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AN APPROACH TO ESTIMATE ANGLING EFFORT, CATCH, AND HARVEST OF BURBOT *LOTA LOTA*

by

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Abstract.- Once commonly thought of as a nuisance, Burbot *Lota lota* are now being frequently targeted by anglers in Minnesota. However, the amount of angling effort directed at Burbot, the distribution of effort, catch, and harvest are unknown. Historically, creel surveys have been used to estimate angling effort, catch, and harvest. Additionally, digital cameras have been used independently and supplementally to estimate angling effort, catch, and harvest. In this study, we estimate angling effort, catch, and harvest of Burbot using creel survey techniques and motion-activated digital cameras on Bad Medicine Lake, Minnesota, while also investigating and exploring the limitations of these methodologies. Using in-person data collection, we estimated Burbot anglers fished for 1,052 hours (3.23 hrs/ha), caught 136 Burbot (0.13 Burbot/angling hour), and harvested 67 Burbot (~50%; 0.06 Burbot/hr). Using digital data collection, we estimated Burbot anglers fished for 1,067 hours (3.28 hrs/ha), caught 173 Burbot (0.16 Burbot/angling hour), and harvested 87 Burbot (~50%; 0.08 Burbot/hr). In-person daily party counts were not significantly different from digital daily party counts ($p = 0.09$). Similarly, there was not a significant difference between in-person daily party counts and digital daily party counts, only when in-person data collection occurred ($p = 0.22$). However, trip lengths of angling parties that were both interviewed and observed on the digital cameras were significantly different ($p = 0.02$). On average, trip lengths of interviewed parties were 0.32 hours shorter than what was observed on the digital cameras. The findings of this research indicated that anglers actively targeted Burbot. Both in-person and digital data collection methods demonstrated to be effective for estimating angling effort.

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LITERATURE REVIEW OF HISTORICAL CREEL SURVEY METHODOLOGIES

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This review briefly summarizes historical creel survey methods. On-site, off-site, and complemented methods are included. Advantages and disadvantages of each method are discussed. This review provides a more extensive description of the methods than what is described within the thesis.

Creel surveys, also known as angler surveys, are used to collect information on angling effort, catch, harvest, economics, and opinions (Pollock et al. 1994; Malvestuto 1996; Soupir et al. 2006; Jones and Pollock 2012; McCormick and Meyer 2017; Nieman et al. 2021). To gather this information, fisheries managers have used two primary techniques, on-site and off-site methods (Pollock et al. 1994; Malvestuto 1996; Jones and Pollock 2012). On-site creel survey methods include access-based surveys, roving surveys, and aerial surveys (Pollock et al. 1994; Malvestuto 1996; Soupir et al. 2006; Jones and Pollock 2012). Access-based surveys commonly occur at areas of public access like boat ramps and fishing piers (Pollock et al. 1994; Soupir et al. 2006; Jones and Pollock 2012). Anglers are interviewed by survey agents when their fishing trip has concluded. Access-based surveys are dependent upon a spatiotemporal frame, in which access points, dates, and times are chosen in a statistically valid manner (Pollock et al. 1994; Jones and Pollock 2012). Obtaining a list of all access points is imperative before conducting a survey of these methods. Knowledge of temporal patterns of angling is recommended, such as length of fishing season, and when fishing occurs, relative to dates and times (Pollock et al. 1994). Surveys should be designed to ensure survey agents sample all hours of the fishing day. Commonly, the duration of a fishing day extends beyond an eight-hour work shift. Therefore, AM and PM shifts are often constructed (Pollock et al. 1994). Sampling can then be conducted with either uniform or non-uniform probabilities (Pollock et al. 1994). If there is more fishing effort during the AM shift, it would be advantageous to sample the AM shift more frequently than the PM shift (Pollock et al. 1994; Jones and Pollock 2012). In fisheries with five or fewer access points, survey agents traditionally visit each access point on different days (Pollock et al. 1994). In fisheries with five or more access points, more than one survey agent is recommended, and bus route designs are frequently implemented (Pollock et al. 1994; Malvestuto 1996; Jones and Pollock 2012). The bus route access-based design is effective for fisheries with many access points that encompass a large spatial scale (Pollock et al. 1994; Malvestuto 1996; Jones and Pollock 2012). All access points are visited each shift, or between two shifts in larger fisheries, with survey agents spending the same amount of time at each allotted access. Additionally, the first sampling site of each day is commonly randomized (Pollock et al. 1994). Access-based surveys provide data on angling effort, catch, and harvest when conducted properly. Biological data can also be obtained through these methods. However, anglers may report inflated catches or sizes, round to numbers such as 5 and 10, and misidentify species, known as prestige bias, rounding bias, and misidentification bias, respectively (Pollock et al. 1994). These methods are also expensive, have complex logistics, and the design does not allow for anglers with private access to be sampled adequately (Pollock et al. 1994; Jones and Pollock 2012).

When roving surveys are implemented, survey agents move throughout the fishery, interviewing anglers while they are fishing (Pollock et al. 1994; Malvestuto 1996; Jones and Pollock 2012). Roving surveys are commonly used in small spatial scales where anglers have many access points, such as streams and rivers (Pollock et al. 1994). Like access-based surveys, roving surveys are based on a spatiotemporal frame, and sampling can be conducted with uniform or non-uniform probabilities (Pollock et al. 1994; Jones and Pollock 2012). Physical characteristics affect travel time and must be assessed prior to the start of the survey. If circuits around the fishery are estimated to take six or more hours, the circuit typically cannot be completed in an eight-hour workday. The time of circuits is dependent on travel time, the number of anglers to be interviewed, the duration of each interview, and the time needed to conduct angler counts (Pollock et al. 1994). If circuit durations are longer than the survey agent’s workday, it may be beneficial to stratify the fishery into smaller physical segments or hire more survey agents (Pollock et al. 1994; Jones and Pollock 2012). Like access-based surveys, knowledge of temporal patterns of angling is recommended. Anglers can be counted using either instantaneous or progressive counts. Instantaneous counts are made from vantage points where the entire fishery is visible (Pollock et al. 1994; Jones and Pollock 2012). Progressive counts are made cumulatively throughout the survey agents shift (Pollock et al. 1994; Jones and Pollock 2012). Roving surveys can provide site-specific data on catch and effort when conducted properly, while sampling both private and public access anglers. However, these methods are subject to prestige bias, rounding bias, misidentification bias, and visibility bias (Pollock et al. 1994). Visibility bias occurs when anglers are difficult to identify. These methods are expensive, safety issues must be addressed, and specific training may be required for survey agents (Pollock et al. 1994; Jones and Pollock 2012).

Aerial surveys involve an aircraft flying over a fishery to conduct instantaneous counts of anglers (Pollock et al. 1994). No angler contact is initiated; however, this method is considered an on-site method because anglers are counted while they are fishing (Jones and Pollock 2012). Anglers are counted individually, but boats are commonly counted as angling parties (Pollock et al. 1994). Like access-based and roving surveys, aerial surveys require a spatiotemporal frame (Pollock et al. 1994). Sampling can be conducted using either uniform or non-uniform probabilities, or through model-based sampling. Model based sampling is commonly designed to occur at the height of angling effort, the count is then modified to reflect daily effort (Pollock et al. 1994). Aerial surveys can be cost effective in fisheries large enough to justify the expense of the aircraft. While aerial surveys sample both private and public access anglers, these methods are subject to visibility bias unless infrared technology is used (Pollock et al. 1994; Jones and Pollock 2012). Additionally, it may be difficult to determine which boats are fishing (Pollock et al. 1994; Jones and Pollock 2012).

Off-site methods include mail, telephone, web-based, door-to-door, and diary surveys. Mail surveys require a frame of angler names and addresses, which can be compiled from fishing license sales or addresses located on or around a fishery (Pollock et al. 1994; Malvestuto 1996; Jones and Pollock 2012). Anglers are sent a questionnaire that requests information about their fishing trip(s). Typically, the first questionnaire received is returned by fewer than 50% of the recipients (Jones and Pollock 2012). Additional questionnaires, reminder cards, and incentives may increase the response rate to 80% or more (Jones and Pollock 2012). Mail surveys can be unreliable because anglers must remember their fishing trips accurately and report them honestly. Recall bias occurs when anglers unintentionally report false information because they misremember past events (Pollock et al. 1994; Jones and Pollock 2012). However, mail surveys that take place less than two months or earlier after a fishing event have been accredited to reduce recall bias (Jones and Pollock 2012). These methods are also subject to non-response error because nonrespondents may have different attributes than respondents. Additionally, biases may result from incomplete frame construction. For instance, mail surveys with frames constructed on license sales would not sample illegal or young anglers that do not require a license (Pollock et al. 1994; Jones and Pollock 2012). Mail surveys can be conducted at a low cost. However, with no in-person interaction there is no way to clarify questions or analyze self-reported data. These methods are also subject to prestige bias and misidentification bias (Pollock et al. 1994).

When telephone surveys are conducted, anglers are contacted via telephone and asked questions from a scripted questionnaire (Pollock et al. 1994; Malvestuto 1996; Jones and Pollock 2012). Like mail surveys, telephone surveys require a frame of anglers' telephone numbers, often acquired through license sales or boat registrations. Telephone surveys can be conducted over a short duration at a low cost. Unlike mail surveys, survey agents can clarify questions with respondents. Like mail surveys, telephone surveys are subject to recall bias, prestige bias, misidentification bias, and nonresponse error. Landlines are becoming less common, and cell phone numbers are often not available, dramatically affecting the practicality of telephone surveys (Jones and Pollock 2012).

When web-based surveys are designed, anglers are typically contacted via email and then directed to a website to complete an interactive survey (Jones and Pollock 2012). Anglers are then asked a set of questions, often in sequence, about topics such as where fishing occurred, what was caught, and the amount of time spent fishing at certain locations (Jones and Pollock 2012). With the interactive nature of the internet, assistance can be provided without direct contact. Response accuracy can be improved by providing interactive pictures of fishing locations and fish species (Jones and Pollock 2012). Additionally, prompts may be used when respondents enter values that appear unrealistic. Web-based surveys are convenient for anglers because the surveys can be completed at their leisure. However, computer literacy is required from both respondents and management. Additionally, some anglers may not have an email account. Therefore, web-based surveys may be subject to nonresponse error, prestige bias, rounding bias, and recall bias (Jones and Pollock 2012).

Door-to-door surveys have rarely been implemented in fisheries management, primarily due to high costs (Pollock et al. 1994). These methods consist of survey agents visiting households and conducting in-person interviews. Frames are typically developed from license sales and addresses (Pollock et al. 1994). Door-to-door surveys allow for complex questions to be asked, because the survey agent can help guide the respondent through the question (Pollock et al. 1994). Ultimately, door-to-door surveys are too expensive to be commonly conducted and are subject to prestige bias, rounding bias, recall bias, misidentification bias, and nonresponse error (Pollock et al. 1994).

Diaries, logbooks, and catch cards are all off-site creel survey methods. Diaries and logbooks are used when information from more than one angling trip is desired (Pollock et al. 1994). Diaries and logbooks tend to be small and compact booklets anglers fill out after completing an angling trip. Once all angling trips have concluded, diaries and logbooks are returned to management, typically via mail (Pollock et al. 1994). Catch cards are used when information from a single fishing trip is desired (Pollock et al. 1994). Catch cards are often pocket-sized cards that are provided at the study site. Anglers are encouraged to complete the catch card when their fishing trip has concluded and then return their responses to an on-site drop box. Catch card methods have demonstrated to be effective in fisheries where angling effort is presumably low (Pollock et al. 1994). Diaries, logbooks, and catch cards are among the most cost-effective off-site creel survey methods; however, low response rates are likely (Pollock et al. 1994). Additionally, these methods are subject to prestige bias, rounding bias, misidentification bias, and nonresponse error (Pollock et al. 1994).

Complemented surveys are comprised of two or more on-site and off-site methods. Complemented surveys can be used to reduce bias, augment data, expand fishery coverage, or to better estimate angling effort, catch, and harvest (Pollock et al. 1994; Malvestuto 1996; Soupir et al. 2006; Jones and Pollock 2012). For example, access-based surveys do not adequately sample anglers with private access. Therefore, an access-based survey could be complemented with a roving survey to assess private anglers. Access-based surveys have also been commonly complemented with mail or telephone surveys (Pollock et al. 1994). Additionally, complemented surveys have demonstrated to be effective for large spatial fisheries. (Pollock et al. 1994; Jones and Pollock 2012).

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Introduction

Burbot *Lota lota* are the only freshwater species of the codfish family, commonly found throughout the Holarctic region (McPhail and Paragamian 2000; Stapanian et al. 2010). Burbot inhabit lakes, rivers, and streams, where they spawn in winter and early spring, commonly under ice, with water temperatures that range from 1-4 °C (McPhail and Paragamian 2000; Stapanian et al. 2010; Eick 2012). In lakes, spawning occurs in shallow water, in substrates of sand, gravel, and rubble (McPhail and Paragamian 2000; Robinson et al. 2024). In rivers, spawning occurs in low velocity points of main channels and smaller tributaries in fine gravel, fine silt, and sand (McPhail and Paragamian 2000; Jones-Wuellner and Guy 2004). In lotic systems, Burbot have been observed to travel 100-200 km to reach spawning grounds (Breeser et al. 1988). In both lentic and lotic environments Burbot have been documented to spawn at night, where numerous males cluster and surround a smaller number of females (Cahn 1936; Jones-Wuellner and Guy 2004). Stapanian et al. (2010) stated Burbot are vulnerable to natural and anthropogenic habitat disturbances because of their spawning behavior.

Burbot have historically provided a vital winter fishery for indigenous people and European settlers across the United States and Canada (Hardy and Paragamian 2013). In the Kootenai River, Idaho, Burbot harvest was historically unregulated and in the thousands of kilograms annually (Paragamian et al. 2000). For example, in 1958, three commercial fishermen combined to harvest an estimated 2,000 kg (Hardy and Paragamian 2013). Burbot were commonly harvested by spearing during the spawning season and with set lines under ice (Hardy and Paragamian 2013). The Burbot fishery collapsed after 1972 and was later closed. The collapse was primarily attributed to the construction of the Libby Dam and overharvest (Paragamian et al. 2000; Hardy and Paragamian 2013). The population was unable to reestablish itself after the closure until supplemental stocking was performed and alternate flows were designed at the Libby Dam (Paragamian et al. 2000; Hardy and Paragamian 2013). From 1933-1972, Burbot were commercially harvested in the Minnesota waters of Lake of the Woods with gill and trawl nets (Muth 1974). A minimum of 9,345 kg of Burbot were harvested annually, and commercial harvest peaked in 1961, reaching 400,323 kg (Muth 1974). In the Upper Copper and Susitna Management Area of Alaska, Burbot harvest was historically unregulated until 1979-1986, when a bag limit of 15 was imposed (Sommerville 2011). Harvest peaked in 1985, with 19,355 fish (Sommerville 2011). In 1987, bag limits were further reduced to five, and even as low as two, in the fisheries of Lake Louise and Hudson Lake (Sommerville 2011). In 1989, emergency management plans were developed in exploited systems such as Lake Louise and Hudson Lake, resulting in closures of both Burbot fisheries (Sommerville 2011). However, after several regulations and gear changes, the abundance of Burbot did not increase in either fishery (Sommerville 2011). A comprehensive knowledge of Burbot ecology may help prevent over-exploitation in the future.

Burbot inhabit different environments throughout their various life stages. In lentic systems, larval Burbot are pelagic, juveniles inhabit the littoral zone, and adults inhabit the profundal zone (Ghan and Sprules 1993; Stapanian et al. 2010). Carl (1995) documented adult Burbot reside below the thermocline in summer months. In lotic environments, larval Burbot inhabit littoral zones with low flow, seeking refuge in aquatic vegetation and rocks, juvenile Burbot inhabit various depths with moderate flow, and adult Burbot are commonly found in main channels (McPhail and Paragamian 2000). Larval Burbot have been documented to feed on rotifers, copepods, and cladocerans (Ryder and Pesendorfer 1992; McPhail and Paragamian 2000). Juvenile Burbot continue to feed on invertebrates; however, as they grow, their diets tend to favor fish (McPhail and Paragamian 2000). Although adult Burbot are commonly labeled as piscivores (McBaine et al. 2018), they may also rely on invertebrates such as crayfish, especially at shorter lengths (Fratt et al. 1997; Robinson et al. 2024).

Burbot have been adequately sampled in the northwestern region of the United States, but rarely within the Great Lake states (Hardy and Paragamian 2013). For example, in Minnesota, standard lake sampling techniques include gillnetting, trap netting (fyke nets), and electrofishing (MNDNR 2017). All of which fail to adequately sample adult Burbot. In Minnesota, all gillnets are placed in depths above the thermocline and Burbot are infrequently sampled (Stapanian et al. 2010). Electrofishing can only sample habitat in which juvenile Burbot are present, and fyke nets are ineffective at sampling Burbot of all life stages (Jones-Wuellner and Guy 2004; MNDNR 2017). Moreso, little is known about the angling pressure Burbot receive. However, with the rising popularity of Burbot angling, it is imperative to better understand and manage the species.

Creel surveys, also known as angler surveys, are a management technique used to estimate recreational angling effort, catch, harvest, economics, and to gather angler opinions (Pollock et al. 1994; Malvestuto 1996; Cook and Younk 1998; Soupir et al. 2006; Jones and Pollock 2012; McCormick and Meyer 2017; Nieman et al. 2021). Creel surveys are conducted using on-site, off-site, or complemented methods. Most creel surveys involve survey agents asking anglers questions from a scripted questionnaire (Pollock et al. 1994; Malvestuto 1996; Jones and Pollock 2012). On-site methods collect data at the study site, traditionally by intercepting anglers while they are fishing or after their trip has concluded (Pollock et al. 1994; Malvestuto 1996; Jones and Pollock 2012). Access-based and roving surveys are the most common on-site survey methods. Off-site methods such as mail, telephone, and web-based surveys, collect angler data away from the study site (Pollock et al. 1994; Jones and Pollock 2012).

Traditionally, creel survey methods have relied on in-person interaction to obtain estimates of angling effort. However, utilizing digital and web cameras can increase efficiency and reduce survey costs (Hartill et al. 2016; Dutterer et al. 2020; Hartill et al. 2020). Common areas of public access, like boat ramps and marina entrances, provide the most pragmatic vantage points because they act as a funnel through which many anglers access the fishery (Hartill et al. 2016). Digital cameras have demonstrated to be an effective method of measuring angling effort in remote lakes, without increasing costs or management effort (Dorsey 2020). Alas, digital cameras have limitations. In large fisheries, extensive time is required to analyze data collected from digital cameras, but this effort may be less than typically required to conduct an intercept creel survey (Eckelbecker 2019). Web cameras that record time-lapse videos may help alleviate the problem because individual captures would not need to be analyzed (Hartill et al. 2020). However, this may prove difficult in remote and dimly lit areas. Another problem encountered with the use of digital and web cameras is accounting for missing data. This can be a result of damage, unexpected battery/power loss, and theft (van Poorten et al. 2015). Fisheries managers commonly program digital cameras to take time-lapse imagery, capture rates have varied from 8 seconds to 20 minutes (Dorsey 2020; Hartill et al. 2020). Additionally, Hartill et al. (2020) describes how digital cameras that take time-lapse captures tend to be a more reliable method than digital cameras that use motion-activated detection. However, inadequate literature is present describing why digital cameras that take time-lapse captures have a better means of detection than motion-activated digital cameras.

Creel surveys have been used by the Minnesota Department of Natural Resources for almost a century and are popular with fisheries managers across the globe (Cook and Younk 1998; Jones and Pollock 2012). However, limitations are present with sampling Burbot anglers. Anecdotal evidence suggests Burbot are commonly targeted by anglers at night. Traditional creel surveys do not have survey agents present during all fishing hours when anglers target Burbot. Burbot anglers on Bad Medicine Lake, Minnesota, have been observed fishing until ice conditions become unsafe, commonly in April. There have been concerns of over-exploitation of

Burbot occurring on Bad Medicine Lake during their spawning period. However, no angling effort or harvest has been measured in this particular body of water.

Angling effort, catch, and harvest of Burbot have been rarely estimated; however, there are a few case studies. Two seasonal winter roving creel surveys with an emphasis to sample Burbot anglers were conducted on North Moyie Lake, British Columbia, Canada (Prince and Cope 2008). Sampling began when adequate ice was formed and concluded when ice conditions were no longer safe (Prince and Cope 2008). Two shifts of equal length were sampled from 08:00-22:00 (Prince and Cope 2008). Prince and Cope (2008) stated that, in 2007, an estimated 525 individuals angled for 2,180 hours and caught 515 Burbot, resulting in a catch rate of 0.24 Burbot caught per targeted angling hour. Of the 515 Burbot caught, 168 (33%) were harvested (Prince and Cope 2008). An estimated 87% of the angling effort occurred during the evening and into the night (Prince and Cope 2008). An identical creel survey was conducted under the same parameters in 2008. An estimated 488 individuals angled for 2,191 hours and caught 1,089 Burbot, resulting in a catch rate of 0.50 Burbot caught per targeted angling hour, doubling the catch rate from the previous survey (Prince and Cope 2008). Of the 1,089 Burbot caught, 366 (34%) were harvested (Prince and Cope 2008). Prince and Cope (2008) also stated that knowledge of successful fishing locations led to a substantial increase in daytime angling effort. Evening and nighttime angling effort decreased from 87% in 2007 to 56% in 2008 (Prince and Cope 2008). Five annual access-based surveys were conducted on Arrow Lakes Reservoir, British Columbia, Canada, from 1998-2002 (Arndt 2004). Each year, the angling effort directed at Burbot was less than 701 hours, catch rates ranged from 0.49-1.02 Burbot caught per targeted hour, and harvest percentages ranged from 51.5-100% (Arndt 2004). Additionally, six winter access-based surveys were conducted on Leech Lake, Walker, Minnesota, from 2004-2020 (Pederson 2020). Two shifts of equal length were sampled from 08:00-21:00 (Pederson 2020). Targeted catch rates ranged from 0.02-0.79 Burbot caught per angling hour (Pederson 2020).

The newly classified game fish, the Burbot, is soon to have a statewide regulation imposed in Minnesota. Beginning March 1, 2025, Burbot will have a bag and possession limit of four fish (Dr. Shannon Fisher, MNDNR, personal communication). Anecdotal evidence suggests anglers are actively targeting and harvesting Burbot. Like the North Moyie Lake surveys, it is possible Burbot will be the most frequently sought after and caught fish in Bad Medicine Lake.

However, the angling effort directed at Burbot, the distribution of effort, Burbot catch, and Burbot harvest are unknown. Furthermore, the effectiveness of motion-activated digital cameras in wintery conditions is not well documented. Therefore, the objectives of this study are to, 1) estimate angling effort, catch, and harvest of Burbot using in-person data collection, 2) estimate angling effort, catch, and harvest of Burbot using data collected from motion-activated digital cameras, 3) directly compare party counts that were estimated using in-person and digital data collection, and 4) directly compare trip lengths of angling parties that were both interviewed and observed on the digital cameras. Primary results aim to provide fisheries managers with effective methods to estimate angling effort, catch, and harvest of Burbot. Secondary results aim to provide fisheries managers with data, benefits, and limitations of using motion-activated digital cameras to estimate angling effort. Thus, fisheries managers will be able to make better-informed decisions on topics such as harvest limits, fishing seasons, and special regulations.

Methods

Study Site. - The proposed study site, Bad Medicine Lake, is located 351 km northwest of Minneapolis, Minnesota, in the White Earth Reservation. A single public access is located at the north end of the lake. The lake features three privately owned resorts, all of which are closed during the winter. Bad Medicine Lake is groundwater fed, with no inlet or outlet. The lake is long and narrow, covering 337 hectares, with a littoral area of 117 hectares. Historically, Bad Medicine Lake has had high water clarity. The Minnesota Pollution Control Agency documented a mean Secchi depth reading of 7.2 m from 1987-2014 (MPCA 2024). Bad Medicine Lake is deep and well oxygenated, providing suitable habitat for cold water species. The lake has been managed as a two-story fishery ever since Rainbow Trout *Oncorhynchus mykiss* were introduced in the 1980s. Two-story fisheries have suitable habitats for species that prefer warm water temperatures and species that prefer cool water temperatures (Budy et al. 2009). Yearling Rainbow Trout are stocked at a rate of 16,000 annually (MNDNR 2024).

Design. - A non-uniform access-based creel survey was conducted on Bad Medicine Lake from February 2-April 11, 2024. Survey agents were stationed at the public access located on the north end of the lake. Sampling was stratified into two five-week periods, February 2-March 7, and March 8-April 11. Day and night shifts were sampled with unequal probabilities. Night shifts were sampled at 60%, and day shifts were sampled the remaining 40%. Shifts were sampled unequally because Burbot have been observed to be sedentary in the day, increasing in activity throughout the evening and into the night (Carl 1995). As a result of this behavior, anecdotal evidence suggests many anglers commonly target the species at dusk and later. However, sampling during the day was selected based on daytime effort observations documented by Prince and Cope (2008). Stations were selected using non-uniform probabilities and randomly sampled without replacement for each period, ensuring each five-week sampling period had 15 night and 10 day shifts randomly arranged. Because of the short duration of this creel survey, sampling with replacement may have created a schedule in which actual station visit probabilities were not close to the assigned probabilities. Schedules were designed to sample most of the fishing day with an emphasis on nighttime angling. Sampling occurred from 10:00-17:00 for the day shift and 17:00-24:00 for the night shift. For this study, weekdays and weekends were not stratified. During each week, two days were randomly assigned as days off. The remaining days were then randomly assigned day and night shifts without replacement. This design was used to construct the schedules of both sampling periods.

Two Reconyx PC 900 trail cameras were stationed at the public access, each secured to different trees that offered contrasting viewpoints. The cameras were to remain in operation for the duration of the in-person data collection. To deter theft, both cameras were elevated above 3 meters. Both cameras were programmed with high sensitivity to ensure anglers without vehicles were detected. The cameras were programmed to take three rapid fire captures when motion was detected. All captures were taken without flash enabled. The batteries of both cameras were changed every ten days. For this study, individual vehicles represented one angling party. However, if multiple vehicles were observed accessing and departing from the fishery at the same time, they were counted as a singular party. All on-road vehicles, such as trucks and cars, were presumed to represent angling parties. Offroad vehicles, such as snowmobiles and ATVs, were included in estimates, only if fishing equipment was visible. Fishing equipment included ice augers, fishing poles, and ice houses/sleds. Similarly, pedestrians were not included in estimates unless they were seen with fishing equipment. Trip lengths were calculated by observing the time between captures taken as angling parties accessed and departed from the fishery. If visible, the party size was also recorded. Angling parties with a trip length shorter than 30 minutes were not included in the estimates. Angling parties that departed from 05:00-17:00 were classified as daytime anglers, and parties that departed from 17:00-05:00 were classified as nighttime anglers. The day of the week was also recorded for each angling party. For example, if an angling party was observed accessing the fishery on Tuesday at 19:00 and departing at 01:00 on Wednesday, that party would be labeled as Tuesday nighttime anglers. The total number of daytime and nighttime angling parties observed departing from the fishery each day represented the daily party count. All captures were analyzed by one individual to reduce variance.

Field Procedures. - A singular reflective sign that stated, "Anglers Please Stop Here" was positioned near the public access and the icehouse where the survey agents were stationed. Survey agents had no authority to make anglers stop and answer their questions. If the anglers agreed to be interviewed, they were asked the questions below:

1. What time did you start fishing?
2. How many anglers are in your party?
3. What is your ZIP code?
4. What kind of sonar did you use?
5. What was your target species?
6. What did you release?
7. What did you harvest?
8. What were the approximate lengths of the released fish?
9. May we measure the fish you harvested?

When anglers were asked to provide their ZIP codes, survey agents repeated their responses to ensure they were correct. The following sonar types ranged from least advanced to most advanced, none (N), down imaging (D), side scan (S), mega 360 (M), and forward facing (F). After recording ZIP codes and sonar types, ages, and genders of the angling party were estimated. The age categories were 14 and younger, 15-24, 25-34, 35-44, 45-54, 55-64, and 65 and older. After all the questions were asked, survey agents clarified with the angling party about the amount of each species that was released and harvested. Immediately following the interview, the interview time was recorded.

In-person Data Processing. - All data, including count data, was collected by survey agents at the public access. A count of angling parties was conducted when survey agents were present. All equations and variables are available in Tables 1 and 2. Daily party counts I_i were calculated as:

$$I_i = \frac{\sum a_i}{\pi_i}, \tag{1}$$

where a represents an angling party and π_i represents the sampling probability. Party counts a_x were also recorded without extrapolation, where x represents either nighttime a_n or daytime a_d sampling. All interview data was combined regardless of the collection date because the second sampling period was unable to be completely fulfilled. Bootstrapping methodologies were used to calculate all estimates of angling effort, catch, and harvest. Confidence intervals at the 95% level were calculated by determining the 2.5 and 97.5 percentiles of the bootstrap samples.

Angling Effort. - Two separate equations were used to calculate total angling effort E. First, daily party counts I, all trip lengths L, and all party sizes Z were used:

$$E = \bar{I}\bar{L}\bar{Z}N, \tag{2}$$

where N represents the number of days in the survey. Secondly, angling effort was calculated independently for the nighttime and daytime sampling periods. Variables denoted with a subscript of either n or d represent nighttime and daytime sampling, respectively. Nighttime and daytime effort E_x was calculated as:

$$E_x = \bar{a}_x\bar{L}_x\bar{Z}_xN. \tag{3}$$

Total angling effort was calculated as:

$$E = E_n + E_d. \tag{4}$$

Targeted angling effort was calculated independently for the nighttime and daytime sampling periods. Variables denoted with a subscript of either n or d represent nighttime and daytime sampling, respectively. Targeted nighttime and daytime effort T_x was calculated as:

$$T_x = \bar{a}_x\bar{L}_x\bar{Z}_xN(p_x), \tag{5}$$

where p represents the percentage of angling parties that listed Burbot as their target species. Additionally, only trip lengths and party sizes from anglers that listed Burbot as their target species were used for these calculations. Total targeted angling effort T was calculated as:

$$T = T_n + T_d. \tag{6}$$

Catch. - Two separate equations were used to calculate total catch C. First, daily party counts were used:

$$C = \bar{I}\bar{c}N, \quad (7)$$

where c represents the number of Burbot caught by an angling party, regardless of their target species, in both the nighttime and daytime sampling periods. Secondly, catch was calculated independently for the nighttime and daytime sampling periods. Variables denoted with a subscript of either n or d represent nighttime and daytime sampling, respectively. Nighttime and daytime catch C_x was calculated as:

$$C_x = \bar{a}_x\bar{c}_xN(p_x), \quad (8)$$

where c represents the number of Burbot caught by a targeted angling party. Total catch C was calculated as:

$$C = C_n + C_d. \quad (9)$$

Harvest. - Two separate equations were used to calculate total harvest H. First, daily party counts were used:

$$H = \bar{I}\bar{h}N, \quad (10)$$

where h represents the number of Burbot harvested by an angling party, regardless of their target species, in both the nighttime and daytime sampling periods. Secondly, harvest was calculated independently for the nighttime and daytime sampling periods. Variables denoted with a subscript of either n or d represent nighttime and daytime sampling, respectively. Nighttime and daytime harvest H_x was calculated as:

$$H_x = \bar{a}_x\bar{h}_xN(p_x), \quad (11)$$

where h represents the number of Burbot harvested by a targeted angling party. Total harvest H was calculated as:

$$H = H_n + H_d. \quad (12)$$

Digital Data Processing. - Simultaneously, data was collected from digital cameras. All data was combined regardless of the collection date because the second in-person sampling period was unable to be completely fulfilled. Angling party catch, party harvest, and the percentage of parties that listed Burbot as their target species were all obtained from in-person data collection. Bootstrapping methodologies were used to calculate all estimates of angling effort, catch, and harvest. Confidence intervals at the 95% level were calculated by determining the 2.5 and 97.5 percentiles of the bootstrap samples. All count data was calculated from images captured on the digital cameras. All equations and variables are available in Tables 1 and 2. Daily party counts I were calculated as:

$$I_i = (\sum a_n^i + \sum a_d^i), \tag{13}$$

where a represents an angling party observed in either the nighttime a_n or daytime a_d period.

Angling Effort. - Angling effort was calculated independently for the nighttime and daytime periods. Variables denoted with a subscript of either n or d represent the nighttime and daytime periods, respectively. Nighttime and daytime effort E_x was calculated as:

$$E_x = \bar{L}_x \bar{Z}_x (\sum a_x), \tag{14}$$

where L represents the length of the fishing trip, Z represents angling party size, and a represents an angling party. Total angling effort E was calculated as:

$$E = E_n + E_d. \tag{15}$$

Targeted angling effort was calculated for the independently for the nighttime and daytime periods. Variables denoted with a subscript of either n or d represent the nighttime and daytime periods, respectively. Targeted nighttime and daytime effort T_x was calculated as:

$$T_x = \bar{L}_x \bar{Z}_x (\sum a_x)(p_x), \tag{16}$$

where p represents the percentage of angling parties that targeted Burbot, obtained from in-person data collection. Total targeted angling effort T was calculated as:

$$T = T_n + T_d. \tag{17}$$

Catch. - Total catch was calculated independently for the nighttime and daytime periods. Nighttime and daytime catch C_x was calculated as:

$$C_x = \bar{c}_x (\sum a_x), \tag{18}$$

where c represents the number of Burbot caught by an angling party regardless of their target species, obtained from in-person data collection. Total catch C was calculated as:

$$C = C_n + C_d. \tag{19}$$

Harvest. - Total harvest was calculated independently for the nighttime and daytime periods. Nighttime and daytime harvest H_x was calculated as:

$$H_x = \bar{h}_x\left(\sum a_x\right), \tag{20}$$

where h represents the number of Burbot harvested by an angling party regardless of their target species, obtained from in-person data collection. Total harvest H was calculated as:

$$H = H_n + H_d. \tag{21}$$

Weight Estimates. - Lengths of harvested Burbot were compiled and used to calculate a length frequency estimate. The following equation was used to estimate the weight of Burbot $\log_{10} W_s$ (g) from total lengths measurements (Fisher et al. 1996):

$$\log_{10} W_s = -4.868 + 2.898 \log_{10} TL, \tag{22}$$

where TL represents the total length of the Burbot (mm). This calculation was performed for both in-person and digital harvest estimates.

Statistical Analysis. - All party count data was found to have non-normal distributions. As a result, a two sample Mann-Whitney test was performed to analyze all daily party counts collected using in-person and digital data collection. A paired Mann-Whitney test was conducted to examine in-person daily party counts and digital daily party counts, only when in-person data collection occurred. Similarly, all trip length data was found to have non-normal distributions. A paired Mann-Whitney test was used to compare trip lengths of angling parties that were both interviewed and observed on the digital cameras.

Results

In-person Data Collection. - Sampling occurred from February 2-March 11, 2024. The complete sampling schedule was unable to be fulfilled due to unsafe ice conditions. A total of 31 angling parties were interviewed. The following estimates were calculated using daily party counts and data from both sampling periods. An estimated 87 parties (95% CI: 48-132), consisting of 187 (95% CI: 102-296) individuals, angled for 1,161 (95% CI: 562-2,235) hours (3.57 hrs/ha). All anglers had a catch rate of 0.12 Burbot caught per angling hour. An estimated 140 (95% CI: 65-253) Burbot were caught, and 72 (95% 28-147) Burbot were harvested, totaling 78.29 (95% CI: 30.45-159.84) kg (0.24 kg/ha). Approximately half of the Burbot (51%) caught were harvested (0.06 Burbot/hr). Harvested Burbot ranged in length from 382-597 mm, with a mean of 529 (SD = 50) mm. Nearly all the interviewed anglers resided in Minnesota (95%), with Becker, Hubbard, and Beltrami counties being most frequently reported.

The following estimates were calculated independently for the nighttime and daytime sampling periods. An estimated 88 (95% CI: 49-135) parties, consisting of 189 (95% CI: 103-299) individuals, angled for 1,236 (95% CI 559-2,779) hours (3.80 hrs/ha; Figure 1; Table 3). An estimated 1,052 (95% CI: 453-2,438) angling hours (3.23 hrs/ha; Figure 1; Table 3) were directed at Burbot. Approximately 520 (95% CI: 247-932) and 502 (95% CI: 54-1,883) hours occurred in the nighttime and daytime sampling periods, respectively (Figure 1; Table 3). An estimated 109 (95% CI: 48-212) and 20 (95% CI: 0-78) Burbot were caught in the nighttime and daytime sampling periods, respectively (Figure 2; Table 3). Targeted anglers had a catch rate of 0.21 and 0.04 Burbot caught per angling hour in the nighttime and daytime periods, respectively. All targeted anglers had a catch rate of 0.13 Burbot caught per angling hour. An estimated 67 (95% CI: 26-139) Burbot were harvested, all harvest occurred during the nighttime sampling period, totaling 72.85 (95% CI: 28.25-144.88) kg (0.22 kg/ha; Figure 2; Table 3). Approximately half the Burbot caught (49%) were harvested (0.06 Burbot/hr).

Digital Data Collection. - A total of 18,335 captures were analyzed. Sampling occurred from February 2-March 28, 2024. Data was used from February 2-March 11, to calculate all estimates. The digital cameras continued to collect data past the conclusion of in-person data collection to ensure angling effort was minimal or none. From March 12-28, only one angling party was observed. Unfortunately, due to an unknown error, likely due to battery loss, one digital camera did not operate from February 11-20. An estimated 111 parties, consisting of 240 (95% CI: 208-274) individuals, angled for 1,426 (95% CI: 1,148-1,776) hours (4.39 hrs/ha; Figure 3; Table 4). Of the 111 observed parties, 84 (76%) were able to have trip lengths calculated, and 62 (56%) had a recorded party size. An estimated 1,067 (95% CI: 774-1,429) angling hours (3.28 hrs/ha; Figure 3; Table 4) were directed at Burbot. An estimated 803 (95%

CI: 584-1,081) and 292 (95% CI: 92-570) hours of the targeted effort occurred in the nighttime and daytime periods, respectively (Figure 3; Table 4). Approximately 138 (95% CI: 83-205) and 34 (95% CI: 0-78) Burbot were caught in the nighttime (0.17 Burbot/hr) and daytime (0.11 Burbot hr) periods, respectively (Figure 4; Table 4). All targeted anglers had a catch rate of 0.16 Burbot caught per angling hour. An estimated 87 (95% CI: 42-138) Burbot were harvested, totaling 94.60 (95% CI: 46.67-150.06) kg (0.29 kg/ha). Approximately half of the Burbot caught (50%) were harvested (0.08 Burbot/hr; Figure 4; Table 4). Additionally, the digital total harvest estimate was greater than the in-person estimate (Figure 5; Table 5). Of the 111 parties, 62% were classified as nighttime anglers and the remaining 38% were classified as daytime anglers. Fridays, Saturdays, and Sundays all had higher average angling party counts in both the daytime and nighttime periods compared to the remaining weekdays (Table 6). All 31 interviewed parties were also observed digitally, suggesting detection rates were near 100%.

Party Count Comparison. - Data was collected from February 2-March 11, 2024. During that time, survey agents were present for 27 days ($n = 27$). The survey duration was 39 days; therefore, the sample size of the digital daily party counts is 39. Daily in-person party counts had a mean of 2.25 (SD = 2.97) and daily digital party counts had a mean of 2.85 (SD = 2.65). There was not a significant statistical difference between the two groups ($p = 0.09$; Figure 6). Likewise, in-person daily party counts ($n = 27$) and digital daily party counts, only when in-person data collection occurred ($n = 27$), did not have a significant statistical difference ($p = 0.22$; Figure 7).

Trip Length Comparison. - Data was collected from February 2-March 11, 2024. A total of 31 angling parties were interviewed and all 31 parties were observed on the digital cameras. Therefore, both groups had a sample size of 31. Interviewed parties had a mean trip length of 6.48 hours (SD = 8.22) and parties observed digitally had a mean trip length of 6.79 hours (SD = 7.79). Interviewed parties reported significantly shorter trip lengths than those observed on the digital cameras ($p = 0.02$; Figure 8). On average, trip lengths of interviewed parties were 0.32 hours shorter than what was observed on the digital cameras (SD = 0.88; Figure 8).

Discussion

Our in-person estimate of targeted angling effort (1,052 hrs; 3.23 hrs/ha) was less than the findings of Prince and Cope (2008), but greater than the findings of Arndt (2004). Prince and Cope (2008) conducted two winter creel surveys in 2007 and 2008 on North Moyie Lake, British

Columbia, Canada, with objectives to sample Burbot anglers like our study; however, they reported higher total and area angling effort estimates (2,180 hrs; 3.74 hrs/ha & 2,191 hrs; 3.76 hrs/ha). Similarly, both surveys conducted by Prince and Cope (2008) were seasonal; however, our survey had a shorter duration. Arndt (2004) conducted five annual creel surveys in Arrow Lakes Reservoir, British Columbia, Canada, from 1998-2002. All five total targeted effort estimates were less than 701 hours (<0.02 hrs/ha). Arndt (2004) stated that most of the angling effort was directed at Rainbow Trout and Bull Trout *Salvelinus confluentus.* Additionally, all targeted effort estimates were likely low because the spawning period was not thoroughly sampled. Our survey concluded on March 11 due to unsafe ice conditions. We suspected that much of the angling effort directed at Burbot would occur during their spawning period. Robinson et al. (2024) stated Burbot typically spawn from March 6-19 in Bad Medicine Lake. It is likely that much of the spawning period was unable to be sampled. Prince and Cope (2008) stated that 57% of the angling effort directed at Burbot occurred in the later third of their 2008 survey, likely attributed to active spawning. If we assume similar angling trends and our survey duration was able to be completely fulfilled, we would then expect a total targeted effort estimate of 2,447 hrs (7.53 hrs/ha). Seasonal angling effort estimates are likely to greatly fluctuate because of environmental conditions. Hartill et al. (2016) suggests recreational effort can change severely based on seasonal and annual cycles.

Our in-person targeted catch rate of 0.13 Burbot caught per angling hour was less than the findings of Prince and Cope (2008), Arndt (2004), and Pederson (2020). Prince and Cope (2008) reported targeted catch rates of 0.24 and 0.50 Burbot caught per angling hour. Arndt (2004) stated targeted catch rates ranged from 0.49-1.02, with an average of 0.71 Burbot caught per angling hour. Pederson (2020) conducted six winter creel surveys on Leech Lake, Walker, Minnesota, from 2004-2020. Targeted catch rates ranged from 0.02-0.79, with an average of 0.28 Burbot caught per angling hour (Pederson 2020). Like Arrow Lakes Reservoir, much of the angling effort on Leech Lake was directed at other species like Walleye *Sander vitreus* and Yellow Perch *Perca flavescens* (Pederson 2020). Arndt (2004) stated that few anglers targeted Burbot in Arrow Lakes Reservoir, but anglers that did had high catch rates. We suspected that much of the total catch would occur during the spawning period. Prince and Cope (2008) stated that 60% of the Burbot catch occurred in the later third of their 2008 survey. If we assume similar angling trends and our survey duration was able to be completely fulfilled, we would then expect a 7% increase in our targeted catch rate (0.14 Burbot/hr). Like angling effort, Hartill et al. (2016) describes how catch estimates can vary greatly because of environmental conditions. This may possibly suggest why our targeted catch rate is less than the findings of previous studies.

Our harvest percentage (~50%) was greater than the findings of Prince and Cope (2008) but less than what Arndt (2004) estimated. Prince and Cope (2008) reported that, in the 2007 and 2008 surveys, targeted anglers harvested 33% and 34% of their catch, respectively. Arndt (2004) calculated five harvest percentages, all of which were greater than 51.5%. Prince and Cope (2008) stated at the time of their surveys, each angler was allowed to keep two Burbot. Arndt (2004) does not state what Burbot regulations were imposed at the time of their surveys. However, Burbot harvest was unregulated at the time of our study. Arndt (2004) stated Burbot are not commonly targeted in Arrow Lakes Reservoir, but anglers that did target Burbot harvested much of their catch. Prince and Cope (2008) stated Burbot typically spawn in February in North Moyie Lake. Both the surveys conducted by Prince and Cope (2008) had durations that encompassed the estimated spawning period. However, our survey concluded on March 11 due to unsafe ice conditions. Prince and Cope (2008) stated that 60% of the Burbot catch occurred in the later third of their 2008 survey. If we assume similar angling trends and our survey duration was able to be completely fulfilled, we would then expect a total of 170 Burbot to be harvested (152.23 kg; 0.47 kg/ha). However, we hypothesize anglers that actively target spawning Burbot may release more fish because they tend to angle in shallow water (<15 m). When Burbot are not actively spawning, anglers commonly target them in depths greater than 15 m, which increases decompression trauma and may result in more fish being harvested (Neufeld and Spence 2004; Prince and Cope 2008). This may suggest why the harvest percentages reported by Arndt (2004) and our findings are greater than those reported by Prince and Cope (2008). Additionally, an implemented harvest regulation may decrease the harvest percentage of Burbot anglers, possibly suggesting why our harvest percentage was greater than the findings of Prince and Cope (2008). Like angling effort and catch, Hartill et al. (2016) stated angler harvest can vary greatly depending on seasonal and annual cycles.

Our total angling effort estimate calculated from digital data collection (1,426 hrs) has no studies fit for direct comparison; however, our angling party detection rate (100%) and general information yield are consistent with studies that have used digital cameras to estimate angling effort. Piszczek et al. (2021) used motion-activated digital cameras to estimate angling effort from 2016-2018 in the lower Bois Brule River, Wisconsin, and stated their detection rate neared 100% at all access points. Stahr and Knudsen (2018) used time-lapse digital cameras in Lake Pleasant, Arizona, to assess angler use and concluded that boat counts were strongly correlated to camera counts. Both Piszczek et al. (2021) and Stahr and Knudsen (2018) state their in-person estimates of angling effort closely resembled their digital angling effort estimates, like our findings, thus suggesting both motion-activated and time-lapse digital cameras can be used to adequately estimate angling effort in diverse settings (Hartill et al. 2016; Stahr and Knudsen 2018; Dorsey 2020; Hartill et al. 2020; Piszczek et al. 2021). Our results and previous literature suggest digital cameras, regardless of their settings, can be used independently or supplementally to estimate angling effort. However, like Dorsey (2020) reported, we also encountered battery failure. Fortunately, we had two cameras in operation at the access point, so it is perceived that no data was lost. Possible approaches to mitigate this problem are to conduct frequent battery checks, have two cameras in operation at every point of interest, and use newer models that allow for battery levels to be monitored remotely.

We discovered on average, anglers reported significantly shorter trip lengths than what was observed on the digital cameras (0.32 hrs) whereas, Piszczek et al. (2021) stated anglers reported a significantly longer trip length than what was observed on the digital cameras. Anglers were not observed on the digital cameras while our in-person interviews occurred, the interview occurred beforehand. This may help explain why our findings suggest trip lengths captured on the digital cameras were on average longer than reported trip lengths. However, interviews were brief and rarely lasted longer than a couple minutes, suggesting camera positioning is not the primary factor affecting trip lengths. The study conducted by Piszczek et al. (2021) had a longer duration and a greater number of interviews. Perhaps, if we had a longer survey duration and a greater number of interviews, our data would be more reflective of the findings of Piszczek et al. (2021). Future research that utilizes digital cameras and in-person methods should investigate this topic further to form more conclusive results.

Our results, which suggested that in-person daily party counts were not significantly different than digital daily party counts, supports the findings of Stahr and Knudsen (2018), where it was discovered that camera-derived boat counts were strongly related to in-person counts. However, we found when in-person daily party counts were estimated to be two or fewer, digital daily party counts on the same day were typically greater. Likely because if no angling parties were observed departing from the fishery when in-person sampling occurred, the daily party count would then be zero. If there was more angling effort, it is probable the relationship would be more strongly correlated. Our results along with the findings of Stahr and Knudsen (2018) suggest digital cameras can be used as a reliable resource when quantifying daily and total angling parties. Future research should investigate if seasonality influences this relationship. We suspect counts made at boat ramps may not be as strongly correlated as counts made when ice fishing occurs, due to a greater number of recreational boats.

The findings of our research demonstrated that anglers actively targeted Burbot. Unfortunately, our entire sampling schedule was unable to be fulfilled due to poor ice conditions. Nonetheless, we still collected vital information, such as the amount of angling effort that occurred, the distribution of effort, and how many Burbot were harvested. Both in-person and digital data collection methods demonstrated to be effective for estimating angling effort. Future research with objectives to estimate angling effort and harvest of Burbot, with larger estimated sample sizes, should use stratified designs. Weekends, including Friday, should be separate from weekdays. We also recommend sampling more frequently during nighttime hours. Additionally, for Burbot and all species in need of management, it would be beneficial to deploy digital cameras a year prior and during in-person sampling to 1) determine sampling probabilities with site specific data, and 2) validate in-person sampling estimates such as daily party counts, total party counts, and total angling effort. Using these methods, any species of concern, regardless of when individuals angle for them, can be adequately sampled in freshwater lentic systems. This approach would provide fisheries managers with information regarding angling effort and harvest to better manage a species like the Burbot, or other species of concern.

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TABLES

Table 1. In-person and digital equations used for all estimates, including daily party counts, nighttime effort, nighttime targeted effort, daytime effort, daytime targeted effort, total effort, total targeted effort, nighttime catch, daytime catch, total catch, nighttime harvest, daytime harvest, and total harvest. All variables are stated in Table 2.

Estimate	In-person	Digital
Daily party count I	$I_i = \frac{\sum a_i}{\pi_i}$	$I_i = (\sum a_n^i + \sum a_d^i)$
Nighttime effort E_n	$E_n = \bar{a}_n \bar{L}_n \bar{Z}_n N$	$E_n = \bar{L}_n \bar{Z}_n (\sum a_n)$
Nighttime targeted effort T_n	$T_n = \bar{a}_n \bar{L}_n \bar{Z}_n N(p_n)$	$T_n = \bar{L}_n \bar{Z}_n (\sum a_n)(p_n)$
Daytime effort E_d	$E_d = a_d \bar{L}_d \bar{Z}_d N$	$E_d = \bar{L}_d \bar{Z}_d (\sum a_d)$
Daytime targeted effort T_d	$T_d = \bar{a}_d \bar{L}_d \bar{Z}_d N(p_d)$	$T_d = \bar{L}_d \bar{Z}_d (\sum a_d)\,(p_d)$
Total effort E	$E = E_n + E_d$	$E = E_n + E_d$
Total targeted effort T	$T = T_n + T_d$	$T = T_n + T_d$
Nighttime catch C_n	$C_n = \bar{a}_n \bar{c}_n N(p_n)$	$C_n = \bar{c}_n (\sum a_n)$
Daytime catch C_d	$C_d = \bar{a}_d \bar{c}_d N(p_d)$	$C_d = \bar{c}_d (\sum a_d)$
Total catch C	$C = C_n + C_d$	$C = C_n + C_d$
Nighttime harvest H_n	$H_n = \bar{a}_n \bar{h}_n N(p_n)$	$H_n = \bar{h}_n (\sum a_n)$
Daytime harvest H_d	$H_d = \bar{a}_d \bar{h}_d N(p_d)$	$H_d = \bar{h}_d (\sum a_d)$
Total harvest H	$H = H_n + H_d$	$H = H_n + H_d$

Total effort E	$E = \bar{I}\bar{L}\bar{Z}N$	N/A
Total catch C	$C = \bar{I}\bar{c}N$	N/A
Total harvest H	$H = \bar{I}\bar{h}N$	N/A

Table 2. Variables and their descriptions used for in-person and digital estimates.

Variable	Description
a	Angling party
c	Sum of Burbot caught by an angling party
h	Sum of Burbot harvested by an angling party
p	Percentage of angling parties that listed Burbot as their target species
L	Angling party trip length
N	Survey duration (days)
Z	Number of individuals in an angling party
π	Sampling probability

Table 3. In-person estimates with 95% confidence intervals for total angling effort, total targeted effort, nighttime targeted effort, daytime targeted effort, total catch, nighttime catch, daytime catch, and total harvest. There was no reported daytime harvest.

Metric	Estimate	Lower limit	Upper limit
Total effort (hrs)	1,236	559	2,779
Total targeted effort (hrs)	1,052	453	2,438
Nighttime targeted effort (hrs)	520	247	932
Daytime targeted effort (hrs)	502	54	1,883
Total catch (#)	136	63	250
Nighttime catch (#)	109	48	212
Daytime catch (#)	20	0	78
Total harvest (#)	67	26	139

Table 4. Digital estimates with 95% confidence intervals for total angling effort, total targeted effort, nighttime targeted effort, daytime targeted effort, total catch, nighttime catch, daytime catch, and total harvest. Angling party catch, party harvest, and the percentage of parties that listed Burbot as their target species were obtained from in-person data collection. There was no reported daytime harvest.

Metric	Estimate	Lower limit	Upper limit
Total effort (hrs)	1,426	1,148	1,776
Total targeted effort (hrs)	1,067	774	1,429
Nighttime targeted effort (hrs)	803	584	1,081
Daytime targeted effort (hrs)	292	92	570
Total catch (#)	173	105	252
Nighttime catch (#)	138	83	205
Daytime catch (#)	34	0	78
Total harvest (#)	87	42	138

Table 5. In-person and digital estimates for total angling effort, total targeted effort, nighttime targeted effort, daytime targeted effort, total catch, nighttime catch, daytime catch, and total harvest. Angling party catch, party harvest, and the percentage of parties that listed Burbot as their target species were obtained from in-person data collection. There was no reported daytime harvest.

Metric	In-person	Digital
Total effort (hrs)	1,236	1,426
Total targeted effort (hrs)	1,052	1,067
Nighttime targeted effort (hrs)	520	803
Daytime targeted effort (hrs)	502	292
Total catch (#)	136	173
Nighttime catch (#)	109	138
Daytime catch (#)	20	34
Total harvest (#)	67	87

Table 6. The mean number of parties observed exiting on the digital cameras in the daytime (05:00-17:00) and the nighttime (17:00-05:00) periods.

Day of the week	Daytime	Nighttime
Monday	0.67	0.50
Tuesday	0.80	0.40
Wednesday	0	0.40
Thursday	0.40	1.40
Friday	0.83	1.83
Saturday	1.33	2.50
Sunday	1.50	2.00

FIGURES

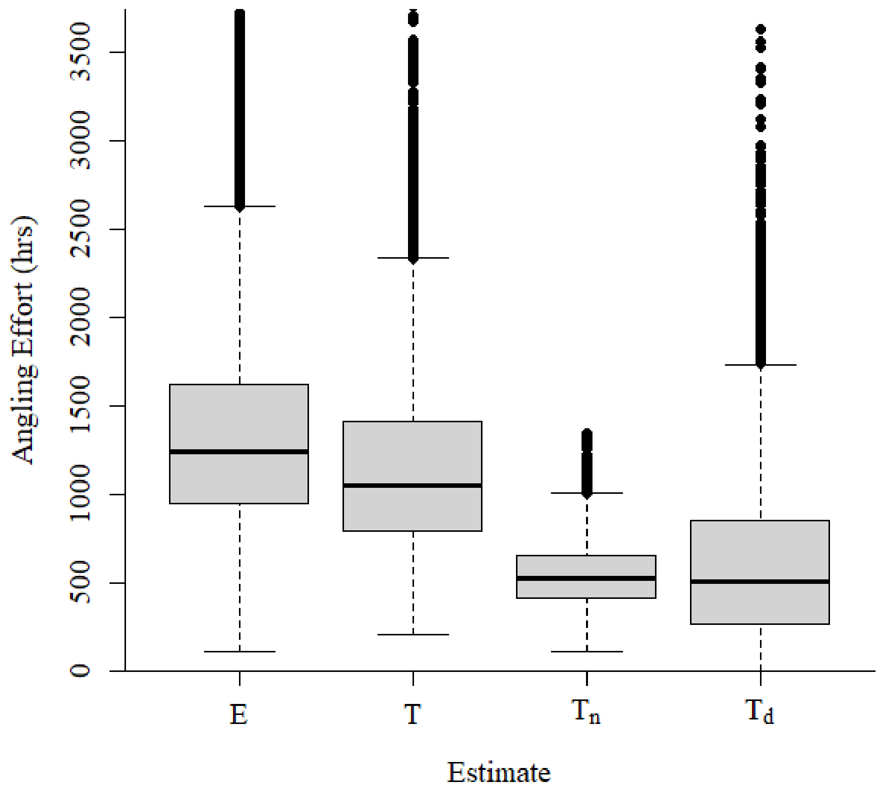

Figure 1. In-person angling effort estimates (hrs), including total angling effort $\boldsymbol{E}$, total targeted angling effort $\boldsymbol{T}$, targeted nighttime effort $\boldsymbol{T_n}$, and targeted daytime effort $\boldsymbol{T_d}$. All distributions are bootstrapped sample means (n = 10,000). The line within the box depicts the median. The lower and upper ends of the box represent the first and third quartiles (Q1 & Q3), respectively. The extent of the box represents the interquartile range (IQR). The whiskers extend to the smallest and largest values within 1.5 * IQR from the first and the third quartiles. Black dots represent outliers.

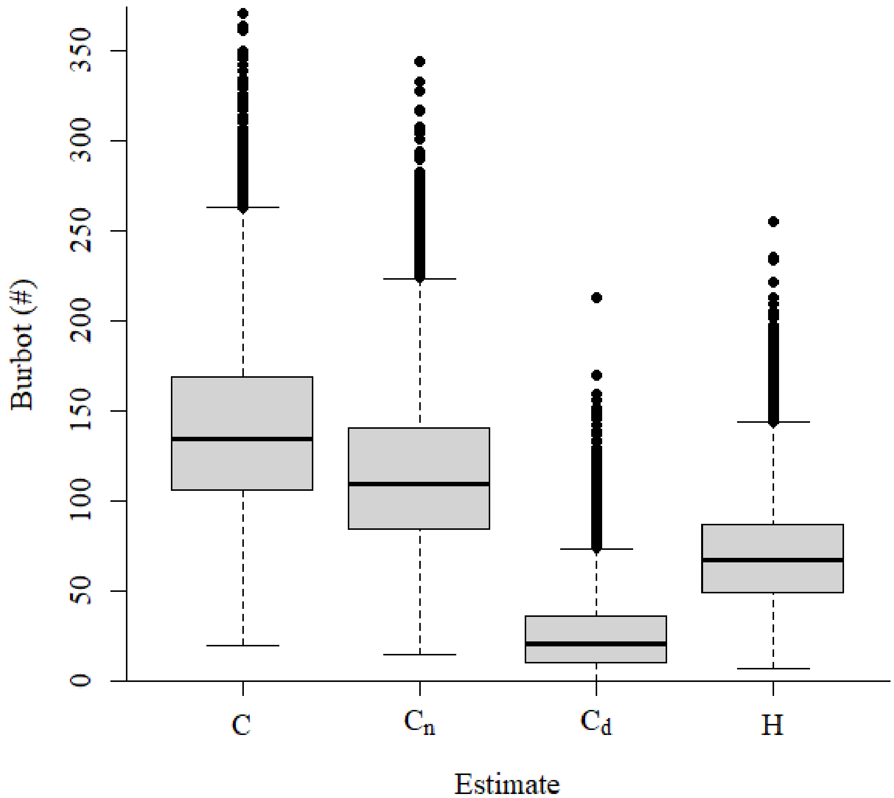

Figure 2. In-person catch and harvest estimates (number of Burbot), including total catch $\boldsymbol{C}$, nighttime catch $\boldsymbol{C_n}$, daytime catch $\boldsymbol{C_d}$, and total harvest $\boldsymbol{H}$. There was no reported daytime harvest. All distributions are bootstrapped sample means (n = 10,000). The line within the box depicts the median. The lower and upper ends of the box represent the first and third quartiles (Q1 & Q3), respectively. The extent of the box represents the interquartile range (IQR). The whiskers extend to the smallest and largest values within 1.5 * IQR from the first and the third quartiles. Black dots represent outliers.

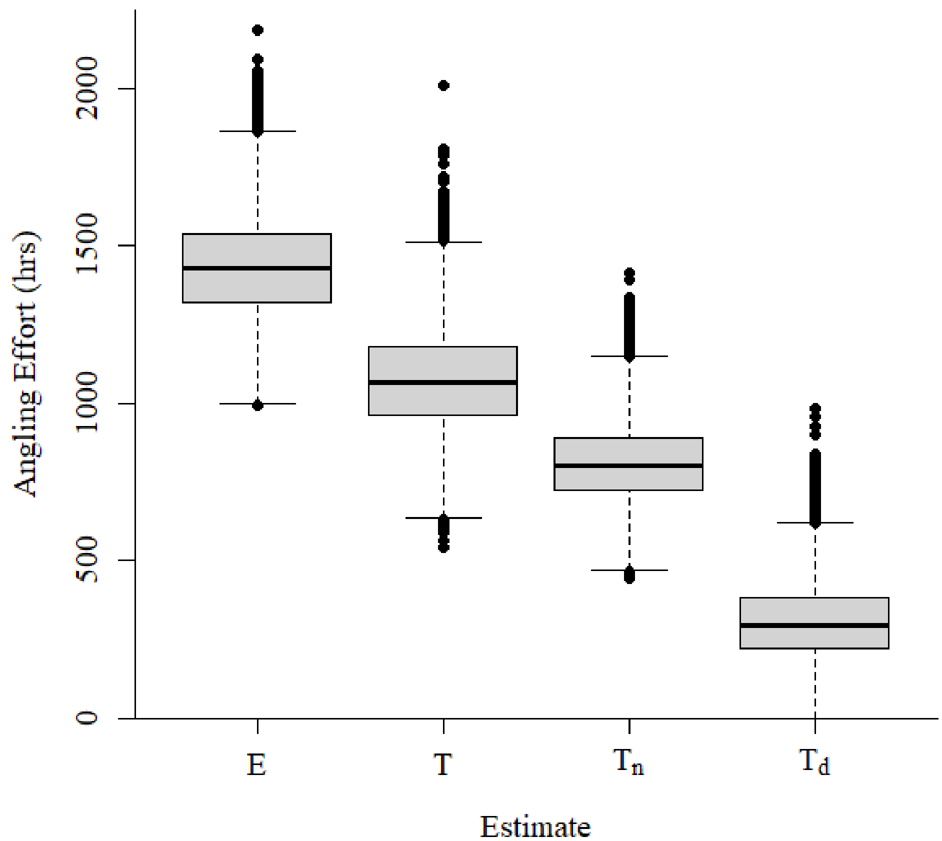

Figure 3. Digital angling effort estimates (hrs), including total angling effort $\boldsymbol{E}$, total targeted angling effort $\boldsymbol{T}$, targeted nighttime effort $\boldsymbol{T_n}$, and targeted daytime effort $\boldsymbol{T_d}$. The percentage of parties that listed Burbot as their target species was obtained from in-person data collection. All distributions are bootstrapped sample means (n = 10,000). The line within the box depicts the median. The lower and upper ends of the box represent the first and third quartiles (Q1 & Q3), respectively. The extent of the box represents the interquartile range (IQR). The whiskers extend to the smallest and largest values within 1.5 * IQR from the first and the third quartiles. Black dots represent outliers.

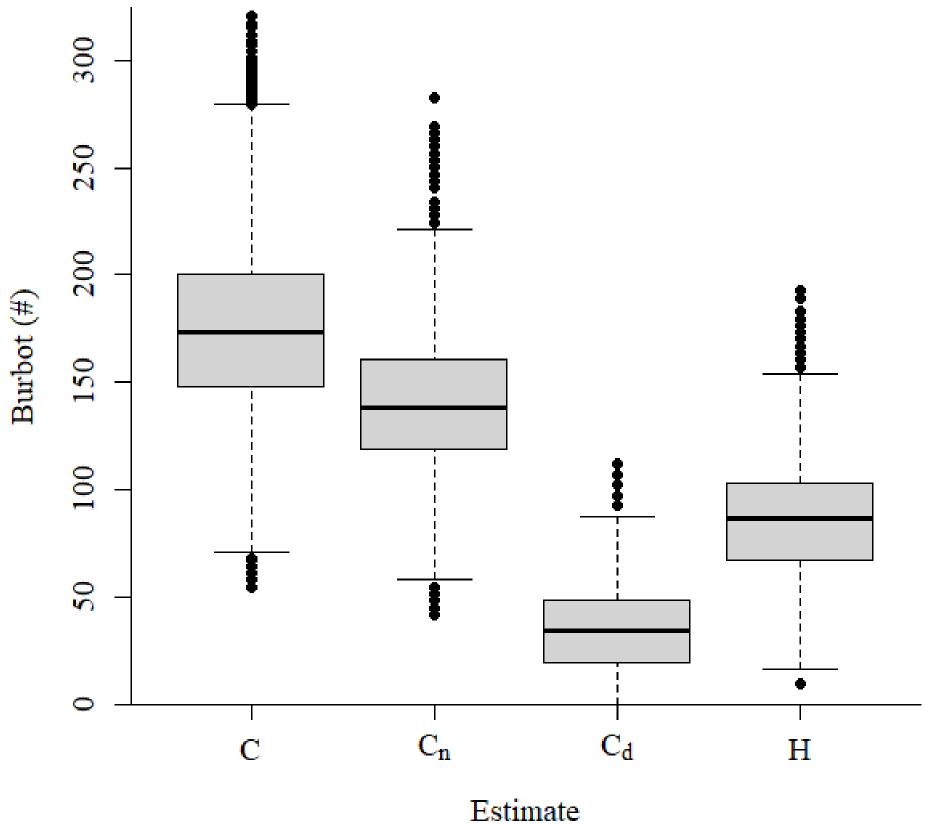

Figure 4. Digital catch and harvest estimates (number of Burbot), including total catch $\boldsymbol{C}$, nighttime catch $\boldsymbol{C_n}$, daytime catch $\boldsymbol{C_d}$, and total harvest $\boldsymbol{H}$. Angling party catch and harvest was obtained from in-person data collection. There was no reported daytime harvest. All distributions are bootstrapped sample means (n = 10,000). The line within the box depicts the median. The lower and upper ends of the box represent the first and third quartiles (Q1 & Q3), respectively. The extent of the box represents the interquartile range (IQR). The whiskers extend to the smallest and largest values within 1.5 * IQR from the first and the third quartiles. Black dots represent outliers.

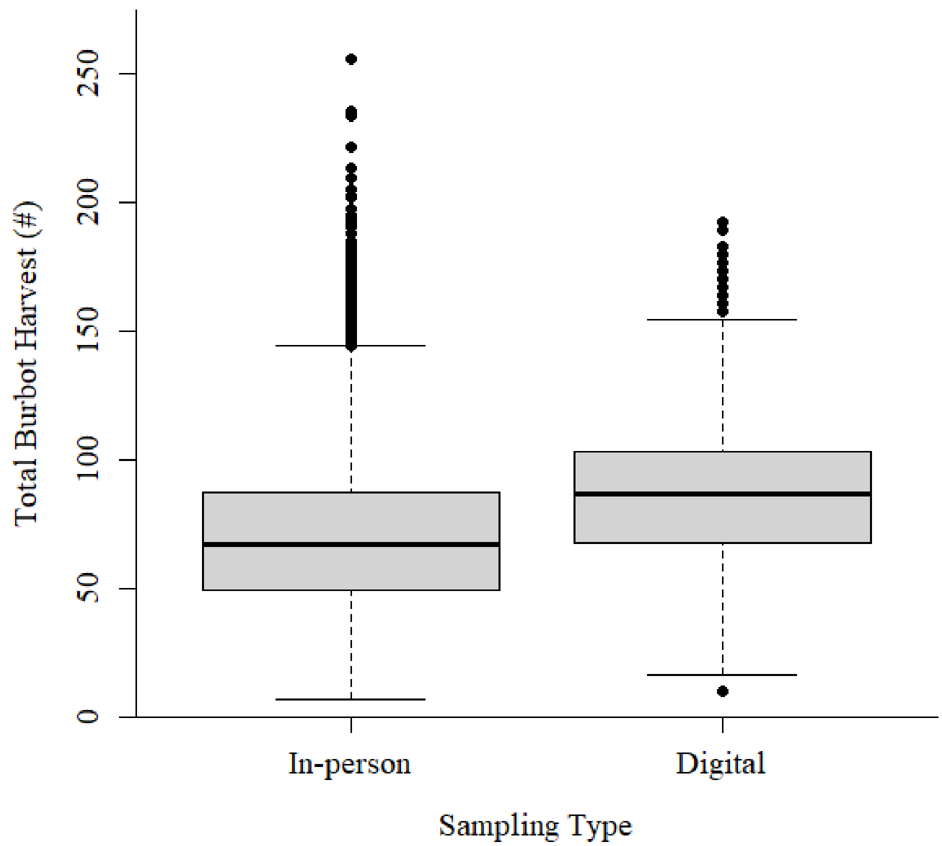

Figure 5. Total harvest estimates (number of Burbot) from in-person and digital data collection. Angling party harvest was obtained from in-person data collection. All distributions are bootstrapped sample means (n = 10,000). The line within the box depicts the median. The lower and upper ends of the box represent the first and third quartiles (Q1 & Q3), respectively. The extent of the box represents the interquartile range (IQR). The whiskers extend to the smallest and largest values within 1.5 * IQR from the first and the third quartiles. Black dots represent outliers.

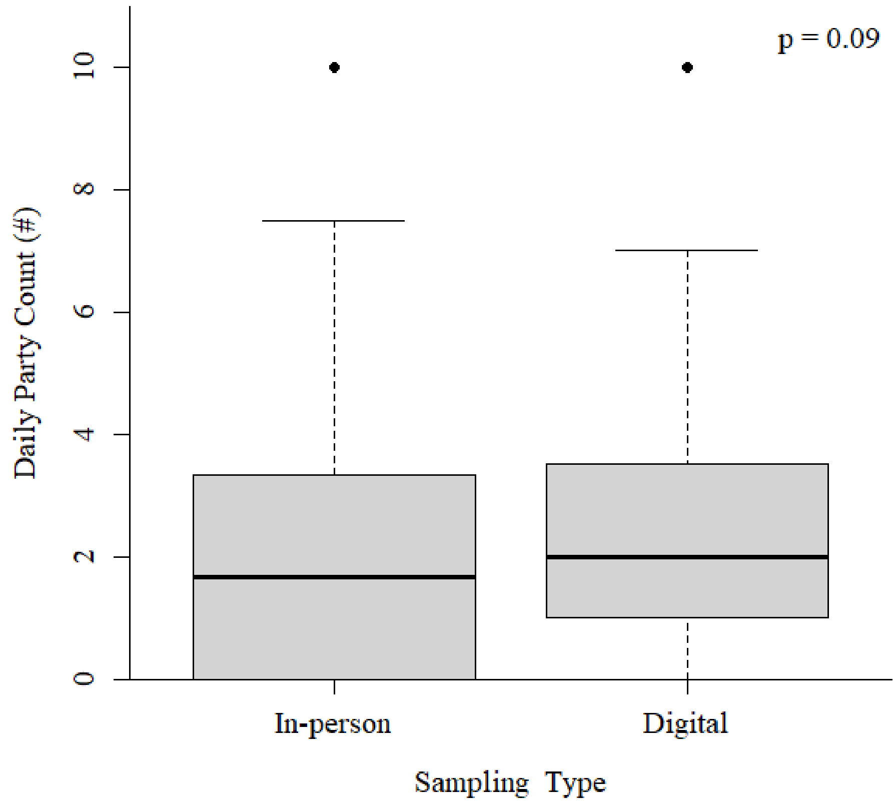

Figure 6. Daily party count estimates from in-person (n = 27) and digital (n = 39) data collection. The line within the box depicts the median. The lower and upper ends of the box represent the first and third quartiles (Q1 & Q3), respectively. The extent of the box represents the interquartile range (IQR). The whiskers extend to the smallest and largest values within 1.5 * IQR from the first and the third quartiles. Black dots represent outliers.

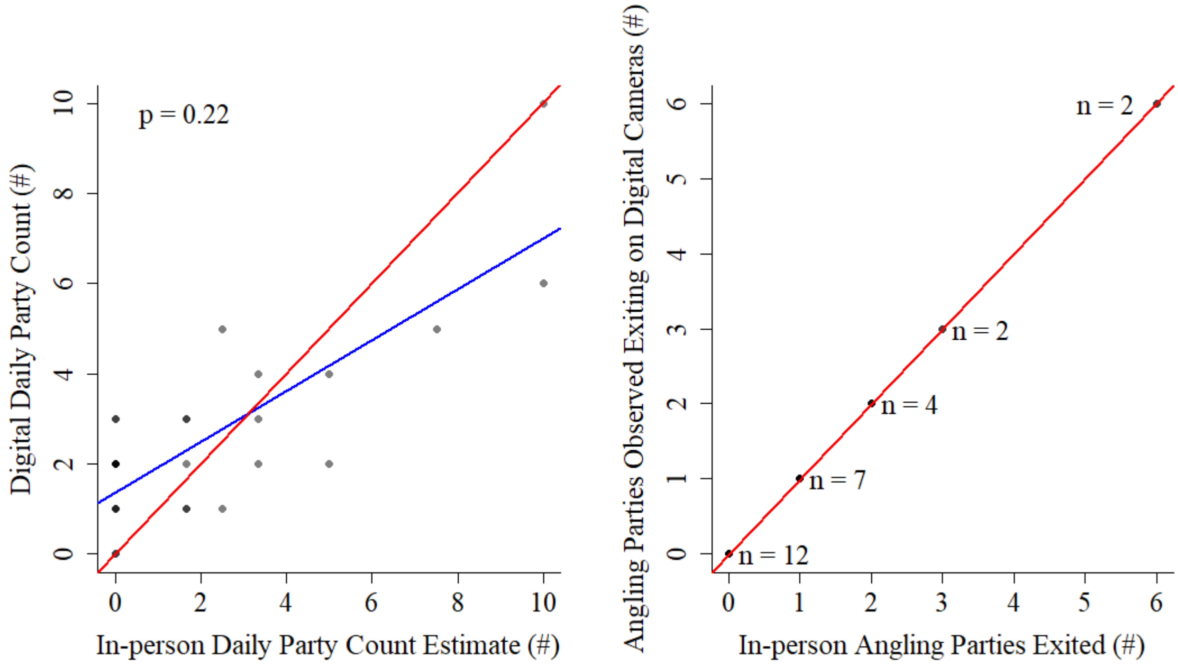

Figure 7. The scatterplot on the left depicts in-person daily party count estimates (#) and digital daily party counts (#), only when in-person data collection occurred. The blue line represents a line of best fit generated from linear regression analysis, and the red line is 45-degree line for comparison purposes. The scatterplot on the right depicts the number of angling parties that exited the fishery when in-person data collection occurred, and the number of angling parties observed exiting on the digital during in-person sampling occurred. The red line is 45-degree line for comparison purposes. All angling parties documented departing when in-person data collection occurred were also observed on the digital cameras, suggesting detection rates were near 100%.

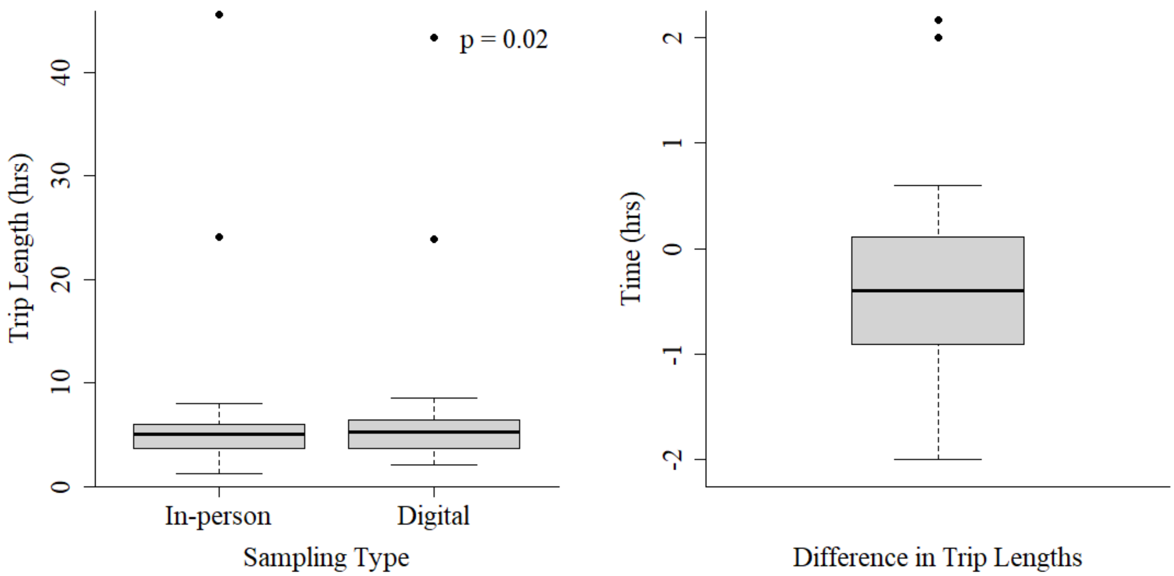

Figure 8. The boxplot on the left depicts trip lengths from angling parties that were both interviewed and observed on the digital cameras. All angling parties that were interviewed were observed accessing and exiting the fishery on the digital cameras. Therefore, both groups had a sample size of 31. The boxplot on the right depicts the distribution of trip lengths obtained from digital data collection, subtracted from reported trip lengths obtained from in-person data collection (n = 31). The line within the box depicts the median. The lower and upper ends of the box represent the first and third quartiles (Q1 & Q3), respectively. The extent of the box represents the interquartile range (IQR). The whiskers extend to the smallest and largest values within 1.5 * IQR from the first and the third quartiles. Black dots represent outliers.

APPENDIX A

Table A 1. Sonar types used by angling parties that listed Burbot as their target species. The highest magnitude of sonar was selected when parties reported multiple sonar types.

Sonar type	Count
None	2
Down imaging	11
Side imaging	6
Mega 360	0
Forward facing	5

Table A 2. Approximate age and gender demographics from interviewed anglers that listed Burbot as their target species.

Age range	Male	Female
<15	2	2
15-24	16	3
25-34	12	0
35-44	9	1
45-54	3	0
55-64	1	1
>64	2	1