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UNIVERSITY OF CALGARY

“Feasibility of using pressure retarded osmosis (PRO) to replace diesel in Bella Coola British
Columbia”

by

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IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE

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Abstract

Can pressure retarded osmosis (PRO) reduce or eliminate diesel dependency in Bella Coola, British Columbia? This study looked into the possibility of using PRO to replace diesel in Bella Coola by analyzing the energy potential of six watersheds in the region, comparing the levelized cost of electricity (LCOE) of PRO to current diesel prices, and examining potential environmental impacts associated with PRO. Analysis showed that the most significant factor preventing PRO from being a viable option in Bella Coola and other markets is contributed to the high cost and poor efficiency of PRO membrane technology. While PRO technology may not currently be economically feasible for Bella Coola, with the introduction of the communities proposed hydroelectric facility in Nooklikonnik Creek, PRO could subsidize the remaining energy demand from diesel in the future with less environmental impacts than current systems.

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Table of Contents

Approval Page	i
Abstract.....	ii
Acknowledgements	iii
Table of Contents	iv
List of Tables	vii
List of Figures.....	viii
Nomenclature	x
Chapter 1 Introduction.....	1
1.1 Background.....	1
1.2 Sustainable Development Goals/ Interdisciplinary Components	2
Chapter 2 Literature Review	4
2.1 History	4
2.2 Salinity Gradient Energy Applications.....	5
2.2.1 Pressure Retarded Osmosis	5
2.2.2 Reverse Electrodialysis	6
2.2.3 PRO vs RED	7
2.2.4 Stand Alone Systems.....	8
2.2.5 Hybrid Systems	8
2.3 Performance Limiting Factors for PRO	9
2.3.1 Membrane Power Density	9
2.3.2 Nonmembrane efficiencies.....	14
2.4 Diesel Dependency	15
2.4.1 Diesel Dependency in Canada.....	15
2.4.2 Diesel Dependency in British Columbia	16
Chapter 3 Capstone Objectives	18
Chapter 4 Site Selection	19
4.1 PRO Power Potential in Canada.....	19
4.2 PRO in Bella Coola British Columbia.....	20
4.3 Selected Watersheds	21
Chapter 5 Energy Potential.....	23
5.1 Introduction	23
5.1.1 Scope	23
5.2 Methods	24

5.2.1 Osmotic Pressure	24
5.2.2 PRO Energy Potential from Osmotic Pressure and Flow Rates.....	24
5.2.3 Comparison of PRO Energy Potential and Diesel Usage in Bella Coola Before and After the Nooklikonnik Creek Hydroelectric Facility	26
5.2.4 Flow Rate Needed to Produce Enough Energy from PRO to Replace Diesel	26
5.2.5 Flow Rate Needed to Produce Enough Energy from PRO to Replace Diesel after the Development of the Nooklikonnik Creek Hydroelectric Facility	27
5.3 Results	28
5.3.1 Osmotic Pressure in Bella Coola	28
5.3.2 Energy Potential of Selected Watersheds.....	28
5.3.3 PRO Energy Potential Compared to the Energy Demand in Bella Coola.....	34
5.3.4 Flow Rate Needed to Replace Diesel in Bella Coola with PRO	36
5.3.5 Flow Rate Needed to Replace Diesel in Bella Coola with PRO after the Development of The Nooklikonnik Creek Hydroelectric Facility.....	37
5.4 Discussion.....	39
5.5 Summary/ Future Research	41
Chapter 6 Economics.....	43
6.1 Introduction	43
6.1.1 Scope	43
6.2 Methods	44
6.2.1 LCOE Calculations.....	44
6.2.2 Comparison of the LCOE for PRO and Diesel in Bella Coola	45
6.3 Results	45
6.3.1 LCOE.....	45
6.3.2 Cost Comparison of PRO and Diesel	46
6.4 Discussion.....	46
6.5 Summary/ Future Research	47
Chapter 7 Environment.....	50
7.1 Introduction	50
7.1.1 Scope	50
7.2 Methods	50
7.2.1 Environmental Impacts Throughout the Lifecycle of a PRO Facility.....	50
7.2.2 Diesel Emissions	51
7.3 Results	51
7.3.1 Life Cycle of PRO	51
7.3.2 Diesel Emissions	52
7.4 Discussion.....	53
7.4.1 Construction	53
7.4.2 Operation	56
7.4.3 Decommission	58

7.4.4 Summary/ Future Research	58
Chapter 8 Conclusion	60
References	61
Appendix A Osmotic Pressure Calculations	83
Appendix B Energy Produced by Diesel Calculations	84
Appendix C Watershed Flow Rate Needed to Replace Diesel Using PRO	86
Appendix D LCOE Calculations	87
Appendix E CO ₂ Emissions from Diesel Use	90
Appendix F Plankton	91
Appendix G Aquatic Vegetation	93
Appendix H Terrestrial Vegetation	94
Appendix I Invertebrates	97
Appendix J Fish	105
Appendix K Reptiles	112
Appendix L Birds	113
Appendix M Marine Mammals	114
Appendix N Terrestrial Mammals	116

List of Tables

Table 1 Efficiencies of Non-Membrane Equipment.....	14
Table 2 Minimum Multiannual Monthly Flow Rates for Selected Watersheds in/Near Bella Coola BC	25
Table 3 Annual Energy Produced by Diesel for the Year 2017 with and without the Addition of the Nooklikonnik Creek Hydroelectric Facility	35
Table 4 Current and Optimal Power Densities of PRO Membrane Technology and the LCOE for a PRO Facility	46
Table 5 Energy Produced, Cost, and Savings of Diesel Vs. PRO at Optimal Conditions in Bella Coola.....	46
Table 6 CO ₂ Produced by Diesel Generators in Bella Coola in 2015 and 2017	53

List of Figures

Figure 1 Depiction of PRO Generation	6
Figure 2 Depiction of RED.....	7
Figure 3 Power Density Losses from Mass Transfer and Polarization in a Commercial Membrane	10
Figure 4 Flat-Sheet PRO Membrane	11
Figure 5 Hollow-Fiber PRO Membrane.....	12
Figure 6 PRO Membrane Power Densities Found in Studies from 1970-2010	13
Figure 7 Remote Communities in British Columbia.....	16
Figure 8 Osmotic Power Potential in Canada.....	20
Figure 9 Location of Bella Coola British Columbia	21
Figure 10 Map of the Locations of the Selected Watersheds.....	22
Figure 11 Minimum Energy Potential of Clayton Falls	29
Figure 12 Minimum Energy Potential of Nusatsum River.....	30
Figure 13 Minimum Energy Potential of Tastsquan Creek.....	31
Figure 14 Minimum Energy Potential of Atnarko River.....	32
Figure 15 Minimum Energy Potential of Dean River	33
Figure 16 Minimum Energy Potential of Salloomt River	34
Figure 17 The Energy Produced by Diesel in 2017 and the Energy Produced by Diesel with the Nooklikonnik Creek Hydroelectric Facility Compared Against the Annual Energy Potential of Selected Watersheds.....	36
Figure 18 Percentage of the Minimum Multiannual Monthly Flow Rate Needed to Replace the Energy Produced by Diesel Generators with PRO in January 2017	37
Figure 19 Percentage of Lowest Monthly Flow Rate Needed to Meet the Energy Demand of Bella Coola with PRO after the Development of the Nooklikonnik Creek Hydroelectric Facility	39
Figure 20 The Trend in PRO Publications and Oil Prices from 1950-2010	48

Figure 21 Environmental Impacts at Different Life Stages of PRO52

Nomenclature

Abbreviation

PRO

Pressure Retarded Osmosis

LCOE

Levelized Cost of Electricity

RED

Reverse Electrodialysis

RO

Reverse Osmosis

SGE

Salinity Gradient Energy

Symbols

c

Concentration (g l^{-1})

i_v

Van't Hoff's coefficient

M

Molar Mass (g mol^{-1})

R_g

Gas Constant ($\text{J mol}^{-1} \text{K}^{-1}$)

T

Temperature (K)

Greek Symbols

π

Osmotic Pressure (Pa)

Chapter 1 Introduction

1.1 Background

Globally, there is still a significant reliance on fossil fuels which produce harmful emissions and contribute to climate change. As a result, there has been an increasing need to further develop renewables and new technologies to transition away from fossil fuels and towards clean energy. One of these proposed technologies is salinity gradient energy (SGE). SGE works by generating electricity from the concentration difference between a water source with a high salt concentration and a water source with a low salt concentration. There is an estimated 2 TW of available SGE globally, or about 13% of the global energy demand (Yip & Elimelech, 2011).

11 coastal Indigenous communities in British Columbia rely on diesel to generate heat and electricity (Coast Funds, 2022). Using diesel to generate heat and electricity comes with many challenges and produces harmful emissions and exhaust (Energy Education, n.d.). As a result, communities reliant on diesel generators are looking into transitioning to more reliable and sustainable energy options; one of these communities is Bella Coola. One of Bella Coola's proposed ways of transitioning away from diesel is through the development of a hydroelectric facility on Nooklikonnik Creek (Thompson, 2019). However, while this hydroelectric facility will significantly reduce diesel use, it will not completely eliminate the reliance of diesel in Bella Coola. This study looks at using pressure retarded osmosis (PRO) which is an application of SGE as a way of replacing diesel use before and after the Nooklikonnik Creek hydroelectric facility in Bella Coola.

1.2 Sustainable Development Goals/ Interdisciplinary Components

The United Nations outline 17 sustainable development goals. This paper focuses mainly on goal 7 (affordable and clean energy), goal 9 (industry, innovation, and infrastructure), and goal 13 (climate action) (United Nations, n.d.). With these goals in mind, this paper primarily focuses on analyzing the energy, economics, and environmental facets of PRO.

Firstly, this paper analyzed the flow rate of six selected watersheds in Bella Coola to determine whether these watersheds had enough freshwater to produce enough energy through PRO to replace diesel in Bella Coola. For PRO to be sustainable and have minimal environmental impact on the selected watersheds, it is important that less than 25% of these watersheds minimum multiannual monthly flow rates are used (Maisonneuve et al., 2015a). Only the Atnarko River would have a high enough freshwater flow rate to produce enough energy through PRO to replace diesel sustainably. However, with the Nooklikonnik Creek hydroelectric facility, Clayton Falls, Nusatsum River, Atnarko River, and the Salloomt River would all have high enough flow rates to produce the energy needed to replace the remaining diesel usage sustainably.

Secondly, this paper analyzed the current and optimistic levelized cost of electricity (LCOE) for PRO which was compared to the LCOE for diesel in Bella Coola. The main factors preventing PRO from becoming commercially viable were low power densities and the high cost of PRO membranes. Optimistic membrane parameters and costs were used to determine the competitiveness of PRO in the future. Under optimistic conditions, it is possible that in the future PRO would be economically favorable over diesel in Bella Coola.

Lastly, this paper analyzed the potential environmental impacts of PRO by looking at the lifecycle of a PRO facility and estimating how activities within each lifecycle stage may impact local environments in Bella Coola.

Chapter 2 Literature Review

2.1 History

Salinity gradient energy was first introduced in 1954 by R.E. Pattle when they proposed that free energy created when freshwater and saltwater mixed could be harnessed and converted into mechanical power using ion-selective membranes (Hsu et al., 2021). Until the early 1960s, membrane technology was only used in a few small applications due to high membrane cost, inefficiency, unreliability, and timeliness. And then, in the 1960s, Sidney Loeb developed PRO membrane technology which encouraged more research into commercial uses of SGE (Kleiterp, 2012). Over the past few decades, membrane technologies have continued to improve. Companies such as “Fujifilm, FumaTech, Nitto Denko, Oasys Water, OsmoBlue, Pentair X Flow, Porifera, and Toray Industries” have all been working on developing membrane technologies. By continuing to improve membrane efficiency and reducing costs, future SGE technologies may become competitive with other renewable energy markets in the future (Hsu et al., 2012, p.3).

The first SGE pilot plant became operational in 2009 in Tofte, Norway, by Statkraft using PRO technology. The Statkraft facility was built within the Sandra Cell Tofte, which is a paper pulp industrial site with proximity to both fresh and salt water. The pilot project was mainly used for research, development, and testing of new technologies (Power Technology, 2009). However, Statkraft shut down operations at the end of 2013, claiming that the technology was not competitive with current markets and would not be “within the foreseeable future” (Statkraft, 2013, para. 2). SGE is likely too expensive because of the low efficiency and high cost of the membrane technology. For SGE to be economically feasible, it is estimated that membrane technology needs to attain a power density of at least 5 W/m^2 up from the current membrane power density of $1.6\text{-}2.9 \text{ W/m}^2$ (Achilli et al., 2009; Altaee et al., 2018).

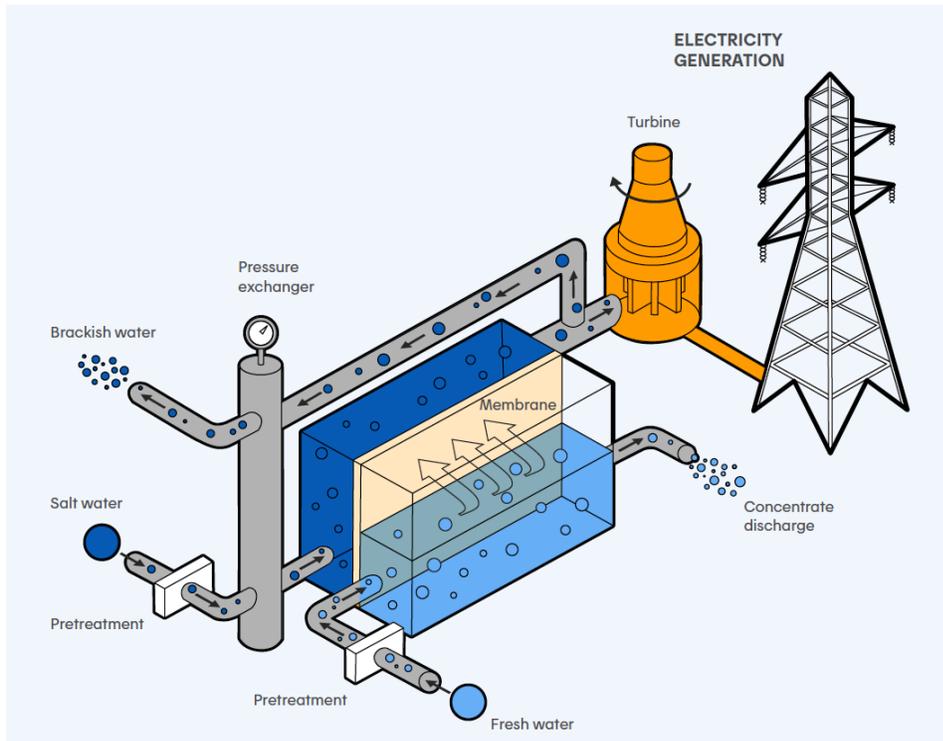
2.2 Salinity Gradient Energy Applications

2.2.1 Pressure Retarded Osmosis

PRO also known as osmotic power operates by pumping water of two different concentrations into a chamber where the concentrated water sources are separated by a semi-impermeable membrane. For example, in figure 1, freshwater and seawater are used to generate electricity by separating the seawater and freshwater with a semi-impermeable membrane, thus creating a pressure gradient. Through reverse osmosis the freshwater moves across the membrane to the seawater side, increasing the volume and therefore the pressure on the seawater side. The increased pressure causes water to move through a penstock towards a turbine. The pressurized water turns the turbine generating electricity as seen in figure 1 (Hydro-Quebec, 2021).

Figure 1

Depiction of PRO Generation



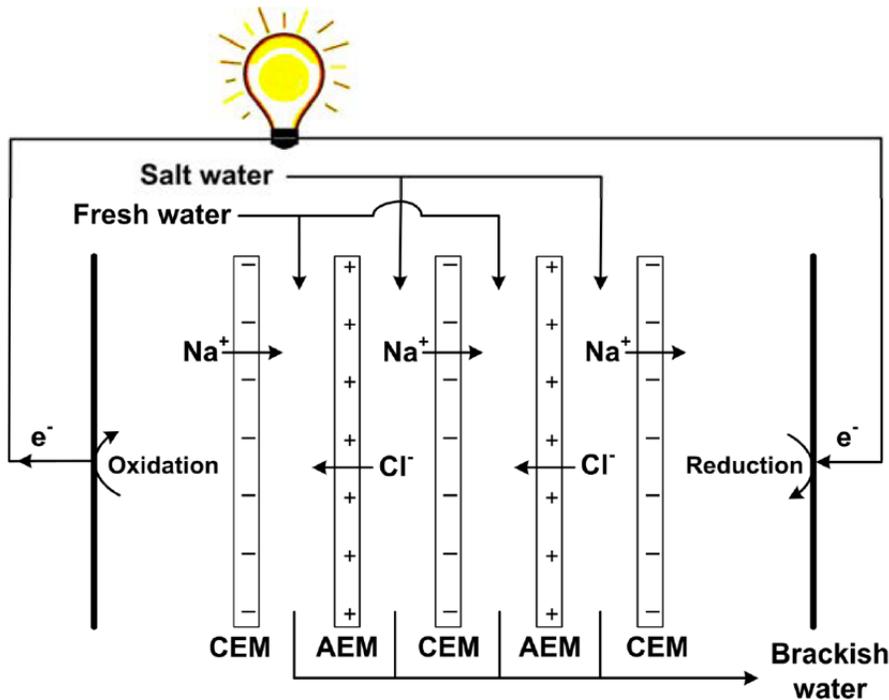
Note. Figure represents the operations of an osmotic power facility. From: “A Renewable Energy Option Osmotic Power” by Hydro-Quebec, 2021, p. 4. In the public domain.

2.2.2 Reverse Electrodialysis

Reverse electrodialysis (RED) works by pumping water of two different salt concentrations through alternating cation and anion exchange membranes. Positively charged Na^+ ions will move to one side of the system and negatively charged Cl^- ions will move to the other, similarly to a salt battery. Having all positive ions and all negative ions on two opposite poles creates a voltage that can be harnessed by connecting the poles, thus creating an electrical current, as seen in figure 2 (Sang et al., 2018).

Figure 2

Depiction of RED



Note. Figure showing the movement of Na^+ ions and Cl^- ions with the mixing of fresh and salt water through alternating cation and anion exchange membranes to produce positive and negative poles and ultimately a voltage that can be harnessed from connecting the two poles.

From “Energy generation from mixing salt water and fresh water”, by D.A. Vermaas, 2013, p. 15, [PHD thesis, University of Twente, The Netherlands], (DOI: 10.3990/1.9789036535731).

Copywrite 2018 by David Vermaas.

2.2.3 PRO vs RED

There are several trade-offs between RED and PRO. RED has been shown to be less affected by fouling and can maintain power densities under fouling conditions, while PRO loses significant power densities to fouling (Ju et al., 2021). While fouling may reduce power

densities, the low conductivity of current RED membranes still results in RED having a lesser power density than PRO. For RED to improve, power densities must become competitive with PRO (Yip & Elimelech, 2014).

RED has struggled to be implemented in real-world environments because ion exchange membranes “due to their limited pore size and internal resistance” limits the efficiency of this technology (Hsu et al., 2021, p.1). Also, laboratory experiments have used NaCl solutions to demonstrate the energy potential of RED; however, in real-world applications, there are more factors to consider, such as temperature changes and other minerals in the water. As a result, RED systems require technological advances to function better in real-world applications (Schaetzle & Buisman 2015).

2.2.4 Stand Alone Systems

SGE standalone systems operate using natural draw and feed solutions. Standalone systems need to be developed near an area that naturally has access to freshwater and saltwater. Typically, standalone systems are developed near the ocean; however, they can be built inland when there is access to natural saltwater, such as in salt lakes or the dead sea (Newby et al., 2021).

2.2.5 Hybrid Systems

Hybrid SGE systems work in conjunction with other industrial plants that have a concentrated brine as a waste product. Hybrid SGE have been proposed as a promising solution to the desalination of wastewater through membrane-based desalination, which also produces SGE (Okampo et al., 2022). Hybrid SGE facilities can be built next to these industries and use freshwater from a local reservoir and industrial wastewater to conduct the same process as a standalone system. The benefits of a hybrid system are that they can occur inland, and they can

produce more energy as the concentrated brine draw solution has a higher salt concentration than seawater which creates a larger concentration difference compared to the feed solution (Matsuyama et al., 2021).

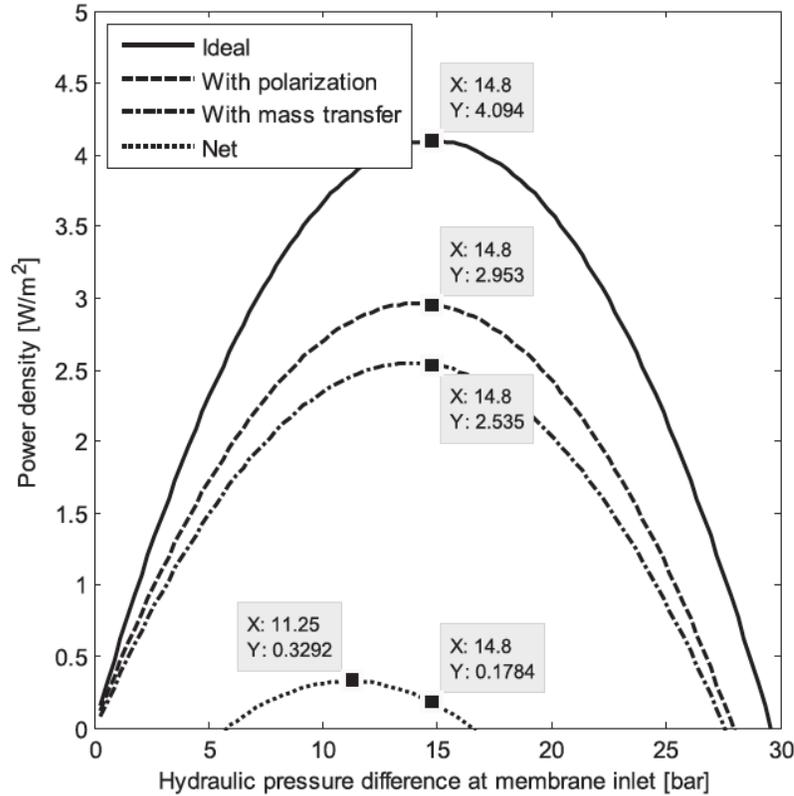
2.3 Performance Limiting Factors for PRO

2.3.1 Membrane Power Density

PRO membranes must be “thin enough to reduce the effect of concentration polarization but strong enough to tolerate the hydraulic pressure on the draw solution side of the membrane” (Altaee et al., 2018, “Introduction” section). Another challenge with PRO membranes is the transfer of salt from the feed side to the draw side, which again reduces effectiveness (Altaee et al., 2018). Losses can occur from mass transfer and polarization, as seen in figure 3, which is based on the membrane parameters described in Maisonneuve et al. (2015b).

Figure 3

Power Density Losses from Mass Transfer and Polarization in a Commercial Membrane



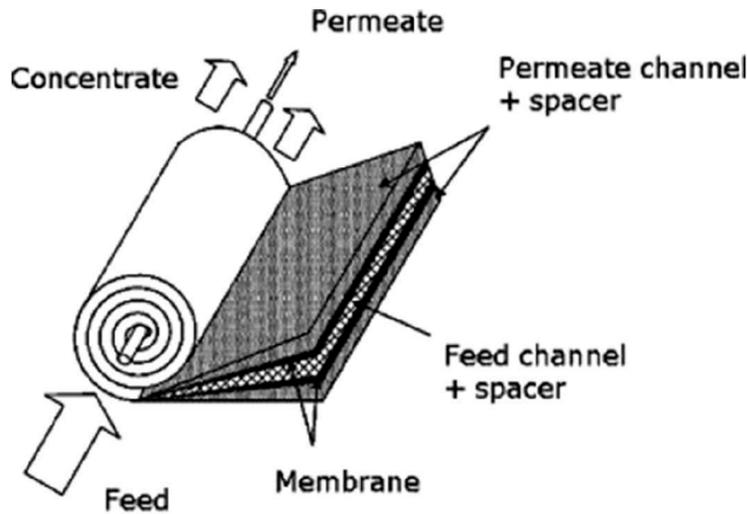
Note. Power density of a commercial membrane considering ideal power densities, with polarization, mass transfer, and net power densities. From “Pressure-retarded osmotic power system model considering non-ideal effects”. By J. Maisonneuve, P. Pillay, and C.B. Laflamme, 2015, *Renewable Energy*, 75, p. 421 (<http://dx.doi.org/10.1016/j.renene.2014.10.011>). Copyright 2014 by Elsevier 2014 Ltd.

Many permeability-selectivity trade-offs exist among different membrane technologies (Yip & Elimelech, 2011). Two common PRO membranes are: flat sheet membranes, as seen in figure 4, and hollow fiber membranes, in figure 5. Recent developments in flat-sheet membranes have found that densities of above 5 W/m² can be reached; however, flat-sheet membranes

require a feed channel spacer to “maintain the flow channel geometry” (p. 34). Feed spacers cause a reduction in hydraulic pressure and water flux across membranes. Also, under the hydraulic pressures needed for PRO, flat-sheet membranes deform. The need for feed spacers and membrane deformation both cause reductions in water flux and power density. As a result, more effective spacers need to be developed as well as better flat sheet membranes to decrease density losses across flat-sheet membranes (Gai & Han, 2020).

Figure 4

Flat-sheet PRO Membrane



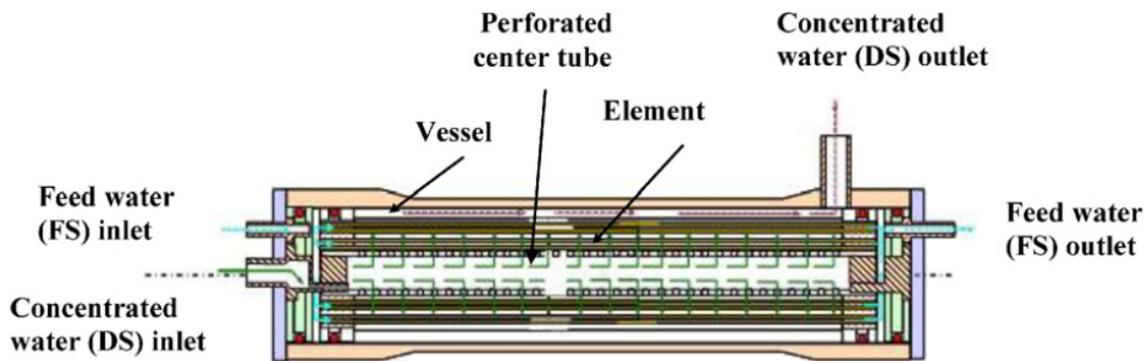
Note. Figure of a commercial spiral wound membrane that is currently used in a variety of applications such as water treatment and desalination. From “Spiral wound modules and spacers Review and analysis”, by J. Schwinge, P.R. Neal, D.E. Wiley, D.F. Fletcher, and A.F. Fane, 2004, *Journal of Membrane Science*, 242, p.130 (doi:10.1016/j.memsci.2003.09.031). Copywrite 2004 by Elsevier B.V.

Hollow-fiber PRO membranes as seen in figure 5, have been shown to produce high power densities with high mechanical strength leading to promising osmotic power potential. To

create the most effective hollow-fiber membrane, membranes “should have a highly porous support layer to reduce the internal concentration polymerization effects, while a relatively dense cushion layer beneath the polyamide-selective layer is desired for mechanical stability” (Gai et al., 2020, p. 58).

Figure 5

Hollow-Fiber PRO Membrane

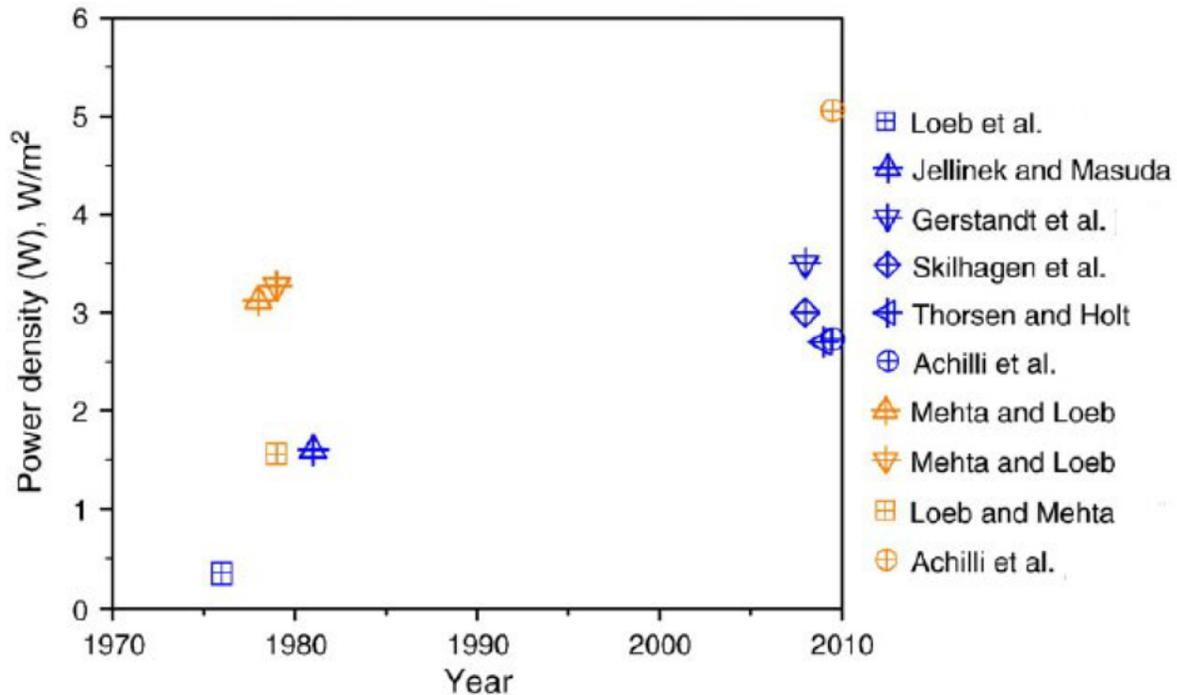


Note. Figure of a hollow-fiber membrane used in PRO. From “Hollow fiber type PRO module and its characteristics”, by A. Kumano, K. Marui, and Y. Terashima, 2016, *Desalination*, 389, p.151 (<http://dx.doi.org/10.1016/j.desal.2016.01.001>) Copyright 2016 by Elsevier B.V.

Researchers have been able to develop PRO membranes that can produce a power density higher than 5 W/m^2 using a concentrated brine solution with a higher salt concentration than seawater. However, PRO membranes have not yielded a power density higher than 5 W/m^2 using seawater as a draw solution, as seen in figure 6 (Achilli & Childress, 2010).

Figure 6

PRO membrane power densities found in studies from 1970-2010



Note. PRO membrane power densities found within studies that occurred from 1970 to 2010 with blue representing studies using seawater as the draw solution and yellow representing studies using a draw solution with a higher salt concentration than seawater. From “Pressure retarded osmosis: From the vision of Sidney Loeb to the first prototype installation- Review”, by A. Achilli, and E. Childress, 2010, *Desalination*, 261, p.209 (doi:10.1016/j.desal.2010.06.017). Copyright 2010 by Elsevier B.V.

Membrane fouling is also a challenge that limits the performance of PRO systems. Fouling occurs when physical, chemical, and biological components are present in the water used to generate energy from PRO. If not treated, these substances can cause a loss in membrane permeability as they accumulate within the membrane. While there are treatments that will be

discussed in future chapters, treatment chemicals can cause negative environmental impacts as chemicals end up in the system’s effluent. Treatments for water used in PRO depends on what properties are found within the water. So, there is no generic treatment regime. (Abbasi-Gerravand, 2016).

2.3.2 Nonmembrane efficiencies

Many losses occur along non-membrane equipment, such as in the pressure exchanger, pump, and turbine, as seen in table 1.

Table 1

Efficiencies of Non-Membrane Equipment

Process Parameters	Realistic	Optimistic
Pressure Exchanger Efficiency (%)	90	98
Pump Efficiency (%)	80	85
Turbine Efficiency (%)	80	90

Note. The estimated current and optimistic pressure exchanger, pump, and turbine efficiencies.

Adapted from “The Economic Infeasibility of Salinity Gradient Energy via Pressure Retarded Osmosis”, by A.N. Newby, T.V. Bartholomew, and M.S. Mauter, 2021, *Engineering*, 1, p. 1115 (<https://doi.org/10.1021/acsestengg.1c00078>). Copyright 2021 American Chemical Society.

Pressure losses can also occur along pipes transporting water from the intake areas to the facility. Pressure losses can also depend on the area in which the facility is located in relation to the intake pipe (Newby et al., 2021). Site specific research will need to be done to determine exactly what the net losses may be for a PRO facility in Bella Coola.

2.4 Diesel Dependency

2.4.1 Diesel Dependency in Canada

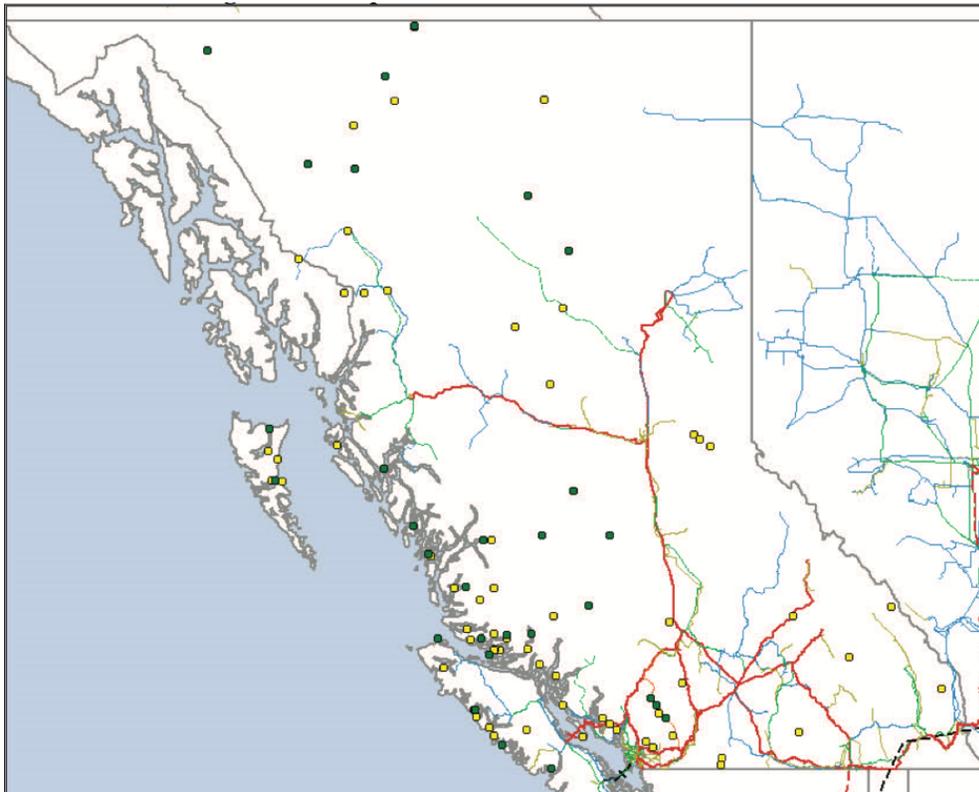
Currently, 176 communities in Canada are still reliant on diesel generators for heat and electricity; 144 are Indigenous communities (Karanasios & Parker, 2018; Natural Resources Canada, 2011). Diesel generators are often unreliable, and as a result, communities that rely on diesel generators for electricity are more susceptible to city-wide blackouts (McCarthy, 2016). Another challenge with diesel generators is the acquisition of diesel. Because communities that rely on diesel for electricity and heat are often located in rural areas, diesel is often trucked, shipped, or flown into communities to be stored until used. The transport and storage of diesel has been prone to spillage (Mitigokaa Development Corp, 2022). For example, the Northwest Territories has indicated that more than 9.1 million liters of diesel have been spilled during transportation and storage in diesel-reliant communities since the 1970s (Thomson, 2019). Diesel generators also emit harmful CO₂, NO₂, and particulate matter (Energy Education, n.d.). Exposure to the exhaust from diesel generators has been known to worsen “asthma, allergies, bronchitis, and lung function” as well as pose an increased “risk of heart problems, premature death and lung cancer” (Kennedy, 2014, p.5). Diesel is also expensive and depending on location, communities reliant on diesel for electricity can end up paying as much as twice what the average Canadian pays for a kWh of electricity, even after subsidies (Lovekin & Heerema, 2019). Not only is diesel not reliable, expensive, hard on the environment, and potentially harmful to residents, but it also limits development in communities as communities are limited to what the generators can support (McCarthy, 2016). As a result, diesel-reliant communities are more susceptible to harsher socioeconomic conditions (Cook, 2019).

2.4.2 Diesel Dependency in British Columbia

In British Columbia, there are 86 remote communities, as seen in figure 7. Of the 86 remote communities in British Columbia, 11 are Indigenous diesel-reliant communities located on the coast (Coast Funds, 2022; Natural Resources Canada, 2011).

Figure 7

Remote Communities in British Columbia



Note. A map of Canada with dots to show communities that are considered remote in British Columbia. Yellow dots indicate non-Indigenous communities while green dots indicate Indigenous communities. From “2011 Status of Remote/ Off-Grid Communities in Canada”, by Natural Resources Canada, 2011, p. 14. In the public domain.

Cumulatively, Indigenous coastal diesel-dependent communities in British Columbia “purchase, transport and burn approximately 15.3 million liters of fuel each year” (“The High

Cost of Diesel Dependency” section). Due to the implications of diesel dependency, many of these communities have been looking into investing in renewable energy and have even become leaders in the field (Coast Funds, 2022).

In Quebec, PRO is currently being considered as a possible energy source for remote coastal communities (Maisonneuve et al., 2015a). In the future, SGE technology may also be considered in British Columbia and could assist in coastal diesel-dependent communities’ transitioning away from diesel and towards renewable energy. Future chapters will look at the feasibility of SGE in Bella Coola, a diesel-dependent coastal community in British Columbia, to determine the possibility of SGE becoming a potential energy source for more communities in the province.

Chapter 3 Capstone Objectives

This paper is written for the community of Bella Coola in hopes of providing a knowledge base on the feasibility of PRO in the community. This paper is also written for other communities looking into PRO as a possible energy source, as well as other academics who are interested in the SGE field. To accomplish this, the main objectives of this paper are as follows:

- Calculate the energy potential of the selected watersheds in the region and compare that to the diesel energy demand in Bella Coola
- Calculate the PRO LCOE and compare this against the current diesel LCOE in Bella Coola
- Determine the possible environmental impacts from the different life stages of SGE and determine what ecosystems in Bella Coola will be vulnerable to negative impacts
- Provide recommendations for future studies and developments

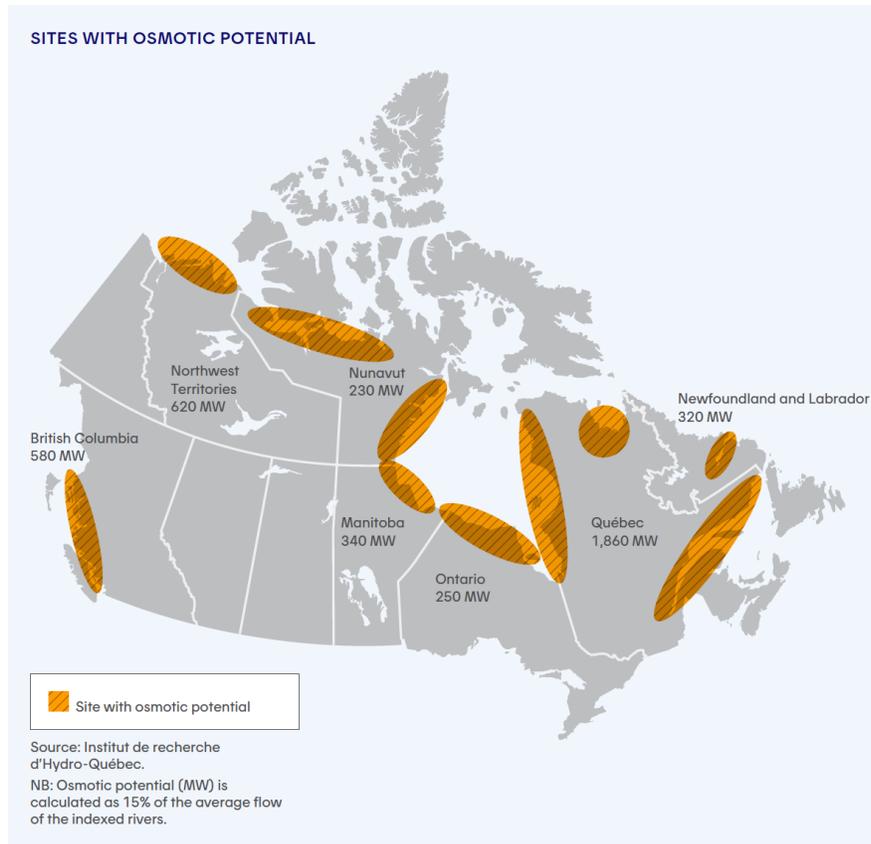
Chapter 4 Site Selection

4.1 PRO Power Potential in Canada

Canada has the longest coastline of any other country, measuring 243,042 km (Government of Canada, 2016b). Canada also has the largest amount of freshwater availability of any other country with an “annual water yield of 3,472 billion cubic meters” with the Pacific Coastal drainage region producing the highest water yield of any other area in Canada (Government of Canada, 2018, “Canada’s water yield” section). As a result, Canada is likely a good candidate for SGE. In figure 8, Hydro-Quebec (2021) has estimated the power potential of PRO across Canadian coastlines. It is estimated that the Pacific Coast of Canada has a power potential of 580 MW (Hydro-Quebec, 2021).

Figure 8

Osmotic Power Potential in Canada



Note. Estimated osmotic power potential of Canada's coastlines. From: "A Renewable Energy Option Osmotic Power" by Hydro-Quebec, 2021, p.5. In the public domain.

4.2 PRO in Bella Coola British Columbia

Bella Coola is home to the Nuxalk First Nations people and is located 100 km inland from the British Columbian coastline along the Bentinck Arm, as seen in figure 9 (Bella Coola, n.d.). Bella Coola is situated in the Great Bear Rainforest. The Great Bear Rainforest contains one of the world's most biodiverse regions and a quarter of the world's temperate rainforest spreading over 64 000 km² of land (Government of British Columbia, n.d.c; Mertens et al., 2015).

Figure 9

Location of Bella Coola British Columbia



Note. The location of Bella Coola is shown with a small red circle just inland of the British Columbian coastline. From “Location” by Bella Coola, n.d. In the public domain.

It is estimated that 50% of the population of Bella Coola is Indigenous, with 1786 people registered within the Nuxalk First Nation, 912 of which live on reserve (Kennedy & Bouchard, 2006; Rural Coordination Center of BC, 2021). The traditional territory of the Nuxalk people is of great cultural importance to those who rely on the territories ecological prosperity to survive (Nuxalk, n.d.).

4.3 Selected Watersheds

This paper looked at six watersheds in Bella Coola, as seen in figure 10. The selected watersheds were Clayton Falls, Nusatsum River, Tastsquan Creek, Atnarko River, Dean River, and Salloomt River. This paper did not include: Thorsen Creek, Snooka Creek, Snootli Creek,

Nooklikonnik Creek, Sawmill Creek, Tseapseahoolz Creek, Noosgulch River, Cacoohiton Creek, Noomst Creek, Burnt Bridge Creek, Tsill Creek, Tsini-Tsini Creek, Nordschow Creek, Ape Creek, Jacobsen Creek, and Talchako River which are also watersheds in the Bella Coola region. These watersheds were not included because they lacked flow rate data to calculate their PRO energy potential (Government of British Columbia, n.d.b).

It is also important to note the distance from freshwater sources and the Bentinck Arm in relation to Bella Coola, as seen in figure 10. While not discussed in this paper, the further away water needs to be pumped to the main facility, the higher energy losses will to be.

Figure 10

Map of the locations of the selected watersheds



Note: Map showing the location of the six selected watersheds within the proximity of Bella Coola. Adapted from “Google Maps”, n.d. In the public domain.

Chapter 5 Energy Potential

5.1 Introduction

In 2017, Bella Coola used 2.36 million liters of diesel to produce approximately 23,469 MWh of electricity. The community is currently looking into ways to reduce or replace diesel generators with other renewable energy options. Bella Coola is proposing a hydroelectric facility in Nooklikonnik Creek that is predicted to reduce diesel demand by 80%; however, based on the 2017 usage, this would mean that 472,000 liters of diesel would still be required to meet the community's annual energy demand (Thompson, 2019). This section analyses the PRO energy potential of selected watersheds in Bella Coola to see whether or not diesel could be replaced with PRO both with and without the Nooklikonnik Creek hydroelectric facility.

5.1.1 Scope

The selected watersheds used in this study were Clayton Falls, Nusatsum River, Tastsquan Creek, Atnarko River, Dean River, and Salloomt River. These watersheds were selected because of data availability on their flow rates. Watersheds still within the Bella Coola area but not included in this study were: Thorsen Creek, Snooka Creek, Snootli Creek, Nooklikonnik Creek, Sawmill Creek, Tseapseahoolz Creek, Noosgulch River, Cacoohiton Creek, Noomst Creek, Burnt Bridge Creek, Tsill Creek, Tsini-Tsini Creek, Nordschow Creek, Ape Creek, Jacobsen Creek, and Talchako River (Government of British Columbia, n.d.b). These watersheds were not included in this study because they lacked available yearly flow rate data.

Generic and approximate temperature and salinity variables were used to calculate the osmotic pressure in the region. Generic and approximate values were used because the fieldwork needed to determine an efficient intake location based on temperature and salinity was outside the scope of this study.

Efficiency of the diesel generators located in Bella Coola and the performance limiting factors within PRO facilities were not included in this study due to lack of information in the literature as well as the lack of resources for site-specific research.

Minimum multiannual monthly flow rates of the selected watersheds were used in this study. This is because the scope of this study focuses on the potential to replace diesel with PRO in Bella Coola even in times of low freshwater availability.

5.2 Methods

5.2.1 Osmotic Pressure

The osmotic pressure difference $\Delta\pi$ was calculated as shown in *appendix a* for the selected watersheds using equation 1 where the Van't Hoff's coefficient $iv = 2$ for NaCl, the universal gas constant was $Rg = \frac{8.314J}{k*mol}$, the temperature was $T=284.15K$ based on the average temperature for the Bentinck Arm, the change in concentration was $\Delta c= 35g/l$ based on the concentration of saltwater in the ocean being 35g/l and freshwater being close to 0 g/l, and finally, the molar mass of salt for NaCl which was $M= 58.44 g/mol$ (California State Polytechnic University, n.d.; Maisonneuve et al., 2015b; Newby et al., 2021; Water Temp, n.d.).

$$\Delta\pi (Pa) \approx iv * Rg * T * \Delta c / M \quad (1)$$

5.2.2 PRO Energy Potential from Osmotic Pressure and Flow Rates

The minimum flow rates from the selected watersheds in table 2 were converted from m^3/s to $m^3/month$ and then multiplied by the osmotic pressure $\Delta\pi$ in Pa or J/s, which was then converted to kWh/m^3 to get the monthly energy potential of the selected watersheds.

Table 2*Minimum Multiannual Monthly Flow Rates for Selected Watersheds in/ Near Bella Coola BC*

Watershed data [year-year]	Flow Rate	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Clayton Falls 1980-1996	Min (m ³ /s)	2	1.7	1.7	2.3	3.8	8.2	6.6	4.8	3.2	5.3	2.4	1.8
Nusatsum River 1965-1996	Min (m ³ /s)	2.5	2.12	2	3.13	9	20.5	22.8	19.2	11.9	9.4	3.4	2.6
Tastsquan Creek 1946-1950	Min (m ³ /s)	0.22	0.31	0.44	0.611	3.26	2.75	2.43	1.27	1.24	0.61	0.62	0.81
Atnarko River 1965-2020	Min (m ³ /s)	5.31	4.76	4.32	6.21	29.3	34.5	20.9	12.9	7.77	5.96	7.56	4.74
Dean River 1997-2007	Min (m ³ /s)	0.28	0.16	0.14	0.948	1.25	0.46	0.17	0.06	0.08	0.13	0.16	0.41
Salloomt River 1965-2020	Min (m ³ /s)	1.8	1.57	1.77	2.67	7.19	9.56	7.02	4.11	2.96	2.86	2.25	1.94

Note. Minimum multiannual monthly flow rates for the six selected watersheds in the proximity to Bella Coola. Adapted from

“Historical Hydroaromatic Data Search” by The Government of Canada, 2022b-g,

(https://wateroffice.ec.gc.ca/search/historical_e.html). In the public domain.

5.2.3 Comparison of PRO Energy Potential and Diesel Usage in Bella Coola Before and After the Nooklikonnik Creek Hydroelectric Facility

Bella Coola's annual diesel usage in 2017 was used to compare the PRO energy potential of the selected watersheds and the diesel energy requirement of the community. The diesel usage in 2017 was used because in 2017, Bella Coola required more diesel than any other year within the recorded 2014-2019 timeframe. The amount of diesel used by Bella Coola in 2017 was estimated to be 2.36 million liters. It was estimated that the Nooklikonnik Creek hydroelectric facility could reduce this annual diesel usage by 80% (Thompson, 2019). The annual diesel energy production for Bella Coola was estimated in *appendix b* with and without the Nooklikonnik Creek hydroelectric facility based on the estimated diesel usage in 2017 using equation 2 adapted from the MIT energy conversion sheet (Supple, n.d.):

$$\text{Energy Produced (kWh)} = \text{Diesel Use (l)} * \frac{35.8\text{MJ}}{\text{l}} * \frac{1\text{kWh}}{3.6\text{MJ}} \quad (2)$$

The energy produced by diesel in 2017 in Bella Coola with and without the Nooklikonnik Creek hydroelectric facility was then compared to the PRO energy potentials of the selected watersheds.

5.2.4 Flow Rate Needed to Produce Enough Energy from PRO to Replace Diesel

As mentioned previously, in 2017, Bella Coola used 2.36 million liters of diesel to generate electricity. During this year, the highest monthly diesel consumption in Bella Coola was in December and January. It is estimated that for January 2017, Bella Coola used 196,000 liters of diesel to generate electricity (Thompson, 2019). The amount of energy produced by diesel for January 2017 was estimated in *appendix b* using equation 2.

The energy produced from diesel in Bella Coola during January was then compared to the PRO energy potential calculated using the lowest multiannual monthly flow rates of the selected watersheds.

The flow rate needed to produce enough energy through PRO to replace diesel use in Bella Coola for January 2017 was calculated in *appendix c* using equation 3.

$$Flow\ Rate\ \frac{m^3}{s} = \frac{Electric\ Energy\ Use\ \left(\frac{kWh}{Month}\right) * \frac{Month}{31\ days} * \frac{day}{86400s}}{Osmotic\ Pressure\ \left(\frac{kWh}{m^3}\right)} \quad (3)$$

The percentage of the lowest multiannual monthly flow rate from the selected watersheds needed to meet the required volume of freshwater to produce enough electricity from PRO to replace diesel was calculated by dividing the required flow rate by the actual flow rate of the watershed and then multiplying that by 100.

5.2.5 Flow Rate Needed to Produce Enough Energy from PRO to Replace Diesel after the Development of the Nooklikonnik Creek Hydroelectric Facility

To calculate the flow rate needed to generate enough electricity from PRO after the development of the Nooklikonnik Creek hydroelectric facility, the annual energy demand was used rather than using the January 2017 energy demand. This was because the literature reports a reduction of annual diesel usage by 80% and not a reduction by this amount during times of high energy demand. As a result, the average monthly flow rate needed to replace diesel was calculated in *appendix c* using equation 4.

$$Flow\ Rate\ \frac{m^3}{s} = \frac{Electric\ Energy\ Use\ \left(\frac{kWh}{yr}\right) * \frac{1\ yr}{365\ days} * \frac{day}{86400s}}{Osmotic\ Pressure\ \left(\frac{kWh}{m^3}\right)} \quad (4)$$

The percentage of the flow rate from the selected watersheds needed to meet the required volume of freshwater to produce enough electricity from PRO to replace diesel after the

development of the hydroelectric facility in Nooklikonnik Creek was calculated by dividing the required flow rate by the actual flow rate of the watershed and then multiplying that by 100.

5.3 Results

5.3.1 Osmotic Pressure in Bella Coola

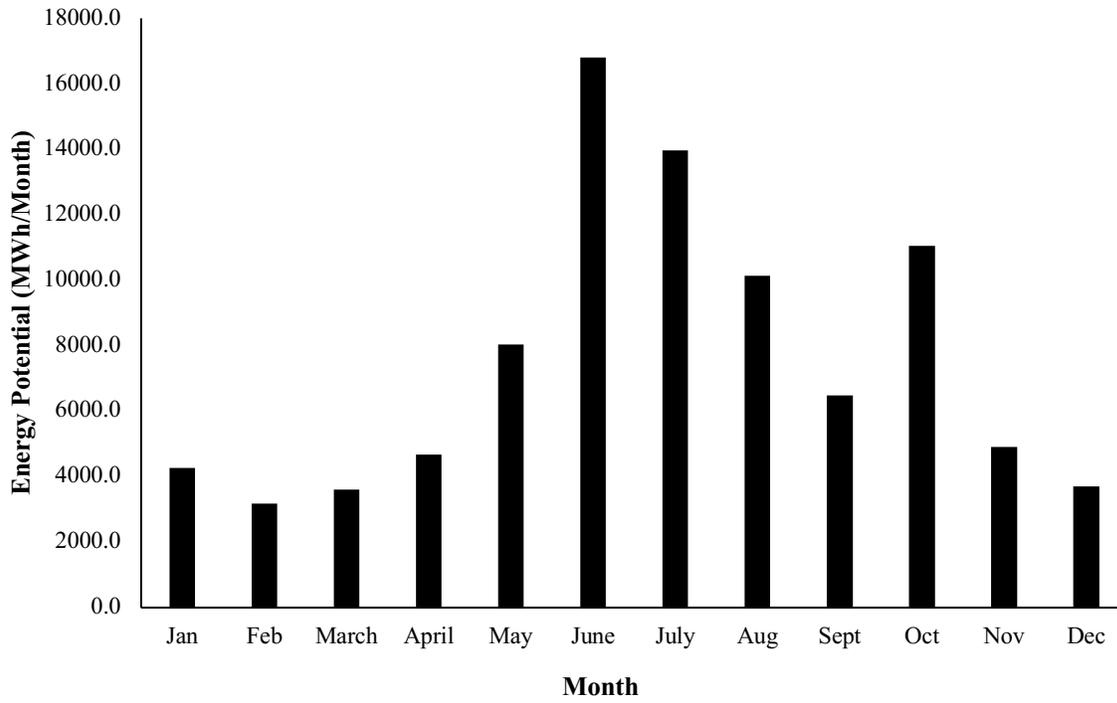
Based on the water temperature in the Bentinck arm and the generalized salinity concentrations of seawater and freshwater, it was determined that the possible osmotic pressure from mixing saltwater with freshwater in Bella Coola is $\Delta\pi = 0.786 \text{ kWh/m}^3$.

5.3.2 Energy Potential of Selected Watersheds

The following figures show the minimum energy potential of selected watersheds based on the lowest multiannual monthly flow rate, as seen in table 2.

Figure 11

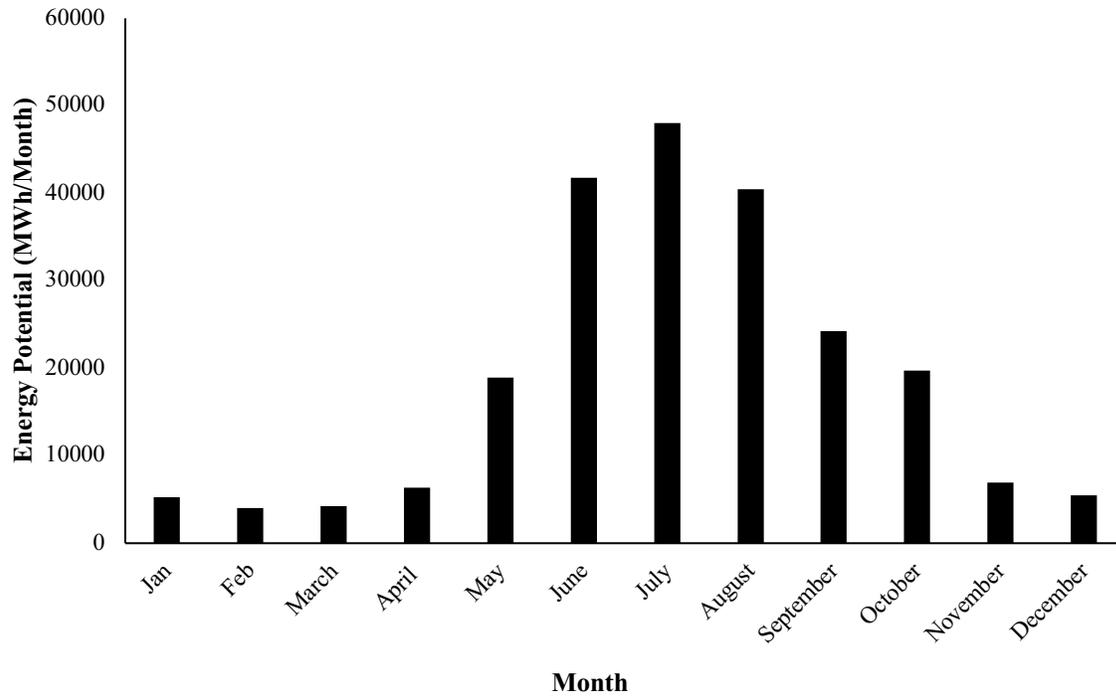
Minimum Energy Potential of Clayton Falls



Note. (Author, 2022). Flow rate of Clayton Falls based on the lowest multiannual monthly flow rate found in Table 2.

Figure 12

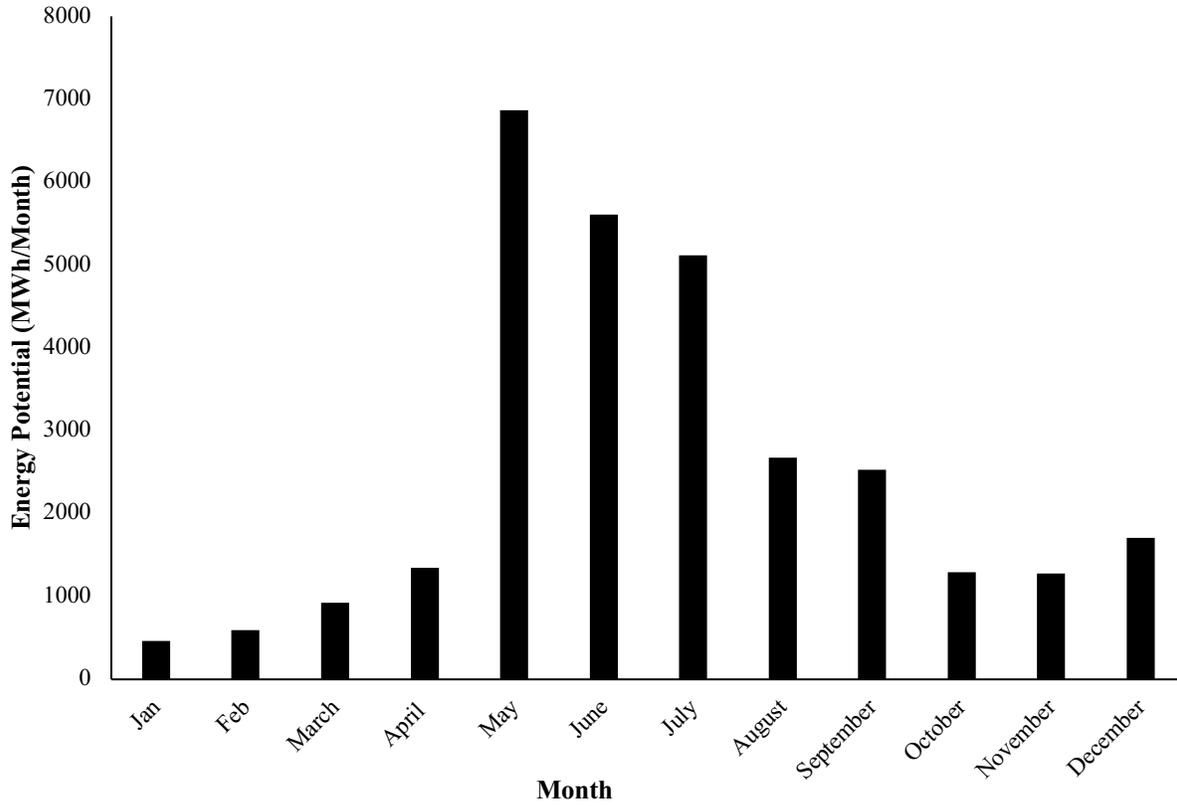
Minimum Energy Potential of Nusatsum River



Note. (Author, 2022). Flow rate of Nusatsum River based on the lowest multiannual monthly flow rate found in Table 2.

Figure 13

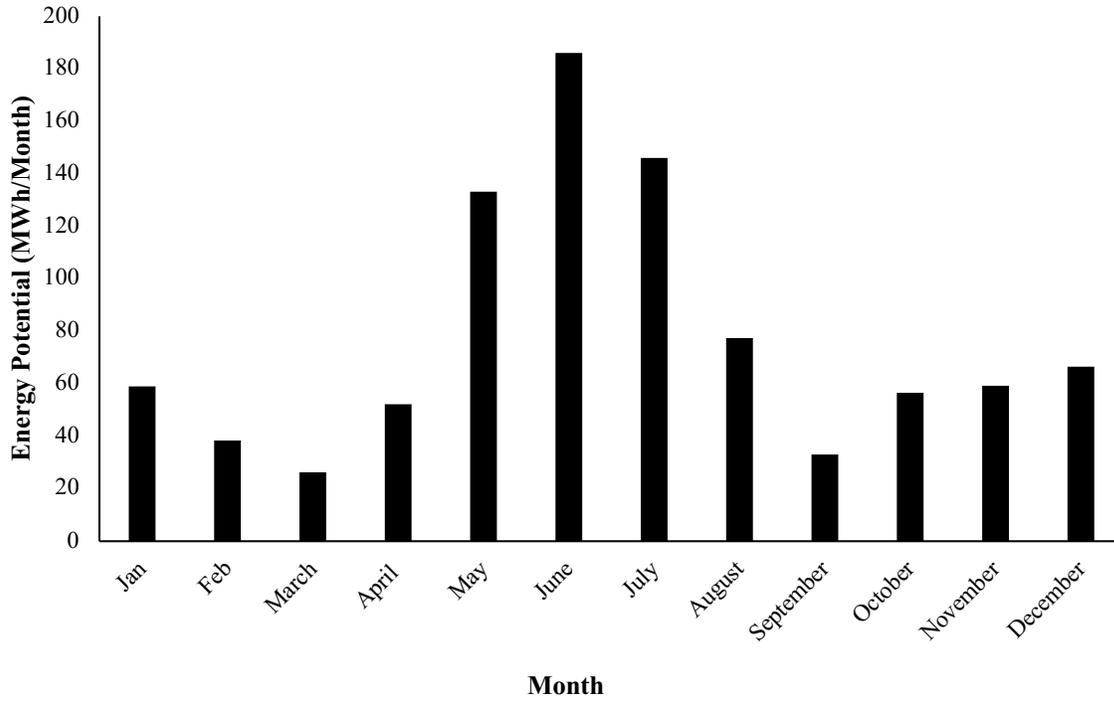
Minimum Energy Potential of Tastsquan Creek



Note. (Author, 2022). Flow rate of Tastsquan Creek based on the lowest multiannual monthly flow rate found in Table 2.

Figure 14

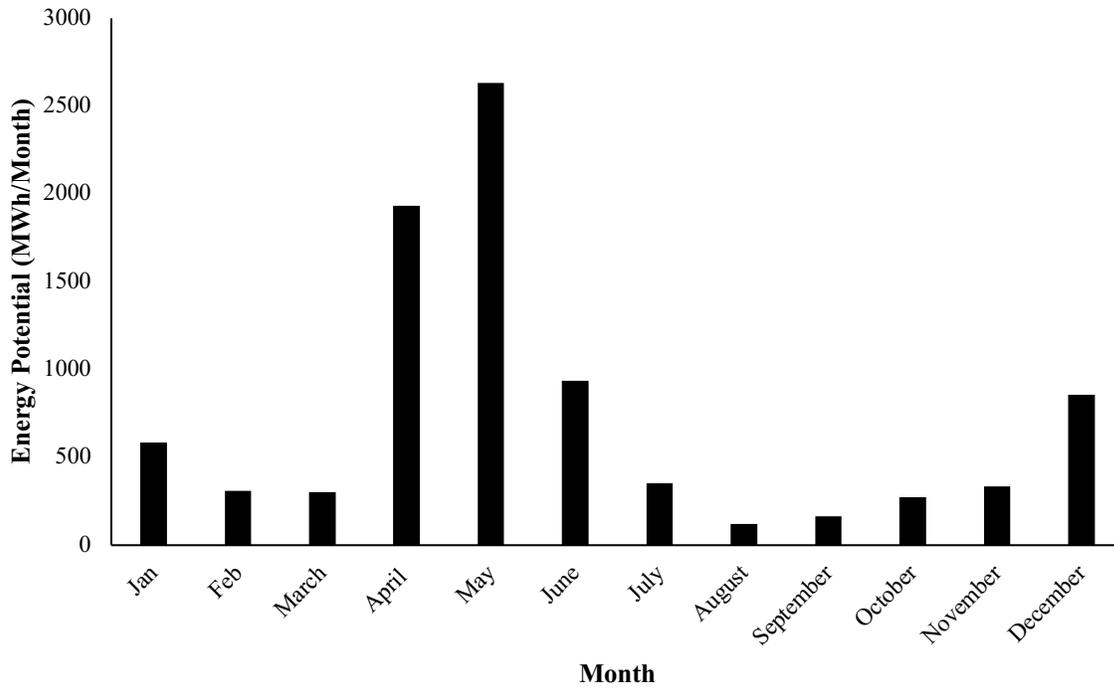
Minimum Energy Potential of Atnarko River



Note. (Author, 2022). Flow rate of Atnarko River based on the lowest multiannual monthly flow rate found in Table 2.

Figure 15

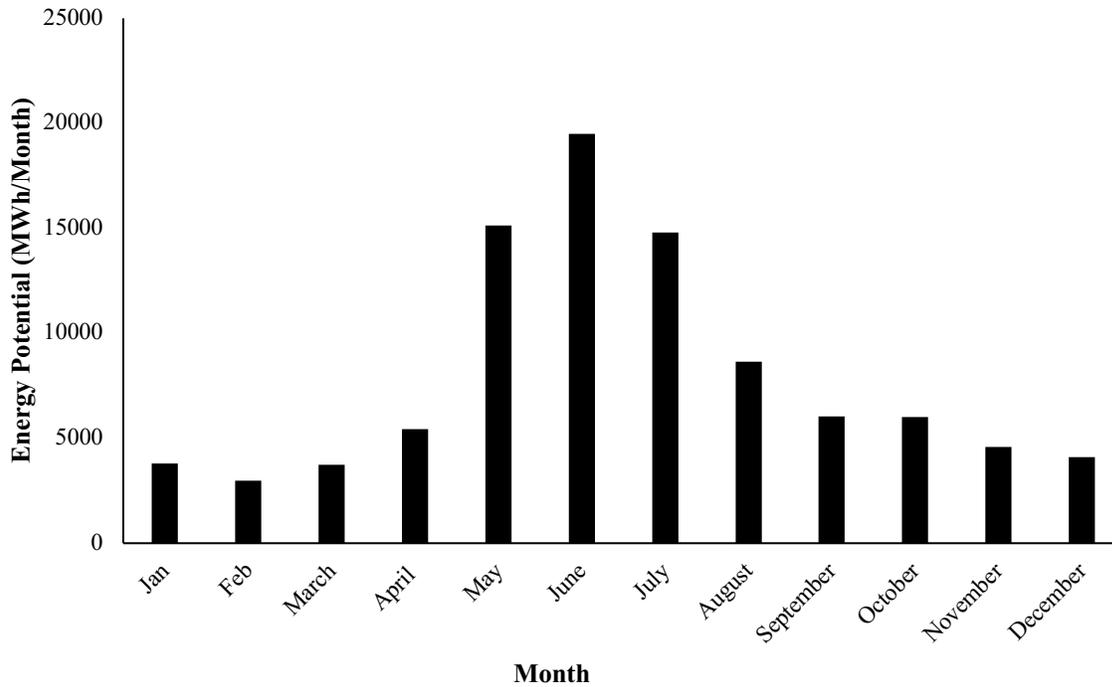
Minimum energy potential of Dean River



Note. (Author, 2022). Flow rate of Dean River based on the lowest multiannual monthly flow rate found in Table 2.

Figure 16

Minimum Energy Potential of Salloomt River



Note. (Author, 2022). Flow rate of Salloomt River based on the lowest multiannual monthly flow rate found in Table 2.

5.3.3 PRO Energy Potential Compared to the Energy Demand in Bella Coola

Table 3 shows the annual diesel usage and energy produced by diesel in 2017 based on data found in Thompson (2019). Table 3 also shows the diesel usage and energy produced by diesel after the development of the Nooklikonnik Creek hydroelectric facility that is estimated to reduce the diesel requirement in Bella Coola by 80% (Thompson, 2019).

Table 3

Annual Energy Produced by Diesel for the Year 2017 with and without the Addition of the Nooklikonnik Creek Hydroelectric Facility

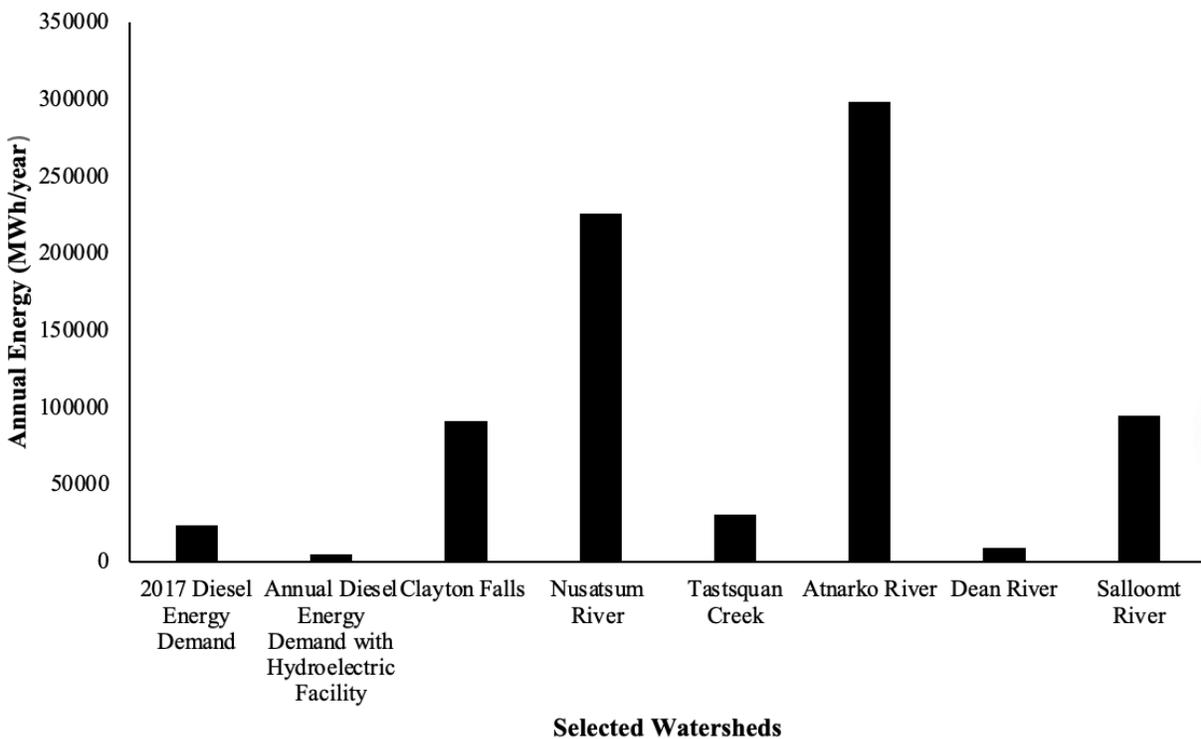
Source	2017 Diesel Use (Liters)	2017 Energy Produced by Diesel (MWh)	2017 Diesel Use with the Nooklikonnik Hydroelectric Facility (Litres)	2017 Energy Produced by Diesel with the Nooklikonnik Hydroelectric Facility (MWh)
Thompson, 2019	2,360,000	23,469	472,000	4694

Note. (Author, 2022). Annual diesel requirement in Bella Coola with and without the Nooklikonnik Creek hydroelectric facility assuming that the Nooklikonnik Creek hydroelectric facility will reduce the 2017 diesel usage in litres by 80%.

Figure 17 shows the energy produced by diesel in 2017 and the energy produced by diesel with the Nooklikonnik Creek hydroelectric facility, as seen in table 3. Energy produced by diesel with and without the Nooklikonnik Creek hydroelectric facility was compared in figure 17 to the annual energy potentials of the six selected watersheds based on the six watersheds minimum multiannual monthly flow rate as seen in table 2.

Figure 17

The Energy Produced by Diesel in 2017 and the Energy Produced by Diesel with the Nooklikonnik Creek Hydroelectric Facility Compared Against the Annual Energy Potential of Selected Watersheds



Note. (Author, 2022). The 2017 diesel energy demand with and without the Nooklikonnik Creek hydroelectric facility compared to the energy potentials of the six watersheds.

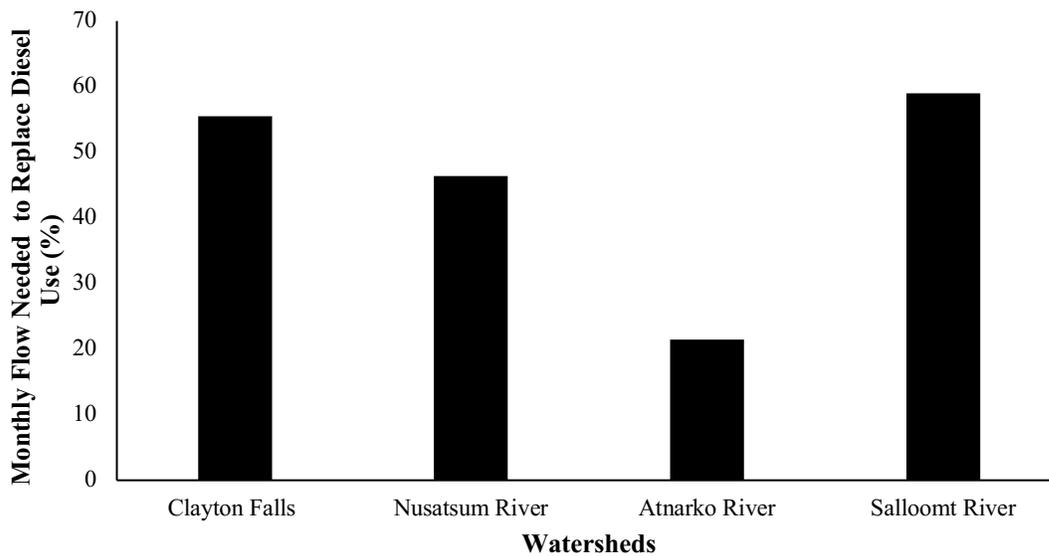
5.3.4 Flow Rate Needed to Replace Diesel in Bella Coola with PRO

At peak diesel use, it was determined that approximately 1949 MWh of electricity was produced by diesel in January 2017. To meet this energy demand with PRO, it was determined that a flow rate of 0.926 m³/s would be needed for the month of January 2017. Figure 18 shows the percentage of the minimum multiannual monthly flow rates of the selected watersheds

required to produce enough energy to replace the highest monthly diesel usage using PRO. Tastsquan Creek and Dean River are left out because more than 100% of the flow rates from these watersheds would be needed to meet the energy demand for January 2017.

Figure 18

Percentage of the Minimum Multiannual Monthly Flow Rate Needed to Replace the Energy Produced by Diesel Generators with PRO in January 2017



Note. (Author, 2022). This figure is based on the lowest multiannual monthly flow rates for the selected watersheds. The Dean River and Tastsquan Creek are not included in this figure because more than 100% of their lowest multiannual monthly flow rates would be needed to meet the January 2017 diesel energy demand.

5.3.5 Flow Rate Needed to Replace Diesel in Bella Coola with PRO after the Development of The Nooklikonnik Creek Hydroelectric Facility

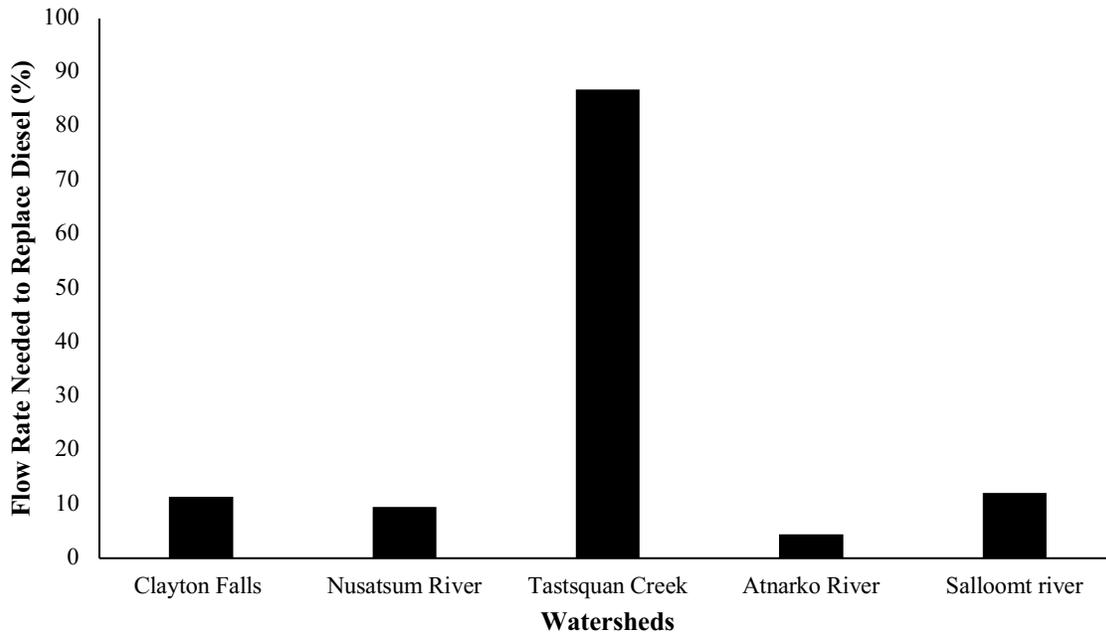
As mentioned previously, a hydroelectric facility has been proposed in Nooklikonnik Creek. It is estimated that the energy produced by this hydroelectric facility will reduce annual diesel use in Bella Coola by 80%. The highest diesel use recorded in Bella Coola from 2014-

2019 was 2.36 million liters in 2017 (Thompson, 2019). 20% of this annual diesel use was determined to be 472,000 liters as shown in table 3. After the development of the Nooklikonnik Creek hydroelectric facility, it was estimated that 4,693,778 kWh/year of electricity would need to be produced by diesel in Bella Coola based on 2017 diesel usage, as seen in table 3. To meet this energy demand with PRO and replace the left-over diesel, it was found that a monthly flow rate of 0.19 m³/s per month would be needed.

The percentage of the minimum multiannual monthly flow rates of the selected watersheds needed to produce enough energy to replace diesel in 2017 using PRO after the development of the Nooklikonnik Creek hydroelectric facility are shown in figure 19.

Figure 19

Percentage of Lowest Monthly Flow Rate Needed to Meet the Energy Demand of Bella Coola with PRO after the Development of the Nooklikonnik Creek Hydroelectric Facility



Note. Note. This figure is based on the lowest multiannual monthly flow rates for the selected watersheds. The Dean River is not included in this figure because more than 100% of its lowest multiannual monthly flow rates would be needed to meet Bella Coola’s diesel energy demand after the introduction of the Nooklikonnik hydroelectric facility.

5.4 Discussion

This study aimed to determine if PRO could completely replace diesel energy in Bella Coola. Because the most significant limitation to the energy potential of PRO is freshwater availability, the minimum multiannual monthly flow rates were used to calculate the energy potential of the selected watersheds (Newby et al., 2021). This was to determine whether or not PRO could replace diesel even under conditions of low freshwater availability. It was determined that all selected watersheds, except for the Dean River, had a high enough minimum multiannual

monthly flow rate to generate enough energy through PRO to replace the annual diesel used in 2017 by Bella Coola, as seen in figure 17.

Figure 17 shows that Clayton Falls, Nusatsum River, Tastsquan Creek, Atnarko River, and Salloomt River all have high enough minimum multiannual monthly flow rates to replace diesel energy with PRO in Bella Coola. However, figure 17 shows the potential energy available from PRO if the entire water volume of those watersheds were used to produce energy with PRO. Using the entire volume would significantly impact the environment. In order to be sustainable, it is recommended that only 25% of the minimum multiannual monthly flow rate of these watersheds are used to generate energy from PRO (Maisonneuve et al., 2015a). Only the Atnarko River has a flow rate high enough to produce enough energy to replace the annual diesel energy demand in 2017 while using under 25% of the river's minimum multiannual monthly flow rate, as seen in figure 18.

The Nooklikonnik Creek hydroelectric facility being proposed in Bella Coola is suggested to reduced annual diesel usage by 80% as previously mentioned (Thompson, 2019). With the reduction of diesel energy demand in Bella Coola after the introduction of the Nooklikonnik Creek hydroelectric facility, Clayton Falls, Nusatsum River, Atnarko River, and the Salloomt River all have high enough flow rates to produce enough energy to replace the annual diesel demand in Bella Coola sustainably based on the communities 2017 diesel demand, as see in figure 19.

It is important to note that the diesel energy demand of Bella Coola calculated in this chapter is likely an overestimated as the study converted liters of diesel used by the community to units of energy without accounting for efficiency losses within diesel generators. Similarly, the PRO energy potential of selected watersheds is also likely overestimated because the losses

discussed in chapter 2 were not included in this study. As a result, more freshwater than predicted in this study may be needed for energy production through PRO to account for losses in the system. Fortunately, in conjunction with the Nooklikonnik Creek hydroelectric facility, to completely replace the 2017 diesel demand with PRO, Clayton Falls, Nusatsum River, Atnarko River, and Salloomt River would all require less than 25% of their lowest multiannual monthly flow rates, meaning more fresh water could be used if necessary. It is also possible to use freshwater from multiple watersheds to take the pressure off of using only one watershed to provide the freshwater needed for PRO in the community.

5.5 Summary/ Future Research

This study assumed the water temperature in the Bentinck Arm to be 284.15K and a salinity concentration of 35g/l to calculate osmotic pressure. To be more accurate, future studies should look into monthly variations in temperature and salinity and include them in their calculations to show how osmotic pressure changes throughout the months. The monthly flow rates of the other 16 watersheds not included in this study should also be measured to see how their PRO energy potential compares to the six watersheds looked at in this study. Future studies should also look into the performance limiting factors of both diesel generators located in Bella Coola and performance limiting factors of PRO facilities to develop a more accurate representation of the PRO energy potential in Bella Coola and how that compares to the community's diesel energy demand.

Currently, several limitations discussed in chapter 2 are preventing PRO from being commercially viable. However, if/when PRO technology advances to a point where PRO is commercially viable, there is likely enough freshwater availability in the region to support a

PRO facility that could replace the community's diesel demand after the development of the Nooklikonnik Creek hydroelectric facility.

Chapter 6 Economics

6.1 Introduction

As mentioned in chapter 2, there are a number of performance limiting factors within PRO systems. There are also many trade-offs between technologies. Trade-offs as well as inefficiencies within PRO are going to have an impact on the levelized cost of electricity (LCOE). While many studies have attempted to estimate the future cost of PRO, PRO technology is highly complex and requires advanced modeling to demonstrate cost frameworks for many scenarios based on trade-off systems (Newby et al., 2021). This section used estimations based on current and optimal membrane parameters to estimate the current and future LCOE for PRO and compare that to what Bella Coola is currently paying for diesel in the community.

6.1.1 Scope

Other studies have done in-depth modeling using computer software such as python to develop cost optimization models for PRO. In-depth modeling is a beneficial strategy as cost affecting components such as the losses described in chapter 2 can be considered within the model (Newby et al., 2021). Unfortunately, this level of analysis is outside the scope of this study. This study looked at the LCOE for PRO as a function of the capital cost of membrane technology.

Diesel generators run at a certain efficiency depending on their make and capacity that they are running at (General Power, n.d.). Calculations on the diesel generators' efficiency are outside this study's scope. As a result, any calculations on annual diesel energy use in Bella Coola are likely overestimations.

Diesel rates in Bella Coola were determined from a 2016 report by Stephen & Mabee. It is likely that given recent increases in fuel prices globally that the price of diesel used in this study is an underestimation.

6.2 Methods

6.2.1 LCOE Calculations

A literature review was conducted to determine the current and optimal power density ranges and membrane technology costs. It was assumed that the cost of the membrane for a PRO system was 10% of the capital cost of the entire PRO facility (Maisonneuve et al., 2015a). Current power densities were used by Achilli et al., (2009) who determined that power densities of current membrane technologies are in the range of 1.6-2.9 W/m² for a seawater draw concentration of 35g/l NaCl. Statkraft determined optimal power densities for PRO membranes should be around 5W/m² (Cheng & Han, 2020). Current and optimal costs of membrane technology were used from the estimates within the Technology Brief (2014), which estimated the current PRO membrane cost to be EUR 10-30\$/m² and 2-5\$/ m², respectively, in 2014. The current and optimal costs were converted in *appendix d* from EUR to CAD based on the assumption that the exchange rate in 2014 was \$1.467CAD per \$1EUR and an inflation rate from 2014 to 2022 of 22.93% (Exchange Rates UK, n.d.; Inflation Tool, n.d.). It was assumed that the lifespan of the PRO facility would be 20 years with membranes needing to be replaced every five years (Maisonneuve et al., 2015a). LCOE was then calculated in *appendix d* using equation 5.

$$LCOE \left(\frac{\$}{kWh} \right) = \frac{\frac{Membrane\ Cost \left(\frac{\$}{m^2} \right)}{Net\ Power\ Density \left(\frac{kW}{m^2} \right) * 5\ yrs * 4\ replacements * 330 \frac{days}{yr} * \frac{24\ hrs}{day}}}{0.1} \quad (5)$$

6.2.2 Comparison of the LCOE for PRO and Diesel in Bella Coola

The optimal LCOE of PRO was compared to what the community of Bella Coola is currently paying for diesel after government subsidies reported by Stephen & Mabee (2016) to be 0.13\$/kWh. This was compared by using the annual maximum and minimum diesel usage of Bella Coola from 2014 and 2019, which was in 2015 for the minimum usage and 2017 for the maximum usage (Thompson, 2019). Based on the usage, the power production of 2015 and 2017 was calculated using equation 2.

The annual power produced was then multiplied by the LCOE for diesel and optimal PRO to get the annual cost for both. The cost of diesel was then subtracted by the cost of PRO to determine what the community of Bella Coola would save if the community chose to switch to PRO in the future if PRO technology ever reached optimal membrane parameters.

6.3 Results

6.3.1 LCOE

It was found that the current membrane cost in CAD is between 18-54.1\$/m² while the optimal cost of PRO membranes that would make PRO consistent with market prices of other renewable energies in CAD is between 3.6-9\$/m².

Using the current and optimal power densities and costs of PRO membrane technology, it was found that the current LCOE for a PRO facility is in the range of 0.32-2.13 \$/kWh, and the optimal LCOE for PRO is in the range of 0.045-0.11 \$/kWh as seen in table 4 (Newby et al., 2021).

Table 4

Current and Optimal Power Densities of PRO Membrane Technology and the LCOE for a PRO Facility

Current Power Density (kW/m ²)	Current Cost (\$/m ²)	Current LCOE (\$/kWh)	Optimal Power Density (kW/m ²)	Optimal Cost (\$/m ²)	Optimal LCOE (\$/kWh)
0.0016-0.0029	18-54.1	0.32-2.13	0.005	3.6-9	0.045-0.11

Note. (Author, 2022). Optimal LCOE is based off of what the research suggests the optimal power density and cost would need to be in order for PRO to become economically viable.

6.3.2 Cost Comparison of PRO and Diesel

Savings from PRO are shown in table 5. Savings are based on 2015 and 2017 diesel use data and were calculated using optimistic LCOE values in table 4.

Table 5

Energy Produced, Cost, and Savings of Diesel Vs. PRO at Optimal Conditions in Bella Coola

Annual Max and Min Diesel Use [l]	Annual Energy Produced from Diesel (kWh)	Annual Cost Given the price of diesel (\$0.13/kWh) [\$]	Annual Cost with PRO (\$0.045-\$0.11/kWh) [\$]	Annual Savings with PRO [\$]
1,731,535 (2015)	17,219,153	2,238,490	774,862-1,894,106	344,384-1,463,628
2,360,000 (2017)	23,468,889	3,050,956	1,056,100-2,581,578	469,378-1,994,856

Note. (Author, 2022). Savings are based off of optimistic membrane densities and costs meaning that Bella Coola will only see these savings if PRO membrane energy densities increase while price decreases.

6.4 Discussion

Currently, PRO membrane power densities and membrane costs result in an LCOE higher than what Bella Coola is currently paying for diesel, as seen in table 4. The most

significant economic barrier to PRO is the high cost and low power density of PRO membranes (Technology Brief, 2014). It is estimated that for membranes to be competitive with other renewables, membrane costs need to be reduced from 18-54.1 $\$/\text{m}^2$ to around 3.6-9 $\$/\text{m}^2$, as seen in table 4. Newby et al. (2021, p.1119) estimates that to make PRO competitive with “solar, wind, hydroelectric, geothermal or natural gas with carbon capture technologies”, the LCOE for PRO would need to be around 0.04-0.10 $\$/\text{kWh}$. The price of current renewables is fairly consistent with the optimal LCOE calculated in this study which puts optimal LCOE for PRO at around 0.045- 0.11 $\$/\text{kWh}$ as seen in table 4.

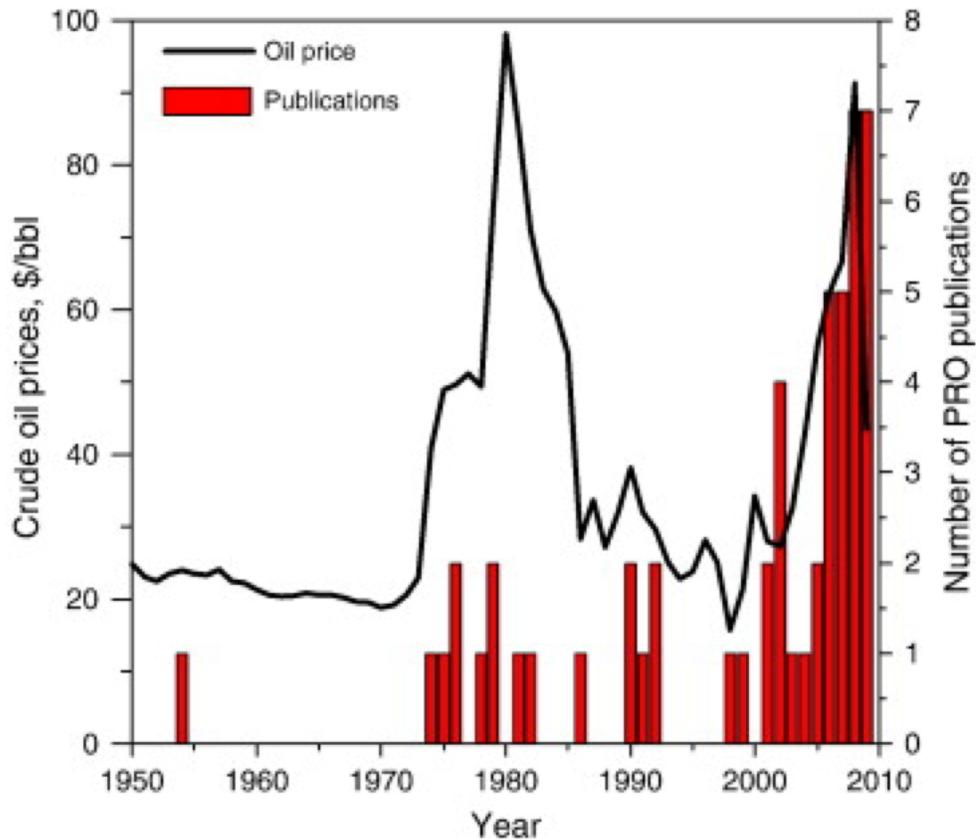
Currently, Bella Coola residents are paying 0.13 $\$/\text{kWh}$ for diesel after subsidies (Stephen & Mabee, 2016). Under the conditions calculated in table 4, at optimal LCOE rates, savings from PRO in the future could range from \$344,384-1,994,856 a year if technology can advance enough to reach the optimal PRO membrane parameters, as seen in table 5.

6.5 Summary/ Future Research

While current PRO membrane power densities are too low and membrane costs are too high to make PRO competitive with other renewables, PRO may be more favorable than diesel in the near future as diesel prices continue to increase. Regardless, more research needs to go into increasing the efficiencies and power densities of PRO membrane technologies to make PRO competitive in the renewable energy market. Fortunately, trends show that more resources are put into researching PRO with the increase in oil prices, as seen in figure 20 (Achilli & Childress, 2010). Currently, oil prices have increased significantly, which given historical trends in PRO research, could result in a significant increase in resources put towards SGE research and development (Trading Economics, 2022).

Figure 20

The Trend in PRO Publications and Oil Prices from 1950-2010



Note. The trend in PRO publications next to the trend in oil price. From “Pressure retarded osmosis: From the vision of Sidney Loeb to the first prototype installation- Review”, by A. Achilli, and A.E. Childress, 2010, *Desalination*, 261(3), p. 206 (<https://doi.org/10.1016/j.desal.2010.06.017>). Copyright 2010 Elsevier B.V.

In summary, current PRO technology is not commercially viable; however, there has been an increase in interest within the SGE field, and more resources and research are going into making this technology more efficient. It is also possible that given the current social climate causing significant increases in oil and gas prices globally there may also be a spike in resources

towards SGE technology. Increased resources may result in PRO technology being commercially viable sooner than what was previously predicted.

Chapter 7 Environment

7.1 Introduction

Bella Coola is located in the Great Bear Rainforest. The Great Bear Rainforest is a highly biodiverse region and is suggested to contribute to biodiversity not only in the region but also on a global scale. The Great Bear Rainforest has a quarter of the total global temperate rainforest consisting of mainly “old growth conifer stands, with species of western hemlock and red cedar” (Mertens et al., 2015, “Introduction” section). The Bella Coola region is a breeding ground, nursing ground, and important habitat for many species seen in *appendix f-n*. As a result, it is important that environmental impacts from PRO are assessed to ensure that PRO technology does not pose a significant threat to the local and global environments (Mertens et al., 2015).

7.1.1 Scope

Unlike other more conventional renewables, SGE, although in the pilot stage of development, has not undergone a detailed environmental impact assessment (Seyfried et al., 2019). As a result, the environmental impacts discussed in this section were based on proxies and estimations in the literature. Site-specific information was also based on species lists from studies on the region and literature outlining potential impacts on particular species groups.

7.2 Methods

7.2.1 Environmental Impacts Throughout the Lifecycle of a PRO Facility

A literature review was conducted to determine the potential environmental impacts of a PRO facility. The life cycle stages of PRO, and associated stressors were structured based on Seyfried et al. (2019), who estimated PRO stressors, effects, and environmental impacts based on coastal renewable energy, other coastal industries, and reverse osmosis (RO).

7.2.2 Diesel Emissions

The lowest and highest annual diesel use in Bella Coola from 2014-2019 was used to calculate the amount of CO₂ produced in *appendix e* using equation 6, which is adapted from the MIT energy conversion sheet (Supple, n.d.).

$$kg\ CO_2 = Diesel\ Use\ (l) * \frac{2.68\ kg\ CO_2}{Diesel\ (l)} \quad (6)$$

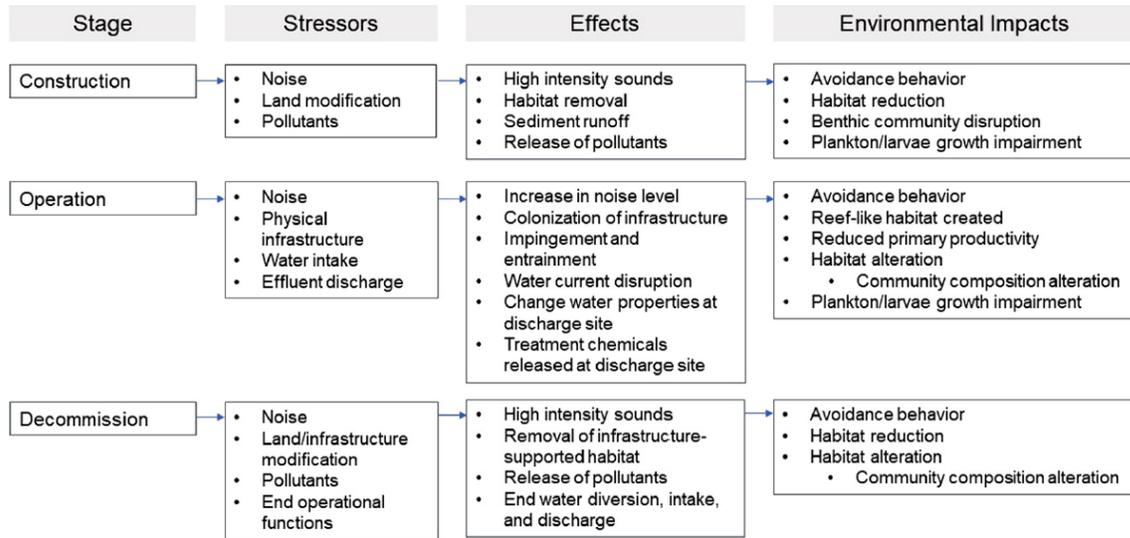
7.3 Results

7.3.1 Life Cycle of PRO

Seyfried et al., (2019) identified three life cycle stages: construction, operation and decommission. Stressors, effects, and environmental impacts were then identified for each life stage as seen in figure 21.

Figure 21

Environmental Impacts at Different Life Stages of PRO



Note. Flow chart of the stages, stressors, effects, and environmental impacts associated with SGE. Environmental impacts are based off of proxies and estimations from other industries. From “Potential local environmental impacts of salinity gradient energy: A review”, by C. Seyfried, H. Palko, and L. Dubbs, 2019, *Renewable and Sustainable Energy Reviews*, 102, p.113, (<https://doi.org/10.1016/j.rser.2018.12.003>). Copyright 2018 by Elsevier Ltd.

7.3.2 Diesel Emissions

In 2015, Bella Coola used the least amount of diesel from 2014-2019 at 1,731,535 liters of diesel which produced 4,643,985 kg of CO₂. In 2017, Bella Coola used the most amount of diesel to generate energy from 2014-2019 at 2.36 million liters which produced 6,329,531 kg of CO₂, as seen in table 6 (Thompson, 2019).

Table 6

CO₂ Produced by Diesel Generators in Bella Coola in 2015 and 2017

Diesel Use (l)	CO ₂ Produced (kg)
1,731,535 (2015)	4,643,983
2,360,000 (2017)	6,328,846

Note. (Author, 2022). The years 2015 and 2017 were used because these years represented the lowest and the highest diesel demand years recorded in Bella Coola from 2014-2019.

7.4 Discussion

7.4.1 Construction

7.4.1.1 Noise Pollution.

Research has shown that naturally occurring sound is fundamental to aquatic life. Many species rely on naturally occurring sound for many reasons such as “habitat during settlement for fishes, and invertebrates, the timing of settlement and metamorphosis of invertebrates, and the reproductive behaviour of fishes involving sound production” (Nichols et al., 2015, p.1). Over the past century, noise pollution has become more prevalent in aquatic environments. Noise pollution has resulted in increased discussions on how activities such as coastal developments are impacting ecosystems and how those impacts can be limited (Convention on Biological Diversity, n.d.).

In studies done on the impact of pile driving on aquatic species, it was found that increased anthropogenic noise pollution can cause significant, localized mortalities in zooplankton and impact plankton growth and development. The ecological importance of plankton and potential impacts of aquatic noise on planktonic species in Bella Coola are described in *appendix f*. Fish species in Bella Coola as seen in *appendix j* and invertebrates in *appendix i* also have planktonic life stages and are subjected to potential development issues and

mortality. Impacts to these species from noise pollution is problematic, especially in an area like Bella Coola, where planktonic and juvenile life stages of fish species are likely to be more prevalent. As a result, impacts to higher trophic levels may occur due to the impact on planktonic species at lower trophic levels including primary producing phytoplankton (Seyfried et al., 2019; Weilgart, 2018).

Increased anthropogenic noise can also negatively impact the statocysts which are used by cephalopods, bivalves, echinoderms, and crustaceans in Bella Coola as seen in *appendix i* to detect particle motion and communicate (Convention on Biological Diversity, n.d.). A study by Zhao et al., (2021) also showed that increased noise could impact the attachment structures of sessile organisms such as mussels, thus severely reducing population sizes. In fish seen in *appendix j*, not only will increased underwater noise affect their planktonic life stages, but noise pollution can also impact reproduction, predator aversion, metabolic processes, nutrient acquisition, etc. (Weilgart, 2018). It is also possible that intermittent noise associated with construction is more damaging to fish than if that noise were to be continuous, as what would be expected during the operation phase (Nichols et al., 2015).

Research on the marine mammals found in *appendix m* suggests that noise from pile driving can cause permanent or temporary hearing loss, interfere with communication, foraging, predator aversion, migration, mating, etc.; however, the level of hearing interference depends on the species (Convention on Biological Diversity, n.d.). Noise associated with construction will likely only cause avoidance of the construction area by terrestrial species, including birds discussed in *appendix m & n* (Seyfried et al., 2019).

Although noise from construction can be detrimental to aquatic species, the impacts discussed are likely an overestimation as PRO development will not require the same level of

noise-producing activities associated with other industries. Noise from PRO construction will likely be localized and not have long-range impacts to organisms. Seyfried et al. (2019) suggested that the most significant effect of noise in the construction phase will likely be species avoidance.

7.4.1.1 Land Modification.

The second impact from construction as seen in figure 21 is land modification. The impact on the land during the construction phase of PRO will be more significant than just where the finished facility site would be located. PRO construction would require the removal of plant species as seen in *appendix h* and habitat at the location of the main PRO facility as well as where water piping would be laid (Seyfried et al., 2019; Marin-Coria et al., 2021). The disturbance to the land could also cause erosion and increased sedimentation into the watershed and ocean. Increased sedimentation in the water column could cover benthic ecosystems, reduce light penetration, and change the chemical composition of the water column. As a result, sedimentation could negatively impact benthic species, reduce primary production, and cause an algae bloom. Land habitat loss and vegetation removal would likely cause species located near the site to relocate especially since construction will occur near watersheds (Seyfried et al., 2019).

7.4.1.3 Pollution.

The third impact from construction, as shown in figure 21 is pollution. During the construction of PRO, heavy machinery and equipment are necessary for the development of a PRO facility. As a result, harmful pollutants such as “VOC’s and CFCs from synthetic paints and varnishes, cleaning solutions, on-site sanitation waste, fluid leakage from machinery, dust generation, and suspension, and accidental spills of hazardous waste” may be introduced into the environment (Seyfried et al., 2019, p.115). To prevent harmful pollutants from entering the environment, there

must be extensive staff training on the handling of hazardous chemicals (Marin-Coria et al., 2021).

7.4.2 Operation

7.4.2.1 Noise Pollution.

Sources of noise associated with PRO operation come from the generator, stabilization pump, and intake pump. While noise associated with operation is unlikely to cause sound at large enough magnitudes to have any real damage on species, it is likely that aquatic and terrestrial life in Bella Coola will avoid the area (Seyfried et al., 2019). Fortunately, SGE can be built underground limiting some of the sound produced by the facility (Technology Brief, 2014).

7.4.2.2 Physical Infrastructure.

The second impact is physical infrastructure. Physical infrastructure can provide a space for sessile organisms to colonize, provide shade to hide, and provide food sources for local species. It can also cause negative impacts on the equipment and environment through biofouling of equipment and encouraging the growth of non-native species and algae blooms (Marin-Coria et al., 2021).

7.4.2.3 Water Intake.

Thirdly, intake zones can affect the hydrodynamics of the watershed (Technology Brief, 2014). Natural currents and hydrodynamics are critical to an ecosystem as waterways carry and disperse “plankton, larvae, seeds”, help species travel, avoid predation, etc. Intake pipes can also take in water that contains small organisms such as plankton and zooplankton (Seyfried et al., 2019, p.118). Many of the watersheds in Bella Coola are important nursing grounds and ecosystems for juvenile fish and invertebrates as seen in *appendix i & j*. As a result, intake zones could

potentially impact population sizes of these species as water from the intake is treated to kill off organisms to prevent biofouling (Marine Planning Initiative, 2015; Seyfried et al., 2019).

7.4.2.4 Effluent Discharge.

Lastly, effluent from PRO contains chemicals used to treat intake water, such as chlorine to prevent fouling and degradation of membranes, metallic salts for coagulating particles in the intake water, phosphonates for suspending fouling particles, and oxidants and detergents for cleaning (Marin-Coria et al., 2021; Seyfried et al., 2019; SUEZ, 2017). Compounds such as chlorine left in the effluent wastewater can be detrimental to invertebrates, algae, and fish in Bella Coola, as seen in *appendix g, i, & j* (Government of Canada, 2014). PRO facilities must test and treat effluent to meet quality standards and limit negative environmental effects (Government of Canada, 2020). Because the aquatic environment in Bella Coola is a breeding and nursing ground for many fish and invertebrate species, reducing impacts to organisms in the area from effluent is a significant concern. Impacts from effluent could potentially affect higher trophic levels by reducing food availability as well as the possibility for bioaccumulation, which could impact more extensive ecosystem networks. It is still unknown the extent to which effluent from PRO could impact the environment (Marine Planning Partnership Initiative, 2015).

Effluent from PRO also contains a salt concentration from the mixed freshwater and saltwater intake sources. To avoid issues with releasing brine effluent into areas with low salinity tolerant organisms, Marin-Coria et al. (2021) suggests that the best place to discharge effluent is directly into the seawater source. Fortunately, this is unlikely to be a significant impact as species in the Bella Coola region should already be somewhat acclimated to slight changes in salinity (Marine Planning Partnership Initiative, 2015; Palko, 2017).

7.4.2.5 Emissions.

Fortunately, during the operation stage, SGE does not produce any emissions into the atmosphere. As a result, if Bella Coola chooses to transition away from diesel and towards PRO, a reduction in 6,329,531 kg of CO_{2eq} emissions could be possible based on the 2017 diesel usage seen in table 6.

7.4.3 Decommission

There are several options for decommissioning: complete removal, partial removal, refurbishing, and alternative use (Seyfried et al., 2019). The option used can depend on the environmental need. For example, any removal during decommissioning can have a similar if not the same impact as construction (Palko, 2017). Infrastructure can be left behind in cases where it has been colonized by other organisms and removing it would cause more harm. However, infrastructure could pose a future threat, such as if it contained hazardous compounds or any product that could potentially leak into the environment and cause further harm, in which case removal may be preferred (Seyfried et al., 2019).

7.4.4 Summary/ Future Research

The species in *appendix f-n* could be impacted by the development of PRO in Bella Coola. The impacts on these species are based on assumptions and estimation. Site-specific research needs to be done in Bella Coola to determine species present in the region and their seasonal variations. There also needs to be more research on the environmental impacts associated with PRO in general that could then be applied in Bella Coola. More research is particularly needed to better understand impacts from effluent. Water treatment methods for PRO are still being investigated; however, harmful chemicals will likely need to be used. More research needs to go into how these treatment chemicals will impact the environment over the

long term. Future research should also look at how much land area would be needed to develop a PRO facility in the Bella Coola.

In conclusion, the impacts of a PRO facility are likely similar to that of hydroelectric energy; however, there are still many unknowns about how PRO will impact the environment (Technology Brief, 2014).

Chapter 8 Conclusion

This paper discussed the PRO energy potential of the six selected watersheds. It is likely that the community of Bella Coola has enough freshwater availability in the region to replace diesel usage with the Nooklikonnik Creek hydroelectric facility. However, more research into performance limiting factors need to be studied to understand the net energy potential in the region.

Currently, the most significant factor holding PRO back from being a commercially viable energy source is the low power density and high cost of membrane technology. Developments into PRO in the region of Bella Coola are unrealistic until PRO can become more competitive with not only other renewable markets but also the price of diesel in Bella Coola.

The environmental impact analysis of PRO in this report was based on proxies and estimations from other industrial projects with similar processes and locational needs (Seyfried et al., 2019). Bella Coola is an essential location for the survival of many species both regionally and globally (Mertens et al., 2015). As a result, an in-depth site-specific environmental impact analysis should be done in the area prior to any PRO developments.

References

- Abbasi-Garravand, E. (2016, September). *Using pressure retarded osmosis technology to generate salinity gradient energy (osmotic power) as a new renewable energy source: pretreatment to reduce PRO membrane fouling* [Unpublished thesis]. Concordia University.
- Abbotsford. (n.d.). *Impacts of sediment to aquatic habitats*.
<https://www.abbotsford.ca/sites/default/files/2021-02/Impacts%20of%20Sediment%20to%20Aquatic%20Habitats.pdf>
- Achilli, A., Cath, T., Y., & Childress, A.E. (2009, November 1). Power generation with pressure retarded osmosis: An experimental and theoretical investigation. *Journal of Membrane Science*, 343(1-2), 42-52. doi:10.1016/j.memsci.2009.07.006
- Achilli, A., & Childress, A.E. (2010, October 31). Pressure retarded osmosis: From the vision of Sidney Loeb to the first prototype installation- Review. *Desalination*, 261(3), 205-211.
<https://doi.org/10.1016/j.desal.2010.06.017>
- Addison, R.F., Ikonomou, M.G., & Smith, T.G. (2005, March). PCDD/F and PCB in harbour seals (*Phoca vitulina*) from British Columbia: response to exposure to pulp mill effluents. *Marine Environmental Research*, 59(2), 165-176. doi:10.1016/j.marenvres.2004.04.005
- Altaee, A., Zou, J., Alanezi, A.A., & Hawari, A.H. (2018, February 20). Osmotic power plant: Process innovation and future potential. *Recent Advances in Petrochemical Science (RAPSCI)*, 4(3), 555640.
doi:10.19080/RAPSCI.2018.04.555640
- Alvarado, J.J. (2010, July 22). Echinoderm diversity in the Caribbean Sea. *Marine Biodiversity*, 41, 261-285. <https://doi.org/10.1007/s12526-010-0053-0>

- Animal Welfare Institute. (2017). *A whale of an effect on ocean life. The ecological and economic value of cetaceans*. <https://awionline.org/awi-quarterly/fall-2017/whale-effect-ocean-life-ecological-and-economic-value-cetaceans>
- Avibase. (2022, July 7). *Avibase- Bird checklist of the world Bella Coola estuary conservancy*. <https://avibase.bsc-eoc.org/checklist.jsp?region=CAbccc42&list=howardmoore>
- Bagočius, D. (2015, March 15). Piling underwater noise impact on migrating salmon fish during Lithuanian LNG terminal construction (Curonian Lagoon, Eastern Baltic Sea Coast). *Marine Pollution Bulletin*, 92(1-2), 45-51. DOI:10.1016/j.marpolbul.2015.01.002
- Barnes, R.D. (2022, June 24). *Arthropod*. Britannica. <https://www.britannica.com/animal/arthropod>
- Bella Coola. (n.d.). *Bella Coola*. <https://bellacoola.ca>
- Bhattacharya, P., Swarnakar, S., Mukhopadhyay, A., & Ghosh, S. (2016, December 22). Exposure of composite tannery effluent on snail, *Pila globose*: a comparative assessment of toxic impacts of the untreated and membrane treated effluents. *Ecotoxicology and Environmental Safety*, 126, 45-55. <https://doi.org/10.1016/j.ecoenv.2015.12.021>
- Bornatowski, H., Navia, A.F., Braga, R.R., Abilhoa, V., & Corrêa, M.F.M. (2014, March 5). Ecological importance of sharks and rays in a structural foodweb analysis in southern Brazil. *ICES Journal of Marine Science*, 71(7), 1586-1592. <https://doi.org/10.1093/icesjms/fsu025>
- Bruno, J. (2004, March). *Effects of two industrial effluents on juvenile white sturgeon (Acipenser transmontanus)*. Sturgeon Contaminants Working Group. https://a100.gov.bc.ca/pub/acat/documents/r7629/SturgeonReportMarch2004_1155248340024_842785c393f94c5cacb796dd9297851f.pdf

- Bunkley, J.P., McClure, C.J.W., Kawahara, A.Y., Francis, C.D., & Barber, J.R. (2017, March 23). Anthropogenic noise changes arthropod abundances. *Ecology and Evolution*, 7(9), 2977-2985. doi: 10.1002/ece3.2698
- California State Polytechnic University. (n.d.). *Values of R (gas constant)*.
<https://www.cpp.edu/~lllee/gasconstant.pdf>
- Cardiff University. (2022, January 25). *Toxic 'forever chemicals' found in otters across England and Wales*. Phys.org. <https://phys.org/news/2022-01-toxic-chemicals-otters-england-wales.html>
- Chapuis, L. (2015, August 6). Is human noise pollution affecting our sharks? Phys.org.
<https://phys.org/news/2015-08-human-noise-pollution-affecting-sharks.html>
- Chamberlin, J., Petrou, E., Duguid, W., Barsh, R., Juanes, F., Qualley, J., & Hauser, L. (2021, September 22). Phenological diversity of a prey species supports life-stage specific foraging opportunity for a mobile consumer. *ICES Journal of Marine Science*, 78(9), 3089-3100. <https://doi.org/10.1093/icesjms/fsab176>
- Cheng, Z.L. & Han, G. (2020). Design of other pressure retarded osmosis hybrid processes (pressure retarded osmosis-membrane distillation and pressure retarded osmosis-forward osmosis). In C.F. Wan & T.S. Chung (Eds.), *Membrane Technology for Osmotic Power Generation by Pressure Retarded Osmosis* (pp. 286-318). Taylor & Francis Group.
- Clout, M.N., & Hay, J.R. (1989). The importance of birds as browsers, pollinators, and seed dispersers in New Zealand forests. *New Zealand Journal of Ecology*, 12, 27-33.
<http://www.jstor.org/stable/24053245>

- Coast Funds. (2022, May 12). *Paths to energy sovereignty: a case for investment in renewable energy*. <https://coastfunds.ca/news/rirc-paths-to-energy-sovereignty/>
- Convention on Biological Diversity. (n.d.). *Anthropogenic underwater noise: impacts on marine and coastal biodiversity and habitats, and mitigation and management measures*. <https://www.cbd.int/doc/notifications/2020/cbd-ts-underwater-noise-peer-review-en.pdf>
- Cook, R.L. (2019). *The social and cultural impacts of reducing the reliance on diesel in Canada's Northern Indigenous communities*. The University of Ottawa. https://ruor.uottawa.ca/bitstream/10393/41023/1/confetti-volume-2019-version_finale-68-84%20cook.pdf
- Cougar Fund. (n.d.). *Science & conservation*. <https://www.cougarfund.org/science/>
- Crooks, V. (2021, February 22). *Bryophytes*. Smithsonian Tropical Research Institute. <https://stri.si.edu/story/bryophytes>
- David Suzuki Foundation. (2013, July). *Cultural and ecological value of boreal woodland caribou habitat*. <https://www.afn.ca/uploads/files/report-caribou.pdf>
- Dheilly, N.M., Lucas, P., Blanchard, Y., & Rosario, K. (2022, May 10). World of viruses nested within parasites: unraveling viral diversity within parasitic flatworms (Platyhelminthes). *American Society for Microbiology*, 10(3), e00138-22. <https://doi.org/10.1128/spectrum.00138-22>
- Discover Life. (n.d.). *Crustacea*. <https://www.discoverlife.org/20/q?search=Crustacea>
- Douglas, W.A., & Lanzing, W.J.R. (1980, August 23). The respiratory mechanisms of the dusky flathead, *Platycephalus fuscus* (Platycephalidae, Scorpaeniformes). *Journal of Fish Biology*, 18(5), 545-552. <https://doi.org/10.1111/j.1095-8649.1981.tb03795.x>

- Drami, D., Yacobi, Y.Z., Stambler, N., & Kress, N. (2011, November 1). Seawater quality and microbial communities at a desalination plant marine outfall. A field study at the Israeli Mediterranean coast. *Water Research*. 45(17), 5449-5462.
<https://doi.org/10.1016/j.watres.2011.08.005>
- Duguid, W.D.P., Boldt, J., Chalifour, L., Greene, C.M., Galbraith, M., Hay, D., Lowry, D., McKinnel, S., Neville, C.M., Qualley, J., Sandell, T., Thompson, M., Trudel, M., Young, K., & Juanes, F. (2019, January). Historical fluctuations and recent observations of Northern Anchovy *Engraulis mordax* in the Salish Sea. *Deep Sea Research Part II: Topical Studies in Oceanography*, 159, 22-41. <https://doi.org/10.1016/j.dsr2.2018.05.018>
- Darimont, C.T., & Paquet, P. (2000). *The gray wolves (Canis lupus) of British Columbia's coastal rainforests*. Raincoat Conservation Society.
<https://www.raincoast.org/files/publications/reports/wolfreport.pdf>
- eAtlas. (n.d.). *Seabirds and shorebirds connectivity*. <https://eatlas.org.au/ne-aus-seascape-connectivity/seabirds-shorebirds>
- Ecology Center. (2022, August 13). *Cnidarians sea anemones corals and jellyfish*.
<https://www.ecologycenter.us/natural-history-2/cnidarians-sea-anemones-corals-and-jellyfish.html>
- Emmet, R.L., Brodeur, R.D., Miller, T.W., Pool, S.S., Krutzikowsky, G.K., Bentley, P.J., & McCrae, J. (2005, December). Pacific sardine (*Sardinops sagax*) abundance, distribution, and ecological relationship on the Pacific Northwest. *Pacific Sardine Northwest Ecology*, 46, 122-143. <https://www.researchgate.net/publication/252533525>
- Energy Education. (n.d.). *Diesel generator*.
https://energyeducation.ca/encyclopedia/Diesel_generator

- Exchange Rates UK. (n.d.). *Euro to Canadian dollar spot exchange rates for 2014*.
<https://www.exchangerates.org.uk/EUR-CAD-spot-exchange-rates-history-2014.html>
- Fisheries and Oceans Canada. (1981). *The Bella Coola River estuary status of environmental knowledge*. <https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/59319.pdf>
- Fisheries and Oceans Canada (2010-2015). *Pacific regional cold-water coral and sponge conservation strategy*. <https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/344719.pdf>
- Ford, J., & Nichol, L. (n.d.). *Marine Mammals of British Columbia*.
http://awsassets.wwf.ca/downloads/ford_1.pdf
- Fortunato, H. (2015, November 13). Mollusks: tools in environmental and climate research. *American Malacological Bulletin*, 33(2):1-15. <http://dx.doi.org/10.4003/006.033.0208>
- Freihofer, W.C. (2022, August 1). *Perciforms*. Britannica.
<https://www.britannica.com/animal/perciform>
- Gai, H., & Han, G. (2020). Recent development of flat-sheet PRO membranes. Membrane technology for osmotic power generation by pressure retarded osmosis. In C.F. Wan & T.S. Chung (Eds.), *Membrane Technology for Osmotic Power Generation by Pressure Retarded Osmosis* (pp. 21-41). Taylor & Francis Group.
- Gartner, H. (n.d.). *Bryozoans of British Columbia*. Royal BC Museum.
<https://royalbcmuseum.bc.ca/collections/research-portal/research-project-profiles/bryozoans-british-columbia>
- General Power. (n.d.). *Diesel generator vs. gas generator: Which is more efficient?*
<https://www.genpowerusa.com/blog/diesel-generator-vs-gas-generator-which-is-more-efficient/>

Ghoul, A. (2012, September 28). *Sea otter and sound*. Seaotters.

<https://www.seaotters.com/2012/09/sea-otters-and-sound/>

Gillingham, M.P. (n.d.). *Ecology of black-tailed deer in north coastal environments*. University of Northern British Columbia.

https://web.unbc.ca/~michael/Pubs/Gillingham_2008_RGIS_Symposium.pdf

Google Maps. (n.d.). *Bella Coola*.

<https://www.google.com/maps/place/Bella+Coola,+BC+V0T+1C0/@52.3721745,-126.7888682,8612m/data=!3m2!1e3!4b1!4m5!3m4!1s0x547a797770abbf4f:0xbd5a034a058400bf18m2!3d52.3721277!4d-126.7539346>

Gottesfeld, L.M. J. (1992). The importance of bark products in the aboriginal economies of Northwestern British Columbia, Canada. *Economy Botany*, 46(2), 148-157. <https://doi-org.ezproxy.lib.ucalgary.ca/10.1007/BF02930629>

Government of British Columbia (n.d.a). *B.C. fish facts*.

<https://a100.gov.bc.ca/pub/eirs/finishDownloadDocument.do;jsessionid=7084F7B3CE346EF7A57C516682FAF643?subdocumentId=962>

Government of British Columbia. (n.d.b) *Bella Coola watershed assessment study*.

https://www.env.gov.bc.ca/cariboo/env_stewardship/wrp/reports/iwap-cwap/bella_coola/finalrpt.html

Government of British Columbia. (n.d.c). *Province launches public engagement on strengthening Great Bear Rainforest*. <https://news.gov.bc.ca/releases/2022FOR0037-000918>

Government of British Columbia. (1993). *Rinichthys cataractae longnose dace*. BC Conservation Data Center: Species Summary.

<https://a100.gov.bc.ca/pub/eswp/speciesSummary.do;jsessionid=cad21ffcea193e9bf2f97e97c3be1a56c98e5ded95320800b98ca486fd07e15b.e3uMah8KbhmLe3aOchqKaNuOci1ynknvrkLOIQzNp65In0?id=15731>

Government of British Columbia. (2022, March). *Current condition report for Grizzly Bear in the west coast region| 2019 analysis.*

<https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/cumulative-effects/west-coast-region/cef-ccr-grizzly-westcoast-march2022.pdf>

Government of Canada. (2014, April 11). *Wastewater pollution.*

<https://www.canada.ca/en/environment-climate-change/services/wastewater/pollution.html>

Government of Canada. (2016, October 6a). *International perspective.*

<https://www150.statcan.gc.ca/n1/pub/11-402-x/2012000/chap/geo/geo01-eng.htm>

Government of Canada. (2016, December 19b). *Surf Smelt.* <https://www.dfo-mpo.gc.ca/species-especies/profiles-profilsmelt-eperlan-eng.html>

Government of Canada. (2018, January 17). *Environment.*

<https://www150.statcan.gc.ca/n1/pub/11-402-x/2011000/chap/env/env-eng.htm>

Government of Canada. (2020, March 10). *Factsheet: regulatory requirements for small*

wastewater systems. <https://www.canada.ca/en/environment-climate-change/services/wastewater/system-effluent-regulations-reporting/overview/factsheet-regulations-owners-operators.html>

Government of Canada (2022a, August 5). *BC tidal areas 8 and 108- Fitz Hugh Sounds, Bella Coola: Sport fishing limits, openings and closures*. <https://www.pac.dfo-mpo.gc.ca/fm-gp/rec/tidal-maree/a-s8-eng.html>

Government of Canada. (2022b, July 27th). *Monthly discharge data for Atnarko River near the mouth*. (08FB006) [BC].

https://wateroffice.ec.gc.ca/report/historical_e.html?stn=08FB006&dataType=Monthly¶meterType=Flow&year=2020&mode=Table&page=historical&start_year=1850&end_year=2022

Government of Canada. (2022c, July 27). *Monthly discharge data for Clayton Falls Creek near the mouth* (08FB009) [BC].

https://wateroffice.ec.gc.ca/report/historical_e.html?stn=08FB009&dataType=Monthly¶meterType=Flow&mode=Table

Government of Canada. (2022d, July 27). *Monthly discharge data for Dean River near Anahim Lake* (08FC005) [BC].

https://wateroffice.ec.gc.ca/report/historical_e.html?stn=08FC005&dataType=Monthly¶meterType=Flow&year=2007&mode=Table&page=historical&start_year=1850&end_year=2022

Government of Canada. (2022e, July 27). *Monthly discharge data for Nusatsum River near Hagensborg* (08FB005) [BC].

https://wateroffice.ec.gc.ca/report/historical_e.html?stn=08FB005&dataType=Monthly¶meterType=Flow&year=1995&mode=Table&page=historical&start_year=1850&end_year=2022

Government of Canada. (2022f, July 27). *Monthly discharge data for Salloomt River near Hagensborg (08FB004) [BC]*.

https://wateroffice.ec.gc.ca/report/historical_e.html?stn=08FB004&dataType=Monthly¶meterType=Flow&year=2020&mode=Table&page=historical&start_year=1850&end_year=2022

Government of Canada. (2022g, July 27). *Monthly discharge data for Tastsquan Creek at Bella Coola (08FB003) [BC]*.

https://wateroffice.ec.gc.ca/report/historical_e.html?stn=08FB003&dataType=Monthly¶meterType=Flow&year=1950&mode=Table

Government of Manitoba. (n.d.). *Hard to be a moose in a changing world*.

https://www.gov.mb.ca/nrnd/fish-wildlife/pubs/fish_wildlife/hard-to-be-a-moose.pdf

Graham, W.M., Gelcich, S., Robinson, K.L., Duarte, C.M., Brotz, L., Purcell, J.E., Madin, L.P., Mianzan, H., Sutherland, K.R., Uye, S., Pitt, K.A., Lucas, C.H., Bøgeberg, M., Brodeur, R.D., & Condon, R.H. (2014, November 1). Linking human well-being and jellyfish: ecosystem services, impacts, and societal responses. *Frontiers in Ecology and the Environment*, 12(9), 515-523. doi:10.1890/130298

Griffin, F.J., Smith, E.H., Vines, C.A., & Cherr, G.N. (2009, February 23). Impact of sediments on fertilization, embryonic development, and early larval stages of the Pacific Herring, *Clupea pallasii*. *The University of Chicago Press Journals* 216(2), 175-187. doi: 10.1086/BBLv216n2p175.

Hall, D. (2022, February). *Echinoderms*. Smithsonian Ocean. <https://ocean.si.edu/ocean-life/invertebrates/echinoderms>

- Halvorsen, M.B., Casper, B.M., Matthews, F., Carlson, T.J., & Popper, A.N. (2012, October 12). Effects of exposure to pile-driving sounds on lake sturgeon, Nile tilapia, and hogchoker. *Proc Bio Sci*, 279(1748): 4705-4714. doi: 10.1098/rspb.2012.1544
- Harris, E.S. (2008). Ethnobotany: traditional uses and folk classification of bryophytes. *The Bryologist*, 111(2): 169-217. <http://www.jstor.org/stable/20110935>
- Hawkins, A.D., & Picciulin, M. (2019). The importance of underwater sounds to gadoid fishes. *The journal of the acoustical society of America*, 146, 3536. <https://doi.org/10.1121/1.5134683>
- Hoffman Nursery. (2016). *Juncus*. <https://hoffmannursery.com/juncus>
- Hsu, W.S., Preet, A., Lin, T.Y., & Lin, T.E. (2021). Miniaturized salinity gradient energy harvesting devices. *Molecules*, 26(18), 5469. doi: 10.3390/molecules26185469
- Hydro-Quebec. (2021). *Osmotic power*. <https://www.hydroquebec.com/data/developpement-durable/pdf/file-osmotic.pdf>
- Inflation Tool. (n.d.). *Value of 2014 Canadian dollar today*. Retrieved August 3rd, 2022, from <https://www.inflationtool.com/canadian-dollar/2014-to-present-value?year2=2022&frequency=yearly>
- Iovenko, C. (2018, August 3). *How an epidemic exposed the ecological importance of sea stars*. Hakai Magazine. <https://hakaimagazine.com/news/how-an-epidemic-exposed-the-ecological-importance-of-sea-stars/>
- Ju, J., Choi, Y., Lee, S., & Jeong, N. (2021). Comparison of fouling characteristics between reverse electrodialysis (RED) and pressure retarded osmosis (PRO). *Desalination*, 497, 114648. <https://doi.org/10.1016/j.desal.2020.114648>

- Karanasios, K., & Parker, P. (2018, July). Tracking the transition to renewable electricity in remote Indigenous communities in Canada. *Energy Policy*, 118, 169-181.
<https://doi.org/10.1016/j.enpol.2018.03.032>
- Kennedy, D., & Bouchard, R. (2006, February 6). *Nuxalk (Bella Coola)*. The Canadian Encyclopedia.
<https://www.thecanadianencyclopedia.ca/en/article/nuxalk-bella-coola>
- Kennedy, M.M. (2014, December 8). *Energy shift: Reducing diesel reliance in remote communities in BC* [Unpublished thesis]. Simon Fraser University.
- Keystone Environmental. (2019, January 24). *White sturgeon | an uncertain future for the dinosaurs of our rivers*. <https://keystoneenvironmental.ca/white-sturgeon-an-uncertain-future-for-the-dinosaur-of-our-rivers/>
- Kleiterp, R. (2012, January). *The feasibility of a commercial osmotic power plant* [Unpublished thesis]. Delft University of Technology.
- Kuhnlein, H.V., & Humphries, M.M. (n.d.). *Mountain Goat*. McGill.
<http://traditionalanimalfoods.org/mammals/hoofed/page.aspx?id=6361>
- Kumano, A., Marui, K., & Terashima, Y. (2016, July 1). Hollow fiber type PRO module and its characteristics. *Desalination*, 389, 149-154. <http://dx.doi.org/10.1016/j.desal.2016.01.001>
- Kunc, H.P., McLaughlin, K.E., & Schmidt, R. (2016, August 17). Aquatic noise pollution: implications for individuals, populations, and ecosystems. *Proc Biol Sci*, 283(1836): 20160839. doi: 10.1098/rspb.2016.0839
- Lamprey Surveys. (n.d.). *Dredging*. <https://lampreysurveys.com/dredging/>

- Lee, S., Aydin, K.Y., Spencer, P.D., Wilderbuer, T.K., & Zhang, C.I. (2010, January 15). The role of flatfishes in the organization and structure of the eastern Bering Sea ecosystem. *Fisheries Science*, DOI: 10.1007/s12562-009-0201-2
- Llanos-Rivera, A., Castro, L.R., Vásquez, P., Silva, J., & Bay-Schmith, E. (2018, June 26). The impact of kraft pulp effluent on egg survival and hatching success in two species of Clupeiformes (Teleostei). *Environmental Science and Pollution Research*, 25, 25269-25279. <https://doi.org/10.1007/s11356-018-2583-0>
- Lovekin, D., & Heerema, D. (2019, March). *The true cost of energy in remote communities: Understanding diesel electricity generation terms and economics*. Pembina Institute. <https://www.pembina.org/reports/diesel-cost-backgrounder-2019.pdf>
- Lucas, B.G., Johannessen, D., & Lindstrom, S. (2007). Appendix e: Marine plants. In B.G. Lucas, S. Verrin, & R. Brown (Eds.), *Ecosystem overview: Pacific north coast integrated management area (PNCIMA)* (pp. 1-23). Fisheries and Oceans Canada.
- Mackas, D., Peña, A., Johannessen, D., Birch, R., Borg, K., & Fissel, D. (2007). Appendix d: Plankton. In B.G. Lucas, S. Verrin, & R. Brown (Eds.), *Ecosystem overview: Pacific north coast integrated management area (PNCIMA)* (pp. 1-33). Fisheries and Oceans Canada.
- Maisonneuve, J., Pillay, P., & Laflamme, C.B. (2015a, September). Osmotic power potential in remote regions of Quebec. *Renewable Energy*, 81, 62-70. <http://dx.doi.org/10.1016/j.renene.2015.03.015>
- Maisonneuve, J., Pillay, P., & Laflamme, C.B. (2015b, March). Pressure-retarded osmotic power system model considering non-ideal effects. *Renewable Energy*, 75, 416-424. <http://dx.doi.org/10.1016/j.renene.2014.10.011>

Marin-Coria, E., Silva, R., Enriquez, C., Martinez, M.L., & Mendoza, E. (2021). Environmental assessment of the impacts and benefits of a salinity gradient energy pilot plant. *Energies*, 14(11), 3252, <https://doi.org/10.3390/en14113252>

Marine Planning Partnership Initiative. (2015). *Central coast marine plan*.
http://mappocean.org/wp-content/uploads/2015/08/MarinePlan_CentralCoast_10082015.pdf

Matsuyama, K., Makabe, R., Ueyama, T., Sakai, H., Saito, K., Okumura, T., Hayashi, H., & Tanioka, A. (2021, February, 1). Power generation system based on pressure retarded osmosis with a commercially available hollow fiber PRO membrane module using seawater and freshwater. *Desalination*, 499, 114805.
<https://doi.org/10.1016/j.desal.2020.114805>

Mehrtens, F. (2022, August 18). *Noise affects life on the seafloor*. Phys.org.
<https://phys.org/news/2022-08-noise-affects-life-seafloor.html>

Mertens, A., Zhang, D., Qi, L., Ye, J., & Mityok, Z. (2015). *Biodiversity and old growth in the Great Bear Rainforest*. The University of British Columbia.
<https://environment.geog.ubc.ca/biodiversity-and-old-growth-in-the-great-bear-rainforest/>

McCarthy, S. (2016, November 23). *Push to end energy poverty in Indigenous communities underway*. The Globe and Mail. <https://www.theglobeandmail.com/news/national/the-push-to-end-energy-poverty-in-indigenous-communities/article33012480/>

McConaughey, R.A., & Smith, K. R. A. (2000, December 20). Associations between flatfish abundance and surficial sediments in the eastern Bering Sea. *Canadian Journal of Fishes*

and Aquatic Sciences, 57: 2410-2419.

<https://www.researchgate.net/publication/237175269>

Mishra, S., Tripathi, A., Tripathi, D.K., & Chauhan, K. (2015, November 13). Role of sedges (Cyperaceae) in wetlands, environmental cleaning and as food material. In M.M. Azooz & P. Ahmad (Eds), *Plant-environment interaction responses and approaches to mitigate stress*. (pp.185-198). John Wiley & Sons, Incorporated.

Mitigokaa Development Corp. (2022). *The impact of diesel*. <https://mitigokaa.com/the-impact-of-diesel/>

Modreski, V.A. (n.d.). *What role do marine worms play in the ecosystem?* Mom.

<https://animals.mom.com/role-marine-worms-play-ecosystem-11067.html>

Moody, M.F. (2008, March). *Eulachon past and present* [Unpublished thesis]. The University of British Columbia.

Natural Resources Canada. (2011, August). *Status of remote/off grid communities in Canada*.

https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/canmetenergy/files/pubs/2013-118_en.pdf

Newby, A.N., Bartholomew, T.V., & Mauter, M.S. (2021, May 3). The economic infeasibility of salinity gradient energy via pressure retarded osmosis. *ACS ES&T Engineering*, 1(7),

1113-1121. DOI: 10.1021/acsestengg.1c00078

Nichols, T.A., Anderson, T.W., & Širvoić, A. (2015, September 24). Intermittent noise induces psychological stress in a coastal marine fish. *PLoS ONE*, 10(9), e0139157.

[doi:10.1371/journal.pone.0139157](https://doi.org/10.1371/journal.pone.0139157)

Nikolich, K., Halliday, W.D., Pine, M.K., Cox, K., Black, M., Morris, C., & Juanes, F. (2021, January 28). The sources and prevalence of anthropogenic noise in Rockfish

- Conservation Areas with implications for marine reserve planning. *Marine Pollution Bulletin*, 164, 112017. <https://doi.org/10.1016/j.marpolbul.2021.112017>
- Nilsen, E.B., Hapke, W.B., McIlraith, B., & Markovchick. (2015, March 3). Reconnaissance of contaminants in larval Pacific lamprey (*Entopneustes tridentatus*) tissues and habitats in the Columbia River Basin, Oregon and Washington, USA. *Environmental Pollution*, 20, 121-130. <http://dx.doi.org/10.1016/j.envpol.2015.03.003>
- Nokolich, K., Halliday, W.D., Pine, M.K., Cox, K., Black, M., Morris, C., & Juanes, F. (2021, March). The sources and prevalence of anthropogenic noise in Rockfish Conservation Areas with implications for marine reserve planning. *Marine Pollution Bulletin*, 164, 112017. DOI: 10.1016/j.marpolbul.2021.112017
- NOAA Technical Memorandum. (n.d.). *Guide to the gadiform fishes of the eastern north pacific*. https://apps-afsc.fisheries.noaa.gov/Publications/AFSC-TM/TM-309_GadiformGuide-Press-Ready.pdf
- Nuxalk. (n.d.). *Preserving our way of life*. http://www.nuxalk.net/html/way_of_life.htm
- Ocean Alliance. (2021). *One of the greatest threats whales face: and what are we doing about it*. <https://whale.org/noise-pollution/>
- Okampo, E.J., Nwulu, N., & Bokoro, P.N. (2022, March 11). Economic and reliability assessment of hybrid PRO-RO desalination systems using brine for salinity gradient energy production. *Sustainability*, 14, 3328. <https://doi.org/10.3390/su14063328>
- O'Neill, S.M., Carey, A., J., Lanksbury, J.A., Niewolny, L.A., Ylitalo, G., Johnson, L., & West, J.E. (2015, October). *Toxic contaminants in juvenile Chinook salmon (Oncorhynchus tshawytscha) migrating through estuary, nearshore and offshore habitats of Puget Sound*.

Washington Department of Fish and Wildlife.

<https://wdfw.wa.gov/sites/default/files/publications/01796/wdfw01796.pdf>

Palko, H.C. (2017). *Exploring potential sites for salinity gradient renewable energy on the North Carolina coast and evaluating the potential effects of local salinity regime variation on SAV communities due to reverse electrodialysis effluent* [Unpublished thesis]. University of North Carolina.

Peters, M. (2022, June 6). *The ancient trees of British Columbia's Great Bear Rainforest*.

Natural Habitat Adventures. https://www.nathab.com/blog/ancient-trees-british-columbias-great-bear-rainforest/?utm_source=rss&utm_medium=rss&utm_campaign=ancient-trees-british-columbias-great-bear-rainforest

Perez, T., Sarrazin, L., Reboullon, P., & Vacelet, J. (2002, November 29). First evidence of surfactant biodegradation by marine sponges (Porifera): an experimental study with a linear alkylbenzenesulfonate. *Hydrobiologia*, 489, 225-233.

<https://doi.org/10.1023/A:1023217218585>

Pineda, M.C., Strehlow, B., Sternel, M., Duckworth, A., Jones, R., & Webster, N.S. (2017, July 10). Effects of suspended sediments on the sponge holobiont with implications for dredging management. *Scientific Reports*, 7: 4925. DOI:10.1038/s41598-017-05241-z

Power Technology. (2009, October 29). *Statkraft osmotic power plant*. <https://www.power-technology.com/projects/statkraft-osmotic/>

Purcell, J.E., Uye, S., Lo, W.T. (2007, November 22). Anthropogenic causes of jellyfish blooms and their direct consequences for humans: a review. *Marine Ecology Progress Series*. 350, 153-174. doi: 10.3354/meps07093

- Ramesh, C., Tulasi, B.R., Raju, M., Thakur, N., & Dufossé L. (2021, May 26). Marine natural products from tunicates and their associated microbes. *Marine Drugs*, 19(6):308.
<https://doi.org/10.3390/md19060308>
- Ricker, K.E., & McDonald, J.W. (1995, December). Biophysical evaluation of the central coast of British Columbia with special reference to aquaculture. *Province of British Columbia*.
<https://www.for.gov.bc.ca/hfd/library/documents/Bib92851.pdf>
- Roberts, D.A., Johnston, E.L., Knott, N.A. (2010). Impacts of desalination plant discharges on the marine environment: a critical review of published studies. *Water Research*, 44(18), 5117-5128. doi:10.1016/j.watres.2010.04.036
- Rural Coordination Center of BC. (2021). *Bella Coola/ Nuxalk Nation*. <https://rccbc.ca/bella-coola/>
- Sang, Y., Karayaka, H.B., Yan, Y., Yilmaz, N., & Souders, D. (2018). Ocean (marine) energy. *Comprehensive Energy Systems*, 1,733-769. <https://doi.org/10.1016/B978-0-12-809597-3.00120-6>
- Schaetzle, O., & Buisman, C.J.N. (2015, June). Salinity gradient energy: current state and new trends. *Engineering Sciences Press*, 1(2), 164-166. <https://doi.org/10.15302/J-ENG-2015046>
- Schweigert, J., Wood, C., Hay, F., McAllister, M., Boldt, J., McCarter, B., Therriault, T.W., & Brekke, H. (2012). *Recovery potential assessment of eulachon (Thaleichthys pacificus) in Canada*. Fisheries and Oceans Canada.
https://publications.gc.ca/collections/collection_2013/mpo-dfo/Fs70-5-2012-098-eng.pdf

- Schwinge, J., Neal, P.R., Wiley, D.E., Fletcher, D.F., & Fane, A.G. (2004, October 15). Spiral wound modules and spacer: review and analysis. *Journal of Membrane Sciences*, 242(1-2), 192-153. doi:10.1016/j.memsci.2003.09.031
- Seyfried, C., Palko, H., & Dubbs, L. (2019). Potential local environmental impacts of salinity gradient energy: a review. *Renewable and Sustainable Energy Reviews*, 102, 111-120, <https://doi.org/10.1016/j.rser.2018.12.003>
- Smart, A. (2019, March 8). *Should B.C. adopt a seal hunt? Scientists warn of consequences*. CTV News. <https://bc.ctvnews.ca/should-b-c-adopt-a-seal-hunt-scientists-warn-of-consequences-1.4328469>
- Statkraft. (2013, December 20). *Statkraft halts osmotic power investments*. <https://www.statkraft.com/newsroom/news-and-stories/archive/2013/Statkraft-halts-osmotic-power-investments/>
- Stephen, J. & Mabee, W. (2016, April 19). *District vs. decentralized bioheat: case study of Bella Coola.BC*. University of British Columbia & Queens University. https://cribe.ca/old/assets/Bioheat_Workshops/7_P1_Jamie_Stephen_Torchlight.pdf
- Stephenson, I., Steenkiste, N.W.L.V., & Leander, B.S. (2018, June 21). Molecular phylogeny of neodalyellid flatworms (Rhabdozoa) including three new species from British Columbia. *Journal of Zoological Systematics and Evolutionary Research*, 57(1), 41-56. DOI: 10.1111/jzs.12243
- Stocker, M. (2002). Ocean bio-acoustics and noise pollution: Fish mollusks and other sea animals' use of sounds, and the impact of anthropogenic noise in the marine acoustic environment. *Soundscape Journal of Acoustic Ecology*, 3(2), 4. https://ocr.org/wp-content/uploads/Ocean_bio-acoustics_and_Noise_Pollution_OCR.pdf

- SUEZ. (2017). *Water technologies & solutions fact sheet*. Retrieved: June 20th, 2022
<https://www.watertechnologies.com/products/membrane-chemicals/ro-membrane-antiscalants>
- Supple, D. (n.d.). *Units & conversion facts sheet*. Massachusetts Institute of Technology.
<https://cngcenter.com/wp-content/uploads/2013/09/UnitsAndConversions.pdf>
- Technology Brief. (2014). *Salinity gradient energy*.
<https://www.irena.org/publications/2014/Jun/Salinity-gradient>
- Thompson, P.M., Hastie, G.D., Nedwell, J., Barham, R., Brookes, K.L., Cordes, L.S., Bailey, H., & McLean, N. (2013, June 29). Framework for assessing impacts of pile-driving noise from offshore wind farm construction on a harbour seal population. *Environmental Impact Assessment Review*, 43, 73-85. <http://dx.doi.org/10.1016/j.eiar.2013.06.005>
- Thompson, C. (2019). *Nuxalk Nation pursuing hydro project*. Coast Mountain News.
<https://www.coastmountainnews.com/news/nuxalk-nation-pursuing-hydro-project/>
- Thomson, J. (2019, February 11). *How can Canada's North get off diesel?* The Narwhal.
<https://thenarwhal.ca/how-canadas-north-get-off-diesel/>
- Trading Economics. (2022). *Crude oil*. Retrieved: August 7, 2022, from
<https://tradingeconomics.com/commodity/crude-oil>
- Turner, N.J., Harvery, T., Burgess, S., Kuhnlein, H.V. (1981-1006). *The Nuxalk food and nutrition program, coastal British Columbia, Canada: 1981-2006*. Indigenous Peoples food systems. http://www.nuxalk.net/media/nuxalk_food.pdf
- United Nations. (n.d.). *Do you know all 17 SDGs?* <https://sdgs.un.org/goals>

- University of British Columbia. (2020, June 11). *Recovery of sea otter populations yield more benefits than costs*. <https://oceans.ubc.ca/2020/06/11/recovery-of-sea-otter-populations-yields-more-benefits-than-costs/>
- Van Isle Marine. (n.d.). *Kinds of groundfish in BC waters*. <https://vanislemarina.com/kinds-of-groundfish-in-bc-waters/>
- Vazzana, M., Mauro, M., Ceraulo, M., Dioguardi, M., Papale, E., Mazzola, S., Arizza, V., Beltrame, F., Inguglia, L., & Buscaino, G. (2020, April). Underwater high frequency noise: Biological responses in sea urchin *Arbacia lixula* (Linnaeus, 1758). *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*, 242, 110650. <https://doi.org/10.1016/j.cbpa.2020.110650>
- Vermaas, D. (2013). Energy generation from mixing salt water and freshwater: Smart flow strategies for reverse electrodialysis [Published PhD thesis. University of Twente]. University of Twente. DOI: 10.3990/1.9789036535731
- Walsh, J.C., Connors, K., Hertz, E., Kehoe, L., Martin, T.G. Connors, B., Frid, A., Freshwater, C., Price, M.H.H., Reynolds, J.D. (2020). *BC central coast: prioritizing strategies for pacific salmon recovery and persistence*. Pacific Salmon Foundation. https://www.taramartin.org/wp-content/uploads/2020/12/BC-Central-Coast_-Prioritizing-Strategies-for-Pacific-Salmon-Recovery-and-Persistence.pdf
- Water Temp. (n.d.). *Water and sea temperature in the North Bentinck Arm*. Retrieved: June 20th, 2022. <https://www.watertemp.org/Canada/British-Columbia/North-Bentinck-Arm/>
- Weilgart, L. (2018, May 1). *The impact of ocean noise pollution on fish and invertebrates*. Dalhousie University. Oceancare & Dalhousie University.

- https://www.oceancare.org/wp-content/uploads/2017/10/OceanNoise_FishInvertebrates_May2018.pdf
- Westerberg, H., Rönnbäck, P., & Frimansson, H. (1996). Effects of suspended sediments on cod egg and larvae and on behaviour of adult herring and cod. *International Council for the Exploration of the Sea*. <https://www.researchgate.net/publication/348995455>
- Wheeler. (n.d.). *Scorpaeniform*. Britannica. <https://www.britannica.com/animal/scorpaeniform>
- Witman, S. (2017, September 13). World's biggest oxygen producers living in swirling ocean waters. EOS. <https://eos.org/research-spotlights/worlds-biggest-oxygen-producers-living-in-swirling-ocean-waters>
- Woods, C. (2015, July 22). *Mediterranean whales bear the brunt of industry's historic toxins*. PBS News Hour. <https://www.pbs.org/newshour/science/mediterranean-whales-bear-the-brunt-of-industrys-historic-toxins>
- WWF. (n.d.). *Leatherback turtle*. <https://www.worldwildlife.org/species/leatherback-turtle>
- Yip, N. Y., & Elimelech, M. (2011, October 24). Performance limiting effects in power generation from salinity gradients by pressure retarded osmosis. *Environmental Science & Technology*, 45, 10273-10282. [dx.doi.org/10.1021/es203197e](https://doi.org/10.1021/es203197e)
- Yip, N.Y., & Elimelech, M. (2014, August 26). Comparison of energy efficiency and power density in pressure retarded osmosis and reverse electro dialysis. *Environmental Science & Technology*, 48, 11002-11012. [dx.doi.org/10.1021/es5029316](https://doi.org/10.1021/es5029316) |
- Zhao, X., Sun, S., Shi, W., Sun, X., Zhang, Y., Zhu, L., Sui, Q., Xia, B., Qu, K., Chen, B., & Liu, G. (2021, December 23). Mussel byssal attachment weakened by anthropogenic noise. *Frontiers in Marine Science*, 8(821019), 1-12. [doi:10.3389/fmars.2021.82101](https://doi.org/10.3389/fmars.2021.82101)

Appendix A

Osmotic Pressure Calculations

$$i_v = 2 \text{ for NaCl}$$

$$Rg = \frac{8.314\text{J}}{\text{k} * \text{mol}}$$

$$T=284.15 \text{ K}$$

$$\Delta c= 35\text{g/l}$$

$$M= 58.44 \text{ g/mol for NaCl}$$

$$\Delta\pi \text{ (Pa)} \approx i_v * Rg * T * \Delta c/M$$

$$\Delta\pi \text{ (Pa)} \approx \frac{2 * \frac{8.314\text{J}}{\text{k} * \text{mol}} * 284.15 \text{ K} * \frac{35\text{g}}{\text{l}} * 1000 \frac{\text{l}}{\text{m}^3}}{58.44 \frac{\text{g}}{\text{mol}}}$$

$$\Delta\pi \text{ (Pa)} \approx 2,829,733.35 \frac{\text{J}}{\text{m}^3}$$

$$J = 2.77778 * 10^{-7} \text{kWh}$$

$$\Delta\pi \approx 2,829,733.35 \frac{\text{J}}{\text{m}^3} * 2.77778 * 10^{-7} \frac{\text{kWh}}{\text{J}}$$

$$\Delta\pi \approx 0.786 \frac{\text{kWh}}{\text{m}^3}$$

Appendix B

Energy Produced by Diesel Calculations

Without the Nooklikonnik Creek hydroelectric facility 2015

Bella Coola 2015 diesel use= 1,731,535 liters

$$\text{Energy Produced (kWh)} = \text{Diesel Use (l)} * \frac{35.8\text{MJ}}{\text{l}} * \frac{\text{kWh}}{3.6\text{MJ}}$$

$$\text{Energy Produced (kWh)} = 1,731,535 \text{ (l)} * \frac{35.8\text{MJ}}{\text{l}} * \frac{\text{kWh}}{3.6\text{MJ}}$$

$$\text{Energy Produced (kWh)} = 17,219,153 \text{ kWh/year}$$

$$\text{Energy Produced (MWh)} = 17,219.153\text{MWh/year}$$

Without the Nooklikonnik Creek hydroelectric facility 2017

Bella Coola 2017 diesel use= 2.36 million liters

$$\text{Energy Produced (kWh)} = \text{Diesel Use (l)} * \frac{35.8\text{MJ}}{\text{l}} * \frac{\text{kWh}}{3.6\text{MJ}}$$

$$\text{Energy Produced (kWh)} = 2,360,000 \text{ (l)} * \frac{35.8\text{MJ}}{\text{l}} * \frac{\text{kWh}}{3.6\text{MJ}}$$

$$\text{Energy Produced (kWh)} = 23,468,888.89\text{kWh/year}$$

$$\text{Energy Produced (MWh)} = 23,468.9\text{MWh/year}$$

With the Nooklikonnik Creek hydroelectric facility

Bella Coola 2017 diesel use= 2.36 million liters

Nooklikonnik hydroelectric facility to reduce annual diesel use in Bella Coola by 80%

(Thompson, 2019).

Bella Coola 2017 diesel use= 2.36 million liters* 0.8= 1,888,000 liters

$$\text{Energy Produced (kWh)} = \text{Diesel Use (l)} * \frac{35.8\text{MJ}}{\text{l}} * \frac{\text{kWh}}{3.6\text{MJ}}$$

$$\text{Energy Produced (kWh)} = 1,888,000 \text{ (l)} * \frac{35.8\text{MJ}}{\text{l}} * \frac{\text{kWh}}{3.6\text{MJ}}$$

$$\text{Energy Produced (kWh)} = 4,693,777.8\text{kWh/year}$$

$$\text{Energy Produced (MWh)} = 4694\text{MWh/year}$$

Energy Produced by Diesel January 2017

Bella Coola January 2017 diesel use= 190,000 liters

$$\text{Energy Produced (kWh)} = 190,000 \text{ (l)} * \frac{35.8\text{MJ}}{\text{l}} * \frac{\text{kWh}}{3.6\text{MJ}}$$

$$\text{Energy Produced (kWh)} = 1,949,111\text{kWh/year}$$

$$\text{Energy Produced (MWh)} = 1949.1\text{MWh/year}$$

Appendix C

Watershed Flow Rate Needed to Replace Diesel Using PRO

Flow Rate Needed to Replace January 2017 Diesel Use

$$\text{Energy use} = 1,949,111 \left(\frac{kWh}{\text{Month}} \right)$$

$$\text{Osmotic pressure} = 0.786 \left(\frac{kWh}{m^3} \right)$$

$$\text{Flow Rate} \frac{m^3}{s} = \frac{\text{Electric Energy Use} \left(\frac{kWh}{\text{Month}} \right) * \frac{\text{Month}}{31 \text{ days}} * \frac{\text{day}}{86400s}}{\text{Osmotic Pressure} \left(\frac{kWh}{m^3} \right)}$$

$$\text{Flow Rate} \frac{m^3}{s} = \frac{1,949,111 \left(\frac{kWh}{\text{Month}} \right) * \frac{\text{Month}}{31 \text{ days}} * \frac{\text{day}}{86400s}}{0.786 \left(\frac{kWh}{m^3} \right)}$$

$$\text{Flow Rate} \frac{m^3}{s} = 0.926 \frac{m^3}{s}$$

Flow Rate Needed to Replace Average Monthly Diesel Use with PRO with the Nooklikonnik

Creek Hydroelectric Facility

$$\text{Energy use} = 4,693,778 \left(\frac{kWh}{\text{yr}} \right)$$

$$\text{Osmotic pressure} = 0.786 \left(\frac{kWh}{m^3} \right)$$

$$\text{Flow Rate} \frac{m^3}{s} = \frac{\text{Electric Energy Use} \left(\frac{kWh}{\text{yr}} \right) * \frac{1 \text{ yr}}{365 \text{ days}} * \frac{\text{day}}{86400s}}{\text{Osmotic Pressure} \left(\frac{kWh}{m^3} \right)}$$

$$\text{Flow Rate} \frac{m^3}{s} = \frac{4,693,778 \left(\frac{kWh}{\text{yr}} \right) * \frac{1 \text{ yr}}{365 \text{ days}} * \frac{\text{day}}{86400s}}{0.786 \left(\frac{kWh}{m^3} \right)}$$

$$\text{Flow Rate} \frac{m^3}{s} = 0.19 \frac{m^3}{s}$$

Appendix D

LCOE Calculations

Current Cost of PRO Membranes

2014 Cost EUR= 10-30 (\$/m²)

2014 EUR to CAD exchanger rate= \$1.467CAD to \$1 EUR

2014 to 2022 CAD inflation rate= 22.93%

$$\text{Current Cost CAD} = 2014 \text{ Cost EUR} * \frac{\$1.467 \text{ CAD}}{\$1 \text{ EUR}} * 0.2293$$

$$\text{Current Cost CAD} = 10(\$/\text{m}^2) * \frac{\$1.467 \text{ CAD}}{\$1 \text{ EUR}} * 0.2293$$

$$\text{Current Cost CAD} = 30(\$/\text{m}^2) * \frac{\$1.467 \text{ CAD}}{\$1 \text{ EUR}} * 0.2293$$

Current Cost CAD= 18-54.1(\$/m²)

Optimal Cost of PRO Membranes

2014 Cost EUR= 2-5 (\$/m²)

2014 EUR to CAD exchanger rate= \$1.467CAD to \$1 EUR

2014 to 2022 CAD inflation rate= 22.93%

$$\text{Optimal Cost CAD} = 2014 \text{ Cost EUR} * \frac{\$1.467 \text{ CAD}}{\$1 \text{ EUR}} * 0.2293$$

$$\text{Optimal Cost CAD} = 2(\$/\text{m}^2) * \frac{\$1.467 \text{ CAD}}{\$1 \text{ EUR}} * 0.2293$$

$$\text{Optimal Cost CAD} = 5(\$/\text{m}^2) * \frac{\$1.467 \text{ CAD}}{\$1 \text{ EUR}} * 0.2293$$

Optimal Cost CAD= 3.6-9(\$/m²)

Current LCOE Calculations

Current power density= 0.0016- 0.0029 (kW/m²)

Current Cost CAD= 18-54.1(\$/m²)

$$LCOE \left(\frac{\$}{kWh} \right) = \frac{\text{Membrane Cost} \left(\frac{\$}{m^2} \right)}{\text{Net Power Density} \left(\frac{kW}{m^2} \right) * 5 \text{ yrs} * 4 \text{ replacements} * 330 \frac{\text{days}}{\text{yr}} * \frac{24 \text{ hrs}}{\text{day}}} 0.1$$

$$LCOE \left(\frac{\$}{kWh} \right) = \frac{18 \left(\frac{\$}{m^2} \right)}{0.0016 \left(\frac{kW}{m^2} \right) * 5 \text{ yrs} * 4 \text{ replacements} * 330 \frac{\text{days}}{\text{yr}} * \frac{24 \text{ hrs}}{\text{day}}} 0.1$$

$$LCOE \left(\frac{\$}{kWh} \right) = 0.7$$

$$LCOE \left(\frac{\$}{kWh} \right) = \frac{18 \left(\frac{\$}{m^2} \right)}{0.0029 \left(\frac{kW}{m^2} \right) * 5 \text{ yrs} * 4 \text{ replacements} * 330 \frac{\text{days}}{\text{yr}} * \frac{24 \text{ hrs}}{\text{day}}} 0.1$$

$$LCOE \left(\frac{\$}{kWh} \right) = 1.178$$

$$LCOE \left(\frac{\$}{kWh} \right) = \frac{54.1 \left(\frac{\$}{m^2} \right)}{0.0016 \left(\frac{kW}{m^2} \right) * 5 \text{ yrs} * 4 \text{ replacements} * 330 \frac{\text{days}}{\text{yr}} * \frac{24 \text{ hrs}}{\text{day}}} 0.1$$

$$LCOE \left(\frac{\$}{kWh} \right) = 2.13$$

$$LCOE \left(\frac{\$}{kWh} \right) = \frac{54.29 \left(\frac{\$}{m^2} \right)}{0.0029 \left(\frac{kW}{m^2} \right) * 5 \text{ yrs} * 4 \text{ replacements} * 330 \frac{\text{days}}{\text{yr}} * \frac{24 \text{ hrs}}{\text{day}}} 0.1$$

$$LCOE \left(\frac{\$}{kWh} \right) = 1.18$$

Optimal LCOE Calculations

Optimal Cost CAD= 3.6-9(\$/m²)

Optimal power density= 0.005 (kW/m²)

$$LCOE \left(\frac{\$}{kWh} \right) = \frac{\text{Membrane Cost} \left(\frac{\$}{m^2} \right)}{0.1 \cdot \text{Net Power Density} \left(\frac{kW}{m^2} \right) * 5 \text{ yrs} * 4 \text{ replacements} * 330 \frac{\text{days}}{\text{yr}} * \frac{24 \text{ hrs}}{\text{day}}}$$

$$LCOE \left(\frac{\$}{kWh} \right) = \frac{3.6 \left(\frac{\$}{m^2} \right)}{0.1 \cdot 0.005 \left(\frac{kW}{m^2} \right) * 5 \text{ yrs} * 4 \text{ replacements} * 330 \frac{\text{days}}{\text{yr}} * \frac{24 \text{ hrs}}{\text{day}}}$$

$$LCOE \left(\frac{\$}{kWh} \right) = 0.045$$

$$LCOE \left(\frac{\$}{kWh} \right) = \frac{9 \left(\frac{\$}{m^2} \right)}{0.1 \cdot 0.005 \left(\frac{kW}{m^2} \right) * 5 \text{ yrs} * 4 \text{ replacements} * 330 \frac{\text{days}}{\text{yr}} * \frac{24 \text{ hrs}}{\text{day}}}$$

$$LCOE \left(\frac{\$}{kWh} \right) = 0.11$$

Appendix E

CO₂ Emissions from Diesel Use

CO₂ Emissions from Diesel Use in 2015

Bella Coola 2015 diesel use= 1,731,535 liters

$$kg\ CO_2 = Diesel\ Use\ (l) * \frac{2.68\ kg\ CO_2}{Diesel\ (l)}$$

$$kg\ CO_2 = 1,735,535\ (l) * \frac{2.68\ kg\ CO_2}{Diesel\ (l)}$$

$$kg\ CO_2 = 4,643,482$$

CO₂ Emissions from Diesel Use in 2017

Bella Coola 2017 diesel use= 2.36 million liters

$$kg\ CO_2 = Diesel\ Use\ (l) * \frac{2.68\ kg\ CO_2}{Diesel\ (l)}$$

$$kg\ CO_2 = 2,360,000\ (l) * \frac{2.68\ kg\ CO_2}{Diesel\ (l)}$$

$$kg\ CO_2 = 6,328,846$$

Appendix F

Plankton

Source	Classification	Examples	Ecological Importance	Potential Impacts from PRO
Drami et al., 2011; Mackas et al., 2007; Seyfried et al., 2019; Ricker & McDonald, 1995; Witman, 2017	Phytoplankton	Diatoms, Dinoflagellates, Silicates	Phytoplankton convert inorganic carbon to organic carbon that higher trophic levels can take up. Phytoplankton also produce an estimated 80% of oxygen globally.	Noise pollution can cause mortality of phytoplankton. Phytoplankton can also get sucked up by the intake and killed during water treatment. Increased sediment in the water column from PRO can limit infrared radiation from penetrating through the water's surface thus impacting phytoplankton's ability to photosynthesize. Increased turbidity at the discharge site coupled with salinity, thermal, and chemical pollution found in the effluent will likely decrease phytoplankton populations at the effluent discharge site.

Table continues...

Source	Classification	Examples	Ecological Importance	Potential Impacts from PRO
Drami et al., 2011; Mackas et al., 2007; Seyfried et al., 2019	Zooplankton	Fish, Invertebrates	Zooplankton often consist of the planktonic life stage of fish and invertebrates. They are also an important food source for higher trophic levels.	Impacts from noise pollution and introduced pollutants can cause zooplankton to experience impacts to development and can cause large mortalities of zooplankton in the region. They can also get sucked up by the intake and killed during treatment. Zooplankton populations will likely decrease at effluent discharge zones.
Drami et al., 2011; Mackas et al., 2007	Bacterioplankton-	Decomposers	Bacterioplankton break down non-living organic matter and return those nutrients to the environment to be available to other species.	A lot is unknown about bacterioplankton. However, based on the literature, it is likely that noise, introduced pollutants, and intake areas will all potentially cause morphological and behavioral impacts as well as mortality. Bacterioplankton populations will likely decrease at effluent discharge zones.

Appendix G

Aquatic Vegetation

Source	Classification	Examples	Ecological Importance	Potential Impacts from PRO
Lucas et al., 2007; Seyfried et al., 2019	Kelp	<i>Nereocystis luetkeana</i> , <i>Macrocystis integrifolia</i>	Kelp creates a habitat for many aquatic invertebrates, fish, and birds. Kelp are important for photosynthesis.	There is very little research on how PRO may affect kelp in the region. However, increased sedimentation and pollutants introduced in the region from PRO could potentially impact kelp, especially if increased sedimentation prevents kelp from photosynthesizing.
Lucas et al., 2007; Palko, 2017; Roberts, et al., 2010; Seyfried et al., 2019	Eelgrass	<i>Zostera marina</i>	Eelgrass creates a habitat for many aquatic invertebrates, fish, and birds. Eelgrass is important for photosynthesis.	Eelgrass is quite sensitive and, as a result, can be severely impacted by changes to the environment. It is possible that chemicals in the effluent and increased sedimentation in the water caused from PRO could affect eelgrass. Fortunately, it is unlikely that the salt brine will impact eelgrass in Bella Coola because this proposal focuses on a seawater draw.

Appendix H

Terrestrial Vegetation

Source	Classification	Examples	Ecological Importance	Potential Impacts from PRO
Crooks, 2021; Fisheries and Oceans Canada, 1981; Harris, 2008	Bryophytes	<i>Hylocomium splendens</i> , <i>Leucolepsis menziessi</i> , <i>Plagiomium insigne</i> , <i>Pogonatum spp.</i> , <i>Ptilium ostrictacastrens-is</i> , <i>Rhizomnium glabrescens</i> , <i>Rhytidiadelphus loreus</i> , <i>R. triquetrus</i> , <i>Strokesiell oregana</i>	Bryophytes are essential to the environment's overall health because they are able to survive in infertile soil. They then absorb nutrients and water, which can be absorbed into the soil, making it healthier and more habitable for other plant species. Although it is thought that bryophytes may play a role in traditional medicines of the First Nations people on the west coast, they have been understudied in western science.	Impact to bryophytes include temporary or permanent removal at and around the site where a PRO facility would be built in Bella Coola.
Fisheries and Oceans Canada, 1981; Hoffman Nursery, n.d. Mishra et al., 2016	Rushes and Sedges	Lygbye's Sedge, Spike Rush, Baltic Rush	Rushes and sedges are ecologically important in a wetland environment. Sedges create food for animals and humans, remove toxins from the water, and prevent erosion as they have an extensive root network.	Impacts to rushes and sedges include temporary or permanent removal at and around the site where a PRO facility would be built in Bella Coola.

Table continues...

Source	Classification	Examples	Ecological Importance	Potential Impacts from PRO
Fisheries and Oceans Canada, 1981; Seyfried et al., 2019; Turner et al., 1981-2006	Forbes and Herbs	Yarrow, Baneberry, Foxtail, Wild Sarsaparilla, Lady Fern, Paintbrush, Prince's Pine, Enchanter's Night Shade, Queen's Cup, Northern Comandra, Spotted Coral Root, Coral Root Orchid, Bunchberry, Tufted Hairgrass, Rough Fruited Fairy-Bell, Spiny Wood-Fern, Fireweed, Fragrant Bedstraw, Western Rattlesnake Plantain, Oak Fern, Large Round-Leaved Orchid, Cow- Parsnip, <i>Hippurie tetraphylla</i> , Marsh Pea, Twayblade, Running Club Moss, Skunk Cabbage, Cow-Wheat, Mint, Monkey-Flower, Sweet Gale, Water Parsley, Devil's Club, Seaside Plantain, Western Sword-Fern, Pacific Cinquefoil, One-Sided Bramble, Strawberry Bramble, Water Parsnip, Star-Flowered Solomon's Seal, Claspingleaved Twisted Stalk, Rosy Twisted- Stalk, Foam Flower, Clover, Seaside Arrowgrass, Stream Violet	Many species of Forbes and herbs are essential traditional foods and medicines of the Nuxalk First Nation. They are also important food for other terrestrial animals such as the Grizzly Bear.	Impacts to Forbes and herbs include temporary or permanent removal at and around the site where a PRO facility would be built in Bella Coola.

Table continues...

Source	Classification	Examples	Ecological Importance	Potential Impacts from PRO
Fisheries and Oceans Canada, 1981; Gottesfeld, 1992; Peters, 2022	Trees and Shrubs	Salal, Twin Flower, False Azalea, False Box, Stink Current, Black Gooseberry, Red Raspberry, thimbleberry, Salmonberry, Red Elderberry, Alaska Blueberry, Big Huckleberry, Oval-Leaf Blueberry, High Bush Cranberry, Red Huckleberry, Douglas Maple, Alder, Yellow Cedar, Engelmann Spruce, Whitebark Pine, Lodgepole Pine, Balsam Poplar, Aspen, Western Black Poplar, Willow, Western Red Cedar, Western Hemlock	Many old-growth trees and shrubs make up the temperate rainforest in Bella Coola. They provide important habitat and shelter for other vegetation and animals in the region. Bark from trees and shrubs can also be an essential source of food and medicine. Trees and shrubs are also important components to communities in the Great Bear Rainforest because bark and wood materials can be used as building materials.	Impacts to trees and shrubs include temporary or permanent removal at and around the site where a PRO facility would be built in Bella Coola.

Appendix I

Invertebrates

Source	Classification	Examples	Ecological Importance	Potential Impacts from PRO
Fisheries and Oceans Canada, 1981; Fisheries and Oceans Canada, 2010-2015; Perez et al., 2002; Pineda et al, 2017; Seyfried et al., 2019;	Porifera	<i>Esperiopsis rigida</i> , <i>Aphrocallistes spp.</i> , <i>Chonelasma spp.</i>	Porifera, more commonly known as sponges create important habitat and nursery grounds for juvenile fish. Although there is a lack of information on this topic, it is thought that sponges may be able to detoxify the water column as they filter feed.	Because sponges are filter-feeding organisms, an increase in sedimentation caused by the construction and decommissioning of a PRO facility could impact sponges' ability to feed. If sedimentation is too significant, sponges could potentially die. Sponges have significant resistance to anthropogenically introduced chemicals in the water column.

Table continues...

Source	Classification	Examples	Ecological Importance	Potential Impacts from PRO
Fisheries and Oceans Canada, 1981; Graham et al., 2014; Ecology Center, 2022; Purcell et al., 2007; Seyfried et al., 2019; Weilgart, 2018	Cnidaria	<i>Pachycerianthys spp.</i> , <i>Actinosola spp.</i> , <i>Metridium spp.</i> , <i>Leioptilus spp.</i> , Hydroids, <i>Epizoanthus spp.</i> , <i>Aurelia spp.</i>	Cnidarians play a vital role in the carbon cycle because they feed on smaller trophic levels and then produce a fecal pellet that can be sequestered into the deep ocean more quickly. Cnidarians can also act as a refuge for other species that can hide within the tentacles of the cnidarian.	Increased noise pollution by PRO activity, especially during construction and decommission, can impact cnidarian statocysts which could cause disorientation. With the increase in activity in the area from a PRO facility being built, medusa stage cnidarians may avoid the area. Polyp stage cnidarians which are sessile and located on the benthos could be covered by increased sedimentation during the construction and decommissioning of PRO. Changes to hydrology and the introduction of anthropogenic waste products, could also create an environment that favors cnidarians. Too many cnidarians can also have negative environmental and economic impacts to the local environment as cnidarians could impede commercial fishing including aquaculture operations and clog intake zones of industrial facilities.

Table continues...

Source	Classification	Examples	Ecological Importance	Potential Impacts from PRO
Fisheries and Oceans Canada, 1981, Ramesh et al., 2021; Roberts et al., 2010; Seyfried et al., 2019	Chordata	<i>Ascidia paratrope</i>	<i>Ascidia paratrope</i> is within the tunicate phylum. Although a lot is still unknown about the role tunicates play in the environment, it is thought that they are an important source of marine natural products. They are also thought to influence the biodiversity of phytoplankton.	Because <i>Ascidia paratrope</i> is a sessile filter feeder, increased sedimentation caused by PRO construction and decommissioning in Bella Coola could impact tunicates' ability to feed. Ascidiarians are particularly sensitive to changes in water composition and the addition of pollutants. They are particularly sensitive to the introduction of copper that could be introduced into the water column both by effluent discharge and sedimentation.

Table continues...

Source	Classification	Examples	Ecological Importance	Potential Impacts from PRO
Alvarado, 2010; Fisheries and Oceans Canada, 1981; Government of Canada 2022a; Hall, 2022, Iovenko, 2018; Roberts et al., 2010; Seyfried et al., 2019; Vazzana et al., 2020	Echinoderms	<i>Strongylocentrotus drobachiensis</i> , <i>Pycnopterias spp.</i> , <i>Permasterias spp.</i> , <i>Solaster dawsoni</i> , <i>Henricia spp.</i> , <i>Pteraster spp.</i> , <i>Hippasteria spp.</i> , <i>Crossaster spp.</i> , <i>Evaneteriae spp.</i> , <i>Parastichopus spp.</i> , <i>Florametra spp.</i> , <i>Gorgonocephalus spp.</i> , <i>Ophiura spp.</i> , Sand Dollar, Sea Cucumber, Sea Urchin, Sea Star	There are five classes of echinoderms: Asteroidea, Ophiuroidea, Holothuroidea, Echinoidea, and Crinoidea. Different classes of echinoderms play different roles in British Columbian waters. For example, sea stars help keep kelp forests intact by feeding on kelp eating sea urchins	While not much is known about the total effects noise pollution has on echinoderms, it is likely they will elicit an increased stress response. Echinoderms populations are likely to decrease due to increased mineral presence in the water column, particularly with the introduction of copper that could be introduced from increased erosion and from the effluent itself. Coastal development causing erosion is one of the more significant threats to echinoderms as increased sediment in the water column can reduce echinoderm recruitment.

Table continues...

Source	Classification	Examples	Ecological Importance	Potential Impacts from PRO
Fisheries and Oceans Canada, 1981; Gartner, n.d.; Roberts et al., 2010; Seyfried et al., 2019	Bryozoa	<i>Heteropora spp.</i> , <i>Membranopora spp.</i> , <i>Phindolopora spp.</i>	Although there is a lack of research on the importance of bryozoans in British Columbia, it is thought that bryozoans are an essential food source for higher trophic levels.	Bryozoans are suspension feeders; as a result, increased sedimentation in the region caused by the construction and decommissioning of a PRO facility in Bella Coola could impact the feeding of bryozoans. Sedimentation could also completely cover these organisms, which could lead to mortality. Bryozoans are also sensitive to pollutants and minerals in the water column. Specifically, minerals such as copper that can end up in the water column from erosion and directly from effluent discharge zones.
Dheilly et al., 2022; Fisheries and Oceans Canada, 1981; Stephenson et al., 2018	Platyhelminthes	<i>Rhabdocalyptue spp.</i>	Not much is known about the role Platyhelminthes plays in the British Columbian environment; although it is thought that they can carry a variety of viruses.	Platyhelminthes are relatively fragile and even the slightest disturbance can result in mortality. Fortunately, Platyhelminthes are abundant on the BC coast, so while PRO activity may cause mortality, it likely won't have a significant impact on population sizes.

Table continues...

Source	Classification	Examples	Ecological Importance	Potential Impacts from PRO
Bhattacharya et al., 2016; Fisheries and Oceans Canada, 1981; Fortunato, 2015; Seyfried et al., 2019; Zhao et al., 2021	Mollusca	<i>Acteocina exima</i> , <i>Axinopsida serricata</i> , <i>Clinocardium nuttalli</i> , <i>Macoma spp.</i> , <i>Nucula tenuis</i> , <i>Psephidia lordi</i> , <i>Trophon spp.</i> , <i>Yolida spp.</i> , <i>Dirona aurantia</i> , <i>Fusitoiton spp.</i> , <i>Anisodoris spp.</i> , California Mussel, Clams, Cockles, Geoduck, Moon Snail, Olympia Oyster, Pacific Oyster, Giant Barnacles, Goose Barnacles, Limpet, Abalone, Octopus Opal Squid	Mollusks are fairly biodiverse and are important in shaping the aquatic environment and providing habitat for many other aquatic species. They are also important food sources for both aquatic animals and humans. There are also many filter feeders within the mollusk group that contribute to cleaning the water column and removing harmful toxins.	Noise associated with PRO construction and decommissioning can impact sessile mollusks by damaging their attachment appendages, such as the byssal threads in mussels. Many mollusks are also filter feeders, so increased sedimentation from the construction and decommissioning of PRO could potentially impact their feeding ability. Exposure to chemicals found in industrial effluent could cause a stress response in mollusks which could impact development.

Table continues...

Source	Classification	Examples	Ecological Importance	Potential Impacts from PRO
Fisheries and Oceans Canada, 1981; Mehrrens, 2022; Modreski, n.d.; Seyfried et al., 2019	Annelida	<i>Melinna cristata</i> , <i>Capitella capitata</i> , <i>Heteromastus filibranchus</i> , <i>Glycinde armigera</i> , <i>Lumbrinereis spp.</i> , <i>Cheilonereis spp.</i> , <i>Nereis spp.</i> , <i>Platynereis bicanaliculata</i> , <i>Ammotrypane aulogaster</i> , <i>Leitoscoloplos spp.</i> , <i>Pectinaria spp.</i> , <i>Anaitides spp.</i> , <i>Eteone spp.</i> , <i>Notophylum spp.</i> , <i>Sabellaria cementarium</i> , <i>Pholoe spp.</i> , <i>Protula spp.</i> , <i>Serpula spp.</i> , <i>Crucigera spp.</i>	Marine annelids or marine worms have critical roles in the aquatic environment. They are essential for helping break down non-living organic matter, and they burrow into the sediment, thus oxidizing the sediment and allowing other oxygen-dependent organisms to survive in that habitat.	Many marine worms are filter feeders. So, an increase in sedimentation from PRO construction and decommission could impact marine worms' eating ability and could potentially cause mortality. Noise pollution may reduce the range in which marine worms borrow and navigate the marine floor. Noise pollution may have cascading effects that impacts other species, and other trophic levels as functions such as nutrient distribution are affected.

Table continues...

Source	Classification	Examples	Ecological Importance	Potential Impacts from PRO
Barnes, 2022; Bunkley et al., 2017; Fisheries and Oceans Canada, 1981; Government of Canada, 2022a; Discover Life, n.d.; Seyfried et al., 2019	Arthropods	<i>Eogammarys spp.</i> , <i>Harpacticoida</i> , <i>Gadius spp.</i> , <i>Gnorinsphaero</i> , <i>aoregoinesis</i> , <i>Litholithodes spp.</i> , <i>Orgonia gracillis</i> , <i>Cermaster spp.</i> , <i>Branchoima spp.</i> , Dungeness Crab, King Crab, Red Rock Crab, Shore Crab, Shrimp	Arthropods make up 84% of all known species globally. They are highly diverse and responsible for a whole variety of ecological functions. Marine arthropods are a main food source for many marine and terrestrial species, including humans. They are also important decomposers.	Arthropods can be both sessile and motile. They feed in a variety of ways, from scavenging to filter feeding. As a result, increased activity due to PRO may cause species who can move out of the area to exhibit avoidance in the location of PRO operations. Sessile species' ability to eat may be impacted by increased sedimentation, which in extreme cases could cause mortality. Arthropods are incredibly diverse; as a result, impacts from PRO, such as noise pollution, will likely impact species differently.

Appendix J

Fish				
Source	Classification	Examples	Ecological Importance	Potential Impact from PRO
Fisheries and Oceans Canada 1981; Lamprey Surveys, n.d.; Nilsen et al., 2015	Petromyzontidae	River Lamprey	The presence of native river lamprey populations indicates the health of the overall ecosystem. Pacific lamprey are important sustenance for some Indigenous groups in western Canada and are important prey for other aquatic species.	Juvenile lampreys live in the silt of riverbeds. If PRO activity impacts this habitat, it could result in relocation and mortality of juvenile river lamprey. Fortunately, lampreys do not have a swim bladder, so impacts from noise pollution may not be as detrimental to river lamprey as it is to other fish species. Pollutants added to the water column from PRO activities may bioaccumulate in lamprey tissues.
Bornatowski et al., 2014; Chapuis, 2015; Fisheries and Oceans Canada 1981; Government of Canada, 2022a; Seyfried et al., 2019	Chondrichthyes	Basking Shark, Spiny Dogfish, Salmon Shark, Basking Shark, Tope Shar, Bluntnose Sixgill Shark, Brown Cat Shark, Great White Shark, Skate, Ratfish	Chondrichthyes hold crucial roles in the balance of marine food webs. Predations from species within Chondrichthyes can keep populations of lower trophic levels in check.	Chondrichthyes, like many other fish, have a lateral line that can detect vibrations in the water column and an inner ear to pick up on sounds. Their hearing is primarily sensitive to lower frequencies common with anthropogenic noise pollution. As a result, noise pollution could elicit a stress response in Chondrichthyes species potentially damaging their inner ear and lateral line. Some species of Chondrichthyes are migratory, so PRO will likely cause these species to avoid the area.

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Source	Classification	Examples	Ecological Importance	Potential Impact from PRO
Bruno, 2004; Fisheries and Oceans Canada 1981; Government of Canada, 2022a; Halvorsen et al; 2012; Keystone Environmental, 2019	Acipensiformes	Sturgeon	Sturgeons are important predators of invertebrates and smaller fish within the aquatic food web.	Acipensiformes have an open swim bladder. As a result, noise pollution can cause damage to the sturgeon as sound vibrates the air found within their swim bladder. Noise pollution has also been known to cause hematomas in the liver and intestine as well. Exposure to industrial effluent has been known to affect the development of sturgeon and even cause mortality. However, under low effluent concentrations, it is unlikely that there will be any significant impact on surgeons. Acipensiformes are all motile species, so it is likely that PRO will cause Acipensiformes species to avoid the area.

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Source	Classification	Examples	Ecological Importance	Potential Impact from PRO
Abbotsford, n.d.; Bagočius, 2015; Fisheries and Oceans Canada 1981; Government of Canada, 2022a; Marine Planning Partnership Initiative, 2015; O’Neill, et al., 2015; Seyfried et al., 2019; Walsh et al., 2020	Salmonoids	Pink Salmon, Chum Salmon, Coho Salmon, Sockeye Salmon, Chinook Salmon, Cutthroat Trout, Steelhead/ Rainbow Trout, Whitefish, Dolly Varden Char	Salmonoids are a keystone species in Bella Coola. They provide food for both aquatic and terrestrial organisms, including humans. Salmonoids also brings industry into the area, so they are also of great economic importance to the region. Bella Coola is an essential area for salmonoids as many come to the area to breed.	Loud noise associated with pile driving can halt migratory salmonoids moving into the region to breed. Noise pollution can elicit high stress responses in salmonoids that can impact their behavior and can cause permanent hearing loss. Fortunately, PRO activity will likely not contribute to the same noise pollution levels as pile diving. Increased sedimentation during the construction and decommissioning phase can be particularly harmful to salmonoids in Bella Coola because many species spend their juvenile years in local watersheds. Increased turbidity can impact physiology, cause habitat alienation, affect growth rates, reproduction, recruitment, and cause mortality. Pollutants introduced into the water column can impact juvenile salmonoids and their sources of sustenance. Pollutants can bioaccumulate within salmonoids tissue and, in extreme cases, cause mortality.

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Source	Classification	Examples	Ecological Importance	Potential Impact from PRO
Chamberlin et al., 2021; Duguid et al., 2019; Emmett et al., 2005; Fisheries and Oceans Canada 1981; Government of Canada, 2022a; Griffin et al., 2009; Llanos-Rivera et al., 2018; Weilgart, 2018	Clupiforms	Pacific Herring, Northern Anchovy, Pacific Sardine	Herring, anchovy, and sardines are important prey species for carnivorous fishes, marine birds, marine mammals, terrestrial animals, humans, etc.	Schooling prey species such as herring have been shown to exhibit avoidance with the presence of sound. Increased sedimentation in the water column is particularly harmful to herring during spawning because sediment can attach to adhesive eggs, which can impact development and cause mortality. Pollutants from effluent may affect species of clupiforms differently. Impacts will likely affect eggs and juvenile clupiforms. Impacts could range from minimal negative impacts to potential mortality.
Government of British Columbia, n.d.a; Government of British Columbia, 1993; Government of Canada, 2022a;	Cypriniformes	Longnose Dace	The longnose dace plays an important role in the ecosystem because they eat larval stages of insects in the water column. This keeps nutrients from insects within the aquatic environment.	The Longnose Dace spawns in spring and summer within BC watersheds. Increased pollutants, noise pollution, and sedimentation from PRO could potentially impact reproducing individuals and juveniles.

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Source	Classification	Examples	Ecological Importance	Potential Impact from PRO
Fisheries and Oceans Canada 1981; Government of Canada, 2016a; Government of Canada, 2022a; Moody, 2008; Schweigert et al., 2012; Seyfried et al., 2019	Osmeriformes	Eulachon, Surf Smelt	There is not much known about the eulachon; however, the eulachon is of significant cultural importance to the Nuxalk First Nations.	Juvenile Osmeriformes may reside in estuaries within Bella Coola. Juveniles may be more susceptible to impacts from pollutants, noise pollution, and sedimentation. Noise pollution on Osmeriforme species in the region can impact spawning. Increased sedimentation, pollutants, and changes to hydrology that occur with the introduction of PRO could impact the habitat and thus Osmeriforme populations. Management practices of other industries in the area suggest halting activities in the region leading up to and following the spawning of eulachon.
Government of Canada, 2022a; Hawkins & Picciulin, 2019; NOAA Technical Memorandum, n.d. Westerberg et al., 1996	Gadiformes	Pacific Hake, Codfish	Gadiforms are important prey species for higher trophic levels.	Gadiformes communicate using vocalizations. Increased noise pollution from PRO could affect Gadiformes ability to communicate. Adult Gadiformes are likely to avoid the region due to increased sedimentation, while early development and juvenile stages can experience an increase in mortality rates.

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Source	Classification	Examples	Ecological Importance	Potential Impact from PRO
Fisheries and Oceans Canada 1981; Government of Canada, 2022a; Lee et al., 2010; Van Isle Marina, n.d.; McConaughey & Smith, 2000; Stocker, 2002	Pleuronectiforms	Dover Sole, Flathead Sole, Pacific Halibut	Pleuronectiforms are import predators that keep the ecosystem in balance. They are also economically important to the region as many people enjoy eating various species of pleuronectiforms.	Noise pollution may not significantly impact pleuronectiforms as they do not have a swim bladder. Sedimentation from PRO development and decommission can impact the benthic prey that pleuronectiforms feed on. Limited food may cause pleuronectiforms to leave the region to find better sources of food.
Fisheries and Oceans Canada 1981; Freihofer, 2022; Government of Canada, 2022a; Kunc et al., 2016	Perciformes	Tuna, Mackerel, Pacific Sand Lance, Perch	Perciforms are a very diverse group. They are also a vital source of food.	Noise pollution can cause increased stress responses from Perciformes. As a result, noise pollution may compromise the perciform immune system, metabolism, and reproduction.

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Source	Classification	Examples	Ecological Importance	Potential Impact from PRO
Douglas & Lanzing, 1980; Fisheries and Oceans Canada 1981; Government of Canada, 2022a; Nikolich et al., 2021 Wheeler, n.d.	Scorpaeniformes	Threespine Stickleback, Coastrange Sculpin, Prickly Sculpin, Sablefish, Kelp Greenling, Whitespotted Greenling, Blackbelly Eelpout, Lingcod, Bocaccio Rockfish, Yelloweye Rockfish, Yelloweye Rockfish	Scorpaeniformes feed on lower trophic levels and invertebrates. They are of great commercial importance.	Scorpaeniformes such as rockfish communicate using vocalizations. Noise pollution from PRO activity could impact these species' ability to communicate. Changes in sediment caused from PRO could impact respiration in Scorpaeniformes.

Appendix K

Reptiles

Source	Species	Ecological Importance	Potential Impact from PRO
Government of Canada, 2022a; Seyfried et al., 2019; WWF, n.d.	Leatherback Sea Turtle	Leatherback sea turtles have a large migration. They mostly feed on jellyfish. Which helps regulate jellyfish populations.	Increased activity from PRO will likely cause sea turtles to avoid the area.

Appendix L

Birds

Source	Species	Ecological Importance	Potential Impacts from PRO
<p>Avibase, 2022; Clout & Hay, 1989; eAtlas, n.d.; Marin-Coria et al., 2021; Seyfried et al., 2019</p>	<p>Trumpeter Swan, Canada Goose, Black Scoter, Common Goldeneye, Barrow’s Goldeneye, Goosander, Red-Breasted Merganser, Gadwall, American Wigeon, Mallard, Northern Pintail, Ruffed Grouse, Band-Tailed Pigeon, Vaux’s Swift, Anna’s Hummingbird, Rufous Hummingbird, Great Blue Heron, Black Turnstone, Spotted Sandpiper, Bonaparte’s Gull, Mew Gull, California Gull, American Herring Gull, Glaucous-Winged Gull, Hen Herrier, Bald Eagle, Red-Tailed Hawk, Northern Flicker, Downy Woodpecker, Hairy Woodpecker, Belted Kingfisher, Merlin, Peregrine Falcon, Willow Flycatcher, Hammond’s Flycatcher, Common Raven, Northwestern Crow, Steller’s Jay, American Pipit, Purple Finch, Pine Siskin, Spotted Towhee, Dark-Eyed Junco, Golden-Crowned Sparrow, Fox Sparrow, Savanna Sparrow, Song Sparrow, Orange-Crowned Warbler, Common Yellothroat, Yellow Warbler, Yellow-Rumped Warbler, Black-Throated Gray Warbler, Wilson’s Warbler, Red-Winged Blackbird, Brown-Headed Cowbird , Western Tanager, Chestnut-Backed Chickadee, Barn Swallow, Tree Swallow, Violet-Green Swallow, Northern Right-Winged Swallow, Ruby-Crowned Kniglet, Golden-Crowned Kinglet, Cedar Waxwing, Red-Breated Nuthatch, Pacific Wren, Common Starling, Varied Thrush, Swainson’s Thrush, American Robin</p>	<p>Birds play many important roles in the ecosystem including the distribution of plants and pollination. Seabirds feed on a variety of fish and invertebrates. They are also responsible for the transfer of nutrients.</p>	<p>The most significant impact to seabirds from PRO will likely be avoidance of the area.</p>

Appendix M

Marine Mammals

Source	Classification	Example	Ecological Importance	Potential Impacts from PRO
Addison et al., 2005; Ford & Nichol, n.d.; Smart, 2019; Thompson et al., 2013	Pinnipeds	Harbour Seal, Steller Sea Lion	Pinnipeds are important predators in the BC ecosystem. They feed on various fish species, including Pacific hake, which predate on salmon. They are also an important food source for cetaceans, in particular orca whales.	The impact from noise pollution from PRO will likely cause pinnipeds to avoid the area. Chemicals found in PRO effluent may bioaccumulate within seals.
Cardiff University, 2022; Ford & Nichol, n.d.; Ghoul, 2012; Seyfried et al., 2019; University of British Columbia, 2020	Mustelid	Sea Otter	Sea Otters are essential in reducing sea urchin populations, which helps maintain kelp forests as sea urchins feed on kelp.	Little is known about how anthropogenic noise could impact sea otters; however, it is possible that noise pollution from PRO could affect sea otter communication, recognition of threats, and even cause hearing loss. Although it is more likely that sea otters may temporarily avoid the area during times of heavy noise pollution. Chemicals from PRO effluent can also accumulate in the tissues of sea otters which can cause mortality at high concentrations.

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Source	Classification	Example	Ecological Importance	Potential Impacts from PRO
Animal Welfare Institute, 2017; Ford & Nichol, n.d.; Ocean Alliance, 2021; Seyfried et al., 2019; Woods, 2015	Mysticetes	Blue Whale, Fin Whale, Sei Whale, Minke Whale, Humpback Whale, Right Whale, Grey Whale	Whales play a significant role in carbon and nutrient cycles. They release significant amounts of nutrients into the water column from their fecal pellets. These nutrients can increase primary production in the area and transport nutrients vertically in the water column as they are deep divers. Increased primary production removes carbon from the atmosphere, which can be sequestered into the deep ocean. When whales die, they sink out of the system sequestering that carbon down to the deep ocean.	Noise pollution can interfere with whale communication, impact feeding, cause stress, impact reproduction, cause permanent hearing loss and even cause mass strandings. Fortunately, PRO isn't predicted to produce noise pollution at levels that will cause significant harm to whales. The most likely impact to whales from PRO noise will likely be avoidance of the area. Cumulative effects of industrial effluents can significantly impact whales, and other species at higher trophic levels as chemicals bioaccumulate in their tissues. Bioaccumulation can cause impacts to whale reproduction, impact overall health, and in extreme cases, cause death.
	Cetaceans	Sperm, Pygmy & Dwarf), Beaked Whales (Hunns, Stejneger's, Baird's, & Cuvier's), Dolphins (Pacific White Sided, Striped, Norther Right Whale, Short-Beaked, Long-Beaked), Dall's Porpoise, Harbour Porpoise, Killer Whale, Short Finned Pilot Whale, False Killer Whale		

Appendix N

Terrestrial Mammals

Source	Species	Ecological Importance	Potential Impacts from PRO
Fisheries and Oceans Canada, 1981; Government of British Columbia, 2022; Seyfried et al., 2019	Grizzly Bear	Grizzly bears hold important ecological and cultural importance in Bella Coola, and are a good indicator of the environment's overall health.	A significant food source for grizzly bears in Bella Coola is salmon. If PRO impacts salmon populations, it could also impact grizzly bear populations. The main impact of PRO in Bella Coola on grizzly bears would likely be avoidance. PRO could also reduce habitat area for grizzly bears.
Fisheries and Oceans Canada, 1981; Kuhnlein & Humphries, n.d., Seyfried et al., 2019	Mountain Goat	Mountain goats are important game animals.	Mountain goats will likely avoid the area where PRO activities are taking place
David Suzuki Foundation, 2013; Fisheries and Oceans Canada, 1981;	Caribou	Caribou are important game animals.	Caribou populations in the region are currently threatened. PRO may further reduce caribou habitat as vegetation is removed. Increased activity and noise in the region will likely cause caribou to avoid the area.
Fisheries and Oceans Canada, 1981; Government of Manitoba, n.d.; Seyfried et al., 2019	Moose	Moose are important sources of sustenance for both people and are prey for other species.	PRO could remove habitat from moose in the region. Increased activity in the region from PRO may also cause moose to avoid the area.
Darimont & Paquet, 2000; Fisheries and Oceans Canada, 1981; Seyfried et al., 2019	Wolf	Wolves are important predators and help regulate population sizes of lower trophic levels.	PRO could remove habitat from wolves in the region. Increased activity in the region from PRO may also cause wolves to avoid the area.

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Source	Species	Ecological Importance	Potential Impacts from PRO
Fisheries and Oceans Canada, 1981; Cougar Fund, n.d.	Cougar	Cougar's help regulate lower trophic levels and population sizes.	PRO could remove habitat from cougars in the region. Increased activity in the region from PRO may also cause cougars to avoid the area.
Fisheries and Oceans Canada, 1981; Gillingham, n.d.	Black Tailed Deer	Black Tailed Deer are important game animals as well as important prey species for higher trophic levels.	PRO could remove habitat from deer in the region. Increased activity in the region from PRO may also cause deer to avoid the area.