Evaluating applications of shore-based camera monitoring to improve estimates of effort, retention, and compliance of recreational salmon fisheries.

By

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Abstract

In addition to being primary targets of recreational fisheries, Pacific salmon provide key ecosystem value in British Columbia, Canada. While data on commercial fisheries are historically well-researched, less is known about recreational fisheries and associated mortality. The purpose of this work is to demonstrate how autonomous shore-based cameras can integrate into, and improve upon, existing creel survey methods while providing new information related to recreational salmon fishery dynamics. Imagery from three locations in Sooke, British Columbia were used to estimate effort and retention by integrating creel survey data, and to improve understanding of compliance to a seasonal area-based fishery closure through two separate empirical studies. The approach here utilizes high-capture rates, allowing for robust temporal resolution, while integrating efficient data processing methods through a novel two-step image annotation process that was developed for the analysis of over 1.5 million images. The results from various temporal analyses suggest that cameras can substantially aid in improving the understanding of daily fishing patterns, while also providing validation for the optimal timing of existing creel surveys. Noncompliant fishing during a seasonal spatial closure was also notable and provides the first known study of salmon fishery compliance using cameras in British Columbia. Lastly, evidence was provided supporting substantial off-season fishing effort, which had previously been lacking in the existing monitoring framework. The subsequent recommendations from this work reveal that this monitoring approach could provide immediate and tangible benefits for improving recreational salmon fishing monitoring in British Columbia. Beyond, the approach that was developed can be applied at broader scales and could benefit managers with tools that can support camera monitoring of recreational fisheries to foster a greater understanding of stressors that impact vulnerable and at-risk fish species.

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Dedication/Acknowledgement

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Co-authorship Statement

Chapters 2 and 3 are co-authored manuscripts, with Chapter 2 (at the time of this thesis submission) having been submitted to an academic journal and awaiting review. Benjamin D. Morrow is the lead and corresponding author for both manuscripts. The list of co-authors are as follows: Dr. Patrick D. O'Hara, Dr. Natalie C. Ban, Tunai P. Marques, Molly D. Fraser, Norma S. Serra-Sogas, and Dr. Chrisopher E. Bone. BDM led the research, fieldwork, data preparation, data processing, analysis, and writing. CEB, PDO, and NCB aided in the development of research objectives, analyses, supervision, and editing. TPM created the deep-learning based vessel detection software used for analyzing camera imagery. MDF contributed to data collection, manipulation, and analyses. NSS aided in data collection and management of the camera and AIS projects (Photographic observation study – POS).

Chapter 1. Introduction

1.1 Overview

With rising anthropogenic encroachment into nature, the protection of threatened, at-risk, and endangered species is increasingly imperative. Within the marine environment, humans continue to navigate oceans and extract resources, which can considerably impact marine wildlife. Fishing is consistently recognized as one of the greatest pressures to marine life (Jackson et al., 2001; Coleman et al., 2004; Swartz et al., 2010; Halpern et al., 2015), with 79% of fish stocks worldwide either fully exploited or overexploited in 2017, while only 3% were underexploited in the same year (FAO, 2018). There is an increasing need to focus efforts on conserving such species, while managing human-induced extraction and mortality.

A large portion of the world relies on recreational fishing for sustenance, income, and pleasure (Cline et al., 2017). It is estimated that between 220 million and 700 million participate in recreational fishing around the world (Cooke & Cowx, 2004; Arlinghaus et al., 2016). Recreational fishing has historically had the perception of extracting fewer fish and causing less environmental stress than commercial fishing (Brownscombe et al., 2019). However, while the literature has focused on commercial fisheries, studies have revealed that recreational fishing can often scale to similar or greater mortality and subsequent impacts to biota as commercial fishing (Coleman et al., 2004; Cooke & Cowx, 2006).

1.2 Synthesis of fisheries management

To attempt to limit the extraction of marine species, fishing is managed in various ways by agencies and governments around the world. Typically, management measures for fishing are

generated at national and regional levels based on using national-scale data collection systems and are based on stock assessments. Stock assessments are models that are created to gauge the level of sustainable fishing that might occur given data on population levels and total estimated mortality from a variety of sources, including fishing (Pollock et al, 1994). However, there is still a significant lack of data on fishing activities worldwide, as 29% of countries failed to report their figures between 2016 and 2018 to the United Nations (FAO, 2018), which can lead to imprecision in the outcomes of stock assessments. To attempt to curb overexploitation to sensitive marine species, common measures include spatial and seasonal restrictions, education, and limit regulations (Gilman, 2002).

Spatial and seasonal restrictions on vessel activities and fishing are well-known tools for assisting fisheries management and protecting species prone to overexploitation (Wallace, 1999; Bergseth et al., 2015). In theory, strictly banning fishing provides a means of protecting specific ecologically or economically vital species within a given area. Areas chosen for these closures are typically correlated with particular ecologically significant habitats and protection of one species of fish may additionally benefit other species within the same habitat (Lynch, 2006; Canessa et al., 2007). Seasonal restrictions can also be timed to protect migrating species and changes in area and quantity of species (Hooker et al., 1999; Gilman, 2002). In practice however, results can be mixed. For example, Lester et al. (2009) found that in a region with small-scale fisheries in the Mediterranean Sea, a protected area where fishing was restricted had much larger fish on average compared to neighbouring areas. By contrast, low levels of compliance to restrictions in a fishery closure can hinder the efficacy of measures (Campbell et al., 2012; Haggarty et al., 2016) and may even lead to misleading estimates in the outcomes of stock assessments if compliance is otherwise assumed (Martin & Blackburn, 2009).

Education has been widely used as a tool for managing fisheries, as it has been seen to have had considerable benefits for the public to foster understanding of regulations, and for compliance rates across various fishing regulations (Alder, 1996; Pollnac et al., 2010; Lancaster et al., 2015). Users may feel more involved in policymaking, conservation and as a result, may more diligently follow rules. For example, in a review of 127 marine protected areas around the world, understanding and being able to recount the regulations of a marine reserve was the primary factor that led to high compliance rates (Pollnac et al., 2010). Effectively involving fishers in fishery planning can also lead to high levels of social acceptance of conservation areas and regulations (Alder, 1996; Leleu et al., 2012). Techniques for advancing education for local fishers have included signage, educational campaigns, questionnaires, advertising, and permanent or temporary moratoriums (Pollnac et al., 2010; Lancaster et al., 2015). A considerable benefit of education is that it is generally less costly than enforcement in the long-term and may have further reaching benefits (Alder, 1996; Watson et al., 2015; Lucrezi et al., 2019). For instance, in the Great Barrier Reef Marine Park, Australia, the cost of an effective education program was estimated to be 2% of the cost of recreational fishing enforcement, while also having wider benefits to communities (Alder, 1996). Charter fishing may provide another avenue for education (Lancaster et al., 2015). For instance, educated charter guides may be able to educate guests on threats to marine health, provided they are aware of, and follow implemented regulations.

Finally, fishing harvest limits are a common management approach around the world and generally involve one or several of the following specifications: daily, weekly, or yearly catch limits, restrictions on types of fish that can be harvested and size and sex of fish, (Brown, 2016). Though widely used, these methods have been effective in some regions and ineffective in others

(Sutinen & Johnston, 2003; Campbell et al., 2012; Bartholomew et al., 2018). Understanding and improving regulations for fisheries is important as "illegal, unreported, and unregulated" (IUU) fishing practices are estimated to comprise up to 26 million tonnes per year (Agnew et al., 2009). The major concern is that non-observation of fishing limits leads to further depletion of overexploited species in some areas and a reduction in the average size of fish, as IUU fishing is not generally accounted for in stock assessments (Arlinghaus et al., 2016). Furthermore, a general inaccuracy with harvest estimates based on imprecise data in stock assessments around the world often results in retroactive management (Jensen et al., 2009). For instance, limit regulations may not exist for a particular species until that stock becomes nearly depleted, as was the case for the Atlantic cod (*Gadus morhua*) fishery in eastern Canada (Rose & Kulka, 1999). In order to improve data considered in stock assessments, monitoring is therefore essential to acquire data on stressors (i.e., fishing), their spatial and temporal distribution, and compliance to various regulations to improve the success of management measures.

1.3 Monitoring marine recreational fisheries

Relative to commercial fisheries, recreational fisheries are typically poorly-informed, data-deficient, and pose various challenges for monitoring (Hartill et al., 2019; Cooke et al., 2021), despite being regularly associated with significant levels of extraction, and hence impacts (Cooke & Cowx, 2004; Cowx et al., 2009). The challenge for managing recreational fishing lies not only in the high numbers of participants, a lack of managerial resources, spatial and temporal dispersion, and varying species targeted, but also how these factors flux over time and space (Gentner & Sutton, 2008; Hyder et al., 2020). Most of the common monitoring approaches are based on creels surveys, which employ a subsampling survey design using on-site methods such as aerial surveys, and roving and access-point interviews, or off-site methods such as telephone,

mail, and internet surveys (Pollock et al., 1994). However, these surveys are not without limitations. For example, on-site surveys can suffer from high operational and data processing costs and may lack temporal resolution and preciseness (Hartill et al., 2019), while off-site surveys are prone to various forms of bias (Brownscombe et al., 2019). However, camera monitoring is beginning to show promise as a supplementary tool, as they allow for filling in temporal gaps while providing a relatively unintrusive, unbiased, and low cost surveillance method (Brownscombe et al., 2019; Hartill et al., 2019).

1.4 Overview of recreational fisheries monitoring in British Columbia

In British Columbia, Canada, Fisheries and Oceans Canada (DFO) is responsible for the management and monitoring of marine recreational fisheries. This is presently achieved via the aerial-roving creel survey method (Pollock et al., 1994), which combine interviews at popular marinas and intermittent aerial surveys. Creel clerks at marinas interview returning anglers to estimate mean composition of species, size, and number of fish caught during a random fishing trip, allowing for calculations of catch-per-unit effort (CPUE), a measure of how efficient anglers are extracting fish. They also record the timing of a fishing trip including location, and time of departure, arrival, and duration. Meanwhile, flights take an instantaneous snapshot of effort (counts of boats fishing), stratified over a delineated area (referred to as Pacific Fishery Management Areas (PFMAs) in BC) and combine observed effort with CPUE for a particular area. Then, the proportion of fishing is calculated in a given day based on the timing of fishing trips from interviews and expanded aerial effort across a day. For example, if 50% of anglers were found to have been fishing at 9:00 and 25% were found at 10:00, and at 9:00, 10 vessels were observed during a 9:00 flight, then the assumption is effort = 5 boats at 10:00. These

calculations are performed for each hour of the day. Daily effort is then stratified based on weekend or weekday and expanded to fill the rest of the month where in-situ data is lacking.

Despite aerial-roving creel surveys being fairly commonplace in recreational fishery monitoring schemes, there are also limitations that are becoming increasingly recognized that have led to bias in effort estimation (Hartill et al., 2019). Both aerial surveys and interviews are costly and labour intensive and are unlikely to capture in-situ data associated with the temporal variability of fisheries (Askey et al., 2018; Brownscombe et al., 2019). Relying on angler testimony can also be problematic. Fishers may either forget or purposely withhold information such as the location of where they fished (especially if it is in a restricted area) (Mackay et al., 2018), the timing of a trip (Taylor et al., 2018), and species caught and retained (including bycatch) (Smallwood et al., 2011; Lancaster et al., 2015). In British Columbia, aside from government statistics, few independent studies have explored recreational salmon retention and compliance (and none have done so using cameras), despite a variety of government regulations being recently amended and implemented to protect these species. Examples include limits to salmon retention by size, species, and time of year, and seasonal measures including area-based fishery closures. As such, there is greater need to improve monitoring and provide independent analyses of recreational salmon fisheries in the Salish Sea. Specifically, this includes developing methods to improve estimates of effort and retention that can integrate with existing creel surveys, as well as methods for monitoring compliance to spatial and seasonal regulations.

1.5 Research objectives

The following thesis aims to test the utility of shore-based cameras for monitoring recreational fisheries in two distinct contexts. The objectives of this work are to provide evidence

for several distinct applications of cameras that can improve upon the estimation of effort and retention alongside creel surveys and to foster a greater understanding of noncompliance of recreational fisheries to spatial fishery closures. Using three different locations as case-studies, this thesis provides evidence for how several applications are possible and how they can provide benefits for recreational fisheries management. Chapters 2 and 3 are described as follows:

Chapter 2) Two shore-based cameras were implemented to monitor a harbour access-point and a popular fishing location, for the purpose of estimating effort and retention and integrating results with existing Fisheries and Oceans Canada creel data. The aims were to demonstrate an application of new tools that can support recreational salmon fishing monitoring method in British Columbia, while providing enhanced temporal resolution and improvements to data that can support stock assessments.

Chapter 3) A camera system receiver was installed to survey a seasonal fishery closure area to gauge compliance of recreational fishing. Compliance was then contextualized relative fishing effort found in Chapter 2, while covariates, which affected noncompliant fishing behaviour, were further explored. The purpose was to demonstrate a monitoring application for recreational fisheries compliance and provide data to support efforts aimed at understanding the efficacy of spatial closures.

1.6 Thesis structure

This thesis is formatted as two stand-alone manuscripts (Chapter 2 and 3) and written to meet the requirements of peer-reviewed publication work. As such, repetition exists within some

of the contextual information and concepts presented in each chapter. The empirical studies conducted in Chapters 2 and 3 are nestled between an introductory chapter (Chapter 1), which outlines broader contextual information and literature, and a concluding chapter (Chapter 4), which synthesizes findings from Chapters 2 and 3, and provides recommendations for management, future work, and scaling up this approach.

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Chapter 2: Improving effort estimates of recreational salmon fishing with autonomous optical cameras

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ABSTRACT

Recreational fisheries often pose various challenges for monitoring. Conventional techniques, such as aerial-roving creel surveys, can exhibit bias in estimation as they are limited to sampling fragments of often fluid and temporally dynamic fisheries. Data from two shore-based autonomous cameras were evaluated to supplement creel data for a high-density recreational salmon fishery in British Columbia, Canada. We employed a novel deep learning-based system for the automatic detection of vessels for the analysis of over one million images. Camera detections resulted in 8444 boat days of effort, 6121 fishing detections, and monthly retention estimates by integrating catch-per-unit effort data. Empirical cumulative distribution and activity pattern analysis revealed detailed diel fishing patterns which were used to validate timing of creel surveys and highlight cameras as a tool for extending the temporal resolution of existing methods. Continuous surveying beyond peak-season provided new insight into off-season fishing effort, currently lacking in creel surveys. Increasing camera monitoring to cover additional sources of fishing traffic could increase the performance of recreational fishery monitoring frameworks and protect vital fish species at risk.

Keywords: Angling, camera monitoring, deep-learning tools, fisheries management, image processing, Pacific salmon, recreational fishing

2.1 Introduction

Monitoring fishing effort is an important part of many management frameworks aimed at improving understanding of fisheries. Fisheries constitute one of the largest anthropogenic pressures on marine life (Jackson et al., 2001), and the intensity of these activities is increasing around the world (Halpern et al., 2015). Approximately 93% of fish stocks worldwide are estimated to be either fully exploited (have reached maximum sustainable limits) or overexploited (are beyond sustainable limits) (FAO, 2018). Without accurate data on fishing effort, managers can face challenges with accurately estimating fishing mortality (Gilman, 2002; Coll et al., 2012), and each fishery presents distinct challenges for monitoring.

Recreational fisheries provide individuals and communities with sustenance, pleasure, and/or small-scale revenue (Schuhbauer & Koch, 2013; Chen et al., 2017; Cillari et al., 2017). Relative to commercial fisheries, recreational fishery stock assessments are typically poorly informed (Arlinghaus & Cooke, 2005) and this fishery has historically had the perception of extracting fewer fish and causing less ecosystem pressure (Cooke & Cowx, 2006). However, in many cases, recreational fisheries can scale to similar or greater pressures than commercial fisheries (Hyder et al., 2018), especially to high-valued fish stocks that may be subject to high rates of artificial selection (Coleman et al., 2004; Jensen et al., 2009) and bycatch (Cooke & Cowx, 2006). While global estimates of recreational fisheries are conservative as they are inherently challenging to study (Arlinghaus et al., 2016), recent research suggests that there is an increasing need to improve the monitoring and estimates derived from stock assessments of these fisheries (Smallwood et al., 2011; Teixeira et al., 2016; Askey et al., 2018; Hartill et al., 2019).

Management of recreational fisheries varies across jurisdictions, and two commonly implemented approaches are limits to retention size and the number of fish allowable by license. However, directly monitoring these activities and estimating fishing effort is often onerous, as fishers can be both spatially and temporally dispersed, and varied in their proficiency to extract fish (Post & Parkinson, 2012; Ward et al., 2013). In addition, self-reporting is seldom mandatory in recreational fisheries, and thus evaluating the total activity within a recreational fishery through direct methods is not always practical (Hartill et al., 2019). Further, techniques applied to monitor commercial fisheries such as automatic identification systems (AIS) and radar are largely ineffective for recreational fisheries monitoring (Merchant et al., 2014; Hermannsen et al., 2019). These limitations result in having to rely on alternative methods such as creel surveys in order to estimate fishing effort and retention (number of fish kept).

Creel surveys typically combine dockside interviews with a form of instant count method acting as proxies for fishing effort. Creel clerks interview individuals who return from fishing (i.e., anglers) at marinas, boat ramps, and vessel access points within a delineated fishery zone to acquire fine-scale fishery metrics such as catch-per-unit-effort (CPUE), as well as the size and species of fish that are caught (Pollock et al., 1994). However, for recreational fisheries, interviewing the entire fishery would be both prohibitively costly and labour intensive (Isermann & Paukert, 2010; Wise & Fletcher, 2013). Interviews on their own may not be able to capture all aspects of a fishery (such as total effort), which is why a quantification method is required to scale-up interview based estimation. Meanwhile, aerial surveys are a commonly applied approach to expand fishing effort across larger spatial scales. Aerial surveys combined with interview surveys across multiple marinas form an aerial-roving creel survey (Pollock et al., 1994). Instantaneous counts of effort allow for estimating total effort and total retention of fish

by species. However, aerial surveys can also be constrained by costs (Hartill & Edwards, 2015), and data often require substantial processing times (Smucker et al., 2010; Stahr & Knudson, 2018). In addition, aerial surveys can lack fine-scale temporal detail, which has been seen to result in temporal bias (Smallwood et al., 2012) and low precision in estimation (Askey et al., 2018). Although aerial-roving creel surveys are widely used, they can only capture a snapshot of fishing effort, which has led others to begin exploring other technologies such as cameras to improve the temporal resolution of monitoring schemes (Hartill et al., 2019).

Autonomous optical cameras are increasingly employed in conservation and wildlife monitoring for targeting a range of human and wildlife activities (Wawerla et al., 2009; Bater et al., 2010; Merkel et al., 2012; Nelms et al., 2018). Robust camera systems can allow for long-term monitoring at fine temporal resolutions across 24-hours at relatively low running costs while providing non-intrusive monitoring (Long et al., 2008). The use of shore-based cameras for recreational fisheries monitoring is an increasingly common approach in lakes (van Poorten et al., 2015), reservoirs (Stahr & Knudsen, 2018), and tidal-water fisheries (Parnell et al., 2010; Smallwood et al., 2012; Powers & Anson, 2016). Shore-based cameras have been used to explore compliance of fishers to restricted zones (Lancaster et al., 2017), nocturnal fishing (Taylor et al., 2018), and to quantify effort (Parnell et al., 2010; Powers & Anson, 2016). When applied to aerial-roving creel surveys, cameras can favourably bridge the temporal gap between the other methods (Hartill et al., 2019), which can ultimately aid in the precision of outcomes of stock assessments (Taylor et al., 2018). Further, in certain scenarios, cameras can reduce the intensity of, or entirely replace, aerial surveys. For instance, a study in New Zealand compared aerial survey counts to camera counts and found minimal deviance between the two effort

estimates, suggesting that stock assessments would not significantly differ with a substitution of methods (Hartill, 2015).

While autonomous cameras are increasingly employed in the context of marine monitoring, their ability to effectively monitor existing tidal-water recreational fishing is often context-dependent. Considerations such as location, field-of-view (FOV), quality of images, environmental/ambient conditions, capture-rate, and the intended objectives of the study are key for high study design integrity (Hartill et al., 2019). Typical camera placements include mounting cameras at boat ramps (Steffe et al., 2017), marinas and docks (Greenberg & Godin, 2015), harbour chokepoints (Kaiser, 2016), ocean buoys (Keller et al., 2016), and at popular fishing locations (Lancaster et al., 2017). The ability to infer effort from camera counts is also important. Other studies routinely define fishing effort from images as a vessel that is seen to be visibly fishing, or carry fishing gear onboard, depending on the placement of the camera and objectives of the study (van Poorten et al., 2015; Stahr & Knudson, 2018). By following this definition, camera-derived fishing effort can then be analogous with aerial effort, as they are both summarized as daily effort (Hartill, 2015).

Historically, designing a camera survey for recreational fisheries monitoring would involve trade-offs between sampling frequency, and logistical considerations such as data storage and processing. Large datasets consisting of hundreds to millions of images require substantial processing times (Greenberg & Godin, 2015; Afrifa-Yamoah et al., 2021). Impediments can also arise from hardware malfunctions, and battery and memory constraints (van Poorten et al., 2015) and camera monitoring frameworks often utilize a subsampling framerate that requires the expansion of data (Keller et al., 2016; Lancaster et al., 2017; Afrifa-Yamoah et al., 2021). However, improvements in technologies have led to an increase in possibilities for monitoring

frameworks. These include the development of cameras that are robust in a range of weather conditions, flexibility and improvements in power supply, increased storage capabilities, higher image quality, and software to aid in data processing (Greenberg & Godin, 2015; Bicknell et al., 2017; Askey et al., 2018; Hartill et al., 2019). Regarding the latter point, the recent prevalence of deep learning-based systems in imaging applications (e.g., image classification, instance segmentation, object detection) can be attributed to the increasingly high performance such methods are able to achieve (Krizhevsky et al., 2012). Among ubiquitous usages, recent works have developed deep learning-based systems tailored specifically to the identification of small marine vessels in environmental monitoring images (Marques et al., 2020), substantially reducing the amount of time and human resources involved in the interpretation of large datasets.

The objective of this study was to evaluate several distinct characteristics of cameras that can contribute to the improvement of existing recreational fisheries monitoring frameworks. We implemented two autonomous time-lapse camera systems to capture vessels and fishing at high frequencies in Sooke, British Columbia (BC), Canada. Despite being an area with high recreational fishing effort, the use of cameras to monitor effort has yet to be explored. We evaluate the ability of autonomous cameras to quantify recreational effort and retention, extend the temporal range and resolution of existing monitoring schemes, and validate the optimal timing of existing creel surveys. The overall aim of this study was to assess whether cameras can integrate into existing monitoring schemes, and whether they can provide managers and researchers a greater understanding of recreational effort and retention to improve the precision of outcomes from stock assessments for fish species of critical importance to British Columbia's economies and marine ecosystems.

2.2 Methods

2.2.1 Fishery overview

Recreational fishing is a popular activity in BC, comprising the highest GDP of all activities in the fisheries and aquaculture sector (BC Stats, 2016). Although commercial fisheries were responsible for the majority of retention of salmon (*Oncorhynchus spp.)* in the 1990s (Gislason, 2006), more recently recreational fishing is thought to have surpassed commercial fisheries in both effort and retention; it is estimated that in 2015, recreational fishers retained approximately 388,000 Chinook salmon (*Oncorhynchus tshawytscha)* and 457,000 Coho salmon *(Oncorhynchus kisutch)* compared to 191,000 Chinook and 300,000 Coho retained by commercial fisheries (Gislason et al., 2017). A popular area in BC for recreational fishing is around the municipal district of Sooke, which lies 45km to the west of the provincial capital Victoria (Fig. 1). Coastwide, recreational fishing management is spatially delineated by Pacific Fishery Management Areas (PFMAs) and monitored by the federal agency, Department of Fisheries and Oceans Canada (DFO). Of all PFMAs coastwide, PFMA 20 (East), which covers the Sooke coastline, comprises the area of highest cumulative effort as estimated in DFOs annual South Coast Creel Data Review Packages (Fisheries and Oceans Canada, 2020). Within PFMA 20 (East), Sooke is the largest and most active harbour for recreational fishing (Fisheries and Oceans Canada, 2020). In addition to government statistics, independent studies have similarly identified large clusters of small vessel activities around Sooke (Zetterberg et al., 2012; Serra-Sogas et al., 2018).

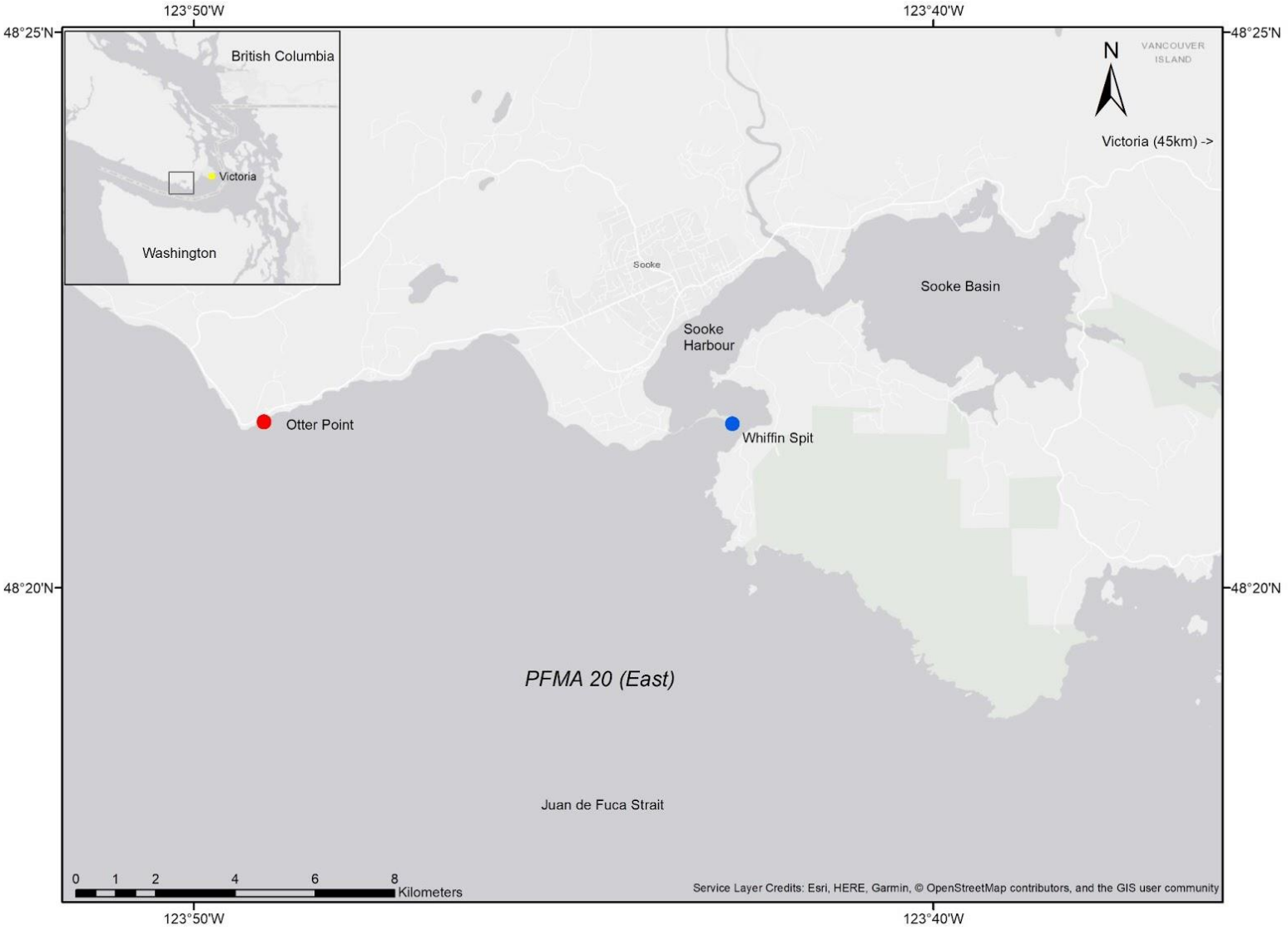

Fig. 2-1. Autonomous shore-based camera monitoring locations within Pacific Fishery Management Area (PFMA) 20 (East). The camera system at Otter Point camera overlooks a popular fishing location in the region, while a camera at Whiffin Spit captures inbound and outbound vessel traffic stemming from Sooke harbour, a major source of recreational fishing vessel traffic within PFMA 20 (East).

For this study, we defined two fishing seasons based on the majority of annual recreational fishing estimated by DFO creel survey data (Fisheries and Oceans Canada, 2020); peak-season (August - October), and off-season (November - July). During peak-season, Chinook and Coho salmon can comprise up to 99% of the catch and retention within PFMA 20 (East), according to DFO survey data. The monitoring of recreational fishing activity in PFMA

20 (East) currently occurs at four harbours (including Sooke) through seasonal aerial-roving creel surveys. Flights provide instantaneous snapshots of effort with individual vessel counts providing fishing effort in boat hours. Boat hours are then combined with interview data whereby the timing of fishing by anglers is used to estimate hourly metrics and to calculate boat days' worth of effort. Interview data on relative effort per boat and CPUE are also used to estimate total effort and retention. Estimates are stratified by weekend/weekday and are further scaled to monthly effort. However, the utility of shore-based cameras in supplementing these existing methods has yet to be explored.

Table 2-1. Existing DFO survey methods for estimating recreational fishery effort and retention.

	Interviews	**Aerial surveys**
Time of day/survey length	Morning or afternoon shifts	Varied, but usually occurred between 9:00-11:00 in PFMA 20 (East)
Type of data collected	Departure and return time, time spent fishing, species, number, and size of fish.	Instantaneous count of vessels engaged in fishing within the PFMA (boat hour of effort)
Spatial stratification	Access-point (marinas)	Entire PFMA
Temporal stratification	Entire day (i.e., asking anglers when they went fishing)	Snapshot

2.2.2 Description of camera data

We collected in-situ data from optical camera systems mounted at two locations within PFMA 20 (East) in 2019 and 2020, Whiffin Spit and Otter Point.

Whiffin Spit

The first system consisted of a trail camera (Reconyx Ultrafire Professional) and operated at the end of Whiffin Spit. Data extracted from imagery collected by this camera were used as a proxy for effort from Sooke harbour, as all vessels departing and arriving from the harbour must pass through this gap (Fig. 2-1), and thus through the camera field of view. The purpose of this camera was to quantify sport fishing vessel effort that stemmed from Sooke harbour. The spit provides a narrow funnel (max. of 300m across) for outbound and inbound vessel traffic and our camera position allowed for easily identifiable vessel characteristics. The camera was installed in a discrete location and powered by two 12V deep-cycle batteries housed in a watertight case. We structured a capture rate of one photo every 10 seconds in order to detect all vessels each given day. We recorded between 4320-6480 images/day depending on the time of year and available daylight. For example, in August the camera operated from 4:00 until 22:00, whereas in December it operated from 6:00 until 18:00. We stored data in 256GB SD cards and data were retrieved every 18-20 days. The process of switching batteries and the SD card took approximately 15 minutes per visit.

Otter Point

DFO's creel estimation structure depends on temporal data (when anglers fished during the day) acquired from interviews. As we were interested in understanding the timing of active fishing events, rather than traffic flux (i.e., Whiffin Spit), a second camera system was installed at Otter Point, a popular salmon fishing location within PFMA 20 (East), approximately 3.8 nautical miles west of Whiffin Spit to monitor the temporal dynamics of fishing in the area. We installed our camera system with permission at a private residence on a headland, overlooking the fishing area. Our system consisted of a digital single-lens reflex (DSLR) camera and a point-tilt-zoom (PTZ) surveillance camera with a wide-angle setting. Two cameras allowed for wider

spatial coverage, and temporal continuity in the event that one camera failed. This system was hardwired to power/ethernet at the residence and controlled by a Raspberry Pi with purpose specific python scripts (open-source link: https://github.com/iainctduncan/photobot) allowing for remote access to adjust capture rate, on/off timing based on sunrise and sunset, and to record calibrated timestamps. We recorded between 1900 and 3200 images/day/camera depending on the time of year and availability of daylight. Data were stored on a 2TB hard drive, all system components were stored inside a watertight box, and mounted in a secure location that overlooked the nearshore region.

As the vast majority of recreational fishing in PFMA 20 (East) targets salmon (Fisheries and Oceans Canada, 2020), our intention was to use imagery from Otter Point to detect active salmon fishing (trolling) events. Trolling is defined as a vessel slowly moving either in a straight line or in a zigzag motion, with no wake, and with fishing line in the water (Eighani et al., 2019). To capture such events, we designed a custom camera capture framework to observe and record this distinguishable behaviour: three captures occurred within the first fifteen seconds in a minute (five-second intervals) followed by a 45-second delay until the beginning of the next minute cycle.

2.2.3 Image processing

Rather than relying upon a subsampling approach and potential bias in estimation, our high temporal resolution at both locations allowed for imagery data to be treated as census. However, manually processing these large quantities of images would be onerous and time-consuming. We therefore developed a two-step process for efficiently thinning datasets. First, we applied a deep learning (DL)-based vessel detection tool (Marques et al., 2020) to automatically sort raw imagery between those where instances of vessels where identified (“positive”) and

otherwise ("negative"). This detector identifies medium- and large-sized vessels with the use of pre-trained end-to-end state-of-the-art (SOTA) object detectors (Ren et al., 2015; Lin et al., 2017; Cai & Vasconcelos, 2018). Since vessels detected at the pixel-level (i.e., those with approximately 80 pixels of area) are challenging even for humans to identify in single images, this detector considers the apparent motion created within a small time series of three sequential frames captured 5 seconds apart from each other. This detection system for the detection of small marine vessels (DSMV) combines the output of the SOTAs with a novel Gaussian Mixture Model (GMM)-based motion detector ("Bidirectional GMM"), as well as a filtering scheme composed of a set of environmental assumptions and custom-trained deep learning-based image classifiers (Szegedy et al., 2015; He et al., 2016; Huang et al., 2017; Xie et al., 2017). As the hyper-parameters of the automatic vessels detector were set to assign a high sensitivity (i.e., favoring *recall* over *precision*), it resulted in a number of false positive detections of visual targets such as kelp, seabirds, and driftwood. In addition, the program did not identify vessel characteristics. These factors required us to perform an additional step to filter false positive and define vessel types and their activities.

Our second step involved annotating thinned datasets from the DSMV using image categorization software developed by Gregory O'Hagan from the University of Victoria, BC, Canada (a detailed description of the tool and instructions for use is located in Appendix A, Fig. A-1). This software allows a technician to quickly note features such as type of vessel, the direction of travel, and whether an active fishing event was detected (see Appendix A, Table A-1. for definitions of vessel types and activities). Our software is similar in nature to software developed by Greenberg & Godin, (2015), but was developed independently to suit the needs of this work. Once a technician annotated all images within a day, the software produced summary

reports and CSV datafiles at any desired timescale. Exploratory results revealed that this two-step process reduced the time spent by a technician to process a days' worth of optical imagery data anywhere from 72-98%. In addition, Greenberg and Godin, (2015) found that they were able to process approximately 120– 490 images per hour, while our two-step process allowed us to sort through over 3000 raw images per hour during peak-season and over 8000 raw images in the off-season at Otter Point.

When annotating imagery, we defined a sport fishing vessel (SFV) as a small vessel that had visible fishing gear onboard (Appendix A, Table A-1). From Whiffin Spit, these characteristics were typically easy to identify, and we also annotated each vessel's direction of travel (inbound or outbound). However, at Otter Point, we could not always reliably see fishing gear on some small vessels, particularly for those transiting in the distance, and thus these vessels were categorized as "motorboats" and excluded from our analyses. When annotating fishing events at Otter Point, we used the same series of three sequential images to define trolling based on their movement patterns (Appendix A, Table A-1). Any vessel that appeared to be fishing but did not meet these three criteria was considered to be engaged in "probable" fishing, to match the definition by two other camera-based recreational fishing studies in BC (Lancaster et al., 2017; Ban et al., 2019). Occasionally, the movement patterns of trolling resulted in vessels appearing in and out of the field of view across a time-series. As we did not want to create a bias for identifying the same vessel multiple times based on visibly distinguishable or unique features, we defined a new fishing event as either (1) a vessel that was clearly unique that day, or (2) a vessel that could have matched an earlier vessel, but over an hour had elapsed since that vessel last appeared. We also did not attempt to identify and track unique vessels, but rather defined observations by detected events.

2.2.4 Quantifying effort and retention

To quantify fishing effort and retention estimates, we applied the same methodology as DFO for extracting effort but substituted aerial counts with SFV traffic counts at the Whiffin Spit camera. We used vessel data for peak-season fishing (n=12985 SFVs observed). To match DFO's definition of effort used in aerial estimates, and to account for inbound and outbound traffic we considered one SFV in the camera FOV as a half of a boat-days' worth of effort in a given day. Occasionally there were small discrepancies between daily outbound and inbound traffic, and we therefore considered the mean of the two numbers as daily observed effort (DOE). We only used days that had uninterrupted imagery (n=82/91 during peak-season) and calculations were stratified by weekend and weekday and expanded the same way aerial data are expanded to monthly effort, by imputing unsampled days using average weekday or weekend metrics. The assumption here was that days with uninterrupted imagery were similar in boating activity to those unsampled. We validated Whiffin Spit by conducting 30 hours of in-person surveys (n=1048 SFVs) over 5 days in a variety of weather conditions, noting that effort did not significantly differ between our validated dataset (n=1020, p=0.97).

To extract estimated retention by species from camera observations, we took monthly DFO CPUE data from interviews in PFMA 20 (East). DFO scales CPUE by month, management area (PFMA), day of week (weekend/weekday), and estimates the number of each species retained at each scale. To scale-up effort for each of these strata, instantaneous aerial counts are used. For our effort calculations, we substituted aerial counts with Whiffin Spit camera counts and applied the same principles for estimating effort and species-specific retention for our calculations (including analogous months and days of week).

DOE (weekend/weekday stratified) *x* CPUE (species specific) = camera effort

Camera effort *x* # of days in month (weekend/weekday stratified) = total monthly effort

Total monthly effort *x* CPUE (species specific) = monthly retention

During the study period within PFMA 20 (East), DFO conducted access point interviews at four marinas (Pedder Bay, Becher Bay, Flemming Bay, and Sooke) which are thought to be the source of the majority of SFV traffic in this PFMA. As such, we then calculated the percentage of which Whiffin Spit SFV traffic represented effort across the entire PFMA 20 (East) for the same months by DFO aerial effort with Whiffin Spit effort. This provided a proxy for Sooke harbour. These calculations assume that aerial counts are relatively accurate estimates of fishing effort across PFMA 20 (East).

2.2.5 Temporal analyses

We performed two analyses to describe diel activity at Whiffin Spit and Otter Point in order to improve understanding of daily fishing activity. As we were interested in both outbound and inbound traffic from the Sooke harbour, we performed empirical cumulative distribution functions on Whiffin Spit imagery to show the net flux into the system (i.e., fishery in PFMA 20 (East)) which stems from Sooke. By contrast, as we were only interested in examining the temporal patterns of trolling events at Otter Point rather than direction of travel, we performed diel activity pattern analyses (DAPA) in R (R Core Team, 2013) at Otter Point in order to estimate the timing of daily fishing activity. DAPAs are fitted using nonparametric kernel density estimators of diel activity with a von Mises (circular) distribution (Best & Fisher, 1978), treating estimates as stochastic samples from a continuous distribution (Ridout & Linke, 2009). We plotted our results for each peak-season month using the function *densityPlot* in R to create smoothed density plots (Meredith & Ridout, 2020). We then recorded detections of fishing

events in the off-season at Otter Point. At present, these off-season months are not surveyed by DFO, and hence fishing effort during these months is not currently factored into estimates from stock assessments.

To determine whether the temporal distribution of fishing activity at Otter Point was related to the distribution from Sooke, we performed the *overlap* function (Meredith & Ridout, 2020) in R (R Core Team, 2013) for the same months during 2020's peak-season fishing. This method has primarily been used in camera trap data for wildlife conservation to examine diel activity between multiple species and the amount of temporal overlap between their activities (Frey et al., 2017; Lashley et al., 2018). This function estimates coefficients of overlapping (Meredith & Ridout, 2020) of two temporal densities and calculates bootstrap estimates. We used the estimator Δ_4 (Dhat4) with 10000 smoothed bootstrap resamples, which is recommended when observations from the smaller of both samples exceed 75 (Meredith & Ridout, 2020).

We then were interested in understanding how diel camera data differed from diel creel data to understand whether there were differences in their temporal distribution to investigate whether creel data was being accurately predicted by camera data. DFO data are discretized by percent of the day's fishing and scaled hourly, and thus continuous density plots were impractical without the exact times anglers were observed fishing. Therefore, for this analysis, to match the format of DFO interview data, we summarized fishing data from Otter Point by weekend and weekday, discretized fishing detections by hour and plotted analogous line graphs to visualize both distributions.

2.3 Results

2.3.1 Effort and retention estimates

From August to October, we detected 7823 expanded boat days' worth of sport fishing effort from Whiffin Spit (Table 2-1). Assuming catches mirror patterns in the monthly CPUE data, retention estimates totaled 2436.36 Chinook salmon, 4941.78 Coho salmon, and 121.59 halibut (Table 2-2). In addition, for the same months, expanded confirmed and probable fishing events at Otter Point totaled 3484 in 2019, and 3584 in 2020 (Table 2-2). Off-season fishing is described in Table 2-3 at Otter Point, where we estimated 486 fishing events out of 1467 small vessels at Otter Point between November 1st, 2019, and April 30th, 2020 and between November 1st and December 31st, 2020. In addition, between November 1st and December 31st, 2020, we detected 621 boat days' worth of effort at Whiffin Spit (Table 2-2). However, off-season retention estimates were not possible as DFO did not perform creel surveys to extract CPUE and species-specific data during winter 2020. When comparing to aerial estimates for all of PFMA 20 (East), we found that effort from Sooke harbour represented 42.51% of the region overall, assuming equivalent metrics between camera and aerial counts, but there was substantial variation by month. For example, 35.18% of the effort in PFMA 20 (East) stemmed from Sooke harbour in September while the percentage was 65.73% in October (Table 2-2).

Table 2-2. Contribution of Sooke harbour (Whiffin Spit camera) within PFMA 20 (East). All creel estimates represent the entirety of PFMA 20 (East) for a given month while camera estimates represent the proportion of sport fishing traffic flow from Sooke harbour compared to the entire PFMA. *n* represents both the number of interviews conducted by creel officers and the average number of sport fishing boats departing and returning to the marina. Metrics to determine retention were calculated using CPUE derived from creel surveys. The metric for effort in both cases is boat days. The species (Chinook, Coho, Halibut) show number of fish retained (mortality) as determined by or expanded from creel surveys. Other species or types of fish are not included as there were none reported in interview surveys for this particular area during the study period.

2020 Sooke estimates	**n**	**Fishing Effort**	**Chinook**	**Coho**	**Halibut**
August (creel)	437	10117	4794	3229	37
August (camera)	5791	4067.1	1967.1	1283.2	12.5
Proportion		0.4020	0.4103	0.3974	0.3365
September (creel)	314	6957	838	5182	159
September (camera)	4467	2447.3	294.8	1794.3	54.8
Proportion		0.3518	0.3517	0.3462	0.3443
October (creel)	147	1991	251	2689	89
October (camera)	2727	1308.7	174.5	1864.4	54.4
Proportion		0.6573	0.6954	0.6933	0.6111
Peak-season (creel)	**898**	**19065**	**5883**	**11103**	**285**
Peak-season (camera)	**12985**	**7823.1**	**2283.7**	**4429.9**	**107.7**
Peak-season Proportion		**0.4429**	**0.4141**	**0.4451**	**0.4266**
November (creel)	N/A	N/A	N/A	N/A	N/A
November (camera)	733	374.2	92.0*	308.5*	8.4*
Proportion		N/A	N/A	N/A	N/A
December (creel)	N/A	N/A	N/A	N/A	N/A
December (camera)	487	246.7	60.7*	203.4*	5.5*
Proportion		N/A	N/A	N/A	N/A
Off-season (creel)	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
Off-season (camera)	**1220**	**620.7**	**152.6**	**511.9**	**13.9**
Off-season Proportion		N/A	N/A	N/A	N/A

**Note: For November and December 2020 where DFO did not collect creel data, we assumed the mean CPUE for August-October when estimating retention by species.*

Table 2-3. Peak-season Otter Point detections. Results include confirmed fishing (trolling) activity and probable fishing activity (boat days of effort per month). Counts are expanded and stratified by the mean effort for weekends (WK) and weekdays (WD). Parentheses indicate mean daily observed fishing, while values without parentheses are total monthly values.

	Confirmed Fishing		Probable Fishing		Small Vessel Detections	
Time strata	*Actual*	*Expanded*	*Actual*	*Expanded*	*Actual*	*Expanded*
August 2019	1178	2239.50	171	299.83	3108	6238.24
WD (mean)	(57.5)	1207.50	(7.08)	155.83	(167.92)	3694.24
WK (mean)	(103.20)	1032	(14.40)	144	(254.40)	2544
September 2019	425	426	102	111.60	1105	1110.8
WD (mean)	(7.95)	159	(2.68)	53.60	(25.89)	517.8
WK (mean)	(26.70)	267	(5.80)	58	(59.30)	593
October 2019	99	127.75	21	90.56	339	362.54
WD (mean)	(1.00)	21	(2.48)	54.56	(11.57)	254.54
WK (mean)	(0.75)	6.75	(4.0)	36	(12.00)	108
Peak-season 2019	**1904**	**2914.25**	**448**	**569.49**	**5053**	**8418.21**
August 2020	736	1915.5	172	454	1435	4577
WD (mean)	(54.25)	1085	(9.5)	190	(120.5)	2410
WK (mean)	(75.5)	830.5	(24)	264	(197)	2167
September 2020	648	648	211	211	1516	1516
WD (mean)	(19.19)	403	(6.29)	132	(42.71)	897
WK (mean)	(27.22)	245	(8.78)	79	(68.78)	619
October 2020	236	236	99	99	517	517
WD (mean)	(6.76)	142	(3.62)	76	(15.05)	316
WK (mean)	(9.4)	94	(2.3)	23	(20.1)	201
Peak-season 2020	**1620**	**2799.5**	**482**	**764**	**3468**	**6610**

Table 2-4. Off season Otter Point detections. Results include confirmed fishing (trolling) activity and probable fishing activity (boat days of effort per month). Counts are expanded and stratified by the mean effort for weekends (WK) and weekdays (WD). Parentheses indicate mean daily observed fishing, while values without parentheses are total monthly values.

	Confirmed Fishing		Probable Fishing		Small Vessel Detections	
Time strata	*Actual*	*Expanded*	*Actual*	*Expanded*	*Actual*	*Expanded*
November 2019	43	46.09	5	5.38	56	59.42
WD (mean)	(1.53)	30.53	(0.16)	3.16	(2.53)	50.53
WK (mean)	(1.56)	15.56	(0.22)	2.22	(4.29)	8.89
December 2019	67	79.79	11	13.21	82	96.88
WD (mean)	(2.71)	54.12	(0.29)	5.88	(4.29)	85.88
WK (mean)	(2.33)	25.67	(0.67)	7.33	(1)	11
January 2020	0	0	1	1.57	56	89.83
WD (mean)	(0)	0	(0.07)	1.57	(3.43)	75.43
WK (mean)	(0)	0	(0)	0	(1.60)	14.40
February 2020	15	21.64	0	0	82	117.07
WD (mean)	(0.93)	17.64	(0)	0	(5.21)	99.07
WK (mean)	(0.40)	4	(0)	0	(1.80)	18
March 2020	35	40.17	10	11.45	228	261.11
WD (mean)	(1.26)	27.79	(0.32)	6.95	(7.37)	162.11
WK (mean)	(1.38)	12.38	(0.5)	4.5	(11)	99
April 2020	51	82.3	11	31.85	325	362.54
WD (mean)	(1.3)	27.3	(0.85)	17.85	(10.40)	218.40
WK (mean)	(0.56)	5	(1.56)	14	(13)	117
November 2020	41	48.38	6	6.49	199	224.07
WD (mean)	(1.14)	26.22	(0.15)	3.45	(4.61)	101.42
WK (mean)	(2.77)	22.16	(0.38)	3.04	(13.62)	122.65
December 2020	52	88.45	7	9.65	223	255.97
WD (mean)	(1.85)	68.45	(0.35)	8.05	(7.8)	179.40
WK (mean)	(2.50)	20	(0.20)	1.6	(9.57)	76.57
Off-season 2019-2020	**304**	**406.82**	**51**	**79.60**	**1251**	**1466.89**

2.3.2 Temporal analyses

At Whiffin Spit, we found that during peak-season, the percent of daily outbound traffic was highly clustered (positively skewed) in the morning, while inbound traffic was more dispersed or negatively skewed (Fig. 2-2). When comparing diel distributions between Otter Point and Whiffin Spit using the overlap analysis with bootstrap estimates, the coefficient of overlapping returned was relatively high (0.8). For fishing detections at Otter Point, the percent of daily activity was highly clustered during peak-season in the mornings, especially in August

and September (Fig. 2-3). Finally, comparisons in diel activity between camera-detected fishing and creel interviews yielded similar trends in all six cases (Fig. 2-4), especially in the mornings. However, in August and September for both 2019 and 2020 during weekdays, percent of fishing effort from cameras yielded higher values in the early afternoons compared to creel estimates (Fig. 2-4).

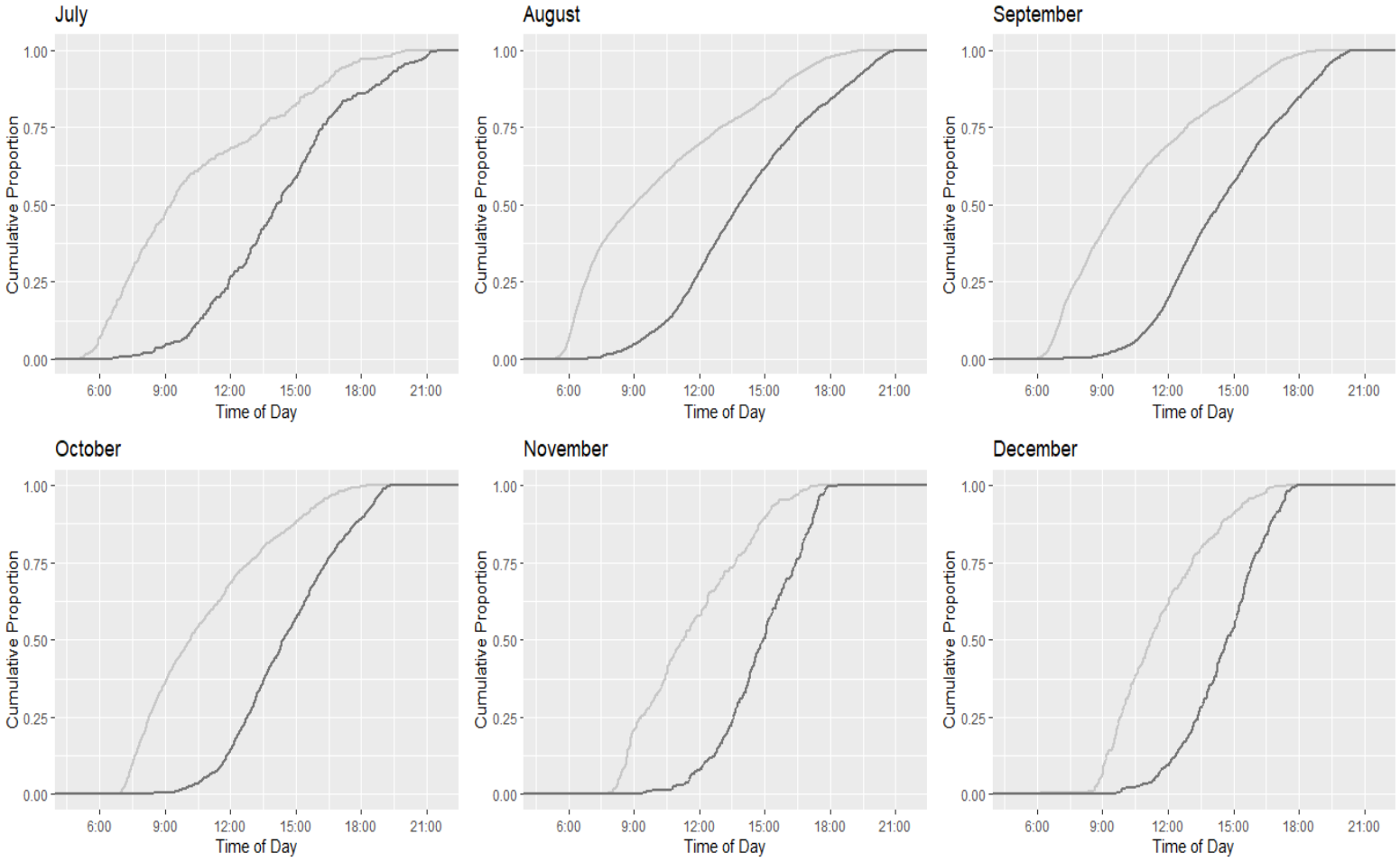

Fig. 2-2. Cumulative proportion of diel vessel activity at Whiffin Spit from July to December 2020. Outbound traffic (grey), inbound traffic (black). The diel window of camera data collection was from 5:00 to 21:00.

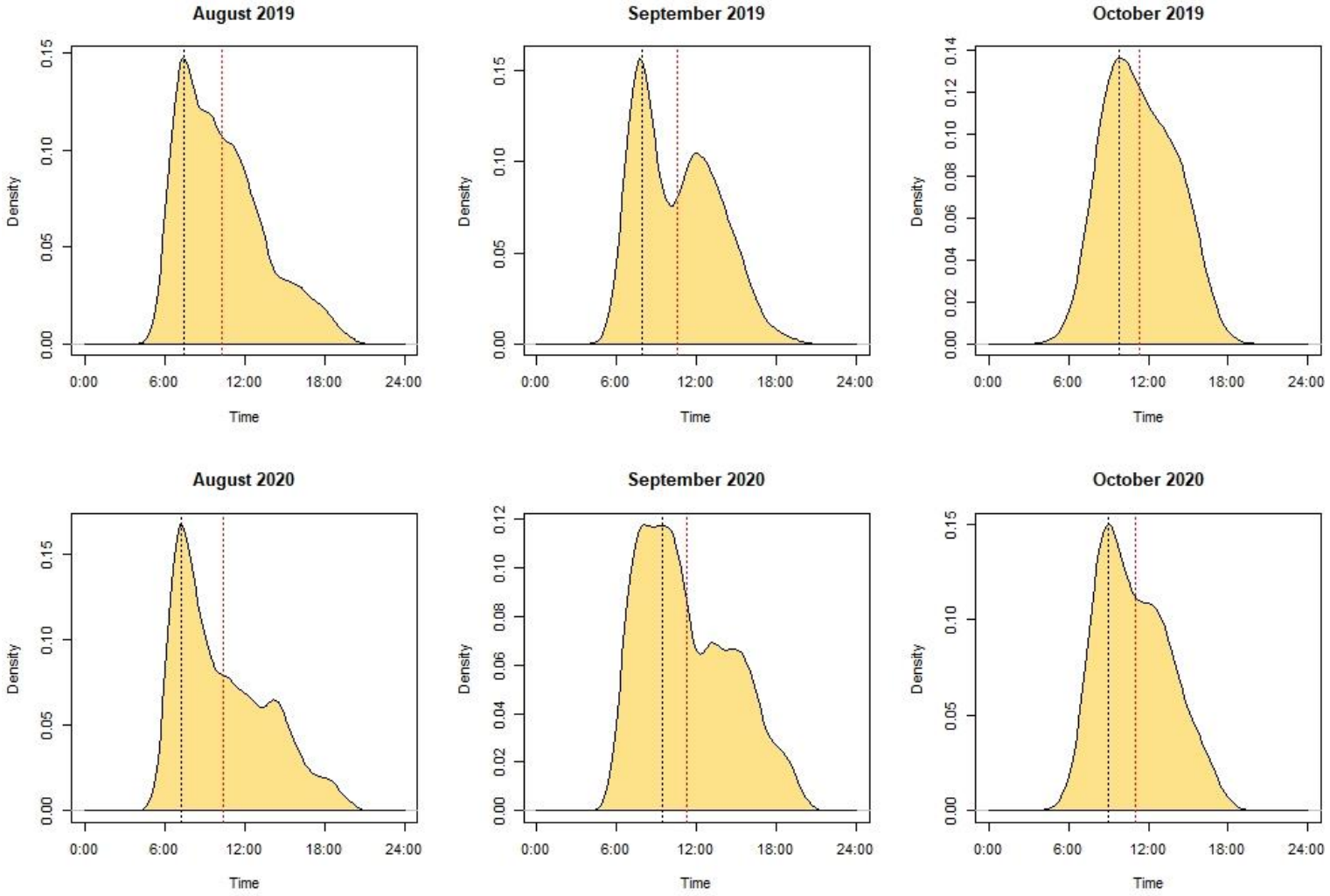

Fig. 2-3. Proportion of diel trolling activity during peak-season at Otter Point in 2019 and 2020. Dotted red lines indicate the mean time and dotted black lines indicates times of highest observed fishing density. The diel window of camera data collection was from 5:00 to 21:00.

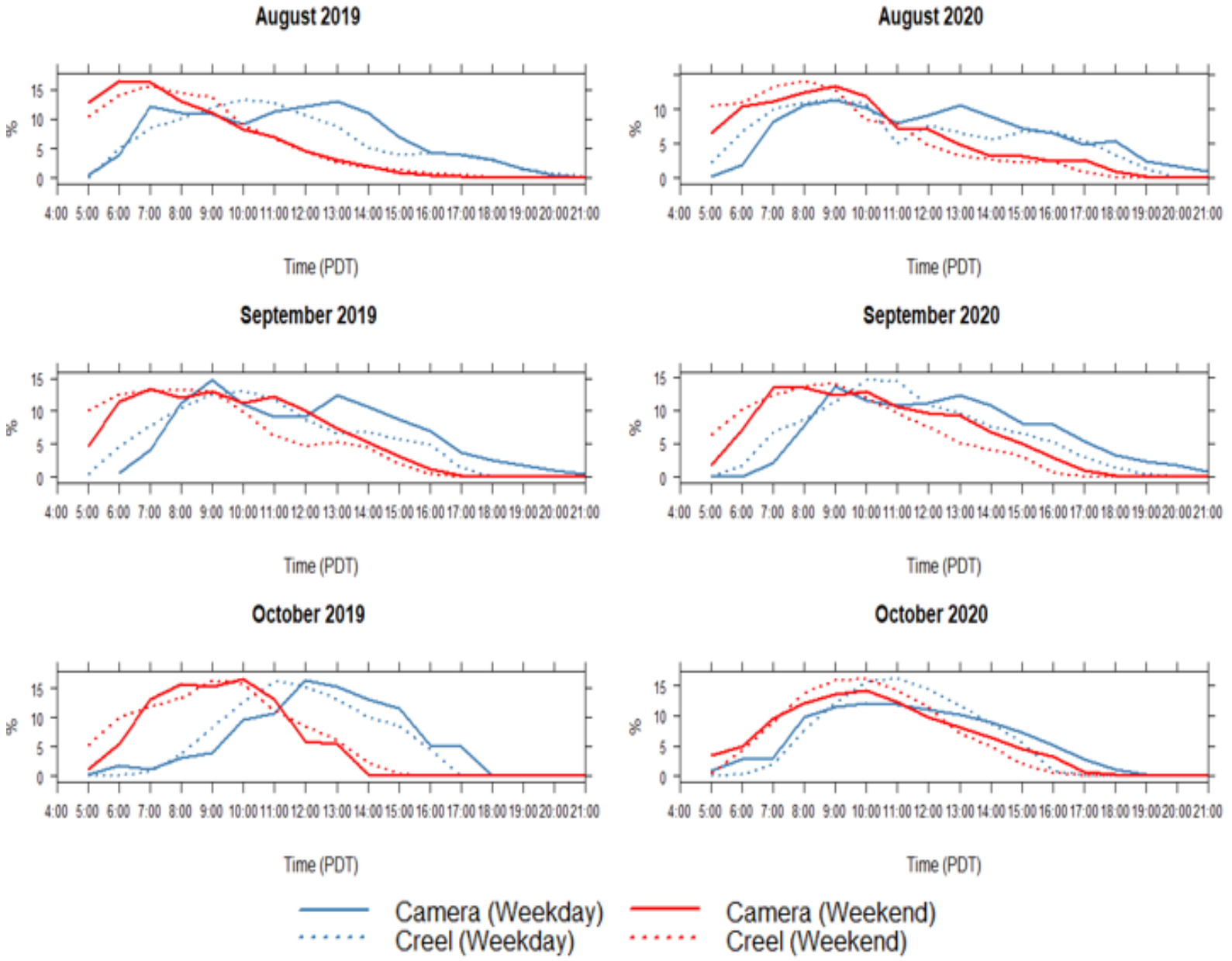

Fig. 2-4. Hourly fishing activity comparison at Otter Point between cameras and creel interview data for peak-season. Y-axis indicated percent of day's fishing. Data are stratified by weekday and weekend (blue/red). Data were retrieved from 5:00 to 21:00 during the day for both sources.

2.4 Discussion

We developed and tested a way to efficiently process and synthesize large quantities of camera data, allowing for increased temporal resolution than previously available, and extended monitoring capabilities into additional months to describe off-season effort (and potential fish

mortality) that is presently missed with creel surveys. As with other studies (Keller et al., 2016; Stahr & Knudson., 2018), we were able to extract effort and retention using interview derived CPUE and species-specific data, and camera counts as a quantification method (Table 2-2). However, our approach was among a limited number of studies that used a census of all footage for analysis (along with Taylor et al., 2021), while being distinct as it appears to be the first to apply a deep learning-based system that automatically distinguished between images that possessed vessels from those that did not, eliminating the need for a subsampling framework and extensive expansion.

Assuming anglers departing Sooke remained within PFMA 20 (East), the camera system at Whiffin Spit was also useful in determining that the contribution of SFV traffic to the PFMA was approximately 42.51%, although this was noticeably different between months (Table 2-2). A much higher contribution of PFMA 20 (East)'s SFVs and fishing stems from Sooke harbour in slower months (i.e., October; over 65% of the effort and almost 70% of retention of Chinook salmon), while fishing seems to be more dispersed across the other three marinas in August and September. This contribution from Sooke harbour into PFMA 20 (East) is also visualized temporally in Fig. 2-2 and shows substantial variation by month. However, the source of this variation across months and marinas is challenging to determine. On one hand, such variation could be explained by anglers being more spatially dispersed during busier (and warmer) months with longer day length, and more concentrated to the larger and more central marina (i.e., Sooke) during slower months. On the other hand, given that our camera captured the large majority of all activity from Sooke across all three peak-season months, creel estimates could have either overpredicted or underpredicted certain months' area-wide effort. In addition, we assumed that the aerial and camera estimates of total trips is unbiased or biased in the same manner, which

could lead to additional errors if untrue. Nevertheless, understanding harbour-specific effort, retention, and proportion of the fishery are all useful metrics for managers which could lead to an improved allocation of resources and optimization of survey times and locations to cover marinas with higher effort.

At Otter Point, we set up an image capture rate structured around a burst of three captures specifically designed to capture trolling (salmon fishing) events at a popular fishing location. This system allowed us the ability to detect and record a substantial number of fishing events in detail both during peak-season and in the off-season, where the fishery is at present not surveyed by DFO. Understanding annual differences in effort is also of importance to managers for adjusting stock assessments and updating regulations to protect populations. Of note, between 2019 and 2020 for peak-season fishing, our expanded detections of small vessel activity decreased substantially from 8418.21 vessels to 6610 (Table 2-3). This may be considered predictable given the COVID-19 pandemic occurring between these strata and assuming a hypothesis of reduced fishing during the pandemic yet estimated fishing at this location actually increased slightly in 2020 (Table 2-3). However, it is unknown whether angler behaviour resulted in changes to spatial fishing patterns or fishing closer to home during the pandemic, or whether other factors existed. Nevertheless, these results could be of interest not only to regional managers, but also to those that have already begun to explore the effects of the pandemic on fisheries around the world (see Bennett et al., 2020; Stokes et al., 2021).

Our findings of off-season effort are the first that we are aware of that have been quantified in the area using onsite methods and allow for inference into management decisions. In two months, we detected an estimated 621 boat days' worth of effort from the Sooke harbour and 486 fishing events in 8 months of monitoring fishing at Otter Point. Finding comparatively

low off-season effort is unsurprising as seasonal variation is typically one of the strongest influencers of recreational fishing (van Poorten et al., 2015; Hartill & Edwards, 2015). It is worth noting that during the off-season months we monitored, the retention of Chinook and Coho salmon was within legal limits, and yet there were no creel data to support our camera findings. Consequently, our estimates for species-specific retention are based on using the mean CPUE from August to October, leaving potential uncertainty in mortality estimates. Although our approach could not address this without interview data, we nonetheless established that cameras could provide a quantification method should managers begin conducting off-season creel interviews. If this were to occur, a more in-depth understanding of recreational effort and retention in the off-season would be possible.

Temporal distribution of recreational fisheries is an important element on which creel surveys rely upon for calculating effort and retention (Post & Parkinson, 2012). For example, DFO effort calculations from aerial counts are dependent on understanding proportion of the days' fishing based on the time of a flight. Although creel interviews involve gathering daily fishing activity data, our findings suggest that the use of cameras can enhance robustness and objectivity. For instance, cameras are effective for describing activity in-situ, rather than relying on angler testimony. Interview data have been identified as prone to prestige bias (Essig & Holliday, 1991), which stems from anglers underreporting or overreporting, length-of-stay bias (Nowell et al., 1988), involving biases to occur from certain anglers exhibiting extremely long or short trips, and avidity bias (Thomson, 1991), which occurs when the same anglers (avid participants) are surveyed repeatedly.

Our findings of large clusters of activity in the mornings at both sites is unsurprising, as this follows well-known angling behaviour in the area, DFO interview data, and other studies on

recreational fishing behaviour (Smallwood et al., 2011; Powers & Anson, 2016). Overall, we found that temporal estimates between DFO and camera data were quite similar, suggesting that we were able to validate that at present, creel surveys provide a relatively accurate view of when anglers fish. However, during certain months, such as August and September, there were often "second waves" identified where fishing was observed with cameras at higher levels in the early afternoons compared to interview data, something that was not seen by looking at harbour traffic flux alone (Fig. 2-4), even though temporal distributions between Otter Point and Whiffin Spit, showed a relatively high degree of overlap (0.8, Δ_4). This finding is important because it gives a new perspective on angling behaviour that was not evident within existing DFO data, suggesting that more anglers are active in the afternoons than previously believed. Of note, in PFMA 20 (East) between August to October in both 2019 and 2020, there was an average of only 2.16 creel interviews per month conducted in the Sooke harbour in weekday afternoons and 3.83 aerial surveys conducted per month during weekdays, with none occurring after 1pm in 6 months (Fisheries and Oceans Canada, 2020).

A stronger understanding of diel activity can additionally be useful to validate the timing and efficacy of aerial surveys. For example, a study on freshwater recreational fisheries in BC found that aerial surveys were poorly predicting angling effort, and that the temporal resolution of cameras could aid in both optimizing flight times and modelling effort (Askey et al., 2018). Based on the findings of this study, the peak flow of SFV activity from Sooke harbour and trolling events observed from the Otter Point camera system both typically occur earlier in the morning (Fig. 2-4) than flights typically fly within PFMA 20 (East) (i.e., generally between 9am and 11am; according to data in Fisheries and Oceans Canada, (2020)). Given that Otter Point was found to relatively well-represent traffic flux from Sooke harbour, we reason that it provides

a useful location for validating and optimizing flight times as well as provide increased detail related to the temporal distribution of fishing to inform creel estimation.

One consideration that was not analyzed in this study was that camera detection and effort derivation could depend on the effects of covariates such as visibility. For example, significant differences between the number of vessel detections given factors such as glare, fog, and sea state could result in bias in detecting vessels. While we did not factor the effects of visibility into our calculations, we provide an additional analysis that explored this potential relationship (see Appendix B). We also note that at Whiffin Spit during our validation survey, our camera detected the same number of vessels as a human observer in 3h of heavy fog. This finding provides another potential benefit of shore-based monitoring over aerial flights. For example, detecting fishing from airplanes has been identified as limited by fog, low clouds, and heavy rain (Pollock & Kendall, 1987), and in practice, flights are often cancelled in these conditions (Hartill & Edwards, 2015). As such, cameras could provide an alternative means to monitoring nearshore fishing activity when flights are limited by these visibility constraints.

Another factor related to detection reliability that we did not explore was image quality. Although we employed relatively high-quality cameras at Otter Point (24MP), occasionally fishing gear was obscured or not visible, resulting in the annotation of a “motorboat”, which we did not factor into our effort calculations. However, these limitations mentioned are also likely to apply to aerial data, perhaps even to a greater extent, where analysts make assumptions when defining a recreational fishing vessel and a fishing event (Hartill & Edwards, 2015). Therefore, all of our effort estimates we presented are expected to be conservative. In addition, improvements to artificial intelligence and DL-based software to automatically recognize fishing gear and categorize vessels by type would be an asset for future studies.

2.4.1 Management recommendations and future considerations

Our camera survey design and image processing methodology demonstrated several distinct applications that highlight the benefits of camera monitoring. The efficient derivation of effort from cameras by filtering out unwanted images using the software and framework we employed is the first we are aware of in recreational fishery camera monitoring and could provide immense benefits for other managers employing similar systems. Throughout this study, it took approximately 0.2s for the detection system to process an image and identify it with positive and negative detections. By contrast, manual sorting by a human operator would be much more time-consuming and onerous, not to mention that the detector can perform its task autonomously. This approach allows for much larger datasets to become viable for analysis, leaves technicians open to performing other tasks, and removes potential technician bias. Future work could automate the number of vessels in images, potentially reducing one step in the effort analysis process.

Although this work focuses mostly on one fishing season, the real benefits of cameras are seen over the long-term, as uninterrupted data can provide high quality information between seasons and years (Askey et al., 2018; Hartill et al., 2019). Scaling this approach up temporally and spatially to other marinas could allow for heightened potential and reduced costs. For instance, using our efficient data management approach, a large portion of the costs for such a monitoring program are upfront equipment costs and the continuation of camera monitoring for five or ten years requires mostly retrieval, maintenance, and data storage costs, but it would also be worth exploring the efficacy of the DL-based software in light of potential shifts in vessel usage type. A scaled-up approach could involve setting up a camera system at each of the four marinas surveyed in PFMA 20 (East) would allow for the pairwise comparison between aerial

and camera-derived effort. If there was high correlation in estimates between the two methods, reducing the intensity of aerial surveys and supplementing monitoring with camera surveys could reduce costs and improve the overall monitoring framework. If we found deviation between the two methods, and assuming continuous monitoring at each marina, we could calculate the proportion of the fishery missed by aerial surveys, allowing managers to calculate error in aerial metrics using camera validation, as was performed in Askey et al., (2018). Further, additional cameras at known fishing locations could provide a greater level of detail in relation to time anglers are engaged in fishing to inform estimation. Lastly, future studies could also explore the cost difference between camera and aerial surveys. Because flying is expensive, reductions in costs from fewer aerial flights could be allocated to expand creel interviews in peak months, which would markedly improve crucial information retrieval such as CPUE and species retention data.

Performing camera monitoring beyond peak-season months alongside concurrent creel interviews would provide additional data on off-season effort and could also be used to weight creel surveys appropriately. For instance, when assigning creel clerks during the off-season, probabilities could be assigned based on camera data to aim to capture appropriate times for interviews. This study established that off-season effort exists in this area, and although its intensity was low relative to peak-season effort, we argue that these data are meaningful and should be recognized in stock assessments. Given that these are estimates from only one marina and fishing location out of many in BC, we reason that cumulative coastwide off-season effort could be substantial, and that current monitoring is likely under-predicting the number of salmon retained from recreational fisheries. It is worth noting that DFO currently conducts the iREC voluntary internet off-site reporting system which can capture some off-season effort, but these

sorts of surveys commonly suffer from truth, nonresponse, and recall bias (Fisher, 1996; Lyle et al., 2002), especially in times of year with less fishing (Hartill & Edwards, 2015). In addition to extending the temporal range throughout the year, our camera system and DL-based detector proved successful in detecting fishing vessels under varying conditions and visibility conditions including in fog and low clouds, and both diurnal and crepuscular fishing activity. However, we did not attempt to detect the presence of nocturnal fishing activity with our approach. Conducting a study to detect this potential activity by using technology such as infrared cameras (see Taylor et al., 2018) would help determine whether nocturnal sources of effort in this area are worth considering. Future studies could also create models to predict variation in fishing using the various parameters we identified when assessing visibility and test their model predictions. These models could then be validated off camera observations, which could lead to further information such as how distance fished to shore is affected by sea state or visibility.

Monitoring spatially and temporally dispersed recreational fisheries is a challenge in many parts of the world. As such, other studies that have implemented shore-based cameras typically seek to position cameras at sources of vessel activity, such as marinas and boat ramps (Smallwood et al., 2012; van Poorten et al., 2015; Kaiser, 2016; Steffe et al., 2017; Askey et al., 2018). However, other studies typically employ a subsampling approach that estimates effort from cameras at a lower framerate. This study is the first that we are aware of that applied a high capture rate, intensive monitoring approach, and efficient processing method for detecting activity from both a marina and a popular fishing spot. Our study highlights several benefits of our approach including extracting effort and retention from cameras alongside creel data and expanding the temporal resolution of monitoring systems. Given our findings, we believe there are substantial opportunities for scaling up our approach to better understand the impact of

recreational fisheries on stocks, and in particular, salmon stocks in British Columbia, Canada. More broadly, this approach can be applied in a number of contexts to improve monitoring and estimates from stock assessments.

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COMPETING INTERESTS STATEMENT

The authors declare there are no competing interests.

CONTRIBUTORS' STATEMENT

BDM conceptualized and designed the study. BDM, PDO, MDF, and NSS contributed to data collection. TPM created the deep-learning vessel detection software and led the study, but BDM, PDO, and NSS are co-authors. BDM and MDF processed all imagery data. BDM performed all analyses and created all outputs. BDM was the principal writer but PDO, NCB, TPM, and CEB also contributed to writing. All authors contributed to editing.

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DATA AVAILABILITY STATEMENT

Open source codes/scripts: https://github.com/iainctduncan/photobot

Camera monitoring system website: https://www.poscanada.org

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Chapter 3: Assessing compliance to seasonal area-based recreational fishery closures using shore-based cameras and automatic identification systems

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ABSTRACT

Regulations to limit harvest by recreational fisheries in key conservation areas are common. Compliance to spatial and seasonal fishing closures is challenging to quantify as information related to spatio-temporal fishing dynamics can be lacking. An autonomous shore-based camera survey was set up to monitor inside and outside a spatial fishing closure for Pacific salmon (*Oncorhynchus spp.*), a species of importance for the coastal ecology of British Columbia, Canada. A capture-rate of photos was implemented that allowed for detection and annotation of the unique movement patterns of salmon fishing (i.e., trolling vessels). Cameras on their own collect little spatial information, and thus, we used automatic identification systems (AIS) data to delineate both the camera field-of-view (FOV) and the fishing closure's spatial boundary. AIS gives position and time of vessels, which was used to link observations in our camera system based on the same timestamps to geo-reference the FOV within imagery, allowing for annotation of compliant and noncompliant fishing events. During the 3-month closure period, 90.6% of fishing events that were detected within the FOV occurred inside the noncompliant area (n = 369/407). Understanding how time influences compliance is also important for policy-makers managing resources. We found that mornings and weekends had higher rates of noncompliance and that these time strata were related to compliance. We also contextualized noncompliance by comparing it to fishing activity at two other locations within the same fishing area from a previous study. Our findings demonstrate a non-intrusive, and passive method for monitoring recreational fisheries compliance that can support the selection and allocation of educational and monitoring resources to protect ecologically key fish species.

Keywords: Angling, compliance, fisheries management, fishing closures, marine protected areas, monitoring, recreational fishing

3.1 Introduction

The escalation of anthropogenic activities and extraction of resources poses serious threats to habitats and species. This reality entails the implementation of management policies and measures that can support efforts that minimize impacts. In marine and aquatic contexts, each measure often differs by region, activity, and user group; yet the performance of such measures necessarily hinges on compliance (Keane et al., 2008; Arias, 2015; Bergseth et al., 2015; Ban et al., 2019; Fraser et al., 2020). As such, identifying the components and contexts of noncompliance is key for fostering successful management actions (Bohman, 2018).

For marine fisheries, commonly implemented forms of management to protect sensitive species include marine spatial planning, protected areas and closures, harvest limit regulations by species and/or size, and educational programmes (Gilman, 2002; Lewin et al., 2006; Van Poorten et al., 2013; Edgar et al., 2014, Dominguez-Tejo et al., 2016; Janßen et al., 2018). Typically, these measures are generated at the national and regional levels based on data collection systems and monitoring, but may also require internationally coordinated conservation efforts, depending on the spatio-temporal distribution reflected by migratory species (Lascelles et al., 2014). However, there is still a significant lack of data on fishing activities worldwide, as 29% of countries did not report their figures to the United Nations between 2016 and 2018 (FAO, 2018). Moreover, reporting jurisdictions can sometimes take a broad-scale approach and can fail to account for in-depth or site-specific fishing activity, leading to data gaps (Pilling et al., 2009).

Spatial fishing closures are well-known tools for assisting fisheries management and protecting species prone to overexploitation (Wallace, 1999; Bergseth et al., 2015). However, despite the suggested ecological benefits identified with these areas, a lack of fisheries

compliance can compromise their effectiveness. For example, for marine protected areas that have spatial fishery closures, compliance to closures has been suggested as one of the most important aspects of what constitutes that area as being high-value (Edgar et al., 2014). A study exploring 63 areas from around the world found that higher levels of noncompliance described a relationship with lower biomass response ratios (inside compared to outside the closure area) (Bergseth et al., 2015). Other studies have also routinely found low compliance in both commercial and recreational fisheries (Sullivan, 2002; Campbell et al., 2012; Smallwood & Beckley, 2012; Lancaster et al., 2015), leading to a greater call to both quantify and improve the understanding of various compliance-related dynamics (Nøstbakken, 2008; Mackay et al., 2018; Ban et al., 2019). Depending on the vulnerability of the habitat and species targeted, even small amounts of noncompliant fishing may seriously compromise the health of marine life, habitats, and ecosystems within an area with fishing restrictions (Little et al., 2005; Sadovy & Domeier, 2005; Graham et al., 2010). Therefore, it becomes even more important to investigate compliance levels within these areas.

For nearshore vessel-based fisheries that are often comprised of a large recreational fleet, ascertaining compliance can be challenging because these vessels carry neither monitoring equipment nor require onboard fishery observers, as is the case for many commercial fishing vessels (Brownscombe et al., 2019; Cooke et al., 2019). This is noteworthy as recreational fishing can be responsible for a higher amount of retention for certain (and especially high-valued) fish species (Cooke & Cowx, 2004). For example, in areas of British Columbia, Canada, recreational fishers extract more Chinook salmon (*Oncorhynchus tshawytscha)*, Coho salmon (*Oncorhynchus kisutch)* (Gislason et al., 2017) and rockfish (*Sebastes spp)* (Haggarty et al., 2016) than commercial fishers, while in France, nine out of every ten pollock *(Pollachius*

pollachius) were found to be harvested from recreational fishing (Herfaut et al., 2013). Certain methods used for monitoring aspects of recreational fishing, such as onsite interviews and telephone and internet surveys, may be less reliable for assessing compliance of recreational fishing within areas of restricted fishing than direct observation (i.e., cameras, aerial surveys), even when using interview techniques to preserve anonymity (Iacarella et al., 2021). For example, biases can stem from questioning such as truth, nonresponse, avidity, telescoping, or recall (Fisher, 1996; Lyle et al., 2002; Jones & Pollock, 2012; Arlinghaus et al., 2017) and responses have the potential to differ if the interviewer is an enforcement officer, rather than a researcher. In some cases, anglers may also be unaware whether the area they fished was an area where fishing is not permitted (Smallwood & Beckley, 2012; Lancaster et al., 2015; Bova, 2019). Further, other active monitoring methods such as aerial surveys and shore-based human observers may require a significant number of resources and person-time to achieve accurate estimation for noncompliant behaviour (Hartill et al., 2019; Hyder et al., 2020).

Given the limited scope of existing tools used for assessing compliance, managers and researchers are increasingly exploring the use of passive monitoring equipment. For example, shore-based cameras have shown promise for compliance in recreational fishing studies (Lancaster et al., 2017; Ban et al., 2019). This method has been identified as cost effective and non-intrusive in collecting robust temporal data that can also aid in validating other forms of surveying (Askey et al., 2018; Hartill et al., 2019). Remotely sensed automatic identification systems (AIS) capturing vessel position, speed, and heading are widely used in large vessel monitoring, as they are required to be broadcast onboard ships exceeding 300 gross tons (International Maritime Organization, 2014). However, small recreational vessels are less likely to utilize this system (Pegler et al., 2007; Robards et al., 2016; Serra-Sogas et al., 2018;

Hermannsen et al., 2019). Monitoring schemes that only employ AIS are likely to miss a substantial portion of small vessel activities, but other studies have combined AIS and other methods to generate a more complete view of vessel traffic (Palmieri et al., 2013; Hermannsen et al., 2019). Each of these monitoring tools (i.e., cameras and AIS) pose distinct advantages for the monitoring of vessels. Cameras allow for visual recognition of the type of vessel and the activity it is engaged in based on its movement pattern across a series of images and can detect all vessels that pass through the field-of view (FOV). Conversely, AIS grants an analyst the ability to acquire vessel positions as well as extend the spatial range of monitoring.

Given the distinct properties each method exhibits, the objective of this study is to evaluate how camera and AIS data can be used together to gauge recreational fishery compliance in a seasonal area-based fishery closure. The focus fishery closure area of this study, with an Eastern border at Sheringham Point, British Columbia, Canada, currently lacks in-situ data on compliance (Fig. 3-1). Here we monitor the nearshore region with a shore-based camera system, which captures within its FOV the Eastern border of the focal fishery closure, as well as a portion of the water outside of the noncompliant area to the East. We aim to quantify recreational fishing noncompliance, which temporal covariates predict noncompliance (time of day, day of week, month), and we compare our findings from this study area to broader fishing effort across the region (Chapter 2). While acknowledging the limitations of focusing on one area, this study can improve managers' capacities for understanding compliance, which can lead to policy adjustments and educational programmes. In addition, we introduce methodology that can be used to enhance protection and predict fishing compliance by using a local fishery closure as a case study for applying this methodology. This case provides an ideal instance of an area-based

fishing closure and can thus help address common challenges in recreational fishing monitoring elsewhere.

3.2 Methods

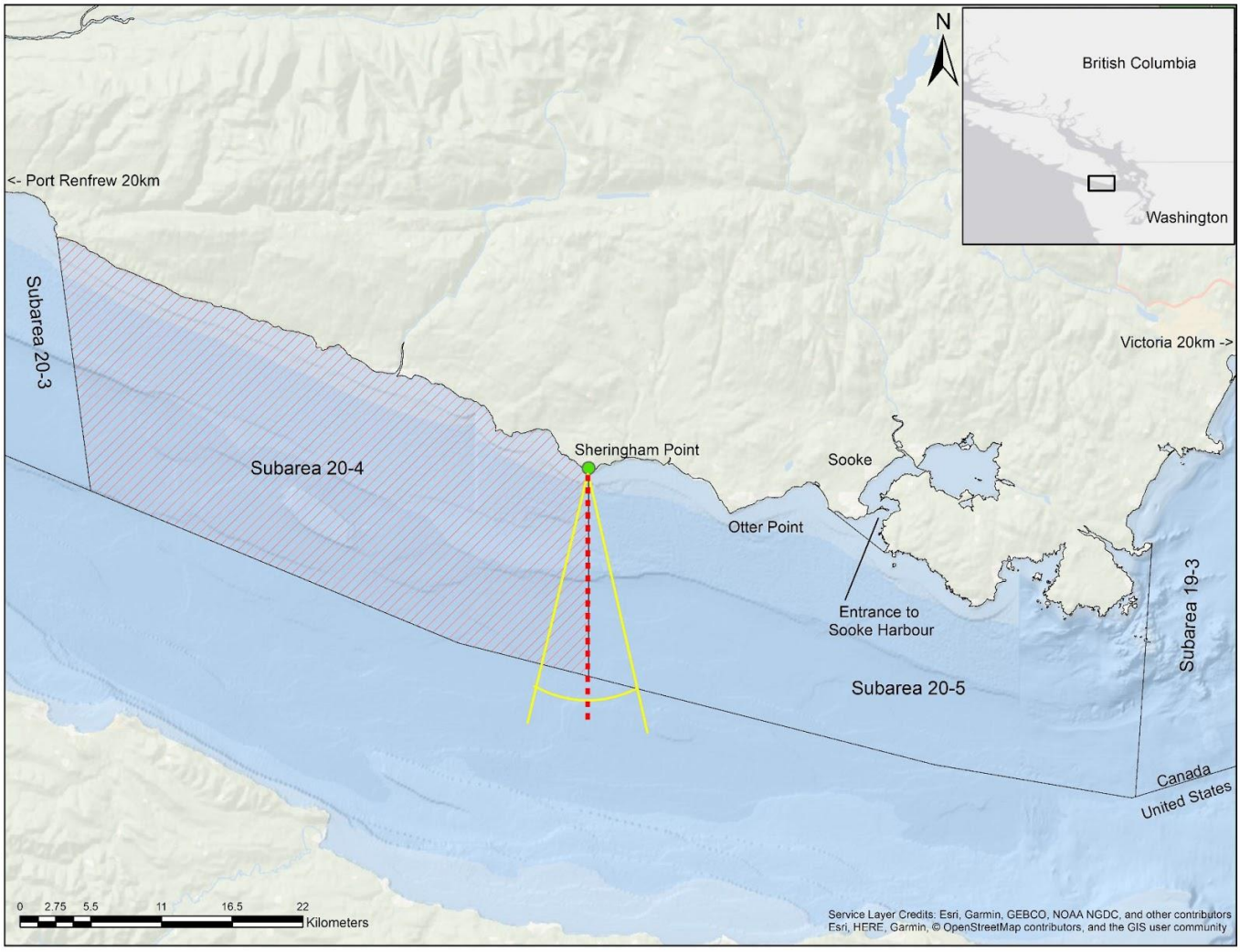

Fig. 3-1. Study area of Sheringham Point, British Columbia. Pacific Fishery Management Area 20-4 was a seasonal fishery closure from August 1st to October 31st, 2020. Field of view (FOV) is not exact and is only meant as a representation in this figure. Specific positional data that we calculated to delineate the approximate FOV, and the closure boundary is described in detail in the methods section.

3.2.1 Study area

Recreational fishing in British Columbia (BC), Canada is a popular pastime and accounts for a substantial portion of total fishery mortality, especially for Pacific salmon (Gislason et al., 2017). In 2020, seasonal area-based fishing closures, banning commercial and recreational fishing, were implemented at various locations across BC to reduce prey competition to the endangered Southern Resident killer whales (SRKW) (*Orcinus orca)* (Fisheries and Oceans Canada, 2020). Identified as prey specialists, SRKW select for salmon, especially Chinook , the largest and richest in lipids of the salmonid species (Ford et al., 1998; Ford & Ellis, 2006). SKRW are highly dependent predators on Chinook salmon. Further, metabolic and prey sampling studies have also revealed strong seasonal selection, with Chinook representing up to 90% of SRKW diet during July and August (Ford et al., 2009).

Sheringham Point is located near the town of Shirley, BC at 48°22'36.4"N 123°55'15.8"W, between the towns of Sooke and Port Renfrew (Fig. 3-1). One of the aforementioned seasonal fishery closures was implemented on an East-West orientation from Sheringham Point, and seaward to the Canada-US border from August 1 to October 31st, 2020 (Appendix C, Fig. C-1). Fisheries and Oceans Canada (DFO) first implemented these fishery closures to protect SRKW in 2019. Spatial restrictions commencing at Sheringham Point began in 2020 (and are now mirrored in 2021); thus, this study allowed for monitoring fishing activity in the first year of these management measures at this particular location. The months chosen for this closure coincides with the bulk 3-5 year old Chinook salmon returning to the Fraser River to spawn (Fisheries and Oceans Canada, 1999) and subsequent high-season for recreational salmon fishing who target these large fish. Further, the nearshore region at the lighthouse is known locally as a highly active salmon fishing area by the Sheringham Lighthouse Society (M. Galizio,

personal communication, February 24, 2020), yet no studies have methodically quantified fishing activity at this location, nor the compliance to the seasonal restrictions.

3.2.2 Data collection

To monitor fishing activity during this timeframe, we installed a digital single lens reflex (DSRL) camera and a point-tilt-zoom (PTZ) camera on the upper balcony of the lighthouse located at Sheringham Point with permission from the Sheringham Lighthouse Preservation Society, a not-for-profit organization who manages the lighthouse. The data collection system, storage, and remote controlling capabilities mirrors that of Otter Point in Chapter 2. Cameras capture 3 images per minute (a burst of three images every 5s with a 45s delay until the next burst), resulting in approximately 2600 photos per day per camera. This rate of capture was designed to capture trolling (i.e., salmon fishing events – see Chapter 2 for how we defined confirmed and probable detections from imagery) and was considered a trade-off between being able to capture enough detail and limiting unwanted imagery. As the lighthouse represents the boundary of the fishery closure, we set up the camera to point due south to capture fishing activity inside and outside the zone, while limiting distortion from the camera angle when delineating the boundary of the fishery closure. We collected imagery from July 7th, 2020, to December 31st, 2020, which included continuous monitoring during the closure period (August 1st to October 31st). Meanwhile, AIS data were acquired from the Canadian Coast Guard (CCG). Sampling design of AIS in this research is consistent with other applications of vessel monitoring with AIS that tracks position, speed, and heading of vessels (Zang et al., 2017; Fujita et al., 2018) and were subsequently plotted in the digital mapping software ArcMap 10.6.1 using NAD 1983 UTM 10 coordinate system and Transverse Mercator projection (ESRI, 2011).

To classify imagery into detections for analysis, the hard drive was retrieved every 3-4 months and we uploaded data to a cloud-based server. Images were then processed through a deep-learning based vessel detection software (Marques et al., 2020) to automatically identify vessels and filter out images without vessels. Next, an image categorizing tool developed by Gregory O'Hagan at the University of Victoria allows for semi-automated categorizing capabilities for images, which is similar to Greenberg & Godin, (2015), but was developed independently. We used this tool to categorize vessels by type, activities (i.e., trolling, transiting). The methodology for processing and annotating vessels in images mirrors that in Chapter 2.

3.2.3 Delineating the fishery closure within camera imagery

A challenge for shore-based camera imagery for spatial compliance monitoring can be the lack of positional information within each image (Hartill et al., 2019). Although best efforts were employed to position the camera FOV to point due south from Sheringham Point (following the closure boundary), it was nevertheless important to geo-reference both the boundaries of the camera FOV (i.e., x- and y-axes within images) as well as where the spatial boundaries of the fishery closure appeared in imagery. To achieve this, we used CCG AIS data for the study period and matched broadcasted points to time stamps that matched within the clipped FOV of the camera. We then assigned AIS positions to pixel coordinates (x,y) of the imagery. We verified the Maritime Mobile Service Identify (MMSI) of the vessel in question using an open source database for AIS vessels (https://www.marinetraffic.com/) (Fig. 3-2). When noting an MMSI, a picture of the vessel appears on the database, which we verified in the captured imagery. We linked AIS vessels on each of the top corners of the image, one approximately halfway down the y-axis on each side, and two where the boundary line was for a

total of six reference points. We then used a minimum x-axis value in imagery to indicate a fishing violation to the spatial closure.

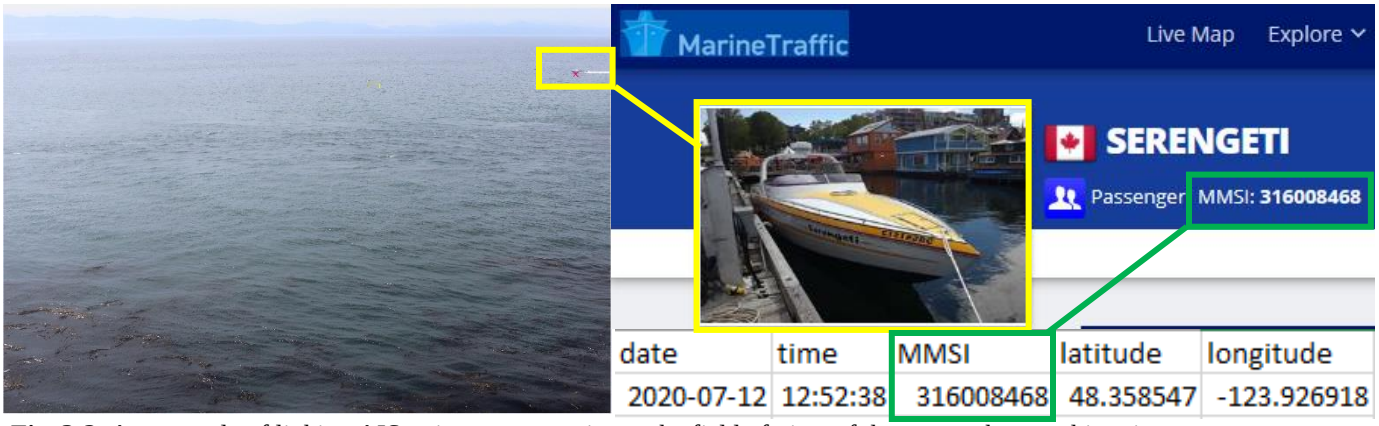

Fig. 3-2. An example of linking AIS to imagery to estimate the field of view of the camera by matching timestamps and assigning a latitude and longitude to imagery.

Based on the newly geo-referenced FOV and associated pixel coordinate x- and y-axis values, we defined a noncompliant event as a vessel engaged in fishing with an x-axis greater than 2588 (i.e., West of the fishery closure boundary). In Chapter 2, we only annotated a fishing event based on the first observed vessel engaged in fishing; however, this was not appropriate for gauging compliance as a vessel could begin fishing in the legal area and continue fishing into the restricted area. As such, we made sure in such instances that this series of events was recorded as a single noncompliant event when annotating imagery.

3.2.4 Analysis

We assessed noncompliance to the seasonal fishery closure at Sheringham Point by extracting only observations that both violated the spatial regulations and fell within the closure period (August 1st to October 31st). Although the same vessel could be confirmed within a series of captures, we would not always be able to determine if that same vessel reappeared later in the

day or the next day, for example. As such, rather than defining observations as unique vessels, we used the term “vessel events”, treating any vessel detection as a new event if over half an hour had passed from the last sighting of that vessel (see Chapter 2). We then assessed whether month, weekday or weekend, and morning or afternoon significantly influenced compliance by performing non-parametric Mann-Whitney U / Wilcoxon rank-sum test tests for two-leveled data (i.e., weekday/weekend and morning/afternoon) and a nonparametric Kruskal-Wallis test for multileveled data (i.e., months) in R (Version 1.2.1335 – © 2009–2019 RStudio, Inc). Fishing activity is further broken down by month and plotted relative to two other monitoring stations from Chapter 2, Otter Point (as a popular fishing spot) and Sooke harbour (as a source for recreational fishing traffic). The distance from Sooke harbour to Otter Point is ~9.5km by sea and from Otter Point to Sheringham Point is ~8km by sea and are all within PFMA 20 (Chapter 2). The purpose of cross-site comparisons was to understand the scale of noncompliance relative to broader-scale fishing effort and traffic flux.

3.3 Results

For the entire study period, we detected a total of 1378 vessel events from camera imagery of which 1047 (76.0%) were comprised of small vessels (Table 3-1). Of the small vessels, the largest proportion were sport fishing vessels (479, 44.4%) followed by undefined small vessels classified as “motorboats” (341, 32.6%). 46.4% of all small vessel detections resulted in a fishing event of which 438 were confirmed fishing (trolling) and 48 were “probable fishing” for a total of 486 total fishing detections. Total fishing was 407 events between August 1st and October 31st, 2020 (the closure period). Of these, 90.6% (n = 369) of the vessels at some point fished within the restricted area, constituting a noncompliant event (Table 3-2). Total

fishing detections across 6 months (n = 486) was 13.6% of the amount at Otter Point (n = 3574) and comprised 6.2% of the traffic coming from the Sooke harbour (n = 7823) (Fig. 3-3)

Table 3-1. Types and numbers of vessels detected at Sheringham Point from July to December 2020. Com. Fishing = commercial fishing vessels

Vessel Type	July	August	September	October	November	December	**Total**
Cargo	26	27	15	20	46	25	**159**
Com. Fishing	19	22	17	15	12	13	**98**
Tourism	13	25	7	3	0	0	**48**
Kayak	2	13	12	5	2	1	**35**
Motorboat	49	120	75	62	27	8	**341**
Sailboat	14	18	9	3	2	0	**46**
Sport fishing	73	257	133	4	10	2	**479**
Tanker	28	33	12	18	32	23	**146**
Tug	8	3	2	5	4	4	**26**
Total	**232**	**518**	**282**	**135**	**135**	**76**	**1378**

Within the closure period, month was related to compliance rates (Kruskal-Wallis, p = < 0.001), with August having not only more noncompliant events, but also a higher proportion of noncompliant events. A larger proportion of fishing during the three month closure period occurred on weekends and holidays (67.6%) (Table 3-2). 86.2% (n = 119/138) of these events on weekdays and 92.7% (n = 255/275) on weekends were noncompliant. Further, mornings were more common for fishing than afternoons (n = 234/407; 57.5%). Noncompliance was slightly but not significantly higher (Mann-Whitney U, p = 0.05347) during the weekends (92.7%, n=255/275) that during the weekdays (86.2%, n=119/138). Likewise, it was also slightly but not significantly higher (Mann-Whitney U, p = 0.0635) during mornings (n = 217/234; 92.7%) than afternoons (n = 154/173; 89.0%).

Table 3-2. Fishing inside and outside the area where the fishery closure was spatially delineated within the camera field-of-view. Months where fishing was considered noncompliant is indicated in bold. December was excluded as no fishing events were observed. Weekends include public holidays.

	Outside		Inside		Total		Proportion
	Trolling	Probable	Trolling	Probable	Trolling	Probable	Inside/Total
Weekdays							
July	3	1	11	2	14	3	0.76
(morning)	1	0	9	1	10	1	0.91
(afternoon)	2	1	2	1	4	2	0.5
August*	**2**	**2**	**74**	**3**	**76**	**5**	**0.95**
(morning)	**1**	**2**	**36**	**2**	**37**	**4**	**0.93**
(afternoon)	**2**	**0**	**37**	**1**	**39**	**1**	**0.95**
September*	**0**	**4**	**34**	**1**	**34**	**5**	**0.90**
(morning)	**0**	**3**	**29**	**1**	**29**	**4**	**0.91**
(afternoon)	**0**	**1**	**5**	**0**	**5**	**1**	**0.83**
October*	**0**	**5**	**3**	**4**	**3**	**9**	**0.58**
(morning)	**0**	**2**	**1**	**1**	**1**	**3**	**0.5**
(afternoon)	**0**	**3**	**2**	**3**	**2**	**6**	**0.63**
November	0	3	2	3	2	6	0.63
(morning)	0	0	0	0	0	0	0
(afternoon)	0	3	2	3	2	6	0.63
Weekends							
July	3	3	43	3	47	6	0.87
(morning)	2	1	42	2	44	3	0.94
(afternoon)	1	2	1	1	3	3	0.33
August*	**9**	**4**	**157**	**6**	**166**	**10**	**0.93**
(morning)	**8**	**0**	**96**	**0**	**104**	**0**	**0.92**
(afternoon)	**1**	**4**	**61**	**6**	**62**	**10**	**0.93**
September*	**5**	**4**	**88**	**1**	**93**	**5**	**0.91**
(morning)	**1**	**0**	**50**	**1**	**51**	**1**	**0.98**
(afternoon)	**4**	**4**	**38**	**0**	**42**	**4**	**0.86**
October*	**0**	**0**	**0**	**1**	**0**	**1**	**1**
(morning)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
(afternoon)	**0**	**0**	**0**	**1**	**0**	**1**	**1**
November	1	0	1	1	2	1	0.66
(morning)	**0**	**0**	**0**	**0**	**0**	**0**	**0**
(afternoon)	1	0	1	1	2	1	0.66
Total	23	23	415	25	438	48	

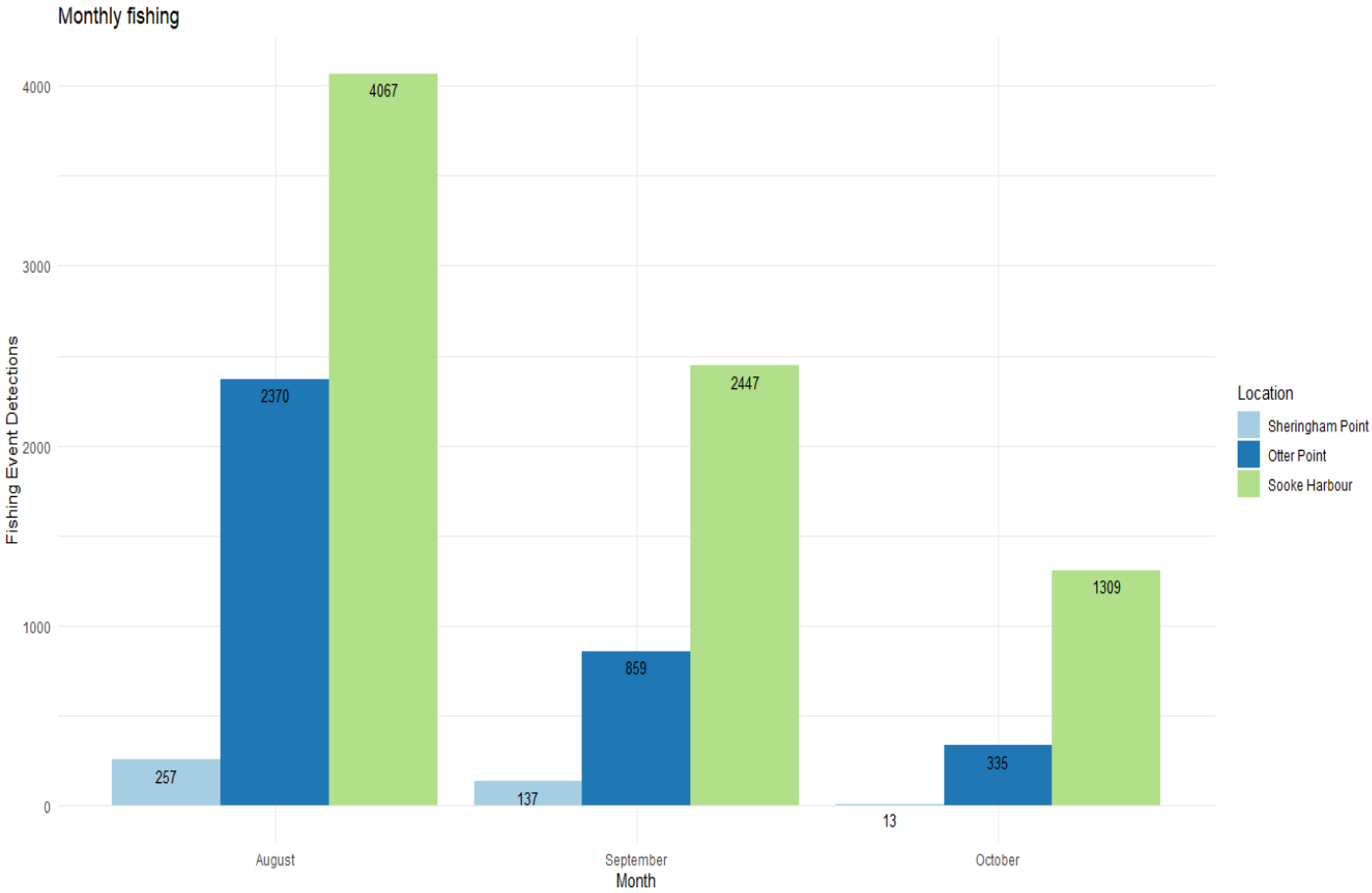

Fig. 3-3. Recreational fishing activity by month at Otter and Sheringham Points and sport fishing vessel traffic from Sooke harbour in August, September, and October 2020. Numbers represent fishing event detections. Distance from Sooke harbour to Otter Point is ~9.5km by sea and from Otter Point to Sheringham Point is ~8km by sea.

3.4 Discussion

Our results indicate that there was a discernable presence of recreational salmon fishing activity (trolling) inside the fishery closure area at Sheringham Point during the period of an area-based closure (August 1st to October 31st, 2020), even though our FOV covered only a small portion of the area. Although sport fishing vessels constituted the largest proportion of all small vessels observed (44.4%), we also recorded 341 motorboats which were annotated when we could not reliably identify fishing gear aboard a small vessel. In most cases, vessels identified as motorboats passed by the camera at distances too great to reliably identify fishing gear. Thus, the absence of such vessels in our analyses might suggest fishing pressure could be even greater than what was recorded in this study, as vessels could have fished elsewhere within the same fishery

closure area that was not captured in our camera FOV. However, we had no means to validate whether these vessels intended to engage in fishing, and if so, where this might have occurred.

In addition, higher numbers of fishing and disproportionately higher noncompliance occurred during weekends and mornings, and albeit none of which were statistically significant. Admittedly, this may be due to a lack of sufficient data as our sample sizes were relatively small when partitioning our data by various temporal strata. Nevertheless, the patterns that emerged have implications for the use of resources to focus on particular temporal strata. For example, enforcement and other monitoring methods that are limited by costs (i.e., aerial surveys) could focus efforts on mornings and weekends (Herfaut et al., 2013). This study supports others who have found fishers to favor mornings (Smallwood et al., 2011) and weekends (Powers & Anson, 2016), while providing insight into how these temporal strata might factor into trends of noncompliance.

One potential explanation for noncompliance in this case study could be that there is either unawareness or apathy towards the seasonal closure regulations. For example, another study in BC found that 60% anglers interviewed were unaware of the locations of Rockfish Conservation Areas, fishing closures designed to protect rockfish (Lancaster et al., 2015). In addition, research in the northwestern Mediterranean Sea found that although fishers have positive perceptions about the ecological benefits of areas where fishing is restricted, they are less likely to be convinced that these zones benefit themselves as anglers (Leleu et al., 2012). Further, Arias & Sutton, (2015) found that anglers' perception of higher numbers of fish within a marine protected area that restricts fishing would more likely lead to noncompliant behaviour than would factors such as the perception of being caught by authorities and perception of impacts to species and ecosystems from their fishing. However, the goals of this particular study

were to provide quantitative evidence for recreational fishery noncompliance; understanding what drove noncompliance in the area is currently unknown and would be valuable for efforts focused on reducing noncompliant fishing.

In this study, we used AIS for the purpose of delineating the FOV of a shore-based camera and the boundary line of a seasonal fishery closure. This study is the first that we are aware of that applies AIS data for georeferencing imagery in order to collect data on fishing compliance. We drew inspiration from the approach of Palmieri et al., (2013) whereby the authors georeferenced a particular FOV using three cameras at different angles to come up with a calculation that triangulated positional data. In our study, we used six unique MMSIs to identify vessels based on their time stamp and their latitude and longitude. We then located photographs with the same timestamps and confirmed that it was the same vessel and used these positions to geo-reference a FOV extent and delineate the fishery closure boundary on the captured imagery. Application of this technique was facilitated by the location of the camera at the northern end of the boundary and focusing it due south to limit distortion. However, we acknowledge that our approach is not without flaws, as at times, we were not able to perfectly match up the timestamp between cameras and AIS. As AIS is often not continuously broadcasting aboard vessels (Merchant et al., 2014), a few timestamps were 1-2 seconds off, which could lead to error in our FOV delineation. It should be noted that our purpose was not to calculate, but rather to approximate the FOV in order to estimate compliance, and future work could improve upon this technique through interpolation of vessel position bands on AIS. However, we reason that we were nevertheless able to achieve a relatively accurate perspective of noncompliance. For instance, what we observed was that the vast majority of vessels came into the FOV from the East already fishing, continued fishing across the entire camera FOV, and then fished out of the

FOV to the West. In these cases, noncompliance was unmistakable, and we argue the preciseness of the FOV was not necessarily relevant. This observation also supports the assumption that Sooke is the major access point for fishing at this location, as we rarely saw vessels coming from the West in the morning.

We also acknowledge that without contextual fishery information on a broader scale, quantifying compliance from our camera study could be misleading. In order to gauge the broader implications of our noncompliant observations, we compared total fishing at Sheringham Point to detected fishing and sport fishing traffic from Otter Point and Sooke harbour respectively from Chapter 2 (Fig. 3-3). Sheringham Point was found to comprise a relatively minor proportion of Sooke harbour traffic (6.2%) and was less popular of a fishing location than Otter Point (13.6% of fishing detections). This is unsurprising due to its further distance from Sooke (~17.5km). From these data, one assumption could be that the regulations were overall being observed by the majority of anglers. However, we acknowledge that without additional data sources to extrapolate spatial trends (i.e., interviews, aerial flights), we caution against such claims. We also acknowledge that this study is limited in its ability to make inferences about whether fishing increased or decreased when these measures were implemented as we do not have data from years prior to the fishery closure.

Future work could integrate other on-site and off-site monitoring methods such as interviews and aerial flights alongside camera monitoring to provide a more well-rounded view of noncompliance. Shore-based cameras are spatially limited, but one of their strongest assets is their ability to continuously monitor and gather long-term data efficiently and at low costs for a variety of marine applications (Dickinson et al., 2012; Bicknell et al., 2016). As such, research has suggested that the combination of multiple data sources is likely to foster a greater

understanding of compliance (Bergseth et al., 2013; Hartill et al., 2019). In addition, there was a considerable proportion of motorboats that could have been sport fishing vessels moving farther into the fishery closure. The relatively low cost of this methodology could lead to more cameras positioned throughout the closure area to potentially capture this activity, especially given that Fisheries and Oceans Canada has already announced that the 2021 measures will mirror those of 2020. In addition, given that Port Renfrew (Fig. 3-1) is another source for sport fishing vessels, capturing this flux and how many vessels fishing within the closure area stem from Port Renfrew could be a next step. Another benefit of continuing monitoring into 2021 would be assessments could be made related to changes in compliance with continued implementation using this initial study as a baseline.

Although the number of vessels observed to be engaged in noncompliant fishing was high within our camera FOV, the data may not represent the larger area when compared to Otter Point and traffic flow from Sooke harbour. However, it nevertheless suggests that there is a proportion of anglers that either do not know the regulations or choose to disregard them, which may be reason enough to increase messaging. For example, education is widely seen as a platform for reducing noncompliance for marine activities and in marine reserves (Karamanlidis et al., 2002; Arias & Sutton, 2013; Goethel et al., 2019; Lucrezi et al., 2019). In addition, solely the existence of such activity warrants concern as the implementation of seasonal fishery closures was intended to protect endangered salmon, which are highly valuable to many species on the British Columbia coast, both ecologically and socio-economically. Recognizing, identifying, and monitoring noncompliance in these areas can aid in improving information related to fish stocks and anthropogenic pressures (Pollnac et al., 2010). Further, given that

resources can be scarce in marine fishery management, passive monitoring equipment that can target specific areas of interest can boost the success of management measures more broadly.

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COMPETING INTERESTS STATEMENT

The authors declare there are no competing interests.

CONTRIBUTORS' STATEMENT

BDM conceptualized and designed the study. BDM, PDO, MDF, and NSS contributed to data collection. TPM created the deep-learning vessel detection software. BDM and MDF processed all imagery data. BDM performed all analyses and created all outputs. BDM was the principal writer but PDO, NCB, TPM, and CEB also contributed to writing. All authors contributed to editing.

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DATA AVAILABILITY STATEMENT

Open source codes/scripts: https://github.com/iainctduncan/photobot

Camera monitoring system website: https://www.poscanada.org

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Chapter 4: Conclusion

4.1 Conclusion

The aim of this research was to test applications of autonomous shore-based cameras to improve estimation of effort and retention by integrating into an existing aerial-roving creel survey and supply important information to managers about recreational salmon fishing noncompliance to a spatial fishery closure. The approach that was used combined high temporal resolution and a novel deep-learning based software for efficiently processing and analyzing large quantities of imagery data. In the context of recreational fisheries monitoring, this thesis can provide a framework for integration of cameras. Further, this work comprised the first known studies that use cameras to improve understanding of recreational salmon fishing in British Columbia and regional managers may find both the methodology and findings useful.

In Chapter 2, cameras were established to be a viable tool at small marine vessel access points for determining harbour-specific fishing activity. Combined with creel data (aerial surveys and interviews), cameras can provide a rich view of effort and species-specific retention, at diel, monthly, and yearly strata. Further, by setting up a camera system at a popular fishing location (Otter Point), it was demonstrated that the rate of capture employed in this study was effective for capturing the movement patterns of recreational salmon fishing (i.e., trolling), and that significant off-season effort existed, which was not being captured in the existing DFO monitoring framework. Effort and retention estimates are presently based on a subsampling monitoring framework and have the potential to lead to bias if flights either overestimate or underestimate mean levels of fishing activity. Cameras therefore can provide a means to fill in this uncertainty by reconciling this potential bias (Askey et al., 2018).

Chapter 3 focused on using a high-quality shore-based camera and automatic identifications systems for the purpose of gauging compliance to a seasonal fishery closure. Using similar approaches for data collection and processing as in Chapter 2, detection of noncompliant fishing was recorded in an uninterrupted fashion across the entire closure period during daylight hours. The results indicated that there was a notable presence of fishing that occurred in the noncompliant area, during the window of which it was closed to fishing. Variation in fishing also existed by month, time of day, and day of week and that when scaled to proportions, each of these factors were found to be related to noncompliant behaviour. The approach of using automatic identification systems for geo-referencing images that otherwise hold no spatial information can also be a future tool that can be used for future studies interested in spatial compliance from cameras (that otherwise hold no spatial information). Using cameras for assessing recreational fishery compliance is beginning to show promise (Lancaster et al., 2017; Ban et al., 2019). However, prior to this study, this has not occurred for salmon fishing in British Columbia. The various seasonal and spatial management measures increasingly implemented by DFO to protect SRKW prey availability provide excellent opportunities for increasing camera coverage. Aside from aerial flights that are costly and do not capture much temporal variability (Askey et al., 2018), known techniques for gauging recreational fishery compliance in the province are limited. As such, by employing more cameras, and gathering data at Sheringham Point in subsequent years that have the same restrictions would allow for an indication of whether compliance is increasing or decreasing. In addition, an approach that combines multiple data sources (such as interviews, aerial surveys, and enforcement records) is likely to only help. Either result, it could be argued, would have important implications for managerial and educational mandates and programmes.

The ability for such detailed temporal information to be acquired in these two studies would not have been possible without the application of a deep-learning based vessel detection system (Marques et al., 2020) and image annotation tool (created by Gregory O'Hagan, CORAL Group, University of Victoria) that was used for processing large quantities of imagery. Across both studies, over 1.5 million raw images were collected and processed. These tools allowed for the removal of all imagery without a detection (and was trained to automatically identify marine vessels of varying scales), and then be able to efficiently annotate detections based on the type, activity, and direction of travel of each vessel. This two-step process that was developed and tested is arguably an advancement to recreational fishing camera monitoring, which has historically struggled with the time-consuming nature of data processing (Greenberg & Godin, 2015; Hartill et al., 2019). As such, the opportunities for a variety of other camera-based studies are now potentially much wider.

4.2 Limitations and future considerations

This work was a pilot study to test several distinct applications of the integration of cameras into recreational fishing monitoring. However, challenges arose throughout the data collection process as it was the first known example of using cameras in this manner, and at times it was an iterative process. Occasional gaps in imagery data resulted from malfunctioning components of the camera systems. During the study period, this totaled 9 out of 152 days (5.9%) at Whiffin Spit, 37 out of 426 days (8.7%) at Otter Point, and 10 out of 152 days at Sheringham Point (6.6%). In addition, when comparing two different methods for quantifying fishing effort (i.e., cameras and aerial surveys), uncertainty and potential bias could have arisen with the treatment of them as analogous methods for quantification. For example, when calculating retention estimates at Whiffin Spit using creel data, the assumption was that boats

fishing within PFMA 20 (East) came from one of the access points in PFMA 20 (East). However, it was possible that a sport fishing vessel could have come from a different PFMA to fish in the Sooke area, such as Victoria harbour or Port Renfrew and was simply captured in flights in Sooke. As such, the estimates of the fishery based on the traffic captured at Whiffin Spit could have overpredicted effort. In order to test this assumption, future work would benefit from installing a camera at each of the four main access-point marinas in PFMA 20 (East). As PFMA 20 (East)'s traffic stems from 4 marinas (according to DFO data), placing a camera at each of these harbours would allow for most traffic to be quantified within the entire PFMA. Then, using creel data, it would be possible to compare fishing effort estimated using the two methods. If they were analogous, it could be reasoned that current methods are estimating effort well. This could subsequently lead to a potential reduction in aerial flights (which are by nature costly) and more resources could be allocated to interviews, which provide crucial information on species data (Pollock et al., 1994; Arlinghaus & Cooke, 2005). On the other hand, if there were significant differences between the estimation of both methods, future work could correct for some of the differences, which could improve population data and ultimately the outcomes of stock assessments. Temporal continuity is ultimately a strength of shore-based cameras and one additional suggestion would be to continue monitoring in future years in order to test assumptions on what effect the COVID-19 pandemic had on the region's fisheries.

An additional limitation is related to potential bias in estimates as a result of existing creel data. As camera-calculated estimates of effort and mortality from Whiffin Spit were based upon catch rate data from creel surveys, there would likely be error, or a level of uncertainty associated with the estimates presented in this thesis. This was not able to be calculated without access to the error metrics associated with DFO creel data. As such, an additional analysis could

be to include standard error into effort and retention estimates. Further, at the two locations where fishing activity was monitored (Otter Point and Sheringham Point), it was only possible to describe observable events, and it was not possible to gauge how much fishing these areas represented in absolute terms, but rather, in relative terms only. For fishing at Sheringham Point, noncompliance was assessed in relative terms only as the camera system was set up during the first year of the seasonal closure at the lighthouse. Without prior or posterior years of data, the annual variability in compliance was inestimable. Such limitations could be addressed through the continuation of monitoring into future seasons and years, as the real strength of cameras is suggested to be their long-term monitoring capabilities (Hartill et al., 2019).

The findings of this work suggest that integrating cameras into existing aerial-roving creel surveys could yield several tangible advantages for the overall monitoring framework. Strategically setting up cameras at access-points that DFO currently surveys would provide enhanced temporal resolution for informing total effort of a particular area. If this were to occur at the same scale as interviews (i.e., monitoring the same marinas within a delineated PFMA), cameras could be filling the effort expansion role that aerial surveys currently achieve. Comparing results between existing estimates and the addition of cameras across multiple seasons would allow for validation and error correction in estimates (Askey et al., 2018). Further, cameras at areas that are identified as popular fishing grounds would provide enhanced temporal data on the timing fishing for a given area and be used in place and/or alongside interview testimony of when fishing occurs in a given day. Logistically, this could occur not only for peak-season, but also run into the off-season, where if substantial effort was found, could inform areas where it would be worthwhile to run occasional creel interviews. Finally, any fishing areas designated as a fishery closure could benefit from camera monitoring to understand the quantity

of noncompliance, and when and how often it might occur. Enforcement, educational campaigns, and other monitoring methods (i.e., flights, interviews) could therefore strategically target specific areas and times based on this information.

By having a greater understanding of the pressures that important marine fish species have, recovery of species and trophic levels may be improved. Recreational fishing is only one of many stressors, but evidence continues to point to high-levels of mortality (Cooke & Cowx, 2004), and selection of large, old, and fertile individuals (Haggarty et al., 2016). This thesis contributes new approaches to monitoring recreational fishing that can improve upon existing methods while providing insight into the temporal dynamics of recreational fishing. Ultimately, this can support goals of improving monitoring methods that can foster a greater understanding of the associated impacts from recreational salmon fishing on populations. The efficient methods and tools that were developed and performed in this thesis can additionally benefit managers and policy makers in a variety of contexts wherever there is interest in the conservation of fish in light of increasing fishing pressure.

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Appendix

Appendix A

Table A-1. Definitions of vessel and activity types.

Type of vessel*	**Definition**
Sport fishing	A small, motorized vessel with clearly visible rods, downriggers, or nets visible on the back deck or visible on the back of the flying bridge. Charter fishing vessels were noted when possible but included as a sport fishing vessel.
Tourism	A vessel clearly recognizable as an tourism vessel such as a 12-passenger zodiac or having the written name of the vessel clearly visible in an image.
Sailboat	A vessel with sails, and under sail. It is feasible that a sailboat could be fishing, in which case it would be labelled as sport fishing, but we during this study, we did not detect such events.
Commercial Fishing	A medium to large size vessels with clearly visible commercial fishing gear onboard. These vessels may or not have AIS onboard and the name of the vessel may or may not be visible.
Motorboat	A small vessel without fishing gear visible or any small vessel with a motor but unknown whether it was sport fishing or tourism
Other	A non-motor vessel such as a kayak, canoe, or stand-up paddleboard
Activity	**Definition**
Trolling	A sport fishing vessel moving in either a straight line or zigzagging, with fishing lines visible in the water, and no wake visible.
Probable fishing**	A small vessel moving in a pattern that was likely indicative of fishing, but the vessel was either not zigzagging across a series of images, or fishing lines were not clearly visible.
Transiting	A vessel moving across the image with wake visible or in some cases, a vessel with no wake, but moving in a roughly horizontal line across the image not indicative of fishing.

**Note: we also recorded all detections of large vessels such as tankers, cargo ships, bulk carriers, tugboats, and ferries but we omitted these vessels in our analyses. However, non-motor vessels such as kayaks were included as we noted a few instances of these vessels engaged in trolling.*

***Other fishing types such as jigging were categorized as probable fishing. During the study period, we only detected one vessel clearly engaged in jigging. Overall, forms of fishing other than trolling were extremely rare, but for different areas, it might be more commonplace.*

Fig A-1. Semi-autonomous vessel annotating tool used to classify vessels within shore-based camera imagery. The options available from the three drop-down menus are located at the top left of the screen, including generating reports (which are displayed at the bottom of the page 1). The various "click-through" options for each category of vessels allowing for additional detail are noted on page 2. Tool was created by Gregory O'Hagan, University of Victoria, British Columbia, Canada.

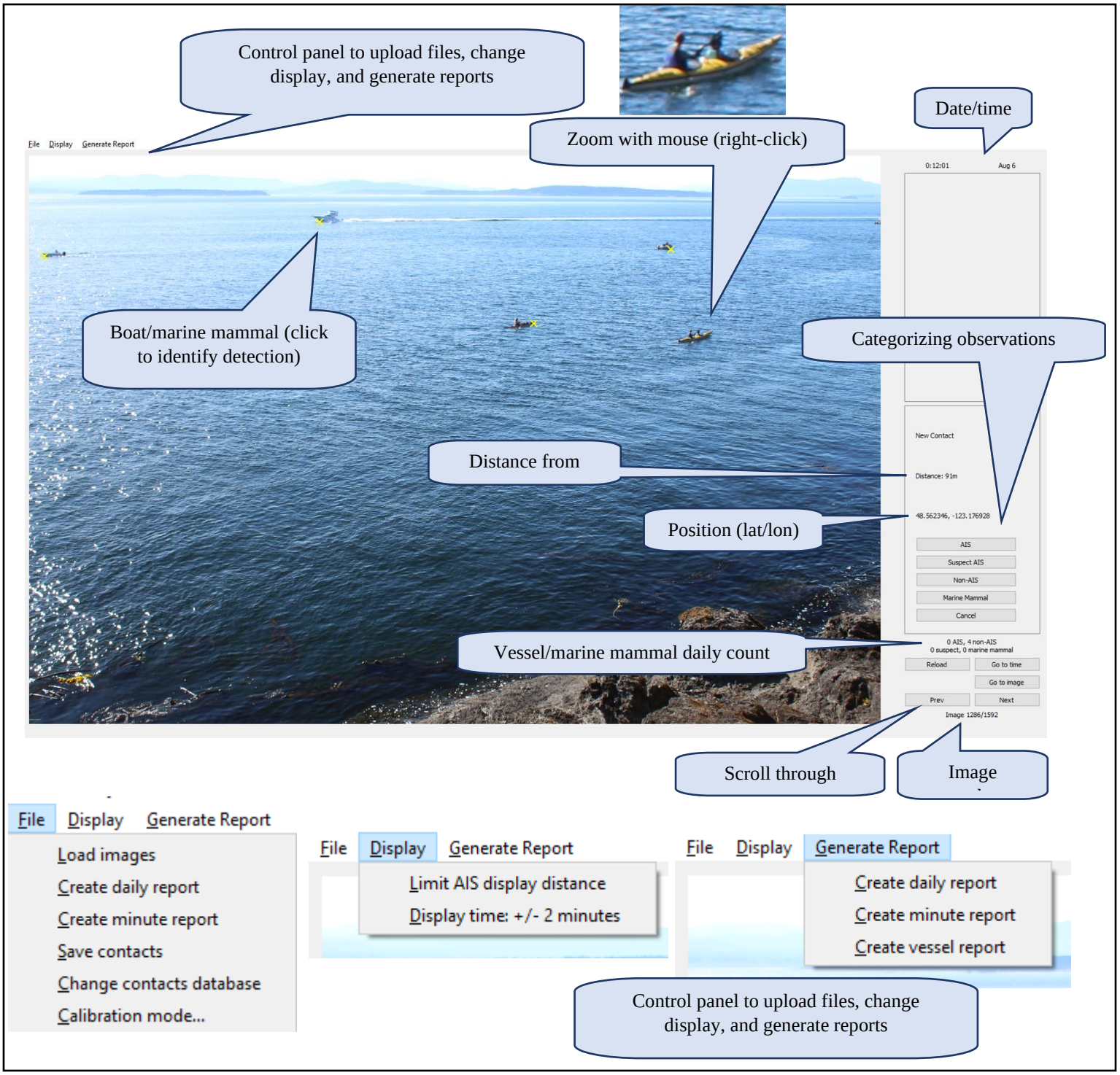
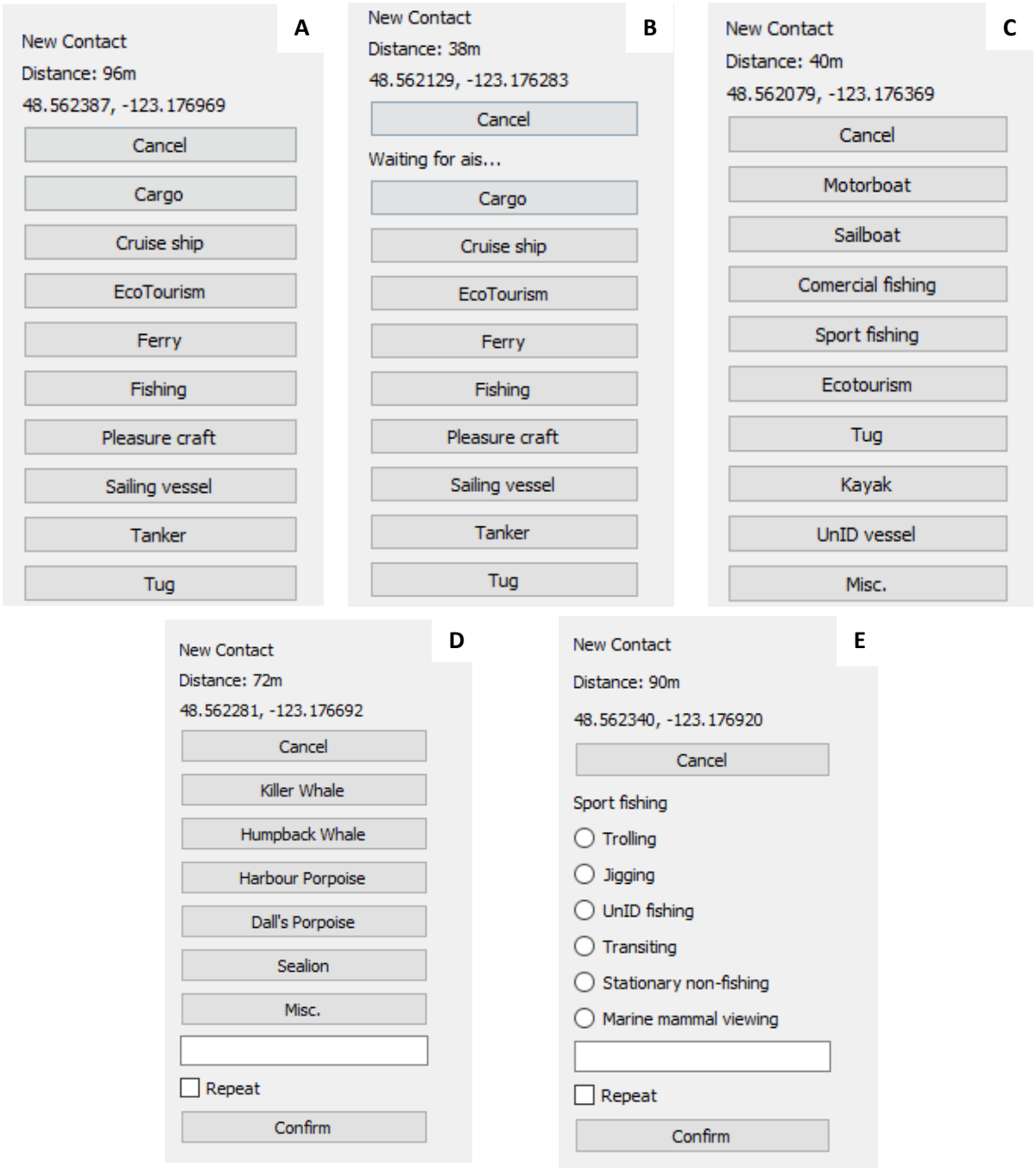


Fig A-1. (cont'd). Categorization options for vessels and marine mammals. Suspect AIS (A), AIS (B), Non-AIS (C), Marine Mammal (D), fishing annotation (E). (E) will subsequently display once a vessel is categorized to denote fishing activities or other behaviour.



Appendix B

B. 1. Camera integrity given visibility constraints

Environmental-induced visibility constraints often present problems for vessel detection and identification in shore-based camera imagery (Parnell et al., 2010[1]). One goal of ours was to assess the integrity of the monitoring design by testing whether our vessel detection methodology was significantly affected by visibility constraints such as fog, mist, and glare. First, we independently sampled visibility each day in 2019 during peak-season at standardized increments from the camera at Otter Point (n=1365). Four thresholds of visibility (vis0, vis1, vis2, vis3; were defined using the landmark discrimination method (Wauben & Roth, 2016[2]), where presence or absence of certain distinguishable features in the background were associated to each threshold. In the process of recording visibility, we also recorded sea state using the Beaufort Scale, as a separate criterion. Definitions of each visibility and sea state threshold is described in detail in Table B-1.

Next, we sampled vessel observations at Otter Point for the same time period. To reduce the effects of influencing covariates, all data were stratified by time of day (3hr increments, five times a day), day of week, sea state, and month. For instance, an example of one stratum was 5:30-8:29, sea state=0, August, and weekdays and weekends stratified. In total, we partitioned the data into 80 strata for the entire dataset. For each stratum, the number of vessel detections observed in each visibility threshold (VO_x) were divided by all vessel observations within the same stratum (TVO_x) to achieve an expected proportion of vessel observations (VO_{EP}). Likewise, we divided the number of occasions of each visibility threshold (VT_x) by the total

number of occurrences of all visibility thresholds within the same stratum (TVT_x) to achieve an expected proportion of visibility thresholds (VT_{EP}).

For each of the 80 strata we defined, we performed 2-sample equality of proportions tests (Thomas, 1960[3]) to determine whether there was a significant difference between VO_{EP} and VT_{EP}. These tests are asymptotic tests that calculate the difference in the weighted sum of squared deviations and return the values of Pearson's chi-squared test statistics, p-values, and 95% confidence intervals ($p<0.05$). For these analyses, the null hypothesis states that there is no significant difference between two expected proportions, while the alternate hypothesis states that there is a significant difference. To avoid bias by sea state and weather conditions, we only used data that was parameterized as sea state = 0. Our parameterized dataset consisted of 4302 vessel detections and 1365 visibility samples (vis0=494, vis1=645, vis2=150, vis3=78)

The results from 2-sample equality of proportions tests on each stratum revealed that the p-value of the proportional difference between VO_{EP} and VT_{EP} was significant in only six cases ($p<0.05$) (Table B-2). Four of these cases fell under the *time3* stratum (11:30-14:29), with two each occurring in September and October and one occurring in each of July and August. We then plotted these data in pairwise boxplots to visualize each pair of expected proportions (Fig. B1). Higher proportions occurred in vis0 and vis1, while vis2 and vis3 had lower proportions, but their values were overall more clustered.

Our results indicate that the difference between expected and observed fishing events were low for all visibility thresholds, times of day and months, and only significantly different in six out of eighty strata when parameterized, with three of them occurring in the time between 11:30 and 14:29. We suspect this could be related to the influence of outliers because anglers often head back before this time period; however certain days exhibited either longer angling

times or a “second wave” of fishing in the early afternoon, which we found is unrelated to sea state, day of week, or month. We suspect these outliers could be related to other factors such as fishing tournaments, which would cause anglers to spend more time away from port, which we did not consider in our study. Future research exploring angler behaviour and other potential covariates influencing time spent fishing would be useful as we were not able to reliably determine the amount of time an individual angler spent on a fishing trip.

Although visibility is linked to environmental conditions, we found exploratory analysis to reveal that sea state seemed to be a much more reliable indicator of fishing activity, leading us to parameterize our data based on a homogenous sea state. For instance, although we expected heavy fog to reduce the number of vessels observed, we instead found that vessels at Otter Point in these conditions did not proportionally decrease, but instead were observed to fish closer to shore (perhaps as a measure of safety). Further, heavy fog normally coincided with light winds and a low sea state, as well as being in the mornings, which we found to be stronger indicators of fishing than the low visibility stemming from fog.

Table B-1. Detection indices. 1) Visibility. Factors influencing visibility may include fog, mist, clouds, glare, rain, or blurry images. 2) Sea state. Sea state index is defined based on the Beaufort Scale.

1) Visibility Index	**Observation**	**Description**
0	High	Visibility in image is clear until the Washington coast across the Strait of Juan De Fuca. No glare obscuring any part of the image.
1	Good	Slight view of the Washington coast or mostly obscured. Visibility is good for a majority of the Strait. Small parts of the image only partially obscured by glare. Little to no decrease in exposure on parts of the image not covered in glare.
2	Low	View beyond the foreground is visible. However, the far side of the Strait is obscured from view. Potentially light fog or rain. Approximately half of the water in the image covered in glare. Some decrease to image exposure.
3	Very low	Only the foreground of the image is clearly visible. Potentially thick fog or mist. Greater than half of the image covered in glare decreasing the exposure of the image.
2) Sea State Index	**Observation**	**Description**
0	Smooth	Beaufort 0-2
1	Slight-moderate	Beaufort 3-5
2	Rough-very rough	Beaufort 6-8
3	Exceptional seas	Beaufort 9-11

Table B-2. Expected proportions of fishing observations (VO_{EP}) compared to expected proportions of visibility thresholds (VT_{EP}) at Otter Point from July to October 2019. Data are stratified by weekend and weekday and are parameterized by sea state, month, and time. Unique strata sampled: n=80. Times are in 3hr increments (time1=5:30-8:29, time2=8:30-11:29, time3=11:30-14:29, time4=14:30-17:29, time5=17:30-20:29). Bold indicates significant values ($p<0.05$) when 2-sample tests for equality of proportions with continuity correction were performed for each pair.

	July		August		September		October	
	VO_{EP}	VT_{EP}	VO_{EP}	VT_{EP}	VO_{EP}	VT_{EP}	VO_{EP}	VT_{EP}
Vis0								
Time1	0.292683	0.175258	0.292683	0.209224	**0.292683**	**0.450758**	0.292683	0.333333
Time2	0.298969	0.308411	0.298969	0.327381	0.092784	0.069204	0.298969	0.474074
Time3	**0.329897**	**0.586667**	0.329897	0.434014	0.329897	0.262238	0.329897	0.402985
Time4	0.43299	0.475	0.43299	0.389785	0.43299	0.47027	0.43299	0.296296
Time5	0.457831	0.434783	0.457831	0.387597	0.433735	0.264706	0.457831	0.363636
Vis1								
Time1	0.463415	0.325773	0.263415	0.318673	0.463415	0.344697	0.463415	0.283333
Time2	0.484536	0.316822	0.484536	0.433333	0.223711	0.186851	0.484536	0.451852
Time3	0.505155	0.386667	0.505155	0.521088	0.305155	0.493007	0.505155	0.522388
Time4	0.463918	0.2	0.463918	0.537634	0.463918	0.37027	0.463918	0.385185
Time5	0.433735	0.478261	0.433735	0.443411	0.243374	0.088235	0.433735	0.181818
Vis2								
Time1	0.170732	0.257732	0.132683	0.130922	0.170732	0.140152	0.170732	0.25
Time2	0.092784	0.093458	0.092784	0.111905	0.092784	0.069204	0.092784	0.074074
Time3	0.123711	0.133333	**0.123711**	**0.02585**	**0.123711**	**0.230769**	**0.123711**	**0.044776**
Time4	0.082474	0.15	0.082474	0.072581	0.082474	0.086486	0.082474	0.092593
Time5	0.084337	0.086957	0.084337	0.124031	0.108434	0.117647	0.084337	0.272727
Vis3								
Time1	0.073171	0.041237	0.163415	0.386727	0.073171	0.064394	0.243902	0.25
Time2	0.123711	0.121495	0.123711	0.127381	0.123711	0.186851	**0.123711**	**0.037037**
Time3	0.041237	0.04	0.041237	0.019048	0.041237	0.034965	0.041237	0.044776
Time4	0.020619	0.25	0.020619	0.01	0.041237	0.048649	0.020619	0.018519
Time5	0.036145	0.043478	0.024096	0.031008	0.292683	0.333333	0.084337	0.181818

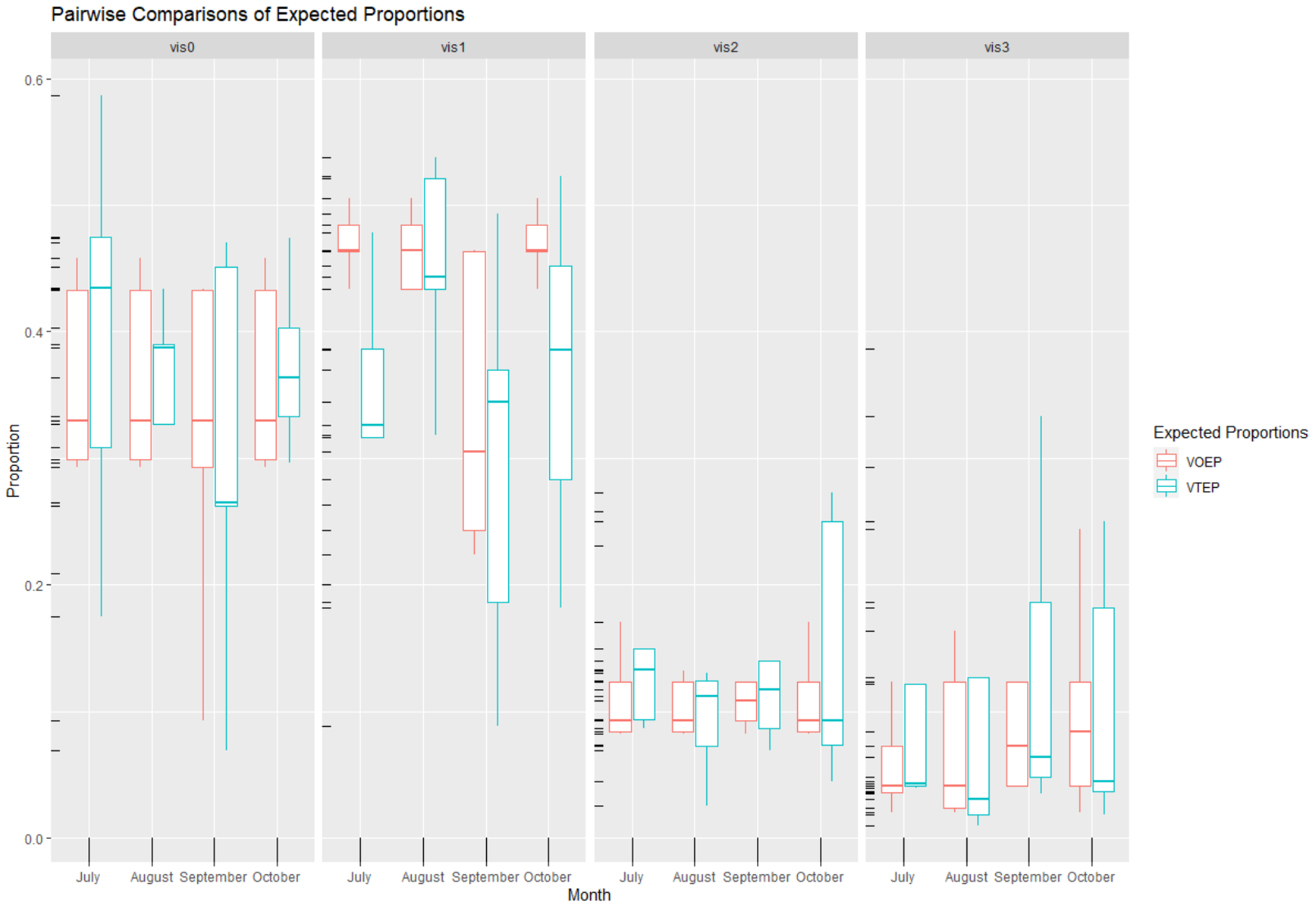


Fig. B-1. Boxplots of expected proportions of fishing events observed and expected proportion of each visibility threshold from data in Table B-2.

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Parnell, P., Dayton, P., Fisher, R., Loarie, C., & Darrow, R. (2010). Spatial patterns of fishing effort off San Diego: Implications for zonal management and ecosystem function. *Ecological Applications, 20*(8), 100319061507001. https://doi.org/10.1890/09-1543

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Wauben, W., & Roth, M. (2016). Exploration of Fog Detection and Visibility Estimation from Camera Images. *Conference Paper for TECO 27-30, Madrid, September 2016.*

Appendix C

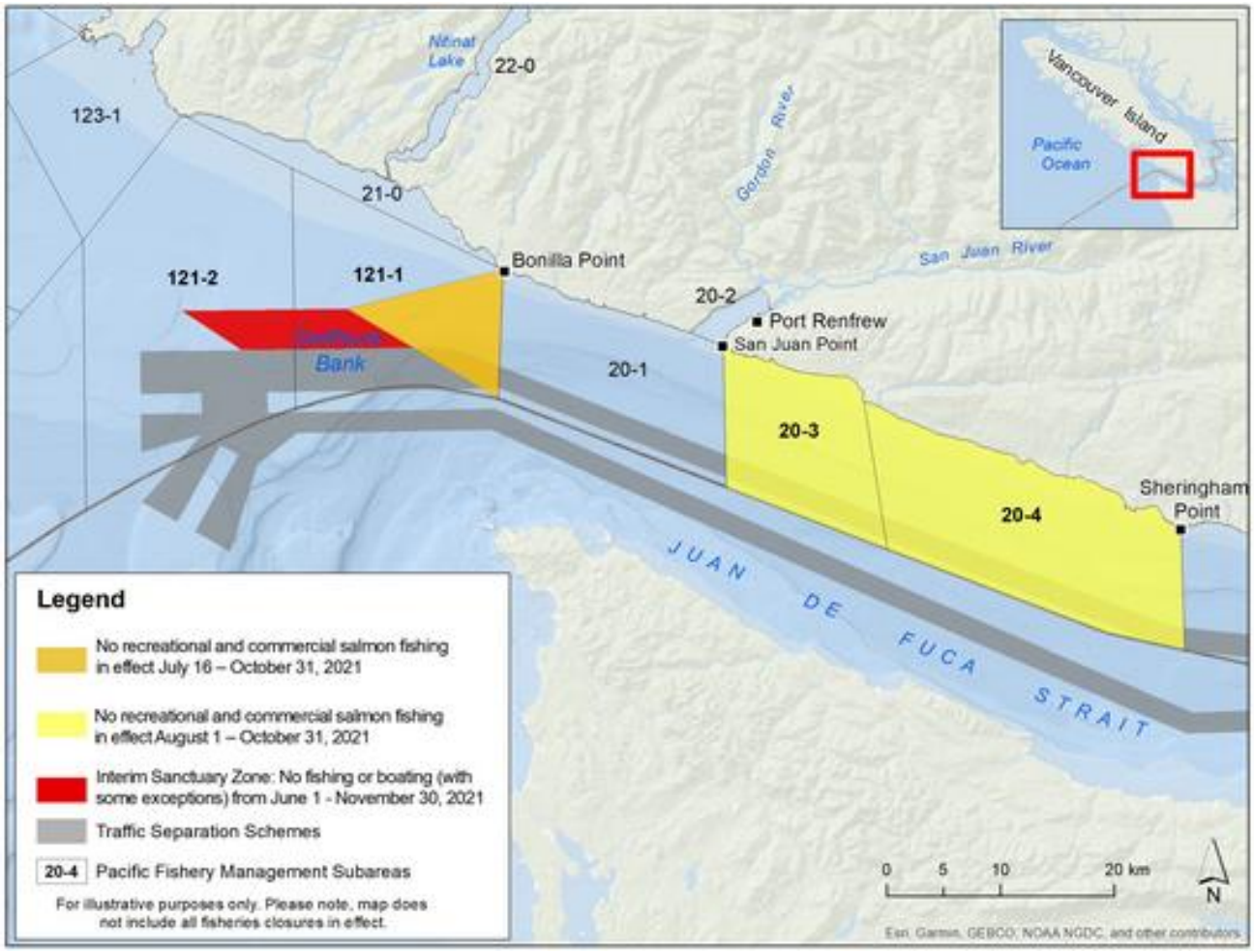

Fig. C-1. Fisheries and Oceans Canada spatial delineation of seasonal fishery closures in the Juan de Fuca Strait, British Columbia, Canada. Although this map was published for 2021 measures, they mirror those of 2020, during the study period. Retrieved from: https://www.pac.dfo-mpo.gc.ca/fm-gp/mammals-mammiferes/whales-baleines/srkw-measures-mesures-ers-eng.html