Eliciting Willingness-to-Pay from Canadian Recreational Anglers to Fish on Watersheds Adopting Novel eDNA Toolkits: A Contingent Valuation Approach

By

Conor Smith

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ABSTRACT

Conor Smith
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Advisor:
Tongzhe Li

This study employs a contingent valuation survey to elicit willingness-to-pay (WTP) responses from Canadian recreational anglers to fish on their preferred watersheds were they to adopt novel eDNA toolkits. The survey gathered responses from 999 Canadian recreational anglers using a double-bounded dichotomous-choice format. Other than WTP elicitation, this study also identifies how the provision of information influences WTP. Results from this study indicate that the provision of information has no significant effect on respondents' WTP. It is found that Canadian recreational anglers would be willing to pay premiums between 7%-33% on previously reported annual fishing expenditure to fish on watersheds adopting novel eDNA toolkits. Findings from this study can be used to influence the future fisheries management policies, and it is argued that the expected increase in social welfare causes recreational anglers to have strong preferences for the adoption of this technology regardless of the information they are exposed to.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1: Introduction

1.1 Background

With fears of food insecurity, climate change, and ecosystem collapse being at the forefront of political and economic discussion, world leaders, policymakers, and researchers are focusing on the sustainability of our natural resources (Barrett, 2010; Nunez et al., 2019). Despite objective measures of efficacy for new 'sustainable' technologies – such as carbon emissions levels and energy consumption – we hypothesize that these technologies must be made available for consumption if we wish to observe their proposed benefits. Herein lies the value of behavioural economics. The study of behavioural economics allows us to model and predict adoption behaviour and preferences for new technologies ex ante. Behavioural studies measuring adoption behaviour and consumer preferences for goods and services in the environmental and agricultural industries have become increasingly popular in the late 20th and early 21st century (MacMillan et al., 2006). Specifically, recent studies pay close attention to emerging genomic and biotechnologies and the potential economic implications of their adoption (Hanley & Barbier, 2009; Thomsen & Willersley, 2015; Li & McCluskey, 2017). However, there are currently no studies describing or assessing the economic implications of recreational anglers' preferences in adopting genomic monitoring and stock assessment technologies in the Canadian fisheries industry.

Stephenson et al. (2019) point out that the Canadian fisheries industry is suffering from inefficiencies pertaining to the dissemination of standardized well-studied management practices. The foundation of their argument is built upon the fact that Canadian fisheries are ineffective at tracking unintended consequences of heterogeneous fisheries management styles (Stephenson et al., 2019). Furthermore, despite much of the literature alluding to the irrationality of using maximum sustainable yield (MSY) as a basis for guiding annual changes in fisheries management practices, it continues to be a relied-upon measure of sustainability among fisheries managers and decision-makers (Gordon, 1954; Bavington 2010). As a solution to mitigating fisheries collapse and overfishing, some managers have introduced quota systems under a predetermined total allowable catch (TAC) for specific species that allows anglers to purchase and trade individual transfer quotas (ITQ) (Emery et al., 2014). Though ITQs do not perfectly address issues related to overfishing and poor management decisions, studies have shown increased efficiencies when quota enforcement and monitoring is prioritized (Parslow, 2010; Emery et al., 2014).

One problem that has not yet been addressed effectively, as described by Paquette et al. (2020), is the absence of data on fish populations and catches in Canadian freshwater regions. In order to improve the quality and quantity of reliable data available on Canadian freshwater bodies from which policies are designed, monitoring programs and community involvement must be incentivized (Paquette et al., 2020). Moreover, recent literature suggests that the development and adoption of environmental DNA (eDNA) technologies can be potentially effective in developing our ability to monitor and assess fish stocks with their ability to target sensitive species across a broad range (Ficetola et al., 2008; Jerde et al., 2013; Jerde, 2021). Under the combined use of traditional capture methods and novel monitoring technologies such as eDNA used for stock assessment, there is reason to believe our knowledge of the health and sustainability of our freshwater fisheries can be greatly improved (Hänfling et al., 2016; Jerde, 2021).

As well, Abbott et al. (2018) describe how recreational fisheries are often significantly underrepresented in fisheries management regimes in comparison to commercial fisheries, where basic catch and harvest limits in recreational fisheries are determined by unreliable estimates of MSY and vary by license and by province. Abbott et al. (2018) identify the ability for us to improve economic and ecological efficiencies in the recreational fisheries industry by addressing issues of overfishing by taking a pragmatic approach to translating effective commercial fisheries policies to the recreational industry. Ultimately, recreational anglers can have a significant impact on the health of our fish populations, and so it follows to consider their preferences when developing new fisheries management policies (Abbott et al., 2018).

1.2 Motivation and Research Objectives

With the inefficiencies observed across Canadian fisheries industries stemming from data deficiencies and stagnant methods of stock of assessment, there is a gap in our approach to managing fisheries (Stepheson et al., 2019; Paquette et al., 2020). Thus, we conducted this study to measure the willingness-to-pay (WTP) of Canadian recreational anglers to fish on both open and frozen watersheds under the adoption of novel eDNA toolkits. This study employs a contingent valuation (CV) survey approach using a double-bounded dichotomous-choice (DBDC) model (Hanemann, 1984; Hanemann et al., 1991) to elicit WTP responses from recreational anglers. In order to measure the effect information has on stated preferences on the adoption of eDNA technologies in Canadian recreational fisheries, we randomly assign one of four information treatments to each participant before asking them to report their WTP using a between-subjects treatment approach.

Another motive for conducting this study stems from findings by researchers from the Genomic Network for Fish Identification, Stress and Health (GEN-FISH) that suggest fisheries managers are concerned with angler perceptions on eDNA toolkits and their potential implications. It is important to gauge recreational anglers' preferences for eDNA technologies given that they are non-users and potential beneficiaries of the technology, meaning the effective adoption ad deployment of eDNA toolkits is reliant on angler acceptance. Fisheries managers and decision-makers can benefit from findings provided by this study in the development of new policies surrounding the use of eDNA toolkits, potentially leading to more effective management practices in Canadian freshwater fisheries.

Ultimately, the objectives of this study are as follows: (1) to determine how Canadian recreational anglers value the adoption of eDNA technologies across Canadian fisheries ex ante; (2) to examine how and if the provision of positive, negative, neutral, and zero information on the technology has a measurable effect on an individual's WTP to fish on watersheds adopting eDNA toolkits; and (3) to provide a basis for the formation and implementation of new policies surrounding fisheries management practices. I hypothesize that acceptance of eDNA technologies among recreational anglers and subsequent end-user adoption can be positively influenced by the greater distribution of information and knowledge regarding the new technology. If we wish to observe whether this argument holds true with innovative genomic technologies in Canadian freshwater fisheries, Canadian recreational anglers' willingness-to-pay (WTP) for this technology must be assessed.

Chapter 2: Literature Review

2.1 Contingent Valuation in Research

CV is a well-documented and commonly employed stated preference (SP) method of eliciting individuals' or target groups' WTP for non-market and environmental goods and services (Hanemann, 1994; Carson, 2000; MacMillan et al., 2006; McFadden & Train, 2017). Although there have been measurable improvements in the methodologies employed in CV studies in recent years, data collection has remained relatively constant (MacMillan et al., 2006). Typically, CV studies elicit WTP responses on specified goods or services from a large sample of a target group through interviews or questionnaires (MacMillan et al., 2006). Given the hypothetical nature of questionnaires and issues with incentive compatibility, especially under ex ante evaluations of WTP elicitations for a new technology, good, or service, the reliability of CV studies has been subject to scrutiny (Diamond & Hausman, 1994; Hudson & Ritchie, 2001; Jacquemet et al., 2011; Banzhaf, 2017; Czajkowski et al., 2017; McFadden & Train, 2017). However, despite the highlighted limitations of CV studies, recent studies posit that, when designed with care and rigor, WTP studies can be an effective method for measuring preference for new technologies (Hanemann, 1994; Carson, 2000; Lin et al., 2013; Bennett et al., 2018).

As it pertains to environmental commodities, Diamond & Hausmann (1994) argue that the CV method is flawed in its ability to measure non-use goods and services. The conclusion presented by Diamond & Hausmann (1994) is that anomalies observed in CV studies stem from internal inconsistencies where survey respondents generally cannot reasonably reveal their true preferences for an environmental commodity, rather than flaws in survey design. Similarly, Kenneth & Train (2017) report that hypothetical biases arising in CV studies promote anti-environmental outcomes, and ultimately lead to the significant overestimation of the benefits of non-use commodities. Kenneth & Train's (2017) argument concludes by stating that it is both scientifically and ecologically responsible to consider the unreliability of CV studies.

Conversely, while Hanemann (1994) acknowledges the limitations of CV studies, he argues that well-designed surveys are a useful tool for measuring preferences for non-use commodities, especially when the alternative is not measuring them at all. In fact, much of the current literature defends the broad applicability of CV surveys to elicit WTP responses for both use and non-use values related to environmental commodities (Hanley & Barbier, 2009; Bennett et al., 2018). Carson (2000) argues, however, that the quality of a CV study is heavily reliant on the survey instrument. He argues that most reliable CV surveys should consider the following: (1) including an introduction to the study which allows participants to understand the decisions they will be making; (2) ensuring participants have a thorough understanding of the good or service being offered; (3) ensuring the study is being conducted in the appropriate institutional setting; (4) transparency on how the good or service will be paid for; (5) paying careful attention to survey design to elicit respondents' preferences; (6) debriefing respondents to understand why they chose some specific answers; and (7) question sets to gauge attitudinal and demographic characteristics (Carson, 2000). As such, recent environmental CV studies have been successfully conducted across a broad range of focuses including environmental tourism, novel biofuel technologies, and ecology (Hudson & Ritchie, 2000; Li & McCluskey, 2017; Bennett et al., 2018).

2.2 Fisheries Management

The current economics literature on Canadian fisheries management and stock assessment practices is abundant, yet many issues with respect to management, sustainability, production, and population sampling remain. Hilborn and Walters (2013) define fisheries stock assessment as the practice of employing statistical and mathematical models to measure and predict how different management practices might affect fish populations. Moreover, Hilborn and Walters (2013) state that the goal of fisheries management and stock assessment practices is to ensure long-term sustainable production from fish stocks while promoting the social and economic wellbeing of fishermen and consumers in the industry. While these descriptions are widely accepted among researchers and professionals in the fisheries industry, there is observable variation in management practices across different regions, governments, and fisheries.

According to Stephenson et al. (2019), fisheries management in Canada is primarily governed by goals outlined by the Federal Sustainable Development Strategy (FSDS) and the Fisheries Act. In line with what was posited by Hilborn and Walters (2013), the Office of the Auditor General (2011) describes the importance of addressing fisheries management decisions from a social, institutional, environmental, and economic context. Stephenson et al. (2019) point out that the broad objectives surrounding sustainability set by Canadian fisheries must be narrowed to address discrepancies in fisheries management efficacy. More specifically, Stephenson et al. (2019) affirm that the economic, social, environmental, and institutional consequences and trade-offs from various fisheries management styles are not properly tracked, often resulting in unintended inefficiencies.

Gordon (1954) was among the first to advocate for integrating the behavioural trends of fishermen in bioeconomic modelling, arguing that anglers are rational decision-makers. Perhaps more emphatically, Gordon (1954) identified the irrationality of using MSY as a basis for employing fisheries management practices, stating that MSY does not account for the associated costs of fishing effort and profit-driven behaviour exhibited by anglers. Gordon (1954) instead promoted the idea of utilizing maximum economic yield (MEY) for the basis of fisheries management, where resource rents are maximized. Bavington (2010) constructed an effective adaptation of the Gordon's (1954) fisheries model, illustrating the theoretical costs, revenues, and fishing effort yielded under open access, MSY-motivated, and MEY-motivated management practices. This adapted Gordon-Schaefer model can be shown in Figure 1 below, where profits are maximized at E_{MEY}, and profits are net-zero at E_0 where the rate of harvest begins to exceed the target species' rate of reproduction (Gordon, 1954; Bavington, 2010).

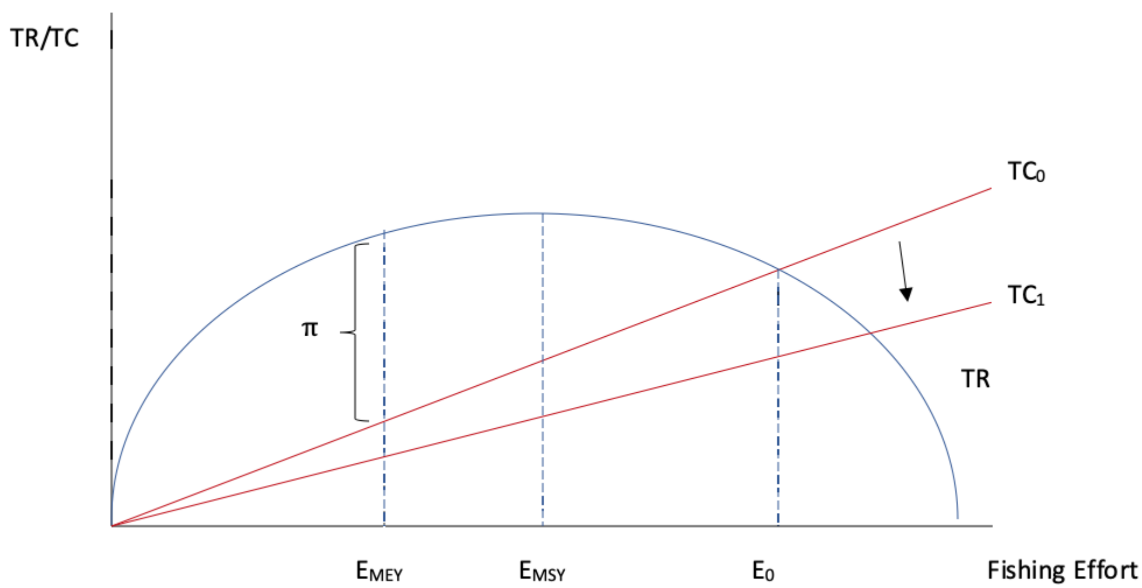

Figure 1: Adapted Gordon-Schaefer Fishery Model

Source: Bavington (2010)

Rent maximization can be identified at E_{MEY}, where the distance between TC and TR is greater than at the MSY, denoted by E_{MSY} in Figure 1 (Bavington, 2010). Furthermore, we can assume that the total cost of fishing efforts will be reduced by the adoption of new fishing technology and equipment and fishing subsidies, illustrated by a downward rotation of the TC curve (Conrad, 1999). It is important to note that, under this assumption, reduced costs of fishing will not lead to overfishing, but rather more efficient fishing efforts. Conversely, fishing vessel and equipment restrictions and fishing in overfished zones will result in increased costs of fishing, which would be illustrated by an upward rotation in the TC curve (Conrad, 1999). Ultimately, Bavington (2010) postulates that theoretical and mathematical abstractions ought to be re-evaluated and perhaps avoided altogether, stating that the practical outcomes of employing management practices on the basis of theoretical models has proven suboptimal time and time again.

One of the most common systems employed in global fisheries takes the form of TACs (Poos et al. 2010). TACs set a maximum quantity of fish from a population to be harvested, often resulting in a 'race to fish' tragedy of the commons scenario where the TAC rate is exceeded through unintentional overfishing and discarding marketable fish (Poos et al. 2010; Emery et al. 2014). To address issues with inefficiency and fisheries collapse, fisheries introduced ITQs where anglers are allocated a portion of the TAC which, in theory, should disincentivize overfishing (Emery et al. 2014). Emery et al. (2014) outline five examples of increased efficiency in ITQ-managed fisheries: (1) Transferability of quota units allow for less productive anglers to sell a portion of their quota. (2) Durability and security of catch shares allows for fishermen to determine their most efficient and effective means for harvesting their quota, mitigating overfishing and overcrowding at the beginning of the season. (3) Durability and security of catch shares will indirectly result in the increased quality of harvested fish through improved care and handling from anglers not facing a 'race to fish' scenario. (4) Durability and security of catch shares allows for anglers to maximize returns from fishing efforts by providing them with temporal flexibility, contingent on weather and vessel conditions. (5) Durability and security of catch shares allows anglers to maximize the value of their harvests in the form of quota units, incentivizing them to preserve future harvests and sustainable fisheries management practices.

However, according to a study published by Acheson et al. (2015), ITQs do not necessarily promote sustainable fisheries management in practice. Acheson et al. (2015) posit that the practical viability of ITQs in preserving fish populations remains dependent on the accurate ascertainment of the TAC limit, and while ITQs mitigate overfishing and overcrowding of fisheries under a tragedy of the commons scenario, they do not address issues relevant to sustainability inherent to TAC-managed fisheries. Moreover, Acheson et al. (2015) argue ITQs do not effectively promote the conservation of vital fish populations. It is stated that ITQ laws are not enforced, nor are ITQ-managed fisheries monitored strictly enough – allowing for the practice of grading and discarding those fish deemed to be 'low-quality' from a harvest. Another recorded pitfall of ITQ-managed fisheries is that their inability to selectively preserve volatile, endangered, or otherwise essential fish such as older females vital to recruitment (Acheson et al. 2015). Finally, Acheson et al. (2015) identify the issues with removing economic and policy issues from biological models and conservation tactics, arguing that the basis of ITQs - being able to accurately model, predict, and control fish populations for harvest – is flawed and therefore detrimental to the viability of future harvests.

One study conducted by Parslow (2010) provides a more optimistic, yet critical assessment of the efficacy and viability of ITQs as a feasible management technique in Canadian fisheries. The study pays particular attention to the contrast between individual and collective incentives under ITQs assuming rent-maximizing is the primary objective of the anglers. A central argument is that it is in the individual's economic self-interest to harvest beyond their quota as the benefits accrued from any additional catch are immediately realized, thus ITQs cannot by themselves incentivize the collective stewardship of fishermen, nor will they eliminate a tragedy of the commons scenario. This holding true, however, Parslow (2010) maintains that there is a place for ITQs in concurrent fisheries management practices under fears of fisheries collapse, so long as enforcement and stock monitoring is strict.

Ultimately, much of the literature concerning issues in fisheries management focuses on the commercial aspect of fishing rather than the recreational aspect (Abbott et al., 2018). However, Abbott et al. (2018) posit that the recreational fisheries industry in the United States (US) suffers from many of the symptoms of poor fisheries management identified in commercial fisheries, thus resulting in significant welfare losses among recreational anglers. For example, under TACs, and when a specific species is relatively abundant and highly valued, a ‘race to fish’ tragedy of the commons is often a result. Abbott et al. (2018) estimate that, under proper management reform, the average US recreational angler may be able to save $139 USD per year. To mitigate management inefficiencies faced in recreational fisheries, Abbott et al. (2018) recommend that decision-makers take a more pragmatic approach to transferring policy similar to ITQs to the recreational sector with purchasable, transferrable rights to harvest a specified number of fish of a specific species for a predetermined duration, such as a limit on allowable fishing days in a season.

2.3 Stock Assessment

Perhaps the most rooted barrier to fisheries management is stock assessment and monitoring. It is simplistic to view stock assessment as a basic measurement of a fish population, their health, and their relative abundance. The issues faced with respect to fisheries stock assessment are not merely a matter of what parameters to measure, but how stocks are assessed and monitored.

According to the World Wildlife Fund's (WWF) 2020 Annual Report, 56 of 167 (34%) Canadian sub-watersheds received "Good" scores under the freshwater fish category, while the remaining 111 (66%) sub-watersheds are data deficient and thus cannot be assessed adequately (Paquette et al., 2020). Although this data does not necessarily imply that Canadian freshwater fish populations are at risk or declining, the lack of available data is of concern. Paquette et al. (2020) report that the absence of key long-term fish population data makes it difficult to form conclusions surrounding the state of freshwater fish stocks given that the available data is not likely representative of the true state of freshwater fisheries. In order to mitigate issues resulting from data deficiencies surrounding Canadian freshwater bodies, Paquette et al. (2020) recommend increasing support for water monitoring in individual communities, expanding freshwater monitoring coverage, investing in large-scale standardized models and databases, creating standardized protocols and operating procedures for data analysis, incentivizing publicly accessible data, and committing to consistent and continuous freshwater assessments.

Schneider and Merna (2000) state that fishing gear commonly used for capturing fish population samples include trap nets, fyke nets, gill nets, seines, trawls, electrofishing booms, and toxicants. With each piece of equipment having varying levels of efficacy and potential harm to target and non-target species depending on the type of watershed they are deployed in, what species they are attempting to measure, and how effectively they are utilized (Schneider & Merna, 2000; Cook et al., 2018). Moreover, non-capture methods such as eDNA hydroacoustics, and data mining can be utilized to complement fish capture data (Radinger et al., 2019). While non-capture methods are generally known to mitigate the harmful effects often imposed on fish when assessed under capture methods, they more frequently lead to misidentification and assessment of targeted species due to lack of capture and classification ambiguity (Joy et al., 2013; Radinger et al., 2019). With this in mind, Bennet et al. (2016) suggest that the welfare of targeted fish species under monitoring programs should be prioritized partially through using the conservation status of the target species to determine which assessment practice to employ and partially through minimizing the optimal sample size required to collect adequate data.

2.4 Genomic Technology Adoption and Environmental DNA

As Canadian fisheries face higher stress levels because of increasing demand for fish products, fears of fisheries collapse are common. With greater innovation in the genetic technologies industry, fisheries assessment tools are becoming more accurate, cost-effective, and environmentally friendly (Dunham, 2011; Jerde, 2021). However, studies show that public acceptance of genomic technologies can be a significant barrier to end-user adoption (Hochschild & Sen, 2015).

When we refer to genomic technologies, it may seem sensible to think of the f industry and strict biological sciences. However, the genomics industry has been rapidly expanding and novel technologies have applications in a wide variety of disciplines (Hoschild & Sen, 2015). Genomic technologies allow us to edit genome sequences in humans through the use of novel innovations such as clustered regularly interspaced short palindromic repeat (CRISPR) technology in order to mitigate or eliminate the risk of hereditary disease (Fu et al., 2014). Additionally, they allow us to increase crop yields in agriculture and improve food security through the use of genetically modified organism (GMO) production and development (Potrykus 2012; Zilberman et al., 2018). Furthermore, and most relevant to this study, genomic technologies such as eDNA toolkits enable and promote the effective tracking and monitoring of wildlife species and microbes through the collection and analysis of genetic material found in a habitat or ecosystem of interest (Crann et al., 2015; Hoschild & Sen, 2015; Thomsen & Willerslev, 2015).

Despite the widespread consensus among researchers from various disciplines being that these technologies are beneficial in their respective applications, barriers to adoption remain (Shokralla et al., 2012; Fu et al., 2014; Crann et al., 2015). Davis (1989) discusses two determinants of innovation adoption: (1) Perceived usefulness and (2) Perceived ease of use. Perceived usefulness may be described as the degree to which the new technology is expected to help an individual perform a task, typically in comparison to another tool or technology used to perform the same task (Davis, 1989). Perceived ease of use, on the other hand, may be described as the level of effort or expertise an individual expects is required to use the technology (Davis, 1989). As it relates to genomic technology adoption, Crann et al. (2015) identify three concerns outlined by study participants. The first being that end-users or beneficiaries of novel technologies may not understand objectively complex mechanisms relevant to genomic technologies that may be considered simplistic to producers, promoting hesitancy around potential adoption (Crann et al., 2015). The second concern is that end-user perceptions must be addressed when proposing a new technology, which is to say that the technology must be perceived to be more efficient compared to the status quo from the perspectives of both practical use and labour required (Crann et al., 2015). The third and final concern reported by Crann et al. (2015) is the expected or revealed cost effectiveness of the genomic technology to be adopted.

Barriers to the adoption of novel genomic and biotechnologies are not only created at the end-user level; public groups and scientific researchers also continue to question the effectiveness of such technologies, often hindering effective implementation (Darling & Mahon, 2011; Zilberman et al., 2018). Specifically, in the agri-food industry, opposition to GMO technologies from the general public, governments, and private entities persist (Curtis et a., 2004; Rodriguez et al., 2009; Zilberman et al., 2018). Zilberman et al. (2018) points out that the European Commission instituted a mandatory GMO labelling policy on all food products, with countries such as France, Germany, and India banning the production of GMO crops altogether. Not only do strict regulatory policies on GMOs threaten food security in targeted countries, they also promote significant economic inefficiencies (Zilberman et al., 2018). Studies conducted by Defrancesco (2013) and Rodriguez et al. (2013) highlight the role of misinformation and poor education on genomic technology adoption, specifically as it pertains to agri-food technology and GMOs. Moreover, Frewer (2017) argues that consumer preferences must be assessed on a case-by-case basis, as there are too many societal and psychological factors affecting preferences for novel technologies across the agri-food industry. Ultimately, the literature suggests that the tension between policymakers imposing strict regulations on GMO technologies and proponents of the technologies and the benefits they create for global food security prevents the true potential of these technologies to be realized (Defrancesco, 2013; Zilberman et al., 2018). As well, while efficiency and environmental risk mitigation are important in the development of novel agri-food technologies, paying attention to societal preferences, perceptions, and requirements is essential for the adoption of such technologies (Frewer, 2017).

Focusing on eDNA technology adoption and attitudes in fisheries industries, Jerde (2021) highlights the hesitancy among fisheries managers and decision-makers to consider the adoption of novel eDNA toolkits due to the uncertainty and perceived unreliability of the data captured under its deployment. Jerde (2021) states that traditional capture methods used for fisheries stock assessment and monitoring are subject to error, but that the data collected are typically more reliable than non-capture data. The literature suggests, however, that the use of eDNA technology allows us to survey sensitive and at-risk species more effectively and across a wider range in comparison to traditional capture methods (Ficetola et al., 2008; Jerde et al., 2013; Jerde, 2021).

Much of the hesitancy of fisheries managers and end-users to adopt and rely on eDNA toolkits for fisheries stock assessment in the Great Lakes region of North America stems from research conducted by Andrew Mahon and Christopher Jerde's research on invasive Asian carp in the region in 2009 (Jerde, 2021). The findings were of particular interest because the researchers detected the presence invasive carp in all watersheds testes, where traditional capture methods failed to detect any presence of the species (Jerde, 2021). This, foreseeably, sparked fisheries managers and scientists to wonder, are traditional sampling methods poor at detecting the presence of invasive species in our watersheds, or is data captured by eDNA samples largely unreliable (Jerde, 2021)? Although the issue remains relatively contentious, the broad consensus after many more studies have been conducted is that the use of eDNA toolkits and other novel sampling technologies used in conjunction with traditional sampling methods, under proper regulation, has the potential to significantly improve our understanding of the state of our freshwater fisheries (Takahara et al., 2012 ;Jerde et al., 2013; Hänfling et al., 2016; Jerde, 2021).

Chapter 3: Data Collection and Description of Variables

3.1 Recruitment and Data Collection

During May and June of 2021, 999 Canadian recreational anglers were recruited online via social media to complete a survey through Qualtrics software with the help of fisheries and aquatic ecology experts with connections to expansive networks of Canadian angling communities. In order to be eligible to participate, potential respondents had to meet the stated inclusion criteria: Participants must be 18 years of age or older; participants must hold a valid Canadian fishing license or be over the age of 65; Participants must be proficient in English; and only one member per household may complete the survey. Of the 999 respondents, one reported only having a valid fishing license outside of Ontario, and 40 reported that they did not need a license given that they are over the age of 65. This means that a large majority of our respondents are recreational anglers in Ontario, though not necessarily exclusively or predominantly.

The survey was conducted online primarily as a result of the Covid-19 pandemic, where we would have otherwise interviewed recreational anglers in person to elicit preference for the adoption of eDNA toolkits on their preferred watersheds. The benefit, however, of conducting the survey online is that it allowed us to target a larger sample of recreational anglers across a broader range at a relatively lower cost.

The structure of the survey is influenced by the current literature on CV studies, and many of the questions as well as the survey length were recommended and examined by researchers at the University of Guelph, Carleton University, and the University of Windsor in affiliation with GEN-FISH. The online survey utilizes a between-subjects design, where questions were laid out in six sections with the goal being to elicit WTP responses for fishing on open and frozen watersheds adopting novel eDNA toolkits under the provision of four different information treatments that were randomly and equally distributed among respondents[1].

The first section of the survey was used to measure respondents' behavioural and attitudinal characteristics pertaining to fishing such as where they primarily fish, how they primarily fish, how often they fish, how much money they spend on open water and ice fishing annually, and how satisfied they are with fishing quality in their preferred region. The second block provided respondents with one of four possible information treatments on eDNA toolkits: (1) Positive information; (2) negative information; (3) neutral information; and (4) no information. It is important to note that each of the information treatments were developed in collaboration with biology and aquatic ecology experts from GEN-FISH. The third section of the survey included questions to elicit WTP responses and was separated into eight blocks. There was one block for each of the four bid values (5%, 10%, 20%, 30%), and each block was duplicated to provide one of two different language treatments related to eDNA technology adoption – respondents either read "eDNA" or "environmental DNA" on all relevant questions. The fourth section of the survey provided respondents with three questions gauging attitudes for eDNA toolkit adoption to aid in fisheries management practices. The fifth section collected demographic characteristics. The sixth and final section promoted incentive provided respondents with the opportunity to visit the GEN-FISH (n.d.) website to learn more about the eDNA technologies being developed, adding an aspect of incentive compatibility to the survey design.

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[1]It is important to note that, in this case, recreational are not the end-users or adopters of eDNA technology. They are classified non-users or beneficiaries of the technology. Fisheries managers are the end-users, or adopters, of this technology.

3.2 Incentive Compatibility

Perhaps the greatest obstacle researchers must overcome when designing SP studies is incentive compatibility. If we recall Hanemann's (1994) argument that CV studies are very useful in measuring the value of non-use commodities, certainly in comparison to the alternative of not measuring them at all. As such, an incentive compatible experiment is not feasible for this study considering the eDNA toolkits being valuated are still being developed. Zawojska & Czajkowski (2015) state that researchers utilizing a CV approach must be confident that respondents' stated preferences should reflect their true preferences for an environmental good or service. Generally speaking, Carson & Hanemann (2005) identify three factors influencing incentive compatibility irrespective of the elicitation format: (1) respondents should believe that the survey may impact future policies pertaining to the good or service in questions; (2) respondents must believe that the good or service in question is realistic; and (3) the instrument expected to impose costs on all parties involved in the adoption or implementation of a new, say, technology or project must be identified.

I posit that our study addresses the first factor raised by Carson & Hanemann (2005) by identifying the potential influence the data collected in the survey will have on decision-makers and Canadian fisheries managers in the consent form. Moreover, the survey was disseminated by reputable researchers within the field of ecology and fisheries research, providing credibility to the potential influence results of this study may have. Our study addresses the second point raised through the provision of information on eDNA toolkits to 740 of the 999 (74.07%) respondents, with the remaining 25.93% being captured by respondents who received the no information treatment, per out study's experimental design (See Table 1 below**)**. As we can see in Table 1, each treatment was almost equally spread among respondents; with 243 (24.32%)

respondents receiving the positive information treatment, 246 (24.62%) receiving the negative information treatment, 251 (25.13%) receiving the neutral information treatment, and 259 (25.93%) receiving the no information treatment. Addressing the third and final factor identified by Carson & Hanemann (2005), given that eDNA toolkits would be adopted by fisheries managers or government bodies, the costs would not be directly imposed on recreational anglers. The potential cost reduction for recreational anglers, should eDNA toolkits be adopted, would be captured by lower transportation costs and the ability to fish more efficiently under the provision of more complete information on the status of specific fish species as it relates to their conservation status, relative abundance, and population stability (GEN-FISH, n.d.).

Table 1: Distribution of information treatments received by respondents (n=999)

Information Treatment Received	Respondents (%)
Positive Information	24.32%
Negative Information	24.62%
Neutral Information	25.13%
No Information	25.93%

3.3 Description of Variables

Table 2 below describes each variable used in analysis.

Table 2: Description of Variables Used in Double-Bounded Dichotomous-Choice Analysis

Variable	Description
Bid	Random bid assigned to each respondent
Response	Response to first and second question from double-bounded dichotomous-choice model 1 = Yes, 0 = No
Treatment	Information treatment randomly assigned to each respondent. Respondents received either positive information, negative information, neutral information, or no information treatment. 1 = received treatment$\mathbf{t}_j$, 0 = did not receive treatment$\mathbf{t}_j$
Money spent fishing	Total amount of money respondents estimate they spend on fishing in an average year.

Money spent ice fishing	Total amount of money respondents estimate they spend on ice fishing in an average year
Years angling	Number of years respondents report they have been recreational anglers
Days angling	Number of days respondents estimate they go fishing in an average year
Keep catch	Whether respondents keep the fish they catch or not 1 = Never 2 = Rarely 3 = Sometimes 4 = Often
Fishing satisfaction	Factor variable comprised of three variables used to measure respondents' fishing satisfaction in their preferred region
Fishing opportunity **Fishing quality** **Fishing costs**	Likert scale from 1 = extremely dissatisfied to 5 = extremely satisfied
Tech Knowledge	Factor variable comprised of two variables used to measure respondent's prior knowledge on technologies used in fisheries stock assessment
eDNA knowledge	1 = Has never heard of eDNA 2 = Not knowledgeable 3 = Somewhat knowledgeable 4 = Very knowledgeable
Stock assessment knowledge	1 = Not knowledgeable 2 = Somewhat knowledgeable 3 = Very knowledgeable
Will eDNA improve management	Whether respondents think adopting eDNA technology will improve fisheries management 1 = Yes, 0 = Otherwise
Invest in genomic tech	Whether respondents think investing in genomic technologies will benefit recreational anglers 1 = Yes, 0 = Otherwise

Stock assessment preferences	Respondent's preferred method of fisheries stock assessment 1 = Unsure 2 = Prefers traditional methods 3 = Prefers combination of traditional and new methods using genomic technology 4 = Prefers new methods using genomic technology
Residence	Respondent's area of residence 1 = Rural 2 = Suburban 3 = Exurban 4 = Urban
Employment	Respondent's employment status 1 = Employed 2 = Self-employed 3 = Unemployed 4 = Retired 5 = Student 6 = Stay-at-home parent/caregiver
Fisheries employee	Whether respondent has ever been employed in the recreational fisheries industry 1 = Yes, 0 = No
Man	1 = Yes, 0 = Otherwise
Age	Respondent's age group 1 = 18-24 2 = 25-30 3 = 31-40 4 = 41-50 5 = 51-64 6 = 65+
Income	Respondent's annual household income. Continuous scale from 1 = Below $20,000CAD to 7 = $150,000CAD+
Education	Respondent's level of education. Continuous scale from 1 = Some high school to 8 = Professional degree
Willingness to learn more about eDNA	Whether the respondent is willing to learn more about eDNA upon completion of the survey. 1 = Yes, 0 = No

3.4 Summary Statistics for Demographic, Attitudinal, and Behavioural Variables

Below I report summary statistics for all key demographic, attitudinal, and behavioural variables. Table 3 shows summary statistics for demographic variables, Table 4 shows summary statistics for attitudinal variables, and Table 5 shows summary statistics for behavioural variables used in analysis.

Table 3: Summary statistics for demographic variables (n = 997)

Variable	Respondents
Employment	
Employed	40.53%
Self-employed	29.48%
Unemployed	8.00%
Retired	21.58%
Student	0.41%
Current/former fisheries employee	
Yes	65.02%
Gender	
Man	77.82%
Woman	21.57%
My gender identity is not listed above	0.10%
Choose not to respond	0.51%
Residence	
Rural	8.43%
Suburban	13.14%
Exurban	33.20%
Urban	45.24%
Age	
18-24	0.91%
25-30	10.43%
31-40	30.77%
41-50	19.94%
51-64	6.28%
65+	31.68%
Household income in 2020	
<$20,000 CAD	1.12%
$20,000 - $49,999 CAD	16.38%
$50,000 - $79,999 CAD	28.28%
$80,000 - $99,999 CAD	26.86%
$100,000 - $119,999 CAD	14.65%
$120,000 - $149,999 CAD	6.82%
>$150,000 CAD	5.90%

Highest level of education achieved	
Some high school	2.41%
Completed high school	8.73%
Some college/university	18.96%
Apprenticeship training and trades	12.54%
Completed college/university	28.39%
Some graduate education	10.43%
Completed graduate education	8.53%
Professional degree	10.03%

Table 4: Summary statistics for behavioural variables (n = 975)

Variable	Respondents	Mean	Median	Std. Dev.
Money spent on fishing in 2020 ($CAD)				
Open water fishing		$2,948.94	$900	$16,120.59
Ice fishing		$1,470.44	$500	$6,334.67
Time spent angling in 2020				
Years angling		14.12	12	9.83
Days angling		114.53	90	84.69
Keep catch				
Never	5.54%			
Rarely	14.15%			
Sometimes	31.18%			
Often	49.13%			

Table 5: Summary statistics for attitudinal variables (n = 999)

Variable	Respondents
Fishing satisfaction	
Fishing opportunity	
Extremely dissatisfied	0.61%
Somewhat dissatisfied	6.45%
Neither satisfied nor dissatisfied	10.54%
Somewhat satisfied	40.23%
Extremely satisfied	42.17%
Fishing quality	
Extremely dissatisfied	0.93%
Somewhat dissatisfied	7.23%
Neither satisfied nor dissatisfied	16.32%
Somewhat satisfied	37.81%
Extremely satisfied	37.71%
Fishing costs	
Extremely dissatisfied	1.76%
Somewhat dissatisfied	8.39%
Neither satisfied nor dissatisfied	17.72%
Somewhat satisfied	37.31%
Extremely satisfied	34.82%

Stock assessment preferences	
Prefers traditional methods	4.51%
Prefers combination of traditional and new methods	39.86%
Prefers new methods using genomic technology	54.12%
Unsure	1.51%
Why might you want to adopt eDNA	
Does not want eDNA to be adopted	1.32%
Indifferent about eDNA adoption	6.79%
Does not want stock assessment workers crowding water bodies	15.60%
Would like to see more environmentally friendly stock assessment methods	41.34%
Would like to know what fish species are present and how many there are	34.45%
Other	0.51%
Why might you not want to adopt eDNA	
Wants eDNA technology to be adopted	25.86%
Indifferent about eDNA adoption	8.95%
Prefers traditional methods of stock assessment	19.82%
Concerned that eDNA technology might harm native species	33.40%
Does not trust eDNA technology will provide accurate fish population data	11.47%
Other	0.50%
Believes eDNA Will Improve Management	
Yes	69.76%
Invest in genomic tech	
Yes	72.02%
Tech knowledge	
eDNA knowledge	
Never heard of eDNA	8.28%
Not knowledgeable	14.85%
Somewhat knowledgeable	41.11%
Very knowledgeable	35.76%
Stock assessment knowledge	
Not knowledgeable	4.07%
Somewhat knowledgeable	57.14%
Very knowledgeable	43.79%
Willingness to learn more about eDNA	
Yes	77.58%

Summary statistics for demographic variables report that, of the 987 respondents who reported their employment status, 40.53% are employed and 23.58% are retired. Of all 972 respondents who answered the questions asking if they have ever been employed in the recreational fisheries industry, 65.02% reported that they are or have been employed within the industry. Of the 983 respondents who answered the question asking them to report their preferred gender, 77.82% reported they were men. Compared to the 2019 Census results for gender, which reports that 49.29% of the Canadian population identifies as men, men are overrepresented in our sample (Statistics Canada, 2020). This overrepresentation is not an unexpected finding for this study at its time, as it follows trends illustrated in a study conducted by Kleiber et al. (2015) which found that men make up roughly 85% of the globe's total anglers. Also unsurprisingly, of the 988 respondents who answered the question asking them to report their age range, 30.77% reported being between the ages of 31-40, and 31.68% reported being 65 years of age or older. Though our sample observes a larger representative sample of individuals 65 years of age and older in comparison with the 2015 Survey of Recreational Fishing in Canada (31.68% vs. 14%), Fisheries and Oceans Canada (2020) reports that the percentage of Canadian anglers 65 years of age and older appears to be increasing. Of the 983 respondents willing to report their 2020 household income, 55% reported 2020 household incomes between \$50,000 and \$99,999, which is consistent with findings from Statistics Canada (2021) for median household income in 2019. Of the 997 respondents who reported their highest level of education achieved, 28.39% reported having completed college or university. Conversely, only 2.41% reported having completed some high school and 10.30% reported having earned a professional degree.

Summary statistics for behavioural variables report that the average total amount of money spent on fishing in 2020 among participants in \$CAD was \$2,948.94 with a median spending amount of \$900.00, where Fisheries and Oceans Canada (2020) reports average spending among recreational anglers in 2015 was \$595.00. For ice fishing, respondents spent an average amount of \$1,470.44 in 2020 with a median spending amount of \$500.00. The average number of years respondents reporting holding a valid Canadian fishing license is 14 years. The average number of days spent fishing per year among respondents is approximately 114 days, which is higher than findings from a report published by Fisheries and Oceans Canada (2020), which reported that the average resident Canadian angler spent roughly 16 days fishing per year in 2015. These findings can likely be explained by the sources we recruited study participants from, being largely occupied by highly skilled, highly experienced recreational anglers. Of the 975 respondents who reported how often they keep their catch, 49.13% reported that they always keep their catch if it is the appropriate species, length, weight, and the season for that species is open, whereas 5.54% reported that they never keep what they catch.

Summary statistics for attitudinal variables report that the majority of respondents are either “Somewhat satisfied” or “Extremely satisfied” with fishing quality, opportunity, and costs in their preferred region. Of the 996 respondents who reported their stock assessment preferences, 54.12% reported that they preferred adopting new methods of stock assessment using genomic technologies, 39.86% reported that they preferred a combination of traditional and novel genomic methods of stock assessment, and only 4.52% reported that they prefer traditional methods of assessment. When respondents were asked why they may want to see the adoption of eDNA technologies, 91.39% respondents reported they wanted eDNA technologies to be adopted for a combination of reasons, with one respondent reporting that they would like to see the technology being used to track traditionally sensitive species that are often difficult to sample under traditional methods. When respondents were asked why they may not want to see eDNA technologies adopted in Canadian fisheries, 25.86% reported that they do in fact want eDNA toolkits to be adopted, and 33.40% respondents expressed concerns that the technology may harm native species. Of the 982 respondents who reported whether or not they think eDNA technology will improve fisheries management in Canada, 69.76% responded “yes”. Of the 997 respondents who reported whether or not they think investing in genomic technology will benefit Canadian recreational anglers, 72.02% responded “yes”. Of the 999 respondents who reported whether or not they were willing to learn more about eDNA toolkits upon completing the CV survey, 77.58% responded “yes”. Of the 982 respondents who reported their level of prior stock assessment knowledge, 95.93% reported being at least "Somewhat knowledgeable" about common stock assessment practices. Of the 990 respondents who reported their level of prior eDNA knowledge, 76.87% reported being at least "Somewhat knowledgeable" about eDNA technology.

Ultimately, when comparing our sample with census statistics and studies with similar target populations, it appears that the gender discrepancy among Canadian recreational anglers is consistent with the literature (Kleiber et al., 2015). Moreover, the age range distribution of our sample aligns closely with the age distributions of Canadian recreational anglers as reported by Fisheries and Oceans Canada (2020), with the only exception being the percentage of anglers age 65 and older. Additionally, our sample's reported income range is representative of median household income as reported by Statistics Canada (2021). Alluding to the perceivable proficiency among anglers in our sample, the most significant inconsistencies in comparison to the 2015 Survey of Recreational Fishing in Canada are reported in annual fishing costs and number of days spent fishing per year (Fisheries and Oceans Canada, 2020). For example, our respondents reported an annual average fishing cost of $2,948.94, where Fisheries and Oceans Canada (2020) reported an annual averaging fishing cost of $595.00. Similarly, respondents of our survey reported spending an average of 114 days angling, where Fisheries and Oceans Canada (2020) reported that the average Canadian angler spends 16 days fishing per year.

Chapter 4: Methods

4.1 Survey Design

We employed a between-subjects CV DBDC survey design in order to assess Canadian recreational anglers' WTP to fish on watersheds adopting novel eDNA technology. To mitigate issues of selection bias in assessing treatment effects, the sample population was randomly assigned to four groups, with each group receiving a different treatment. The control group received no information treatment on the function and applicability of eDNA toolkits in fisheries management. One group was provided with a positive information treatment message, providing knowledge on the potential economic and environmental benefits of the toolkits. Another group was provided with a negative information treatment message on the potential economic and environmental costs of the toolkits. The last group was provided with a neutral information treatment message briefly defining and describing the applications of eDNA technology and similar genomic toolkits, highlighting that employing the technology in fisheries management is a new development. We analyze DBDC data using two models derived from Hanemann's (1984) expansion of the single-bounded dichotoumous-choice (SBDC) model. These models have become increasingly popular in recent research, specifically in ex ante studies where the technology or product is under development but not yet publically available (Li & McCluskey, 2017). One model measures respondents' WTP to fish on open watersheds adopting eDNA toolkits, while the other model measures respondents' WTP to fish on frozen watersheds adopting eDNA toolkits.

To promote certain levels of incentive compatibility, we included a question at the end of the survey gauging respondents' willingness to learn more about eDNA toolkits as they relate to Canadian fisheries management and stock assessment. If respondents revealed that they are willing to learn more about the toolkits, they were provided with a link forwarding them to the GEN-FISH website, which describes the functions of the toolkits and their potential applications in depth. The justification behind the inclusion of this question is that, regardless of a respondent's elicited WTP under the DBDC questions, their actual decision to, or not to learn more about the technology reveals valuable information regarding their preferences for the adoption of eDNA in their preferred fishing region. In order to analyze what factors might influence a respondent's decision to learn more about eDNA toolkits, we employ a logit model to measure the effects of specific independent variables, where the individual's willingness to learn more about the toolkits is the dependent variable.

4.2 Double-Bounded Dichotomous-Choice Model

The DBDC approach to CV studies was developed by Hanemann (1984) and was first employed by Carson et al. (1986). Hanemann et al. (1991) describes the evolution of the single and double-bounded models, stating that the single-bounded approach to CV was developed before the DBDC model and involves asking respondents whether they would be willing to pay a specified amount for a new technology, good, or service to which they must reply either "yes" or "no". The double-bounded approach, however, presents respondents with two bids, with the value of the second bid being contingent upon the response to the initial bid. Under this double-bounded model, if the respondent responds "yes" to the initial bid offered, they are presented with a follow-up question asking if they would be willing to pay some specified amount that is higher than the initial bid, to which they respond "yes" or "no". On the other hand, if the respondent responds "no" to the initial bid offered, they are presented with a lower bid offer, to which they answer either "yes" or "no". Thus, as described by Hanemann et al. (1991), there are four possible outcomes under the DBDC model: (1) a "no" followed by a "no", indicating that the respondent is not willing to pay for the new technology even at the specified discounted bid; (2) a “no” followed by a “yes”, indicating that the respondent is willing to pay at or above the specified discounted bid, but below the initial bid; (3) a “yes” followed by a “no”, indicating that the respondent is willing to pay at least at or above the initial bid, but below the specified premium bid; (3); or (4) a “yes” followed by a “yes”, indicating that the respondent is willing to pay at least at or above the specified premium bid (Hanemann et al., 1991).

Hanemann et al. (1991) argues that the maximum likelihood (ML) estimation under the DBDC model is asymptotically more efficient than the ML estimation under the single-bounded model assuming optimal survey design in both cases. Hanemann et al. (1991) shows, through the analysis of survey data collected from a CV study conducted in California used to elicit WTP responses for protecting wildlife habitats and wetlands, that the ML estimator under the double-bounded model yields greater statistical efficiency than the single-bounded model. Hanemann et al. (1991), through statistical analysis, proves that the DBDC model significantly reduces confidence intervals, and is more efficient than the single-bounded model under a finite sample. One common criticism of DBDC studies takes the form of concerns of anchoring bias (Hanemann et al., 1991; Oh et al. 2019). The anchoring effect, or starting point bias, is observed when a respondent bases their WTP responses on the amount displayed in the initial bid, indicating that they believe the cost of the good or service is equal or similar to the first bid value (Oh et al. 2019). Oh et al. (2019) state that, in the presence of anchoring effects, WTP is often overestimated. Flachaire et al. (2007) argue that individuals with enhanced preferences are more likely to behave according real world market behaviour. That is, their prior level of knowledge on the subject makes it less likely for the bid values presented to influence their CV responses (Flachaire et al., 2007).

Under our survey design, respondents are not anchored to a homogenous set of initial bid values given that their initial bids represent their previously reported estimated spending on fishing in the last calendar year. It is plausible to assume that respondents cannot avoid anchoring at these heterogeneous values regardless of the elicitation method. Moreover, summary statistics report that 942 (95.93%) respondents reported being at least "Somewhat knowledgeable" about common stock assessment practices and 761 (76.87%) respondents reported being at least "Somewhat knowledgeable" about eDNA technology. Combined with justification on why a hypothetical survey approach was used instead of incentive-compatible experiments—the novel technology was being developed and not available in the market—we therefore argue the DBDC was the best available approach for the purpose of this study.

The DBDC model for both open water and ice fishing is structured as follows:

$$D = \begin{cases} 1 & WTP < B_D \quad (No, No) \\ 2 & B_D \leq WTP < B_I \quad (No, Yes) \\ 3 & B_I \leq WTP < B_P \quad (Yes, No) \\ 4 & B_P \leq WTP \quad (Yes, Yes) \end{cases} \qquad 1$$

Where *WTP* represents a respondent's reported WTP which is calculated under the delta method[2] and *B* represents the specified bid value (Greene, 2008).

Under the DBDC model, there are four possible outcomes: (1) The respondent rejects the initial bid, B_I, at their baseline – which is equal to their reported estimated amount spent on fishing in the 2020 calendar year – and they reject the follow-up specified discounted bid, B_D; (2) the respondent rejects the initial bid but reveals they are willing to pay to fish on the watershed adopting the new technology at the discounted bid; (3) the respondent accepts the

[2]Mean WTP is calculated using the delta method with the following formula: $WTP = 1/\rho(\hat{\alpha} + \hat{Z}'\bar{X})$

initial bid, but rejects the follow-up specified premium bid, B_P; and (4) the respondent accepts both the initial bid and the specified premium bid (Hanemann et al., 1991; Li & McCluskey, 2017)

Furthermore, as described by Li & McCluskey (2017), the probabilities of each outcome occurring are shown below:

$$\Pr(Y = j) = \begin{Bmatrix} F\big(v(B_D, Z)\big) \\ F\big(v(B_I, Z)\big) - F\big(v(B_D, Z)\big) \\ F\big(v(B_P, Z)\big) - F\big(v(B_I, Z)\big) \\ 1 - F\big(v(B_P, Z)\big) \end{Bmatrix} \text{ for } j = \begin{Bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{Bmatrix} \qquad 2$$

Where $F(\bullet)$ is a cumulative distribution function defining the random factors which influence an individual's utility with mean 0 and variance $\sigma^2 = (\frac{\pi}{\sqrt{3}})^2$, $v(B,Z)$ represents the difference in indirect utility between accepting the eDNA toolkit at the specified bid and rejecting the bid, and Z describes a vector of independent variables to be estimated which defines the individual's indirect utility (Li & McCluskey, 2017). Thus, expanding our function from equation (2), we define the function $v(B_i,Z_i)$ for each individual, i, as follows:

$$v(B_i, Z_i) = \alpha - \rho' B_i + \lambda' X_i,\ \ i = 1, 2, 3, \dots, n \qquad 3$$

Where B_i is the specified bid offered to respondent i, X_i represents a vector of independent variables defining respondent i, and α, ρ, and λ are unknown estimates (Li & McCluskey, 2017). Finally, the log-likelihood function is described by:

$$\ln L = \sum_{i=1}^{n} \begin{Bmatrix} I_{Y_{i=1}} \ln F(\alpha - \rho B_D + \lambda' X_i) + \\ I_{Y_{i=2}} \ln[F(\alpha - \rho B_{Ii} + \lambda' X_i) - F(\alpha - \rho B_{Di} + \lambda' X_i)] + \\ I_{Y_{i=3}} \ln[F(\alpha - \rho B_{Pi} + \lambda' X_i) - F(\alpha - \rho B_{Ii} + \lambda' X_i)] + \\ I_{Y_{i=4}} \ln[1 - F(\alpha - \rho B_{Pi} + \lambda' X_i)] \end{Bmatrix} \qquad 4$$

Where $I_{Y_{i=j}}$ represents the indicator value for each of the four possible outcomes j = 1,…,4 for each individual i (Li & McCluskey, 2017).

4.3 Logit Model

In order to estimate the effect each independent variable has on respondents' willingness to learn more about the eDNA toolkits, a logit regression model was used in addition to the DBDC model. As defined by Kubak et al. (2020), the logit regression can be described as follows:

$$\Pr(Y = 1) = \frac{1}{1 + e^{-(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k)}} \quad 5$$

Where $Y = 1$ represents the respondent selecting "yes" when asked whether they want to learn more about eDNA toolkits as they relate to Canadian fisheries management, and β_k is a coefficient estimate for independent variable x_k for individual *i*.

Chapter 5: Results

5.1 Double-Bounded Dichotomous-Choice Results

My primary findings for respondents' overall WTP to fish on watersheds adopting novel eDNA toolkits for fisheries stock assessment can be found in Figure 2. Figure 2 illustrates the total number of respondents who are willing to pay to fish on their preferred watersheds if they were to adopt eDNA toolkits at each designated bid amount. The bid values can be observed on the horizontal axis, ranging from 0.7 to 1.3. Before I discuss the implications of the findings presented in Figure 2 in depth, it is important to specify what each bid value represents. Under the DBDC model, each individual bid value can be treated as a coefficient for the specified amount each respondent estimates they spent on fishing in the last calendar year. For example, an initial bid value of 1.00 will represent no change in spending from the individual respondent's reported amount, a bid value of 0.70 represents a 30% discount on a respondent's reported amount, and a bid value of 1.30 represents a 30% premium on a respondent's reported amount.

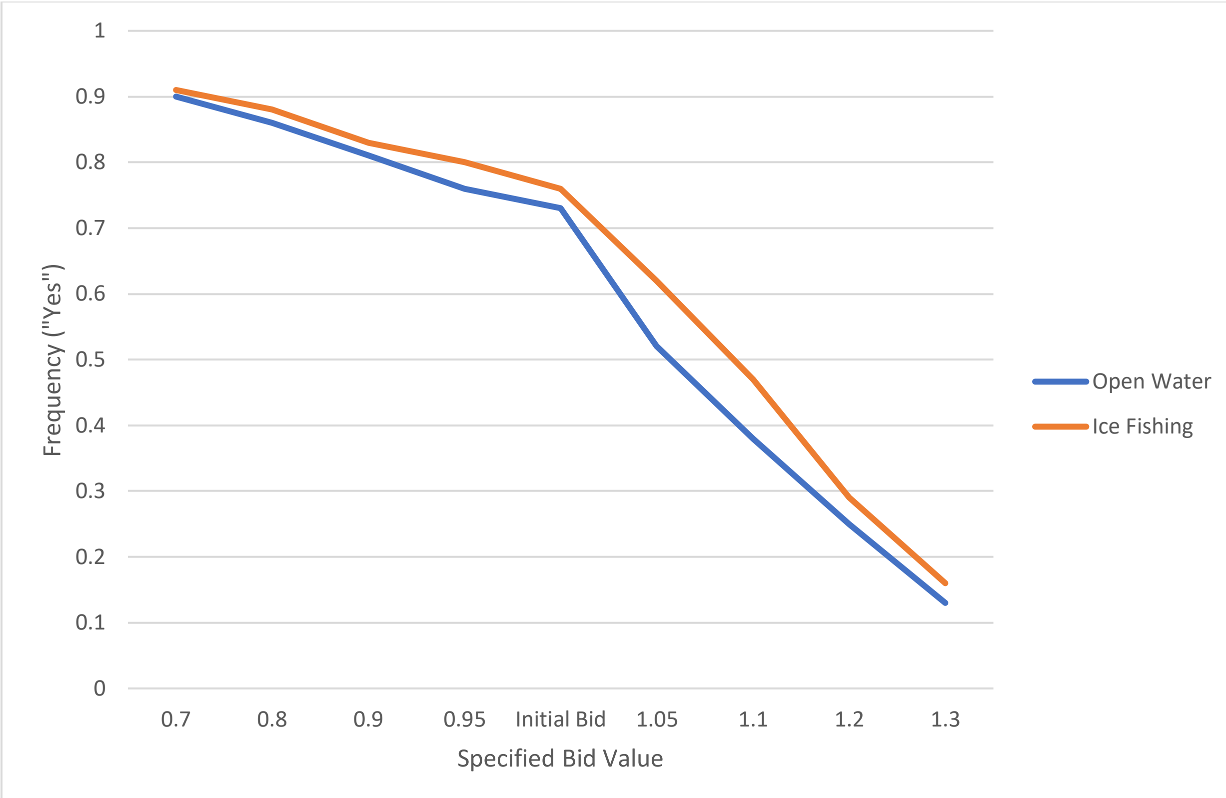

Figure 2: Percentage of respondents willing to fish on waterbodies adopting eDNA technology at their specified bid value

Observing Figure 2, it is clear that the majority of respondents are sensitive to higher price premiums for both open water and ice fishing when considering the adoption of novel eDNA toolkits in their preferred regions. The higher sensitivity to premium bids is shown by the steeper slopes to the right of the initial bid values for both open water and ice fishing. This increase in the slope of the curve is indicative of increased demand elasticities among recreational anglers for all premium bids, meaning they are more sensitive to changes in cost when the indirect costs imposed by the eDNA toolkit are higher than traditional alternative sampling methods. Considering the potential policy implications of this finding, there is clear incentive for fisheries managers and decision-makers to promote cost-saving programs under the adoption of eDNA toolkits to incentivize recreational anglers to fish on watersheds adopting the technology.

Breaking down Figure 2, of the 972 respondents for all open water DBDC questions from the CV survey, 90.2% (877) were willing to pay a 30% discount on their estimated annual fishing costs to fish on their preferred watershed if it were to adopt eDNA toolkits. At the upper bound, at least 13.1% (127) of respondents were willing to pay a 30% premium on their estimated fishing costs. If we take a step back to look at the practical implications of these findings, perhaps the most important observation we can make is that 72.8% (708) of respondents are willing to pay at least as much as their estimated annual fishing costs to fish on open watersheds adopting eDNA toolkits.

Of the 377 respondents for all ice fishing DBDC questions, 91.2% (344) were willing to pay a 30% discount on their estimated annual ice fishing costs to fish in their preferred region if it were to adopt eDNA technology. At the upper limit, at least 16.4% (62) of respondents were willing to pay a 30% premium on their reported annual ice fishing costs if their preferred region were to adopt eDNA technology. More importantly though, it seems that 75.6% (285) of respondents would be willing to pay at least as much as their estimated annual ice fishing costs to fish on frozen watersheds adopting eDNA toolkits. These findings suggest that, generally, among Canadian fisheries managers, opposition from recreational anglers will not be a significant barrier to adoption.

Moving on, Table 6, Table 7, and Table 8 report my results from the DBDC regressions for both open water and ice fishing with significance levels for all respondents, respondents subjected to the "environmental DNA" language treatment, and respondents subjected to the "eDNA" language treatment, respectively.

Table 6: Double-bounded dichotomous-choice results for open water and ice fishing from all respondents

	Open Water			Ice Fishing		
	Coef.	Std. Err.	P>z	Coef.	Std. Err.	P>z
Explanatory Variables						
Positive Information	0.02	0.03	0.42	0.01	0.06	0.82
Negative Information	0.02	0.03	0.39	0.05	0.06	0.43
Neutral Information	-0.01	0.03	0.79	0.03	0.06	0.61
No Information	___	___	___	___	___	___
Money Spent Fishing	-2.18e-7	5.62e-7	0.70	___	___	___
Money Spent Ice Fishing	___	___	___	1.76e-5	1.98e-5	0.37
Years Angling	1.78e-3	1.30e-3	0.17	0.01**	2.25e-3	0.03
Days Angling per Year	2.03e-4	1.47e-4	0.17	5.33e-4*	3.13e-4	0.09
Keep Catch	0.03**	0.01	0.04	0.01	0.03	0.76
Fishing Satisfaction	0.02	0.02	0.21	0.11***	0.03	0.00
Tech Knowledge	0.05***	0.02	0.00	-0.03	0.04	0.50
Believes eDNA Will Improve Management	0.05*	0.02	0.06	0.07	0.06	0.24
Invest in Genomic Tech	0.06**	0.03	0.02	0.08	0.07	0.23
Stock Assessment Preferences	-0.02	0.02	0.21	0.01	0.03	0.77
Residence	-0.04***	0.01	1.00e-3	-0.07***	0.02	4.00e-3
Fisheries Employee	0.07***	0.02	3.00e-3	0.15***	0.05	2.00e-3
Man	0.04	0.03	0.17	0.01	0.06	0.83
Age	-0.02**	0.01	0.02	-4.94e-3	0.02	0.80
Income	0.03***	0.01	0.00	0.03*	0.02	0.05
Education	0.01	0.01	0.16	0.01	0.01	0.64
Willingness to learn more about eDNA	-0.03	0.03	0.26	-0.12*	0.06	0.08
No. of Observations	906			367		
Log Likelihood	-1083.25			-375.10		

**** p<.01, ** p<.05, * p<.1*

Table 7: Double-bounded dichotomous-choice results for open water and ice fishing from respondents under "environmental DNA" language treatment

	Open Water			Ice Fishing		
	Coef.	Std. Err.	P>z	Coef.	Std. Err.	P>z
Explanatory Variables						
Positive Information	0.05	0.04	0.22	0.08	0.07	0.28
Negative Information	0.06	0.04	0.11	0.03	0.08	0.73
Neutral Information	0.03	0.04	0.50	-0.03	0.07	0.69
No Information	___	___	___	___	___	___
Money Spent Fishing	-2.81e-7	8.25e-7	0.73	___	___	___
Money Spent Ice Fishing	___	___	___	4.86e-5	3.06e-5	0.11
Years Angling	5.41e-4	1.86e-3	0.77	0.01*	2.93e-3	0.08
Days Angling per Year	4.04e-4*	2.20e-4	0.07	4.79e-4	4.29e-4	0.26
Keep Catch	0.03*	0.02	0.09	0.01	0.04	0.74
Fishing Satisfaction	0.02	0.02	0.31	0.11**	0.05	0.02
Tech Knowledge	0.03	0.03	0.24	-0.09	0.06	0.13
Believes eDNA Will Improve Management	0.03	0.03	0.35	0.13	0.08	0.10
Invest in Genomic Tech	0.08**	0.04	0.03	0.14*	0.09	0.12
Stock Assessment Preferences	-0.04	0.02	0.12	0.01	0.04	0.86
Residence	-0.05***	0.02	0.00	-0.05	0.03	0.12
Fisheries Employee	0.06*	0.03	0.06	0.17**	0.07	0.02
Man	0.06	0.04	0.13	-0.06	0.09	0.47
Age	-0.02	0.01	0.10	-0.01	0.03	0.60
Income	0.02	0.01	0.10	0.03	0.02	0.24
Education	0.02*	0.01	0.06	0.03	0.02	0.12
Willingness to learn more about eDNA	-0.03	0.04	0.48	-0.08	0.09	0.33
No. of Observations	450			195		
Log Likelihood	-534.66			-195.90		

****** $p<.01$, ** $p<.05$, * $p<.1$*

Table 8: Double-bounded dichotomous-choice results for open water and ice fishing from respondents under "eDNA" language treatment

	Open Water			Ice Fishing		
	Coef.	Std. Err.	P>z	Coef.	Std. Err.	P>z
Explanatory Variables						
Positive Information	-0.00	0.04	0.93	-0.05	0.09	0.60
Negative Information	-0.01	0.04	0.72	0.04	0.08	0.59
Neutral Information	-0.04	0.04	0.32	0.10	0.08	0.26
No Information	___	___	___	___	___	___
Money Spent Fishing	-1.91e-7	7.69e-7	0.80	___	___	___
Money Spent Ice Fishing	___	___	___	6.85e-6	8.68e-6	0.43
Years Angling	2.32e-3	1.85e-3	0.21	3.74e-3	3.57e-3	0.30
Days Angling per Year	3.95e-5	2.03e-4	0.85	6.90e-4	4.75e-4	0.15
Keep Catch	0.02	0.02	0.23	0.01	0.04	0.83
Fishing Satisfaction	0.02	0.02	0.38	0.12**	0.05	0.01
Tech Knowledge	0.07**	0.03	0.02	0.02	0.06	0.72
Believes eDNA Will Improve Management	0.07*	0.04	0.07	-0.03	0.09	0.78
Invest in Genomic Tech	0.04	0.04	0.24	0.05	0.10	0.59
Stock Assessment Preferences	-0.01	0.02	0.67	3.86e-3	0.05	0.93
Residence	-0.04**	0.02	0.02	-0.09**	0.04	0.01
Fisheries Employee	0.08**	0.03	0.01	0.12*	0.07	0.09
Man	0.02	0.04	0.59	0.08	0.08	0.31
Age	-0.02	0.01	0.14	0.01	0.03	0.68
Income	0.04***	0.01	1.00e-3	0.03**	0.02	0.18
Education	0.00	0.01	0.71	-0.01	0.02	0.65
Willingness to learn more about eDNA	-0.03	0.04	0.44	-0.23**	0.11	0.04
No. of Observations	456			172		
Log Likelihood	-542.52			-170.89		

*** $p<.01$, ** $p<.05$, * $p<.1$

Looking at the results, it becomes clear that none of the four information treatments yield a statistically significant effect on respondents' WTP to fish on watersheds adopting eDNA toolkits for both open water and ice fishing. This finding is of particular interest, as the transfer and provision of information on a new technology is often recognized as a primary factor in diffusion of innovations theory (Montalvo & Kemp, 2008). With this in mind, I posit that Canadian recreational anglers, on average, are willing to adopt novel eDNA toolkits regardless of the direction of the information treatment received.

Below I provide an explanation drawn from observing summary statistics reported for attitudinal variables that supports this hypothesis. In observing data collected on fishery technology knowledge, which displays positive statistical significance for open water fishing among all respondents excluding those subjected to the "environmental DNA" language treatment, we can see that most respondents report high levels of prior knowledge on eDNA technology and stock assessment practices. When asked about their level of eDNA technology knowledge before receiving any information treatments, it is shown that 35.76% (354) of respondents reported that they are "Very knowledgeable", and 41.11% (407) reported being "Somewhat knowledgeable". Similarly, when asked about knowledge about common fisheries stock assessment practices in their preferred region, 43.7% (430) of respondents reported being "Very knowledgeable", and 57.14% (512) reported being "Somewhat knowledgeable". These results suggest that the majority of survey respondents had at least some level of prior knowledge on eDNA technology and common stock assessment practices prior to participating in this study, making it reasonable to assume that most participants had predetermined opinions on the potential implications of eDNA technology adoption across Canadian fisheries to improve stock assessment practices, which is consistent with findings reported by Spash (2007).

Behavioural variables showed very little significance across all models overall, with the number of estimated days spent angling in 2020 reporting a small significant positive effect on WTP for ice fishing among all respondents, and a small significant positive effect on open water fishing among respondents under the "environmental DNA" language treatment. Similarly, the number of years respondents reported holding a recreational angling license showed a small positive effect on WTP for ice fishing among all respondents at the 5% significance level and among respondents under the “environmental DNA” language treatment at the 10% significance level. Additionally, respondents who were more likely to keep their catch after fishing were shown to have an increased WTP for open water fishing among all respondents and respondents under the “environmental DNA” language treatment at the 5% and 10% significance levels, respectively. Somewhat surprisingly, the total amount of money spent on fishing and ice fishing in 2020 yielded insignificant results, which may be explained by the high level of heterogeneity across responses for this question.

Attitudinal variables showed varying levels of significance for open water and ice fishing across the three different models. Respondents’ overall level of fishing satisfaction reports a positive effect on WTP for only ice fishing across both language treatment models at the 5% significance level with a positive effect being observed among all respondents for ice fishing at the 1% significance level. Respondents’ prior knowledge of eDNA technology and common stock assessment practices yields a positive effect on WTP for open water fishing among all respondents and respondents subjected to the “eDNA” language treatment at the 1% and 5% significance levels, respectively. Respondents who indicated they believe adopting eDNA technologies will improve Canadian fisheries management yielded a small positive significant effect on WTP for open water fishing among all respondents and respondents under the “eDNA” language treatment. Respondents subjected to the “environmental DNA” language treatment who reported that they believe investing in genomic technologies will benefit Canadian recreational anglers were also shown to have a positive effect on WTP for open water and ice fishing. Among all respondents, those reporting that they believe investing in genomic technologies will be beneficial for recreational anglers were shown to have a significant positive effect on WTP for open water fishing. Lastly, respondents' willingness to learn more about eDNA following completion of the CV survey yielded little significance overall, showing a negative significant correlation with WTP for ice fishing among all respondents and respondents under the "eDNA" language treatment. While examining attitudinal variable coefficient estimates for ice fishing, especially under the "environmental DNA" and "eDNA" language treatments, it is important to note that results from should be examined with caution due to the smaller sample sizes.

Demographic variables also displayed varying levels of significance across all three models. Looking at the effect of a respondent's region of residence on their WTP to fish on watersheds adopting eDNA toolkits, we can observe that as respondents move further from rural areas, their WTP decreases. This finding holds true for both open water and ice fishing across all models excluding ice fishing under the "environmental DNA" language treatment. Age had little overall effect on WTP, with coefficient estimates reporting a small significant negative effect on WTP as age increases for open water fishing among all respondents. Higher incomes, however, had on overall significant positive effect for both open water and ice fishing across all models excluding open water fishing under the "environmental DNA" language treatment. Finally, higher levels of education yielded a small positive effect on WTP open water fishing among respondents subjected to the "environmental DNA" language treatment, but results showed little significance.

Upon observing that being a current or former recreational fisheries employee yielded a significant positive effect on WTP for both open water and ice fishing across all models, I decided to run two more DBDC models: One including only observations from respondents who reported that they are a current or former fisheries employee, and the second including observations from respondents who reported that they have never been fisheries employees, shown in Table 9.

Table 9: DBDC Results for respondents reporting being current or former fisheries employees compared to respondents reporting never having been fisheries employees

	Fisheries Employees			Non Fisheries Employees		
	Coef.	Std. Err.	P>z	Coef.	Std. Err.	P>z
Explanatory Variables						
Positive Information	1.61e-3	0.07	0.98	0.03	0.06	0.54
Negative Information	0.07	0.07	0.29	-0.02	0.06	0.70
Neutral Information	0.02	0.06	0.80	-0.01	0.06	0.88
No Information	—	—	—	—	—	—
Money Spent Fishing	-7.30e-6	1.10e-5	0.51	-5.38e-6*	3.10e-6	0.08
Money Spent Ice Fishing	1.99e-5	2.77e-5	0.47	7.35e-6	5.49e-6	0.18
Years Angling	0.01**	2.94e-3	0.04	-3.14e-3	2.22e-3	0.16
Days Angling per Year	5.06e-4	3.53e-4	0.15	-2.99e-4	3.90e-4	0.44
Keep Catch	0.10***	0.04	6.00e-3	-0.01	0.03	0.76
Fishing Satisfaction	0.11***	0.04	6.00e-3	0.01	0.04	0.83
Tech Knowledge	-0.13**	0.06	0.02	-0.03	0.04	0.45
Believes eDNA Will Improve Management	-3.03e-3	0.08	0.97	-0.01	0.06	0.83
Invest in Genomic Tech	0.07	0.08	0.36	0.17**	0.07	0.03
Stock Assessment Preferences	3.58e-3	0.04	0.93	-0.02	0.03	0.51
Residence	-0.08***	0.03	5.00e-3	-0.06***	0.02	7.00e-3
Fisheries Employee	—	—	—	—	—	—
Man	-0.01	0.07	0.91	-0.02	0.06	0.76
Age	-0.02	0.02	0.48	0.03	0.02	0.25
Income	0.04*	0.02	0.09	0.05**	0.02	0.01
Education	0.03	0.02	0.13	-0.02	0.02	0.50
Willingness to learn more about eDNA	-0.25***	0.10	0.00	-4.95e-3	0.06	0.94
No. of Observations	260			105		
Log Likelihood	-675.78			-138.94		

**** p<.01, ** p<.05, * p<.1*

Under the model including only respondents reporting they are current or former employees of the recreational fishing industry, two behavioural variables, three attitudinal variables, and two demographic variables yielded significance. Respondents' reported years angling yielded a positive significant effect on WTP. Respondents more likely to keep their catch yielded a positive significant effect on WTP. Respondents' level of fishing satisfaction displayed a positive significant effect on WTP. Respondents' level of prior knowledge on eDNA technology and stock assessment practices yielded a significant negative effect on WTP. A respondent's area of residence, as reported by proximity to urban areas, yielded a significant negative effect on WTP. Respondents' reported income range showed a positive significant effect on WTP. Respondents who reported being willing to learn more about eDNA toolkits yielded a significant negative effect

Under the model including only respondents reporting they have never been employed in the fisheries industry, one attitudinal, one behavioural, and two demographics variables yielded significance. Respondents' annual open water fishing costs showed a small negative significant effect on WTP. Respondents' opinions on investing in future genomic technologies yielded a significant positive effect on WTP. Respondents' proximity to rural areas displayed a negative significant effect on WTP. Respondents' reported income range yielded a positive significant effect on WTP.

5.2 Mean WTP Across All Double-Bounded Dichotomous-Choice Models

Table 10 reports overall mean WTP as compared to respondents' initial bid for both open water and ice fishing across all three DBDC models. Where the confidence intervals for mean WTP is calculated under the DBDC approach using the delta method (Hole, 2008). It is important to specify that mean WTP coefficients are represented as bid values, meaning all values can be interpreted as percent changes in WTP from a respondent's reported estimated annual fishing costs, or their initial bid.

Table 10: Mean WTP across all DBDC models for both open water and ice fishing

	Coef.	[95% Confidence Interval]	
WTP - Open Water (pooled data)	1.19***	1.17	1.22
WTP – Ice Fishing (pooled data)	1.23***	1.18	1.29
WTP – Open Water (environmental DNA)	1.18***	1.14	1.21
WTP – Ice Fishing (environmental DNA)	1.23***	1.15	1.31
WTP – Open Water (eDNA)	1.21***	1.17	1.24
WTP – Ice Fishing (eDNA)	1.27***	1.18	1.35
WTP – Fisheries Employees (pooled data)	1.33***	1.20	1.26
WTP – Non-Fisheries Employees (pooled data)	1.07***	1.01	1.13

*** $p<.01$, ** $p<.05$, * $p<.1$

Note: Mean WTP coefficients represent the premium respondents would pay as a percentage compared to base fishing costs under conventional technology.

Observing mean overall WTP results above, respondents are willing to pay a premium to fish on watersheds adopting eDNA technology independent of the season or language treatment they received. Respondents are shown to be willing to pay, on average, a 19% premium on their estimated annual fishing costs to fish on open watersheds adopting eDNA toolkits, and a 23% premium to fish on frozen watersheds adopting eDNA toolkits. Under the "environmental DNA" language treatment, respondents are willing to pay an 18% premium to fish on open watersheds and a 23% premium to fish on frozen watersheds adopting eDNA toolkits. Under the "eDNA" language treatment, it is shown that respondents are willing to pay a 21% premium on open watersheds and a 27% premium on frozen watersheds adopting eDNA toolkits. Among self-reported current or former recreational fisheries employees, respondents are willing to pay a 33% premium overall on their estimated annual fishing costs. Respondents who reported never having been employed in the recreational fishing industry are willing to pay a 7% premium, overall.

5.3 Logit results for respondents' willingness to learn more about eDNA toolkits

Table 10 displays coefficient estimates, marginal effects, and significance levels for the simple logit model used to measure factors affecting a respondent's willingness to learn more about novel eDNA toolkits as they relate to fisheries management upon completion of the CV survey.

Table 11: Factors affecting respondents' willingness to learn more about eDNA toolkits

Willingness to learn more about eDNA	Coef.	Std. Err.	p-value	Marginal Effects	Std. Err.
Positive Information	-0.04	0.49	0.94	-1.67e-3	0.02
Negative Information	0.52	0.56	0.36	0.02	0.02
Neutral Information	0.30	0.50	0.54	0.01	0.02
No Information	___	___	___	___	___
Money Spent Fishing	2.06e-5	9.72e-5	0.83	8.09e-7	4.26e-6
Money Spent Ice Fishing	7.88e-4**	3.70e-4	0.03	3.44e-5***	9.94e-6
Years Angling	0.03	0.02	0.20	1.20e-3	9.85e-4
Days Angling per Year	0.01*	2.90e-3	0.05	2.46e-4*	1.47e-4
Keep Catch	0.23	0.24	0.33	0.01	0.01
Fishing Satisfaction	0.67**	0.31	0.03	0.03*	0.02
Tech Knowledge	0.31	0.39	0.42	0.01	0.02
Believes eDNA Will Improve Management	-0.35	0.55	0.53	-0.02	0.02
Invest in Genomic Tech	0.01	0.57	0.99	-3.74e-4	0.02
Stock Assessment Preferences	0.20	0.26	0.44	0.01	0.01
Residence	0.09	0.22	0.67	4.14e-3	0.01
Fisheries Employee	-0.16	0.46	0.72	-0.01	0.02
Man	-0.33	0.53	0.54	-0.01	0.02
Age	-0.10	0.17	0.56	-4.38e-3	0.01
Income	-0.29**	0.14	0.04	-0.01*	0.01
Education	-0.01	0.12	0.93	4.72e-4	0.01
Constant	0.74	1.63	0.65		

No. of Observations	366
Log likelihood	-105.18
Mean dependent var	0.32
Pseudo r-squared	361.00
Chi-square	0.00
Akaike crit. (AIC)	335.65

**** p<.01, ** p<.05, * p<.1*

The logit regression results report statistical significance for four independent variables. The amount of money respondents spent in the last calendar year on ice fishing yields a positive effect on willingness to learn more about eDNA toolkits at the 9% significance level. When we interpret the marginal effect of each extra dollar spent on ice fishing per year, it is shown that one extra dollar yields a near-zero change in our dependent variable. The number of days spent angling in the last calendar year reports a small positive effect on a respondent's willingness to learn more about eDNA toolkits. A respondent's overall level of fishing satisfaction has a positive effect on their willingness to learn more about eDNA toolkits at the 5% significance level. This means that the more satisfied a respondent is with the quality, costs, and opportunity in their preferred fishing region, the more likely they are to report a willingness to learn more about eDNA toolkits. Higher reported household incomes also display a negative effect on a respondent's willingness to learn more about eDNA toolkits and their potential applications in Canadian fisheries at the 5% significance level, which may be explained by a lower concern for adopting novel technologies that have the potential to save time and money among individuals with higher household incomes, or more disposable income.

Chapter 6: Conclusion

6.1 Discussion of Findings

The objectives of this study were threefold: (1) to measure Canadian recreational anglers' WTP to fish on their preferred watersheds under the adoption of novel eDNA toolkits; (2) to examine the effect of providing positive, negative, neutral, and zero information treatments regarding the toolkits on recreational anglers' WTP to fish on watersheds adopting the technology; and (3) to provide a foundation to develop and adopt new policies to improve fisheries management and stock assessment practices.

Interestingly, and perhaps most importantly, regardless of information treatment received, language treatment received, or whether or not they are current or former fisheries employees, results show that respondents for both open water and ice fishing are generally willing to pay a 7%-33% premium on their reported annual fishing costs to fish on watersheds adopting eDNA toolkits. Specifically, results from pooled respondents for both open water and ice fishing reveal that respondents are willing to pay premiums of 19% and 23%, respectively. Results from respondents under the "environmental DNA" language treatment show that for open water and ice fishing, respondents are willing to pay premiums of 18% and 23%, respectively. Results from respondents under the "eDNA" language treatment elucidate that for open water and ice fishing, respondents are willing to pay premiums of 21% and 27%, respectively. Results from the model measuring WTP for only respondents who reported being current or former fisheries employees report that they are willing to pay a premium of 33%. Results from the model measuring WTP for only respondents who reported having never been fisheries employees report that they are willing to pay a premium of 7%. Furthermore, given that 95.93% of respondents reported being at least "Somewhat knowledgeable" about common stock assessment practices and 76.87%

reported being at least “Somewhat knowledgeable” about eDNA technology, it is not unreasonable to conclude that the majority of our respondents held predetermined preferences surrounding eDNA and similar genomic technologies, making them less sensitive to the provision of information.

Ultimately, my findings fail to reject the null hypothesis that positive, negative, neutral, and zero information treatments yield no effect on an individual’s WTP to fish on watersheds adopting eDNA toolkits. When interpreting results for ice fishing, especially under the “environmental DNA” and “eDNA” language treatments, it is important to exercise caution given the limited relative sample sizes. Nonetheless, none of the information treatments yielded a significant effect on respondents’ WTP for both open water and ice fishing. Factors that showed a significant positive effect on their relationship with recreational anglers’ WTP to fish on watersheds adopting eDNA toolkits include days per year spent fishing, number of years reported as a recreational angler, if they are more likely to keep their catch, level of fishing satisfaction, levels of prior knowledge on eDNA technology and stock assessment practices, if they support investment into developing genomic technologies, being a current or former recreational fisheries employee, and their level of household income. Conversely, some factors that yielded a significant negative effect on respondents’ WTP include their proximity to urban centers, age, and, among all respondents for ice fishing, their willingness to learn more about eDNA toolkits. This is an interesting finding, and it may be explained by recreational anglers who spend a majority of their days fishing on frozen watersheds having a lower perceived utility for eDNA technologies.

6.2 Policy Implications

Results from this study can be used to promote policy development and improved fisheries management regulations under the adoption and employment of novel eDNA toolkits to monitor and assess our freshwater fish stocks. My findings show that proficient recreational anglers are generally willing to pay a high premium to fish on watersheds adopting eDNA toolkits, not necessarily because they are knowledgeable on eDNA technologies and their potential applications in fisheries management, but perhaps because they have lower preferences current traditional capture methods used in stock assessment.

On a broader scale, findings form this study provide valuable insights on preferences for novel eDNA toolkits ex ante. With fisheries managers and decision-makers being hesitant to adopt eDNA technologies for monitoring and stock assessment, the evidence presented on recreational anglers' preferences for adoption is telling (Jerde, 2021). My results display strong preferences for the adoption of eDNA toolkits among recreational anglers in Canada over the use of traditional sampling methods that are often unreliable and potentially harmful to fish species (Joy et al., 2013; Cook et al., 2018; Radinger et al., 2019). Furthermore, with much of the current literature describing the expected benefits of adopting eDNA alongside traditional methods to data collection, cost effectiveness, and subsequently fisheries sustainability, the positive perceptions of avid recreational anglers in this study further promote the adoption of these technologies (Takahara et al., 2012; Jerde et al., 2013; Hänfling et al., 2016; Jerde, 2021). We can conclusively state that Canadian recreational anglers tend to be largely unaffected by any preconceived spill-over affect of aversion to the adoption and employment of genomic technologies in the health and agrifood industries. Thus, the adoption of novel eDNA toolkits to improve fisheries monitoring and stock assessment will likely yield high levels of acceptance among members within the Canadian recreational fisheries.

Ultimately, when discussing potential policy implications from findings in this study, it is important to note that the directional effects from our models are more important than the magnitudes of the effects. Given the hypothetical nature of results produced in this study, it is important to identify that budget constraints in practical applications of this study may limit recreational anglers' ability to pay the exact premiums reported here. With that said, however, we can confidently conclude that, regardless of budget constraints, Canadian recreational anglers are willing to pay a premium to fish on watersheds adopting eDNA toolkits and will likely pay at least as much to fish on watersheds adopting the technology as they would to fish on watersheds without the technology if they cannot pay a premium.

6.3 Limitations and Future Research

This study was among the first of its kind, employing a CV DBDC survey design to measure the preferences of recreational anglers to fish on watersheds adopting novel genomic toolkits. We decided to utilize on online CV survey study instead of conducting in-person interviews across Ontario due to the Covid-19 pandemic. Nonetheless, it acts as an effective foundation for similar and replicate studies to be conducted in the future.

One limitation of this study is that it was conducted ex ante. That is, we measured stated WTP responses for a technology that is not commercially available nor widely used, specifically in Canadian fisheries management regimes. Moreover, the eDNA technology being valued is a non-use technology in this context as we elicited WTP responses for recreational anglers, who are not the end-users of this technology. Though Diamond & Hausmann (1994) argue that CV studies can be quite useful in measuring the value of non-use goods, especially when the alternative is to not measure them at all, it is difficult to accurately capture cost savings to recreational anglers homogeneously under the adoption and employment of eDNA technologies in Canadian fisheries, as they are expected to be embedded in transportation costs and fishing equipment. It is important to reiterate the caution which must be exercised when examining results from the DBDC results tables for the "environmental DNA" and "eDNA" language treatments, given the relative significant reduction in sample size when compared to the first table which includes responses from all participants, regardless of language treatment received.

It is recommended that similar studies are conducted in the future when the technology becomes commercially available. Specifically, it would be a worthy contribution to the existing literature to develop a randomized control trial to measure revealed preferences for the adoption of eDNA toolkits where, perhaps, subsets of the sample are informed to varying degrees on how to effectively access and interpret the data provided by the technology and are then compared to a control group. Results from this study may also be useful in performing ex-ante cost-benefit analyses under various levels of eDNA technology adoption, informing end-user adoption decisions.

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Appendix A: Survey Instructions

Please review the following consent form before continuing to the survey.

Acknowledgement of Consent

Upon completion of this survey, you will be paid **$5 CAD** via **PayPal**. In order to receive your payment, please provide us with the email address linked to your PayPal account at the end of the survey. If you do not have a PayPal account, an email will be sent to the email address you provide at the end of the survey prompting you to create one so you can collect your payment. You should expect to receive your payment within 5 business days.

Please note that in order to participate, you must:

- Be 18 years of age or older
- Hold a valid Canadian fishing license **and/or** be over 65 years of age
- Acknowledge that neither you nor any member of your household has taken this survey
- Be proficient in English

We will be closing the survey after **1,000** responses have been collected or after it has been open for **30 days,** whichever comes first.

By selecting "I agree" below, you are indicating that you have read and acknowledged the consent form. If you select "I do not agree", you will no longer be eligible to participate in this study.

Thank you for your participation.

Please note: You will not be able to move backwards in this survey. Please read each question thoroughly before answering.

Have you or any members of your household taken this survey before? (If you answer Yes, you are not eligible to continue on in this study)

○ Yes

○ No

Appendix B: Questionnaire

Appendix B.1: Fishing Questions

Do you currently hold a valid recreational fishing licence in Canada? (If you answer **No**, you are not eligible to continue on in this study **unless** you are over the age of 65)

- ◯ Yes
- ◯ No (but I am over the age of 65)
- ◯ No

Skip To: End of Survey If Do you currently hold a valid recreational fishing licence in Canada? (If you answer No, you are... = No

---

In what province(s) is/are your fishing licence(s) valid? (Check all that apply)

- ☐ Ontario
- ☐ Other (Please specify) ________________
- ☐ None (I am over the age of 65)

What type(s) of fishing license(s) do you hold? (Check all that apply)

- ☐ Ontario Sport Fishing Licence
- ☐ Ontario Conservation Fishing Licence
- ☐ Other (please specify) ________________
- ☐ Not sure
- ☐ None (I am over the age of 65)

For how many years have you been a recreational angler?

____

Approximately how many days do you go fishing in the average year?

____

How do you primarily fish? (Check all that apply)

- ☐ From a boat (including kayaks, canoes, belly boats, etc.)
- ☐ From shore
- ☐ Wading
- ☐ Ice fishing

Where do you primarily fish? (Check all that apply)

- ☐ Lakes
- ☐ Ponds
- ☐ Rivers
- ☐ Streams
- ☐ Other (please specify)

____

If you fish in Ontario, please identify which Fisheries Management Zone you primarily fish in in the text box below (please proceed to the next question if you do not fish in Ontario)

____

Do you ever eat/keep what you catch?

- ◯ Yes, if the fish is of the proper species, length, and weight, and the season for that species is open, I will eat/keep it
- ◯ Sometimes
- ◯ Rarely
- ◯ No, I always release what I catch

How satisfied are you with the following?

	Extremely satisfied	Somewhat satisfied	Neither satisfied nor dissatisfied	Somewhat dissatisfied	Extremely dissatisfied
Fishing opportunity in your region	◯	◯	◯	◯	◯
The quality of fish in your region	◯	◯	◯	◯	◯
Costs of fishing in your region	◯	◯	◯	◯	◯

How would you describe your knowledge of eDNA technology?

○ Very knowledgeable

○ Somewhat knowledgeable

○ Not knowledgeable

○ I have never heard of eDNA prior to this study

Appendix B.2: Information Treatments

Please read the following statement carefully and acknowledge you have read it before continuing the survey

With the use of cutting-edge eDNA technologies, scientists are able to non-invasively sample the genetic material of an organism instead of the organism itself. eDNA can be detected from a water sample. This allows scientists to monitor fish populations more effectively, providing fisheries managers and anglers with a better understanding of population health, relative abundance, and distribution across regions that have adopted the technology. Moreover, the employment of eDNA technologies will allow experts to monitor fish populations in frozen waterbodies, providing ice anglers with credible population data that isn't available with traditional sampling methods.

○ I have read and understand the above statement

Please read the following statement carefully and acknowledge you have read it before continuing the survey

Although there are some expected benefits from using eDNA technologies, studies have shown that these technologies may fail at capturing reliable population data since it uses the genetic material of an organism instead of the organism itself for monitoring. One consequence of assessing fish populations without physically assessing any fish is that it may lead us to believe there are more or less fish in a waterbody than there actually are. With this being a real possibility, the employment of eDNA technologies in Canadian fisheries may not only be inefficient, it may also increase the level of uncertainty surrounding the state of fish stocks.

○ I have read and understand the above statement

Please read the following statement carefully and acknowledge you have read it before continuing the survey eDNA technologies are genomic technologies being developed to monitor and assess fish populations. Existing genomic technologies have been most widely implemented in the health and agrifood industries. In the health industry, gene editing technologies such as CRISPr have been developed in order to mitigate risk involved with genetic defects and illness. In the agrifood industry, similar technologies have been introduced with the aim of reducing the spread of disease across food crops by manipulating plant genomes to make them more robust. Using genomic technologies in fisheries is a new development.

- ◯ I have read and understand the above statement

Appendix B.3: eDNA Adoption "eDNA" language treatment

According to Fisheries and Oceans Canada, the average angler spent $262 on transportation and $233 on food/lodging in 2015. Keeping this in mind, how much, in your estimation, do you spend on all fishing equipment and trips in the average year? (In $CAD. Try to take food, fuel, travel costs, accommodations, permits, licensing, etc. into account)

____

Now, assume you will spend the same amount of time on fishing this upcoming year as you would in the average year. If your preferred region adopted eDNA technology, would you pay the same price to fish there as you would to fish on a waterbody without the technology?

- ◯ Yes
- ◯ No

Now, for the upcoming year, if your preferred region adopted eDNA technology, would you pay a price to fish there that is *5%, 10%, 20%, 30%* higher than the price you would pay to fish on a waterbody without the technology?

- ◯ Yes
- ◯ No

Now, for the upcoming year, if your preferred region adopted eDNA technology, would you pay a price to fish there that is *5%, 10%, 20%, 30%* lower than the price you would pay to fish on a waterbody without the technology?

○ Yes

○ No

Do you ice fish?

○ Yes

○ No

How much, in your estimation, do you spend on ice fishing equipment and trips in an average year? (In $CAD. Try to take food, fuel, travel costs, accommodations, permits, licensing, etc. into account)

____

Now, assume you will spend the same amount of time on ice fishing this upcoming year as you would in an average year. If your preferred region adopted eDNA technology, would you pay the same price to ice fish there as you would to ice fish on a waterbody without the technology?

○ Yes

○ No

Now, for the upcoming year, if your preferred ice fishing region adopted eDNA technology, would you pay a price to ice fish there that is *5%, 10%, 20%, 30%* higher than the price you would pay to fish on a waterbody without the technology?

○ Yes

○ No

Now, for the upcoming year, if your preferred ice fishing region adopted eDNA technology, would you pay a price to ice fish there that is *5%, 10%, 20%, 30%* lower than the price you would pay to ice fish on a waterbody without the technology?

○ Yes

○ No

How would you describe your knowledge of fisheries stock assessment practices in your preferred region?

○ Very Knowledgeable

○ Somewhat Knowledgeable

○ Not Knowledgeable

Do you think eDNA technologies can help improve fisheries management in Canada?

○ Yes

○ No

○ Unsure

Do you believe investment into researching and developing genomic technologies is beneficial for recreational anglers?

○ Yes

○ No

○ Unsure

Appendix B.4: eDNA Adoption "environmental DNA" language treatment

According to Fisheries and Oceans Canada, the average angler spent $262 on transportation and $233 on food/lodging in 2015. Keeping this in mind, how much, in your estimation, do you spend on all fishing equipment and trips in the average year? (In $CAD. Try to take food, fuel, travel costs, accommodations, permits, licensing, etc. into account)

____

Now, assume you will spend the same amount of time on fishing this upcoming year as you would in the average year. If your preferred region adopted environmental DNA (eDNA) technology, would you pay the same price to fish there as you would to fish on a waterbody without the technology?

○ Yes

○ No

Now, for the upcoming year, if your preferred region adopted environmental DNA (eDNA) technology, would you pay a price to fish there that is *5%, 10%, 20%, 30%* higher than the price you would pay to fish on a waterbody without the technology?

○ Yes

○ No

Now, for the upcoming year, if your preferred region adopted environmental DNA (eDNA) technology, would you pay a price to fish there that is *5%, 10%, 20%, 30%* lower than the price you would pay to fish on a waterbody without the technology?

○ Yes

○ No

Do you ice fish?

○ Yes

○ No

How much, in your estimation, do you spend on ice fishing equipment and trips in an average year? (In $CAD. Try to take food, fuel, travel costs, accommodations, permits, licensing, etc. into account)

____

Now, assume you will spend the same amount of time on ice fishing this upcoming year as you would in an average year. If your preferred region adopted environmental DNA (eDNA) technology, would you pay the same price to ice fish there as you would to ice fish on a waterbody without the technology?

○ Yes

○ No

Now, for the upcoming year, if your preferred ice fishing region adopted environmental DNA (eDNA) technology, would you pay a price to ice fish there that is *5%, 10%, 20%, 30%* higher than the price you would pay to fish on a waterbody without the technology?

○ Yes

○ No

Now, for the upcoming year, if your preferred ice fishing region adopted environmental DNA (eDNA) technology, would you pay a price to ice fish there that is *5%, 10%, 20%, 30%* lower than the price you would pay to ice fish on a waterbody without the technology?

○ Yes

○ No

How would you describe your knowledge of fisheries stock assessment practices in your preferred region?

○ Very Knowledgeable

○ Somewhat Knowledgeable

○ Not Knowledgeable

Do you think environmental DNA (eDNA) technologies can help improve fisheries management in Canada?

○ Yes

○ No

○ Unsure

Do you believe investment into researching and developing genomic technologies is beneficial for recreational anglers?

- ◯ Yes
- ◯ No
- ◯ Unsure

Appendix B.5: Preferences for Stock Assessment

Suppose you are out fishing one day. You notice someone out collecting water samples, so you decide to ask them what they are doing. They then tell you that they are collecting samples for fisheries stock assessment. They say that from the water samples they have collected, they will be able to tell you what species are in this waterbody and how many there are. Would you prefer this method of stock assessment over traditional methods (i.e. nets, traps, electrofishing)?

- ◯ Yes, I would prefer for this method of stock assessment to replace traditional methods
- ◯ Yes, but only if it is used in combination with traditional methods, not as a replacement
- ◯ No, I prefer traditional methods of stock assessment
- ◯ Unsure

Why might you want eDNA technology to be adopted in your preferred fishing region?

- ◯ I would like to know what fish species are in my preferred region and how many there are
- ◯ I would like to see more environmentally friendly stock assessment methods being adopted
- ◯ I do not want stock assessment workers crowding my preferred fishing region
- ◯ I am indifferent about the adoption of eDNA technology in my preferred fishing region
- ◯ I do not want eDNA technology to be adopted in my preferred fishing region
- ◯ Other (please specify) ____

Why might you NOT want eDNA technology to be adopted in your preferred fishing region?

○ I do not trust eDNA technology will provide accurate fish population data

○ I am concerned that eDNA technology might harm the native species in my preferred fishing region

○ I prefer traditional methods of stock assessment since we already know they work

○ I am indifferent about the adoption of eDNA technology in my preferred fishing region

○ I want eDNA technology to be adopted in my preferred fishing region

○ Other (please specify)

Appendix B.6: Demographic and Behavioural Questions

Please provide the first 3 characters of your postal code.

____

How would you describe your area of residence?

○ Urban

○ Suburban

○ Exurban

○ Rural

○ Other (please specify) ______________________________

What is your employment status?

○ Employed

○ Self-employed

○ Unemployed

- ○ Retired
- ○ Student
- ○ Stay-at-home parent/caregiver

Have you ever been employed in the recreational fisheries industry?

- ○ Yes
- ○ No

What is your gender?

- ○ Woman
- ○ Man
- ○ My gender identity is not listed above ____________________
- ○ Choose not to respond

What is your age range?

- ○ 18-24
- ○ 25-30
- ○ 31-40
- ○ 41-50
- ○ 51-64
- ○ 65+

What is your annual household income in the last year?

- ◯ Below $20,000 CAD
- ◯ $20,000-$49,999 CAD
- ◯ $50,000-$79,999 CAD
- ◯ $80,000-$99,999 CAD
- ◯ $100,000-$119,999 CAD
- ◯ $120,000-$149,999 CAD
- ◯ $150,000 CAD or more

What is your highest achieved level of education?

- ◯ Some high school
- ◯ Completed high school
- ◯ Some college/university
- ◯ Apprenticeship training and trades
- ◯ Completed college/university
- ◯ Some graduate education
- ◯ Completed graduate education
- ◯ Professional degree

Appendix B.7: Willingness to Learn more about eDNA

Are you willing to learn more about the status of eDNA technology adoption in Canadian fisheries? (If you answer Yes, we will provide you with a link to a website where you can learn more about eDNA technologies and their role in Canadian fisheries management)

- ○ Yes
- ○ No

Please click the link below to learn more about eDNA technology (please return to this page after using the link so you can finish the survey).
[Toolkits - GEN-FISH]

Please provide the email address linked to your PayPal account below so you can receive your compensation for completing this survey. If you do not have a PayPal account, an email will be sent to the address you provide at the end of the survey prompting you to create one so you can collect your payment.

Appendix C: Map of Ontario Fisheries Management Zones