1. NWRT Project Number: NWRT-2023-0000000008

2. Project Title: Resolving Contributions to Harvest in the Cambridge Bay Arctic Char Fishery

3. Project Leader:

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4. Summary:

Anadromous Arctic Char have been vitally important to the Inuit Nunangat who have relied on this species for millennia. Its importance as a commercial resource has also been realized with the Cambridge Bay region of Nunavut boasting the largest commercial fishery for this species in Canada, harvesting close to 70,000 kg annually and employing dozens of Nunavummiut yearly. The Cambridge Bay Arctic Char commercial fishery is also the first for this species in Canada to have formalized an IFMP that guides the adaptive co-management of this fishery between government and local resource users. Within this plan, there are long-term objectives identified to guide the management of the fishery categorized under stock conservation, ecosystem, shared stewardship, and social, cultural and economic objectives. Within stock conservation, improving knowledge of Arctic Char stock delineation and quantifying the degree of mixing among discrete stocks has been identified as a top priority (Harris et al. 2020). Several studies in the Cambridge Bay region have suggested that stock mixing in the region is a pervasive concern, however, the degree and extent of stock-mixing has never been assessed. This hinders our understanding of removal levels of specific stocks in the region due to commercial fishing and therefore our ability to effectively manage this fishery. This study will use baseline samples collected from each commercial fishing system, genetic samples collected as part of the commercial plant sampling program and a mixed-stock fishery analysis (MSFA) using genomic data to resolve the

contributions of each stock to commercial harvest in the region. MSFA will be performed on samples
spanning multiple years to assess if annual differences in environmental and climatic conditions may
have an effect on the commercial harvest of Arctic Char in the region. All told, the results of this study
will be important for the sustainable management of this fishery and for potentially refining quota
management strategies.

5. Project Objectives:

Because of the unknowns that still remain with respect to stock-mixing in marine habitats and freshwater habits where and when commercial fishing occurs in the Cambridge Bay area, the objectives of the present study involve:

1. Collecting/consolidating baseline genetic samples from each commercial system in the Cambridge Bay area. Baselines have previously been collected from some locations and this study will involve collecting baselines and bolstering baseline sample sizes in the Ekalluk, Greiner and possibly Lauchlan systems to round out the baseline collection.

2. Collect samples from commercially harvested (in 2023 and onward) Arctic char through the
commercial plant sampling program and consolidate all samples that have been collected (N=~2400) in the past as part of this program.

3. Using genomic data and mixed-stock fishery analysis to estimate proportional contributions of discrete stocks to the commercial harvest of Arctic char at each location in the Cambridge Bay Arctic char commercial fishery for all years that commercially harvested samples are available.

4. Assessing the possible effects of inter-annual variation in environmental variables on stock mixing and contributions to harvest.

6. Materials and Methods:

Sample Collection: Baseline genetic samples were collected in the Greiner system near the community of Cambridge Bay and the Ekalluk/Ferguson Lake system. Unfortunately due to plain availability and inclement weather, we were not able to sample the Lauchlan River. Coastal samples collected during the upstream run in 2021 were thus used as the baseline for this location. Arctic char were captured via angling and gill nets.

All captured char were measured for fork length, and round weight. Sex and maturity of each fish were also recorded and structures for determining the age were collected. A genetic sample (piece of fin) from each Arctic char was placed into a solution of 95% ethanol. Mixed stock fishery samples (N=800, 200 from each commercially fished waterbody) were collected as part of the ongoing commercial plant sampling program.

Development of the low-cost genomic tool and mixed-stock fishery analysis: A Genotyping-in-Thousands by sequencing (GT-seq) panels was developed for population assignment and mixed-stock analyses of
Using low-coverage Whole Genome Sequencing data from Cambridge Bay Arctic a bioinformatic SNP filtering workflow was developed to select informative single nucleotide polymorphism markers from genotype likelihoods. These markers were then used to design GT-seq panels, thus enabling high-throughput genotyping for Cambridge Bay Arctic char. The methods for this approach our outlined in **Bemmelman's et al. (In press**, Figure 1). In brief, large genome-wide datasets from reference samples were analyzed in order to identify a few hundred single nucleotide polymorphisms (SNP) markers (N=398) that are were most differentiated among targeted stocks. Pairs or primers for multiplex PCRs are then designed to amplify only the selected regions, thus vastly reducing the costs of sequencing.

Mixed-stock fishery analyses. Mixed-stock fishery analyses and assignment tests will be used to assign mixed-stock samples to their population of origin. Briefly, assignment accuracy (cross-validation simulation and leave-one-out, LOO, analysis) and mixed-stock composition (summing individual assignments within collections) will be estimated with the R-package rubias (Moran and Andersson, 2016).

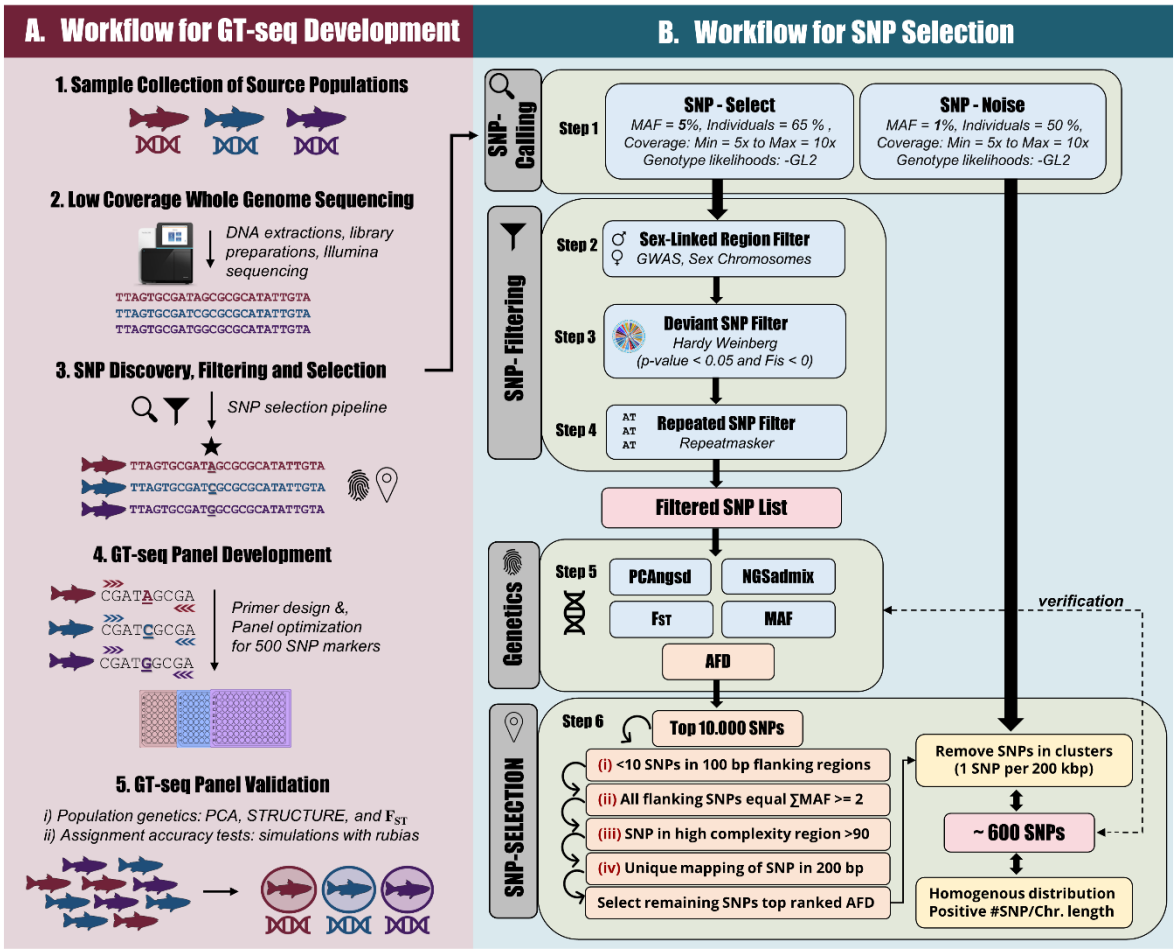

Figure 1. From Beemalman et al. (in press). Workflow for Genotyping-in-Thousands by sequencing (GT-seq) panel development using low-coverage Whole Genome

Sequencing (lcWGS) data. Schematic illustration of a general workflow to design customized GT-seq SNP panels for genetic stock identification (GIS). The main steps of the workflow are: 1) Sample collection of source populations 2) DNA extraction, lcWGS library preparation and sequencing; 3) SNP calling, filtering and selecting 600 SNPs capable to differentiate among source populations (see part B); 4) GT-seq panel development targeting 500 SNP markers (see part B) 5) GT-seq panel validation and accuracy testing using simulation approaches (e.g., *rubias*). B) SNP marker selection procedure to select 600 maximally informative loci for GT-seq panel development. A customized sequential 6-step sequential SNP filtering procedure using *ANGSD v0.931* to obtain high quality SNPs and select the most informative SNP makers for GT-seq panel development. Step 1: SNP calling and Genotype Likelihood (GL) computations. SNP filtering procedure: Step 2: exclude SNPs located in pre-determined sex-linked genomic regions; Step 3: remove deviant SNPs in putative duplicated genomic regions; Step 4: omit SNPs located in repeated genomic regions; Step 5: use the obtained 'filtered SNP list' perform population genetic structure analyses. Step 6: select 600 candidates based on ranked AFD values and following four main penalties (*i-iv*) and considering an equalized chromosomal distribution at a minimum distance of 200 kbp ideally covering all chromosomes. Finally, perform iterating verification analyses between Step 5 and 6 (see dotted 2-way arrow) to verify the best selection of 600 maximally informative SNP positions.

Community employment and capacity building: In 2023, we employed 8 beneficiaries for various parts of this work. This work was not possible without the amazing team of field assistants and boat guides that joined us that year. We especially thank, Kevin Kanayok, Richard and Mary Ekpakohak, Jamie Panioyak, George (Kaitak) Kavanna, Randy Klengenberg, Dennis Kamoyak, George (Pamiok) Angohiatok who were exceptional guides and field assistants while out on the land and the water.

7. Results

SNP Filtering, selection and GT-seq panel development: Results of the SNP Filtering, selection and GT-seq panel development are provided in detail in Beemalman et al. (in press). Briefly, after lcWGS data processing, reads from 161 individuals for Arctic Char were retained. 7,734,214 SNPs were initially called, yet 2,364,631 were identified as paralogous SNPs due to high excess of heterozygotes. Of the remaining 5,369,583 SNPs, 4,059,430 (75.6%) located within repetitive regions were removed, leaving 1,310,153 filtered SNPs to investigate population genetic structure.

A set of 651 SNP positions was provided to GTseek for primer development. Following multiplex PCR primer design and filtering, primers targeting 499 autosomal loci and one presence/absence marker for sex genotyping were designed. During panel optimization, 99 primer pairs responsible for large off-target amplification and primer artifacts were removed and a set of 400 total loci and one sex marker remained in the finalized panel (Table 2). These selected 401 loci are evenly distributed across 38 chromosomes, with an average of 13 SNPs per chromosome.

Mixed-stock fishery analyses: Preliminary analyses indicate that this panel will successfully estimate the relative contribution of the major commercial stocks into commercial fisheries and subsistence fisheries, thus offering the opportunity to evaluate the extent of mixed-stock captures in many fisheries throughout Nunavut. Preliminary results highlight that all commercial stocks in the region contribute to mixed-stock fisheries and that these contributions vary annually. Once stock contributions to the commercial harvest have been identified, we will assess whether inter-annual variation in marine ice conditions and river break-up influences these proportions using general linear model approaches.

8. Discussion and management implications:

At present this project is on schedule as proposed. Fieldwork has been completed, and data analysis is ongoing. General analyses have commenced, and are being completed by a PhD student at Universite Laval. Summary reports for the Ekaluktutiak HTO have been prepared and distributed and HTO meetings (IFMP working group meetings) were attended and community presentations were given a the EHTO Annual General Meeting. Below is a general discussion on the importance of Arctic char and how this work will inform the management and conservation of this species in the Cambridge Bay region of Nunavut where the largest commercial fishery for char is executed.

Arctic char is widely considered one of the most important natural resources in Nunavut. It is the most harvested species of wildlife in the territory (Priest and Usher 2004) and is used by Inuit across the territory for both subsistence and commercial purposes. Arctic char has also been crucial to food security and to the cultural base of northern indigenous communities.
The federal government (Fisheries and Oceans Canada (DFO)) and the government of Nunavut (GN) have both identified the development of commercial fisheries for anadromous (i.e., sea run) Arctic char as a priority because it provides a sustainable and culturally meaningful opportunity for economic development. Commercial fishing for Arctic char currently generates approximately $1.4 million annually and employs tens dozens of Nunavumiut both seasonally and permanently in several communities (Government of Nunavut and NTI 2005). The Cambridge Bay region is home to the most important commercial fishery for anadromous Arctic char in Nunavut, with annual quotas totaling 68,000 kg (Day and Harris 2013). The management of anadromous char in the Cambridge Bay area is based on the notion that char in each system represents a discrete stock. 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, the baseline samples collected and assessed in this study, will 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.

This will provide insights into the spatial scale at which these stocks should be managed.

In the Arctic regions of Canada, mixed-stock fishing, the simultaneous harvest of multiple discrete stocks (Utter and Ryman 1993; Manel et al. 2005), is a pervasive issue for fisheries that target anadromous Arctic char (Harris et al. 2016a, 2016b). The management of anadromous Arctic char also assumes discrete populations, applying quotas on a river-by-river basis (Roux et al. 2011, 2019). Past genetic/genomic (Harris et al. 2016a, Moore et al. 2017) and acoustic telemetry assessments (Harris et al. 2022) have inferred mixed stock fishing in the Cambridge Region; however, the percent contribution of discrete stocks to commercial harvest has never formally been assessed. This will be the first study to formally perform mixed-stock fishery analyses which will shed on which populations specifically being harvested and to what extent at each commercial fishing location. We will also assess how inter-annual variation in environmental and climatic variable will influence these proportions (see Harris et al. 2022).

The Integrated Fisheries Management Plan for Cambridge Bay Arctic Char highlights the need for understanding stock contributions to the commercial harvest (DFO 2021). Recent stock assessments that were conducted on fisheries in the region (Harris et al. 2021; Zhu et al. 2021), as well as studies elsewhere (Moore et al. 2014; Harris et al. 2016a), have also highlighted the need for mixed-stock fishery analyses for understanding the proportions of stocks being harvested. Such information will contribute to the modification or removal of levels of Arctic char in the Cambridge Bay region. For example, if it is clear that a mixture of populations are harvested at discrete fishing locations, quota transfers among locations could be implemented if the quota is not filled at one location. Such an approach could provide increased yield and thus value for the commercial fishers without compromising the sustainability of the stocks. Such an approach, however, has yet to be formally implemented in the Cambridge Bay region.

Last, DFO has also been moving towards harvest strategies compliant with the Precautionary Approach to fisheries management. Quantitative stock assessment models are currently being developed for Cambridge Bay Arctic char fisheries as a means to estimate abundance/biomass of each stock and for resolving sustainable in accordance with the health of the stock. Unfortunately, at present, the degree of mixing among discrete Arctic char populations is currently not known. The results produced from these initial models, thus does not incorporate stock mixing and mixed-stock harvest in fisheries, and therefore they should be used cautiously and adjustments should be made to refine the model once new information/data on these fisheries becomes available. The refinement of models using the data collected as part of this research will be vital in doing so and in eventually allowing fisheries managers to modify quotas or removal levels based on the most up-to-date information on the fishery.

9. Report by Inuit participants:

This report will be included in the coming weeks. We have communicated with the EHTO and have confirmed a report from them is forthcoming.

10. Reporting to communities/resource users:

Numerous telephone and email communications took place with the EHTO manager (Beverly Maksagak) to discuss the project prior to the 2023 field season. Meetings in Cambridge Bay with the EHTO occurred throughout the summer while we were in the community. We also attended an EHTO board meeting to discuss the project and provide updates in August 2023. We also attended the EHTO AGM in January 2024 to provide updates to the board and residents of Cambridge Bay. Summary reports for the Ekaluktutiak HTO and residents of Cambridge Bay have been prepared and distributed. In 2023, we had also planned a "Chars Research Day" bbq to discuss our work and highlight our methodologies, but this was canceled due to weather. We did host this bbq in August of 2024.

11. References

Fisheries and Oceans Canada (DFO). 2021. Cambridge Bay Arctic Char commercial fishery, Nunavut Settlement Area. Integrated Fisheries Management Plan.

Harris, L. N., Moore, J. S., Bajno, R., & Tallman, R. F. (2016a). 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 American Journal of Fisheries Management, 36(6), 1473-1488.

Harris, L. N., Boguski, D. A., Gallagher, C. P., & Howland, K. L. (2016b). Genetic stock identification and relative contribution of Arctic Char (Salvelinus alpinus) from the Hornaday and Brock rivers to subsistence fisheries in Darnley Bay, Northwest Territories. Arctic, 231-245.

Harris, L. N., Yurkowski, D. J., Malley, B. K., Jones, S. F., Else, B. G., Tallman, R. F., ... & Moore, J. S. (2022). Acoustic Telemetry Reveals the Complex Nature of Mixed-Stock Fishing in Canada's Largest Arctic Char Commercial Fishery. North American Journal of Fisheries Management, 42(5), 1250-1268.

Harris LN, Cahill CL, Jivan T, Zhu X, Tallman RF. 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. Fisheries and Oceans Canada Canadian Science Advisory Secretariat Research Document. v + 97p.

Manel, S., Gaggiotti, O. E., & Waples, R. S. (2005). Assignment methods: matching biological questions with appropriate techniques. *Trends in ecology & evolution*, *20*(3), 136-142.

Moore, J. S., Harris, L. N., Le Luyer, J., Sutherland, B. J., Rougemont, Q., Tallman, R. F., ... & 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. Molecular Ecology, 26(24), 6784-6800.

Moore, J.-S., L.N. Harris, and R.F. Tallman. 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.

Moran, B. M., & Anderson, E. C. (2019). Bayesian inference from the conditional genetic stock identification model. Canadian Journal of Fisheries and Aquatic Sciences, 76(4), 551-560.

Priest, H., & Usher, P. J. (2004). The Nunavut wildlife harvest study, August 2004. Nunavut Wildlife Management Board= Nunavumi Umayuligiyit Katimayiit.

Utter, F., & Ryman, N. (1993). Genetic markers and mixed stock fisheries. *Fisheries*, *18*(8), 11-21.

Zhu, X., Harris, L., Cahill, C., and 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. iv + 34 p.

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Pertaining to Project NWRT Project Number: NWRT-2023-0000000008
Project Title: Cambridge Bay Arctic Char Research: Resolving Contributions to Harvest in the Cambridge Bay Arctic Char Fishery

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1. Were you involved in the development of the methods? If so, do you feel that your input was considered and applied?

The EHTO was not directly involved in the development of the methods for this project. The EHTO and however, did provide input on personnel for all sampling and field trips.

2. Do you think that the methods of the project were appropriate for the purpose? If not, how could they be improved?

Yes. Sampling was done in a similar fashion to that outlined in the initial proposal that was approved and supported by the EHTO and at important commercial fishing locations in Cambridge Bay. We look forward to seeing the results.

3. Did the project effectively incorporate Inuit Qaujimajatuqangit? If not, how could it be improved?

Yes, as mentioned above, the timing of and specific locations for sampling fish were all chosen or identified through the use of Inuit Qaujimajatuqangit provided by the EHTO and local field assistants.

4. Were the methods undertaken in the project respectful of wildlife? Would you change anything about the methods of the project?

Yes. Besides the Arctic char that were sacrificed as part of the study, no other wildlife was hurt or disturbed. All harvested fish were made into piffi or kept fresh and retained by the subsistence harvester and in many cases distributed to other members in the community including to the wellness center, to elders and food insecure households.

5. Were you involved in the analysis and interpretation of the project's results? If so, do you feel that your input was considered and applied?

Not directly, however much of the analysis is ongoing. Additionally, the EHTO is intimately involved in contributing to and evaluating the Integrated Fisheries Management Plan for this fishery and the results of this work will be directly relevant for revised IFMPs in the future.

6. How do you think that the results of the project could best be applied to wildlife management in Nunavut?

The results of this revised project will not allow us to better understand contributions of discrete stocks to commercial harvest ultimately helping us understand the sustainability of harvested Arctic char in the region. Such information will be directly used by DFO Fisheries Management and the Nunavut Wildlife Management Board and will improve the advice provided for the co-management of the fisheries which will contribute to the conservation and sustainable harvest of Arctic char in our region.

7. Is there any information not included in the Final Project Report that you think is important to the outcomes of the project?

The EHTO has long supported the Arctic char research of DFO and specifically that proposed by Les Harris since 2009. He has been working in the Cambridge Bay region for over a decade where he is very engaged with the community with nearly 50 different beneficiaries hired over that time. His work is very relevant for ensuring Arctic char populations remain sustainable so that these fish will be around for generations to come. We look forward to working with him for many years to come.

Sincerely,

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