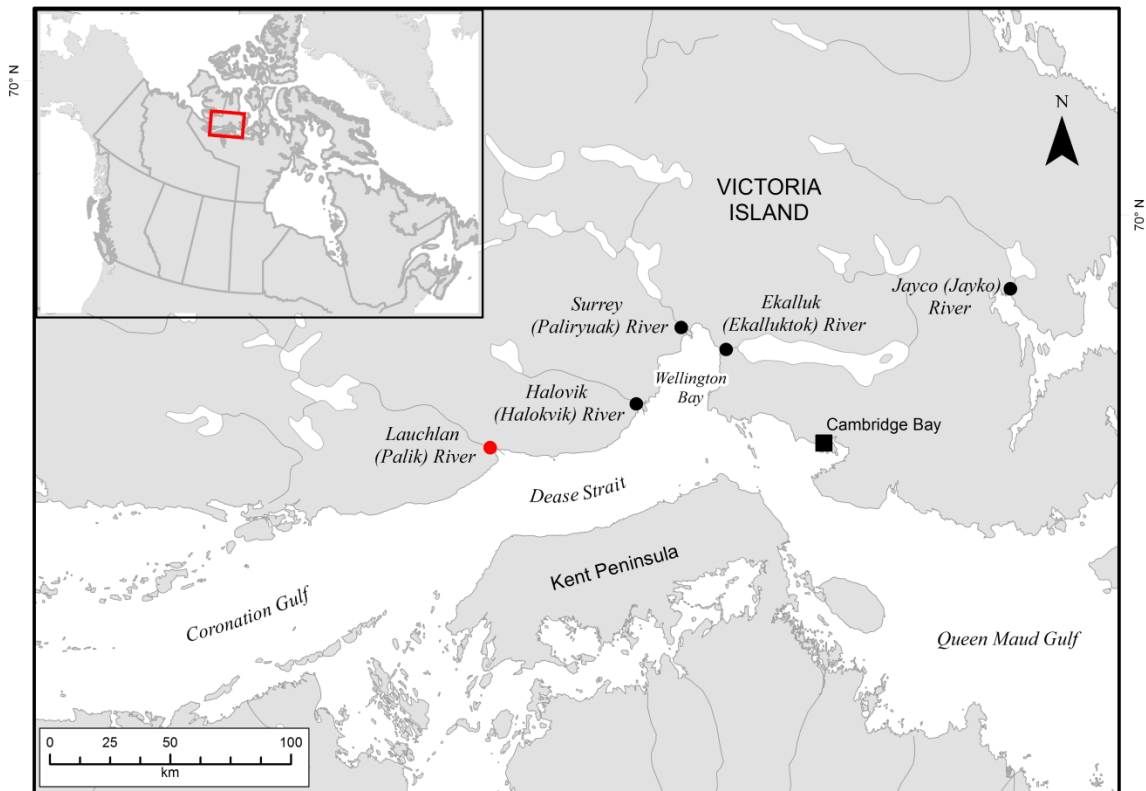
Figure 1. Cambridge Bay area showing the location of the Lauchlan River (red circle), other commercial fishing sites (black circle) and the community of Cambridge Bay (black square).

Table 1. Annual quota (kg) and harvest (kg) levels for the Lauchlan River Arctic Char fishery from 1970 to 2010. Fishing seasons are denoted in the year column by S (spring) and F (fall).

| Year	Quota	Harvest	Year	Quota	Harvest	Year	Quota	Harvest
1970	-	2420	1984 S+F	9100	9876	1998 F	2400	1430
1971	-	19051	1985 S	9100	9056	1999 F	2400	2740
1972 S+F	18160	20994	1986 S	9100	8243	2000	2400	-
1973 F	18160	9657	1987 S	9100	9553	2001 F	2400	436
1974 F	11350	8125	1988 S	9100	9425	2002	2400	-
1975	-	-	1989 S	9100	9184	2003 F	9100	1519
1976	-	-	1990 S	9100	8938	2004 F	9100	3267
1977 S	6800	1519	1991 S	9100	8807	2005 F	9100	2913
1978 S	6800	8536	1992 S	9100	9320	2006 S	2400	8814
1979 S	9100	10845	1993 S	9100	9306	2007 S	2400	8684
1980 S	9100	9151	1994	9100	-	2008 S	2400	1621
1981 S+F	9100	8724	1995 F	2400	1439	2009	2400	-
1982 S+F	9100	8918	1996 F	2400	2352	2010 S	2400	2533
1983 F	9100	9106	1997 F	2400	900	-	-	-
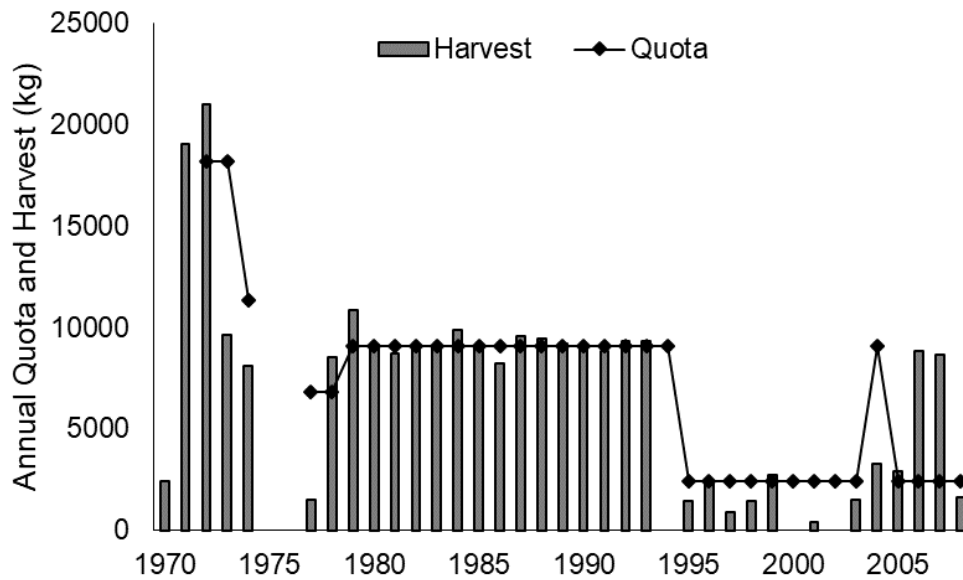
Figure 2. Annual quota (kg, black line) and harvest (kg, grey bars) levels for the Lauchlan River Arctic Char fishery from 1970 to 2010.

Analysis

The data used in this analysis were collected through an annual Cambridge Bay fish plant sampling program. The fishery is being evaluated to determine the effects of fishing on stocks of Arctic Char in the Cambridge Bay area; consequently long-term data sets are available. The annual sampling program involves sampling commercially harvested char at the Cambridge Bay fish plant to determine the fork length, dressed weight, and age (read from sagittal otoliths) of individual fish.

For fish length and weight, the mean sample number was 180 ± 70 fish per year; for fish age mean sample number was 135 ± 46 fish per year. When round weight was not measured in the field or fish plant, it was estimated from dressed weight using the following equation that was calculated for the Lauchlan River fishery (Day and de March 2004):

$$Round\ Weight\ (g) = (Dressed\ weight\ (g) \times 1.210) - 71.782$$

Fulton's condition factor (Fulton 1902) was calculated for each sampled char as:

$$Fulton's\ Condition\ Factor = \frac{Round\ Weight\ (g) \times 10^5}{Fork\ Length\ (mm)^3}$$

Trend Analysis

Arctic Char growth was examined as plots of mean fork length on age after pooling the data within four temporal periods (1971-1979, 1980-1989, 1990-1999, 2000-2009; Figure 3).
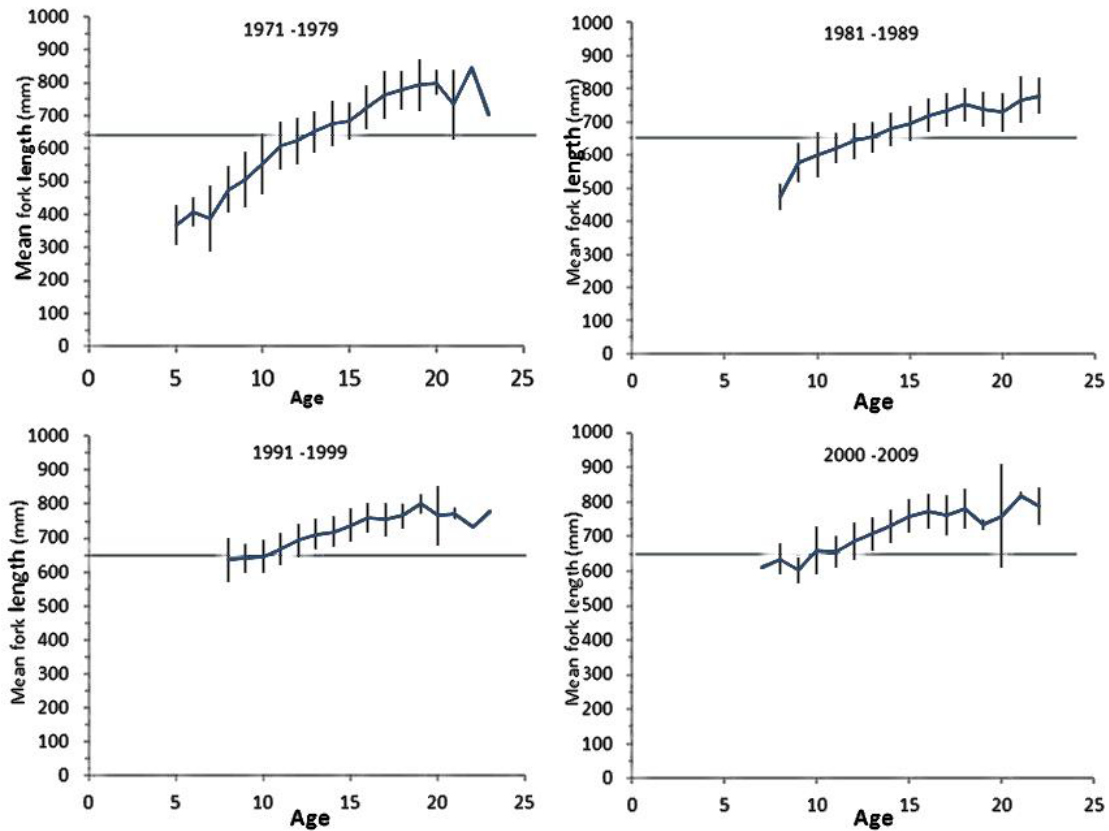
Figure 3. Mean fork length at age (±2 standard deviation, horizontal bars) by period (1971-1979, 1980-1989, 1990-1999, 2000-2009) for anadromous Arctic Char sampled from the Lauchlan River commercial fishery.

Differences in the Von Bertalanffy Growth Function (VBGF), which describes the growth of most gill-breathing animals, among temporal periods were detected using a Likelihood Ratio Test for Comparing Two von Bertalanffy Growth Curves (Kimura 1980). Fish growth was significantly different in pairwise comparisons between decades from 1971 to 2009 (p< 0.01), except between 1990-1999 and 2000-2009 when growth was not statistically different (X^2 = 2.53, p= 0.470). Mean age was variable among sampling years but did not show consistent increasing or decreasing trends (r^2 = 0.01, p-value of slope = 0.71), suggesting there was some stability in response to harvest (Figure 4).
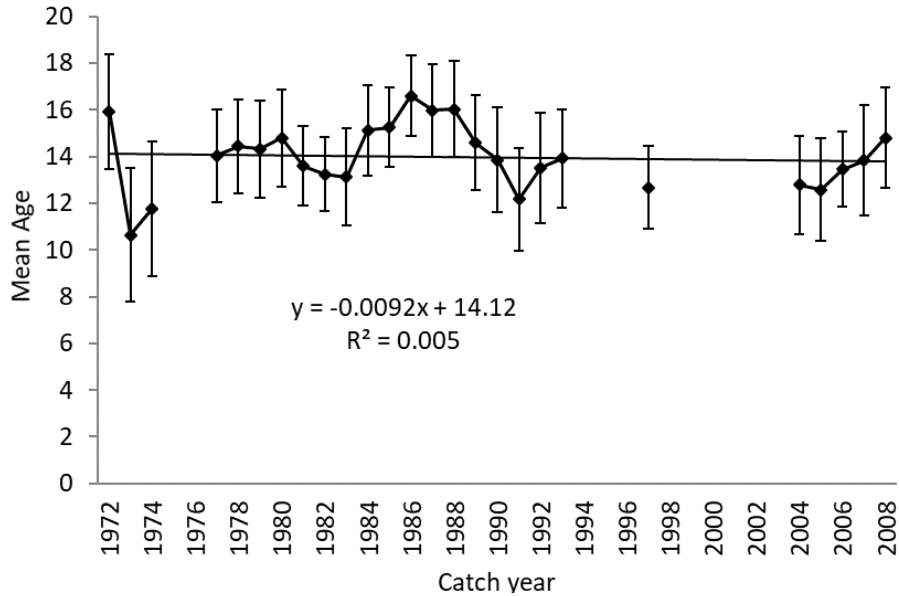
Figure 4. Mean age (±2 standard deviation) of anadromous Arctic Char sampled from the Lauchlan River commercial fishery.

Mean fork length showed a slightly significant increasing trend over time (r^2 = 0.21, p-value of slope < 0.05), which also suggests there was stability within the stock despite the commercial harvest (Figure 5).

Similarly, mean weight (Figure 6) also showed a statistically significant increasing trend over time (r^2 = 0.02, p-value of slope < 0.05) during the period of sampling. Condition factor varied without trend (r^2 = 0.02, p-value of slope = 0.50), similar to mean age (Figure 7).
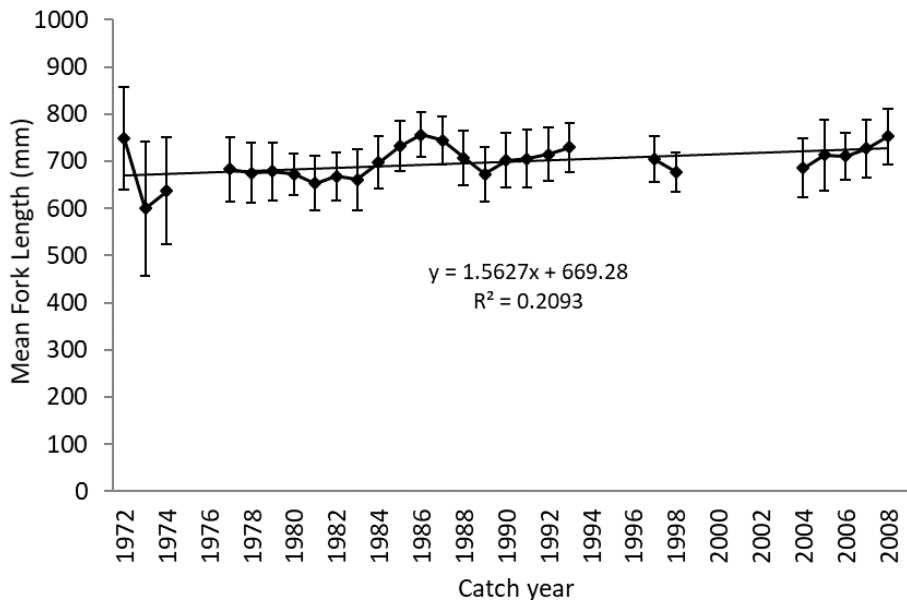

Figure 5. Mean fork length (±2 standard deviations) of anadromous Arctic Char sampled from the Lauchlan River commercial fishery.
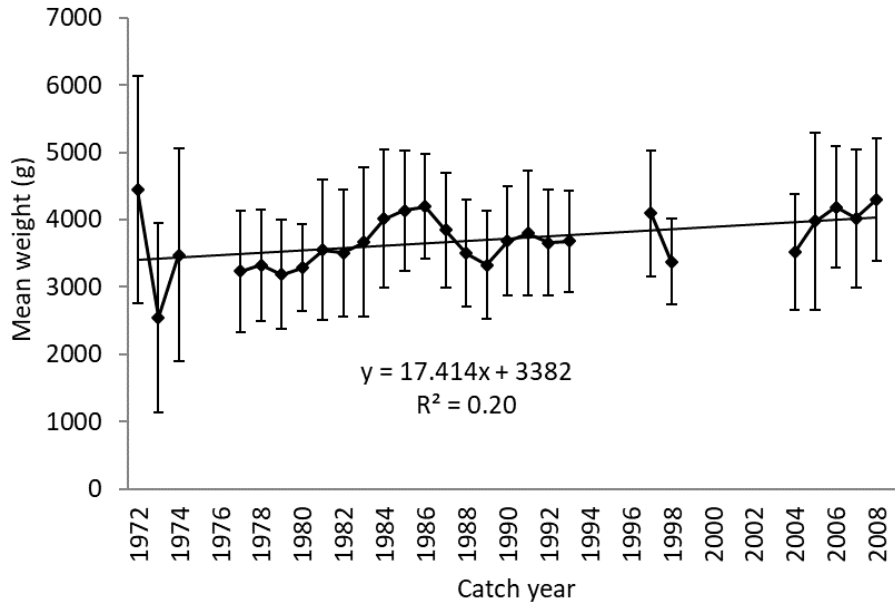
Figure 6. Mean round weight (±2 standard deviations) of anadromous Arctic Char sampled from the Lauchlan River commercial fishery.
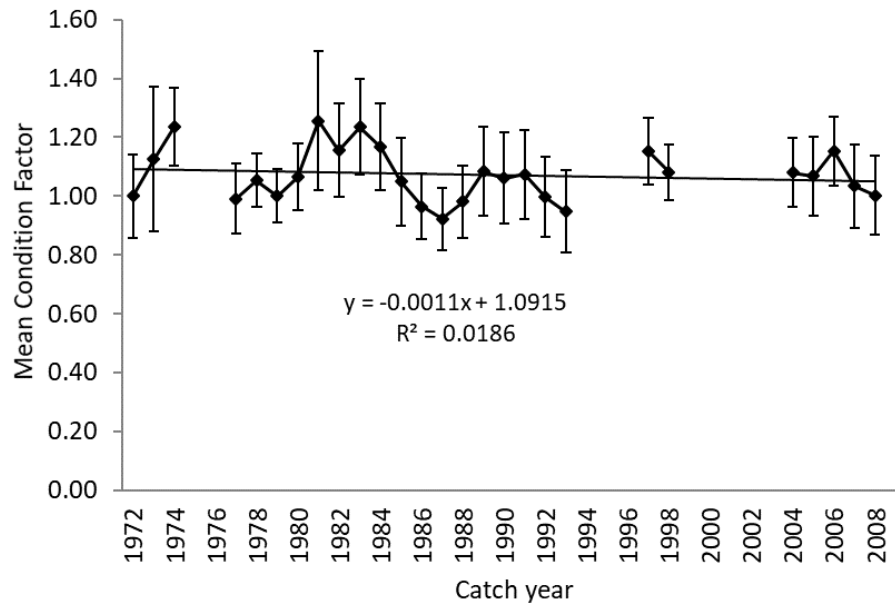

Figure 7. Mean condition factor (±2 standard deviations) of anadromous Arctic Char sampled from the Lauchlan River commercial fishery.

Surplus Production Equations

The effective management and conservation of fisheries resources requires accurate knowledge of fish mortality and the level of exploitation of fish stocks. Randomly caught samples from Cambridge Bay river systems may represent a mixture of discrete stocks, with the proportional contribution of each stock to the fishery remaining unknown (Kristofferson 2002). This situation presents a challenge for conventional stock assessment approaches. However,

discrete stocks may respond similarly to variation in environmental conditions and fishing mortality. Therefore, mixed-stock samples could reflect the responses of distinct stocks to exploitation even if the source stock of each individual is unknown (DFO 2004). Despite the presence of uncertainty and mixed stocks, in the absence of any other data, we assume that fish population parameters for the mixed stock in the Lauchlan River represents the stock situation and can be used to assess the status of the fish stock and determine sustainable fishing limits.

For population dynamics analysis, fork length was converted to total length using a mean conversion factor of 1.05 for Arctic Char (FishXing 2006). The VBGF was parameterized using length-age data in the FiSAT program (FAO-ICLARM Stock Assessment Tools for Fisheries Management; Gayanilo et al. 2005). The instantaneous natural mortality rate (M), which represents the rate at which fish die from all causes except fishing, was estimated using Pauly's (1980) equation. The instantaneous rate of total mortality (Z), which is the percentage of fish that die from both fishing and natural causes, was estimated using length converted catch curve analysis in FiSAT. The fishing mortality coefficient (F), a measurement of the rate of removal of fish from a population by fishing, was obtained by subtracting M from Z. The exploitation ratio, which is the ratio of fish caught to total mortality, was calculated using the formula E = F/Z (Gulland 1971). Exploitation rate (%), which is the proportion of a population caught, was calculated using Beverton and Holt's (1956) equation:

$$Exploitation\ rate\ (\%) = \frac{F}{Z}\ (1 - e^{-Z}) * 100$$

The only abundance information available for the Lauchlan River comes from one year of weir enumeration during the upstream migration in 1983 (McGowan 1990); these data are 34 years old. In situations where no real catch and effort time series exist, the estimation of potential sustainable yield is usually based on rough estimates of standing stocks and general knowledge of the biological characteristics of the species. If fishing mortality at maximum sustainable production (F_{MSP}) is assumed to be a specific function of natural mortality, it is possible to describe the surplus function by estimating maximum sustainable production (MSP) when the available data are limited to estimates of catch and mean biomass. Various equations have been proposed in the past to estimate MSP. For this analysis we used the following formula, based on an approach proposed by Walters and Martell (2002), to estimate MSP:

$$MSP = 0.33 \times Z \times B$$

Where B is the estimated biomass in the fish stock. This is a modified version of Gulland's (1971) equation (MSP = 0.5 M*B) that addresses criticisms that the original formula tended to overestimate MSP (Beddington and Cook 1983) and that fishing mortality rates above 0.67*M are often associated with stock declines (Patterson 1992).

Estimates of F were calculated sporadically from 1978 to 2008 (Table 2). These values suggest that mortality levels were higher in 2006 and 2007 compared to 2004 and 2008. The 2008 results show minimum mortality rates and an exploitation rate of 5.31 %. The exploitation ratio (E) for Lauchlan River fisheries was almost at the level of 0.39 from the 1970s to 1990s, with an exploitation rate around 10 % (Table 2). However, in 2007, E was close to 0.5 with a harvest of 8,684 kg (12 % exploitation rate). Exploitation rates should be kept to conservative levels for relatively long-lived species. Also, because of the presence of a mixed stock, a high level of uncertainty is associated with the data. Therefore, in the interest of sustainability of this resource, management strategies should ensure that E does not exceed 0.30, which corresponds to F = 0.5*M. There is a strong correlation between harvest level (Y, yield) and F (r = 0.743) during the above mentioned years; therefore, we can assume that F represents the stock situation and we can use these data to predict biomass using Gulland's (1971) equation

(B = Y/F). In 2008, the fish harvest was very low in the Lauchlan River, possibly because the stock was missed rather than because of a decline in the fish stock. Fish harvest during 2006 and 2007 might provide a better idea of the available yield and can be used to estimate biomass. Therefore, we used 2006 and 2007 data to estimate standing stock biomass; B was estimated to be 73,450 kg in 2006 and 62,000 kg in 2007, with a mean value of 67,739 kg between these two years.

Assuming an average B of 67,739 and Z = 0.30, an MSP is calculated as 6,706 kg which is almost a 10 % exploitation rate. These biomass estimates were based on commercial harvest only. Therefore, these removal limits are suitable for estimating commercial fisheries production limits.

Table 2. Asymptotic length (Loo), VBGF growth parameter (K), natural mortality (M), total mortality (Z), fishing mortality (F), exploitation ratio (E), harvest (kg) and exploitation rate (%) in the Lauchlan River Arctic Char fishery.

Year	$L_{oo\ (TL,\ cm)}$	K	M	Z	F (Z-M)	E (F/Z)	Harvest (kg)	Exploitation Rate %
1978	90.47	0.14	0.18	0.31	0.13	0.42	8536	11.18
1988	91.39	0.11	0.17	0.28	0.11	0.39	9425	9.59
1993	90.47	0.14	0.18	0.28	0.10	0.36	9306	8.72
2004	89.37	0.14	0.18	0.26	0.08	0.31	3267	7.04
2006	88.69	0.15	0.19	0.31	0.12	0.39	8814	10.32
2007	92.4	0.13	0.17	0.31	0.14	0.45	8684	12.04
2008	91.99	0.15	0.19	0.25	0.06	0.24	1621	5.31

Hierarchical Bayesian Modeling

To address a request for science advice from DFO Fisheries and Aquaculture Management in 2011, a surplus production model-based stock assessment process was formulated to define precautionary reference points within a precautionary approach (PA) framework for Arctic Char in Cambridge Bay (Zhu et al. 2014). Treating Arctic Char in Cambridge Bay as a single population, the hierarchical Bayesian statistics generated a series of management-related population dynamic parameters, such as carrying capacity (*K*, virgin biomass), intrinsic population growth rate (*r*), maximum sustainable production (MSP), and harvest or biomass at MSP (B_{MSP} and F_{MSP}). Combined with CPUE series from 140 mm gillnets and commercial harvest statistics, the B_{MSP} for the Cambridge Bay Arctic Char fisheries was estimated to be 1,045 tons with a total MSP of 92 tons. Of the total MSP, commercial fisheries were assigned 61 tons; the remaining 31 tons were allocated for subsistence use. The combined optimal fishable quantity for the Ekalluk, Paliryuak, Halovik, Lauchlan, and Jayco rivers was determined to be 46.5 tons (Table 3). During 2000-2010, commercial fisheries in the Lauchlan River only caught 8.64 % of the total harvest from all of the river systems. Allocating the harvest proportionally to recent harvest levels based on 2000-2010 data, an optimal fishable quantity of 4 tons is derived for the Arctic Char fishery in the Lauchlan River. These interim harvest levels are specific to the Arctic Char populations in Cambridge Bay and its adjacent waters and should be re-examined and revised as new information is obtained.

Table 3. Estimate of fishable harvest for Arctic Char in Cambridge Bay. This allocation is simply based on proportional harvest over 2000-2010 and maximum sustainable production in terms of surplus production model (DFO unpubl. data). All quantities of harvest and quota are in tons.

Year	Ekalluk	Paliryuak	Halovik	Lauchlan	Jayco	Total
Harvest	14.31	7.22	5.44	3.67	11.8	42.5
% of harvest (2000-2010)	33.69	17.01	12.81	8.64	27.9	100
Quota (2009)	20	9.1	5	2.4	17	53.5
Optimal fishable quantity	15.5	8	6	4	13	46.5
Change from 2009 harvest	-4.5	-1.1	1	1.6	-4	-7

Sources of Uncertainty

Stock assessment models quantify parameters either by incorporating values based on data or by making assumptions about parameter values. When applying the estimated biological reference points and harvest control rules, it is also necessary to be cautious with appropriate information, uncertainty and model assumptions. Several sources of uncertainty in the data were discussed. Error in any of these sources will impact uncertainty in the assessment process. Bayesian formulation of the surplus production model for assessments of biomass dynamics estimated process and observational uncertainties are discussed in Zhu (2014).

Sampling error

Assessment of the Lauchlan River and other fisheries in the Cambridge Bay area relies solely on biological data derived from fish sampled at the fish plant. These fish are caught in a mixed-stock fishery that does not sample fish randomly within a run or systematically by population. Fish runs are composed of stock mixtures that may change from year to year. Fishers could also miss part of a run in any given year. Annual or seasonal variation in stock mixtures or age or population structuring within the runs could explain any possible trends in biological data used to assess fisheries. Catch curves based on these data could also vary from year to year for the same reason. It is also uncertain how the fish are processed before they are sent to the plant. If small fish, for example, are sometimes kept for personal consumption, there could be bias in the biological data. In addition, annual variability in catches is more likely correlated with fisher behavior rather than with changes in stock abundance or run size. Fisheries independent sampling should be done to provide a basis for assessing populations.

Lack of information

There are many key parameters for which data are not collected for these fisheries. The lack of sufficient information regarding mixed-stock CPUE, the stock-recruitment relationship, age structure, discrete stock discrimination, the vulnerability of fishing effort, and localized variations in productivity and environmental factors are responsible for observation uncertainties in the risk assessment. There are no effort data from which to assess possible changes in abundance. There is limited information on abundance and no biomass estimates based on field sampling. Weir counts made in the 1980s showed substantial variation in run sizes from year to year for rivers where counts were done in more than one year. The Lauchlan River fall run was counted in only one year, therefore the magnitude of variability in the run size is unknown. The 11,000 fish estimated in 1983 could not possibly support the fishery in that river so runs during other years must have been larger. The amount of catch in the subsistence fishery is also unknown. Estimates of Total Allowable Removal should be based on harvest data from both the

commercial and subsistence fisheries. Tag recovery data from the 1990s indicated that spring fisheries recovered tags from the Ekalluk River in other systems such as the Lauchlan. There was no fall effort to recover tagged fish nor was it known how many fish tagged in the Ekalluk River originated from other systems. Tag data confirm that fisheries target mixed stocks but are not sufficient to allow assessment of the risk of a spring or fall fishery to these mixed stocks fished on the Lauchlan River.

Conclusions

It is difficult to determine a sustainable harvest level for the Lauchlan River fishery in the absence of a true estimate of population size and with a lack of effort data. Because of the presence of high uncertainty, the availability of limited information for assessing population characteristics, and the limitation of using an old population estimate based on a single weir enumeration, there is a need to follow a precautionary approach with stepwise increases. The sustainability of an increased quota could be tested by the assessment of monitoring data in coming years and the consideration of mortality factors.

The total harvest (commercial and subsistence combined) and estimates of population size are important in determining the sustainable harvest level of a fish stock. With a management goal of long-term sustainability under continued harvest, the exploitation rate for a stock should not be so high as to cause population decline. An exploitation rate of 5-10 % of the model population biomass estimate is advisable keeping in view the previous practices and studies on Arctic Char populations in Arctic Canada (Johnson 1980, DFO 2009).

From biomass estimates for 2006 and 2007, a harvest rate of 5 % or 3,400 kg would pose a low risk of stock decline. A rate of 7 % or 4,750 kg would pose a low to moderate risk of decline. A rate of 10 % or 6,800 kg would pose a moderate to high risk of stock decline. The requested removal of 9,100 kg would be a high-risk option at a 13 % harvest rate (Table 4).

If we consider that the fishery in the Lauchlan River has been sustainable during the last thirty years, then another possible approach which would result in a moderate risk harvest level is to use the mean harvest level (6,240 kg) in the Lauchlan River from 1979 to 2010 (Table 4). Finally, another alternative approach, based on Zhu et al. (2014), using a surplus production model and status quo allocation, proposed a commercial quota of 4,000 kg for the Lauchlan River stock which also is identified as moderate risk.

Table 4. Risk level of various harvest options estimated by three different approaches.

Basis	Removal level	Harvest Rate	Risk category
Quota Demand	9,100 kg	13 %	High
Predictive Equations (2006-2007 harvest)	= or >6,800 kg <6,800 kg <3,400 kg	= or >10 % <10 % <5 %	High Moderate Low
Hierarchical Bayesian Model (2000-2010)	4,000-5,270 kg	-	Moderate
Mean Harvest (1979-2010)	6,240 kg	-	Moderate

There is uncertainty around the current levels of total harvest, including subsistence fisheries. Limited information is available to undertake a new assessment of population characteristics. A new population estimate, accurate records of total harvest levels and fisheries independent CPUE are needed to refine the exploitation rate for the Lauchlan River Arctic Char population. Considering all of these factors, a precautionary adaptive management approach may be an appropriate method for the management of this fishery, as was suggested by Kristofferson and Berkes (2005). An initial increase in quota from 2,400 kg to 4,400 kg represents approximately the mean of the two methods described above, including a low to moderate risk of exploitation at 7 % (4,741 kg) and the results from a surplus production model (4,000 kg). The extent of stock stability should be monitored for three years following an increase in harvest allocation, after which the quota level should be reviewed again.

Recommendations for research

It is recommended that data on fishing effort be collected. The collection of effort data from the fishery would enable the development of a series of more sophisticated analyses, such as virtual population analysis, to determine the sustainability of various removal options. The development of fishery logbooks to be completed by the harvesters would be an effective approach to collect effort data. As well, fishery-independent sampling of the biological characteristics of the stock and the recording of associate CPUE would allow a clearer understanding of the dynamics of the stock. Changes in recruitment patterns could be anticipated, and more accurate forecasting could be undertaken. The fishery independent information would also allow "tuning" (Rivard 1989) of an age-structured analysis.

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