Technical, Logistical, and Economic Considerations for the Development and Implementation of a Scottish Salmon Counter Network

Scottish Marine and Freshwater Science Vol 7 No 2

D Braun, D McCubbing, D Ramos-Espinoza, M Chung, L Burroughs, N Burnett, J Thorley, J Ladell, C Melville, B Chillibeck and M Lefevre

Technical, Logistical, and Economic Considerations for the Development and Implementation of a Scottish Salmon Counter Network

Scottish Marine and Freshwater Science Vol 7 No 2

D Braun, D McCubbing, D Ramos-Espinoza, M Chung, L Burroughs, N Burnett, J Thorley, J Ladell, C Melville, B Chillibeck and M Lefevre

Published by Marine Scotland Science

ISSN: 2043-7722
DOI: 10.7489/1689-1

Marine Scotland is the directorate of the Scottish Government responsible for the integrated management of Scotland's seas. Marine Scotland Science (formerly Fisheries Research Services) provides expert scientific and technical advice on marine and fisheries issues. Scottish Marine and Freshwater Science is a series of reports that publishes results of research and monitoring carried out by Marine Scotland Science. It also publishes the results of marine and freshwater scientific work that has been carried out for Marine Scotland under external commission. These reports are not subject to formal external peer-review.

This report presents the results of marine and freshwater scientific work carried out for Marine Scotland under external commission.

Technical, Logistical, and Economic Considerations for the Development and Implementation of a Scottish Salmon Counter Network

Douglas Braun, Don McCubbing, Daniel Ramos-Espinoza, Michael Chung, Lloyd Burroughs, Nicholas Burnett, Joseph Thorley, Jason Ladell, Caroline Melville, Barry Chillibeck, and Marylise Lefevre

Prepared for: Marine Scotland Science

InStream Fisheries Research
2323 Boundary Road, Unit 215
Vancouver, BC V5M 4V8
Canada
+1 (604) 428-8819
info@instream.net

Executive Summary

Chapter 1 – Introduction

Atlantic salmon (*Salmo salar*) are culturally and economically important to Scotland. Salmon are now the target of large conservation actions due to growing concerns about their population status and the potential impacts of human activities on their productivity. To adequately assess the current and future status of salmon populations, accurate estimates of their population sizes are needed. In Scotland, electronic fish counter technology has been the cornerstone methodology used to accurately assess salmon population sizes. Marine Scotland Science (MSS) seeks to expand the current counter distribution to include new counter sites throughout Scotland. An expanded network will provide valuable information for salmon fisheries management, sustainable marine planning, the development of renewable energy, and the growth of aquaculture.

Planning and implementing a counter network requires knowledge of the technical constraints, engineering requirements, operational protocols and economic costs. This report was commissioned by MSS to address a knowledge gap in the technical, logistical and economic understanding in the development of a Scottish salmon counter network. The overall objective of this report was to inform the future development of a fish counter network for Scotland. Specific objectives of this report were:

1. **Technical Constraints and Installation Costs.** Assess the technical benefits and limitations, and economic costs of deploying different counter technologies in different environmental settings, including a consideration of engineering requirements.

2. **Automating Counts and Quality Control.** Assess the opportunities for automating signal processing and quality control associated with different counter technologies, considering existing processes and protocols where these can be identified.

3. **Operational Costs.** Determine the costs of maintaining and validating the various counter options in the range of environmental contexts explored, including the costs of data processing and validation.

4. **Integration of Technological and Economic Considerations to Determine Choice of Counter Technology.** Combine data collated from Objectives 1-3 to produce an economic and technical optimization model to inform the choice of counter options in particular environments.

The report meets these objectives in seven detailed chapters. Chapter 1 provides a review of the limitations and benefits of fish counter technologies. Chapter 2 discusses installation and operation considerations (Obj. 1). Chapter 3 explores software for automating counts and quality control of data

(Obj. 2). This chapter evaluates the cost and effectiveness of Echoview software for semi-automating counts using mulitbeam sonar technology among other proprietary counter software, new methods for data management (FishCounter R package), and explores species identification models for estimating ratios of species passing through a counter using length data. Chapter 4 reviews the operational costs and validation (Obj. 3). This chapter provides a general review of operational considerations common to all counters, and then reviews typical counter setups for a range of technologies. The second part of this chapter focuses on exploring validation effort to determine how much validation is necessary to achieve management objectives.

Chapter 5 (Obj. 4) presents a decision and cost model that incorporates all of the information from Chapters 2-4 to determine the feasibility and cost of over 180 counter setups given the characteristics of a potential counter site. The decision model is the main deliverable of the project and is a priority for MSS. Case studies of Scottish rivers are presented to illustrate how the model would prioritize different counter options. Chapters 6 and 7 focus on additional considerations for a counter network. Chapter 6 discusses examples and ideas about combining other technologies such as telemetry and genetics with fish counters to increase the value and diversity of data. Chapter 7 presents a novel approach to evaluating the spatial coverage of a counter network that will provide an additional metric for comparing different counter network designs (Chapter 6).

Chapter 2 – Technical Considerations and Capital Costs

The aim of Chapter 2 is to provide information on the basic function of each counter technology and discuss the performance of counters across various operational sites. A literature review and the experience of InStream Fisheries Research Inc. (IFR) staff has determined that counter performance varies across sites and is primarily due to differences in their technical limitations and benefits. This chapter reviews all technical considerations, capital costs and the various manufacturers of the major types of counter technology:

- **Hydroacoustic counters**
- **Resistivity counters**
- **Optical beam counters**
- **Video**

Hydroacoustic Counters

Hydroacoustic counters use sound wave technology to emit pulses of sound into the water and listen for the returning echo. The counter then converts the returning echo to image data. Here we provide an overview of the two major types of hydroacoustic counters: multibeam and splitbeam.

Multibeam Counters

Multibeam counters function by emitting numerous small acoustic beams at a fixed frequency and convert the returning echoes into a high quality video-like image. The videos can be analyzed using proprietary or third-party software. Several different manufacturers produce multibeam counters (Teledyne BlueView and Sound Metrics), with Sound Metric's DIDSON being considered the industry standard, although other manufactures are producing new cost-effective models such as the Teledyne BlueView M900 Series.

Advantages of multibeam counters include:

1. Ease of use (plug and play)
2. High quality data
3. Flexibility in software used for analysis (proprietary and third-party)
4. Low engineering or structural requirements for deployment
5. Low maintenance
6. Operability in high turbidity and low conductivity environments

Limitations of multibeam counters include:

1. High initial cost of equipment
2. Requires operation of personal computer to log and store data
3. High power requirements
4. Post-processing of data is time intensive
5. Validation of counter is not possible under high turbidity conditions
6. Requires personnel on site to manage data daily
7. Specific river profile and bed material required

Splitbeam Counters

Splitbeam echosounders transmit a short sound pulse and listen for the returning echo. The echosounder then magnifies and filters the returning echoes to produce an image echogram; this is the main difference from multibeam counters. The image echogram are then analyzed for further information. Several manufacturers produce splitbeam counters: Simrad, HTI, and BioSonics. We focus on BioSonics DT-X echosounder in our review.

Advantages of splitbeam counters include:

1. Ease of use (plug and play)
2. Automatic counting and data storage capabilities
3. Potential for remote operation
4. Low engineering and structural requirements for deployment
5. Low maintenance
6. Can operate in high turbidity and low conductivity environments

Limitations of splitbeam counters include:

1. High initial cost of equipment
2. Requires operation of personal computer to log and store data
3. High power requirements
4. Post-processing of data is time intensive
5. Validation of counter is not possible under high turbidity conditions
6. Requires personnel on site to manage data daily or purchase of costly remote operating equipment
7. Specific river profile and bed material necessary

Resistivity Counters

Resistivity counters function with the aid of an electrode sensor unit to measures the bulk resistance of the water between pairs of electrodes. When a fish (more conductive than the water displaced) passes over a pair of electrodes, the counter records the momentary reduction in resistance. As the fish moves to another pair of electrodes, the counter assigns a direction to the movement. Currently there are two manufacturers of resistivity counters: Aquantic (Logie 2100C), and EA Technologies and Scottish Southern Energy (Mark 12).

Advantages of resistivity counters include:

1. Moderate cost for counter unit
2. Automatic counting and data storage
3. Potential for real-time backup of data
4. Potential for remote downloading
5. Small file size and large storage capacity
6. Proprietary software reduces amount of time required for validation (for Mark 12)
7. Low power requirements
8. Low counter maintenance
9. Adaptive through the use of various types of sensor configurations to suit river conditions

Limitations of resistivity counters include:

1. Can only operate in water with conductivity > 20µS
2. Need a computer or other recording device for data backup
3. Software has limited functionality (no analysis capabilities; for Logie)
4. Operating validation equipment requires higher power demands
5. Third-party fabrication of sensor units (potential for high costs)
6. Deployable in fish pass structures only (for Mark 12)
7. High engineering costs for some sensor unit structures
8. Most practicable in small- and medium-sized rivers (bankfull width < 40 m)

Optical Beam Counters

Optical beam counters use vertical optical infrared beams to count fish as they pass through the counter. Vaki is the only commercial supplier of optical beam counters, and they manufacture the Riverwatcher specifically for enumerating migratory fish.

Advantages of optical beam counters include:

1. Moderate cost of counter unit (includes sensor and validation camera)
2. Automatic counting and data storage
3. Potential for data backup
4. Capable of remote downloading
5. Proprietary software is excellent (analysis capabilities)
6. Small file size and large storage capacity
7. Low power requirements
8. Low counter maintenance
9. Sensors are well designed and prefabricated by the manufacturer to fit specific site
10. Validation equipment can be added to sensor unit

Limitations of optical beam counters include:

1. Can only function in waters with low turbidity < 90 NTU
2. Sensor units are small (< 1 m) and always require additional structure in rivers
3. Most practical in small- to medium-sized rivers (bankfull width < 40 m) and fish passes
4. May require multiple units if migration rates are high

Video

Video counters function by placing cameras in fish passes or other areas. Video are then manually counted or analyzed by third-party software.

Advantages of video counters include:

1. Equipment is readily available
2. Low cost
3. Simple to operate

Limitations of video counters include:

1. Can only function in waters with low turbidity < 30 NTU
2. Images require manual processing or third party software
3. Post-processing is time consuming

Structures

Electronic counters cannot function as standalone units. Each technology requires specific structures to allow counter units to operate at their full potential. In this section, we examine structures commonly used with fish counters and discuss general capital costs. In particular, the report focused on:

- **Fences**
- **Resistivity counter sensor structures**

Fences

Fences generally include a full-span barrier across a river or fish pass, along with a trap box or passageway into which fish are directed and counted using a fish counter. Our review of counter structures showed that two types of temporary fences are commonly used: picket fences and Alaskan floating fences.

Picket Fences

Picket fences are structures of vertical pickets held together by aluminum rails, connected horizontally between metal tripods.

Advantages of picket fences include:

1. Low cost of fabrication and installation
2. Portability
3. Versatility – can be used in a variety of configurations to fit specific river needs

Limitations of picket fences include:

1. Risk of fence breach due to debris loading
2. Daily maintenance for debris removal
3. Risk of fence loss during high flow events
4. High cost of materials

Floating Fences

Alaskan floating fences use a combination of air-filled pipes held together by a metal frame to form panels. Panels, along with planar boards, are held in place on the riverbed by a wire (fixed to a mooring point on riverbed) running through cleats on the panels' upstream end. Panels float at an angle to provide a barrier for any fish moving upstream or downstream.

Advantages of floating fences include:

1. Low maintenance and installation costs
2. Semi-portable
3. Low risk of fence loss during high flow events

Limitations of floating fences include:

1. Risk of fence sinking from debris build up
2. Require mounting structure on riverbed
3. Risk of damage to PVC pickets in debris-laden events

Fence costs are integrated into the decision and cost model through functions that scale costs according to bankfull width.

Resistivity Counter Sensor Structures

Resistivity counters do not come with sensors and require an electrode sensor unit to function. Sensor units are built by third-party fabricators and are purpose-built for specific sites, thus resistivity counters are versatile in their mode of application and can adapt to a variety of structures. Four common types of structures are commonly used to mount electrode sensors: Crump weirs, flat pads, boxes and tubes. Our review outlines the advantages and disadvantages of each sensor type.

Crump Weirs

Crump weirs are full-river structures that originally measure open flow channels to predict discharge and change flow characteristics in rivers. Design of the structure modifies the behaviour of fish as they swim over the structure, forcing the fish to swim at a constant height, which is ideal for resistivity counters.

Advantages of Crump weirs include:

1. Modifies fish behaviour to swim at a constant height, reducing variation in counter measurement height
2. Typically high counter accuracy (> 90% accurate)
3. Consistent counter accuracy

Limitations of Crump weirs include:

1. High cost of installation
2. High impact to the river
3. Most practicable in small- to medium-sized rivers (bankfull width < 40 m)

Flat pads

Flat pads are rectangular frames placed on the riverbed. Frames are constructed out of non-conductive materials (e.g., fiberglass, plastic) and provide a mounting location for the electrodes. Pads can be used in series to provide multiple channels covering the desired wetted width of the site.

Advantages of flat pads include:

1. Low cost of fabrication and installation
2. Low impact to the river
3. Very adaptive to site-specific requirements

Limitations of flat pads include:

1. Counter accuracy decreases with depth
2. Counter accuracy can change with discharge
3. Useful for shallow sites only
4. Susceptible to loss during high flow events
5. Most practicable in small- to medium-sized rivers (bankfull width < 40 m)

Box and Tube Sensors

Box and tube sensors have been developed for specific applications in fish passes, and provide consistent accurate counts due to the constant conditions under which they occur.

Chapter 3 – Software: Automating Counts and Quality Control

DIDSON Software

We provide a review of the proprietary software included with the DIDSON multibeam sonar system (DIDSON Display and Control Software [DCS]). Literature review and personal communication with DIDSON operators identified the DCS to be both the hardware controller and data collection interface.

Limitations of DIDSON Display and Control Software include:

1. Cannot count migrating fish automatically, and as such, a large time investment is required for users to review the video data footage to enumerate fish
2. Bias may occur due to human subjectivity

Echoview Software

The Echoview third-party hydroacoustic analysis software is reviewed. Echoview's functionality, time estimation of a typical analysis, training time, software cost, and advantages and disadvantages are described. Our evaluation of Echoview was accomplished through a literature review and an analysis of DIDSON data using the software.

Our analysis found two main disadvantages of DIDSON DCS (manual analysis) in comparison to Echoview (semi-automated analysis).

1. When performing manual analysis in DCS, budgetary and time constraints often force users to increase the viewing speed of the hydroacoustic data to complete the analysis on time. This results in a reduction in the effectiveness of fish counts due to missed or misidentified fish (see Case Study 1).
2. To improve the effectiveness of fish counts when using DCS, the viewing speed of videos need to be reduced. This results in additional time and costs (see Case Study 2).

Advantages of using Echoview include:

1. Ability to semi-automate counting of fish in hydroacoustic data files
2. Integrating an objective method into analyses
3. Ability to interpret fish tracks that are impossible to detect with the naked eye (see Case Study 1)

Disadvantages of using Echoview include:

1. Initial cost is high
2. Separating fish tracks is time consuming when migration densities are high (see Case Study 2)
3. Results are dependent on the quality of the raw data used

Based on our findings, we recommend the use of Echoview when possible in the analysis of multibeam data as we show that it dramatically reduces operational costs, which far outweigh the high initial cost of the software.

Case Study 1 – Kitwanga River Steelhead Enumeration Using Low Resolution (0.7 MHz) DIDSON Data

This case study provides an in depth comparison on the effectiveness and time efficiency of analyzing low resolution DIDSON raw data (0.7 MHz) using Echoview, compared to the traditional method of manually counting fish by watching raw DIDSON video data. We compare fish length in relation to distance from the sonar head and signal strengths, as determined by both analysis methods.

Our analysis found that the fish length data from the two methods differ, resulting in misidentification of fish species using target lengths. Echoview's ability to detect fish is much greater than the human eye. Low signal strengths (due to low resolution data) translate to an inaccurate length measurement using both methods.

The most important finding was that Echoview reduces the effort and subjectivity in generating fish data compared to manual enumeration. For example, Echoview's semi-automated process for counting fish was up to 50% faster than manual counting fish. For periods of low or single-file fish migration, the software was able to identify fish with ease. Accurate counts for clusters of fish were difficult for both Echoview and manual enumeration. One limitation of Case Study 1 is that accurate fish target sizing is not present. Fish length data generated by both methods needs to be validated to determine accuracy.

Case Study 2 – Mitchell River Sockeye Enumeration Using High Resolution (1.8 MHz) DIDSON Data

Case Study 2 provides a comparison on the accuracy and efficiency of analyzing high resolution DIDSON raw data (1.8 MHz) using Echoview compared to the traditional method of manually counting fish by watching raw DIDSON video data. We compared the fish counts generated by both analysis methods.

Our analysis found no significant difference in the total number of fish counted between the two methods but did find substantial time savings when counting fish using Echoview compared to manual counting. Echoview provided similar counts compared to manual enumeration methods. High-resolution DIDSON data enabled us to readily verify each fish compared to the low-resolution DIDSON data used in Case Study 1. For periods of low or single-file fish migration, the software was able to accurately identify fish. Accurate counts for clusters of fish were difficult for both Echoview and manual enumeration methods. A limitation of Case Study 2 is a comparison of fish lengths between the two methods could not be made, as fish were not measured during the manual analysis.

BlueView

We provide a review of the proprietary software included with the BlueView multibeam sonar system (ProViewer 4.2). ProViewer functions as both the hardware controller and data collection interface. We found the data analysis tools cannot count migrating fish automatically, and as such, should only be used as a viewing and operating software.

We noted two key limitations of this software. Firstly, users have to review the video data footage to count the number of migrating fish, requiring a large time investment for manual analysis. Finally, bias may occur due to human subjectivity.

We found the functionality of ProViewer to be substandard compared to the third-party software Echoview. We recommend the use of Echoview as it substantially reduces analysis time and subjectivity of fish counts compared to manual counts using ProViewer.

Vaki

We provide a review of the proprietary software (Winari) included with the Riverwatcher fish counter. Literature review and personal communication with the manufacturer identified Winari to be both a hardware controller and data collection, analysis, and export interface. Unlike the hydroacoustic multibeam sonars, fish data is only collected when an object breaks the optical beam in the counter. Fish length, size, timestamp, visibility, temperature, and image data are collected when the counter is triggered. Data can be exported separately or synchronized, allowing the user to verify each fish with ease and accuracy. We found the functionality of Winari to be superb, as it provides the user with a multitude of verification options to optimize data quality control.

Mark 12

We provide a description of the counter controlling interface and proprietary software for the Mark 12 counter. Mark counters operate through a text-based menu system and can be accessed from any text-based terminal application. Setup and control of the counter is described in detail.

Through personal communication with the Mark 12 manufacturer we identified that a separate proprietary analysis software exists. We have not had the chance to view or review Mark's proprietary analysis software, but through personal communication with the manufacturer, it is suggested the software will become invaluable. Mark's software should allow users to link all the corresponding fish events or partial events data from each of the files, thereby facilitating the validation process, which is similar to Vaki's Winari functionality.

Logie Software

We provide a review of the three proprietary software included with the Logie fish counter: 2100C PC Control Program, 2100C Graphics Programme, and the 2100B/C Windows Graph Programme with Video Capture. Through extensive experience, we found the 2100C PC Control Program to function as both a hardware controller and data collection and export interface. 2100C Graphics Programme and 2100B/C Windows Graph Programme with Video Capture are designed to collect and view Logie counters graphical output files used to verify fish counts generated by the counter.

Our assessment found the functionality of the proprietary software to be adequate for fish enumeration but lacks some of the more advanced capabilities and stability of other software (e.g., Vaki's Winari software).

SalmonSoft: FishTick Software

We provide a review of the video analysis software FishTick, a motion detection software developed by SalmonSoft. Through a literature review and personal communication with the manufacturer, we found the software functions as a video-capture program (FishCap) and a video-review program (FishRev). Program setup, functionality and cost are described in depth. A UK Environment Agency report determined that FishTick can analyze large amounts of video data quickly, with a detection rate of 90%. Our evaluation found the functionality of FishTick to be promising. If the program performs as intended, it can save valuable time by providing the user with features that can aid in the analysis of digital video recordings.

New Methods

Some counter technologies lack software for managing and visually displaying counter data such as the Logie counter by Aquantic. To fill this software gap, IFR developed an open source software package for the statistical program R called FishCounter that can be used to manage datasets and generate data visualizations. Specific functions of the FishCounter software package are to:

- **Remove erroneous data** – These are errors in the dataset that are generated during the download process and while testing the counter. FishCounter provides functions for removing erroneous data and can report the errors that are removed.
- **Assemble master datasets** – A new file is created every time the counter is downloaded. Files may also contain duplicate data depending on the download protocol being used. Duplicate data need to be removed and the individual files compiled into a master dataset for organizational purposes and for further analysis. FishCounter provides user-friendly functions for creating master datasets from individual download files.
- **Diagnostic plots** – Plotting raw counter data can be used to evaluate how well the counter is operating. FishCounter provides a series of functions that automate the visualization of data for diagnostic purposes.
- **Summary plots** – Summary plots of counter data in-season can provide immediate and valuable information about fish abundance and migration behaviour to fisheries managers. FishCounter provides a series of functions that automates the visualization of data for summary purposes.

Species Identification Models

Identifying the species of individual fish passing over an electronic fish counter is difficult and can prevent species-specific estimates of abundance. While video validation can provide information about species identification, most rivers in Scotland have turbid water during some periods of salmon migrations that prevents some species of fish from being identified. IFR created species identification models that estimate the species proportions using length-species relationships whereby some species are smaller on average than another species (e.g., sea trout are typically smaller than salmon). Proportions from these models can be used to estimate the abundance of two species. Two models were developed:

- **Historic model** uses all data on length-species relationships, which is most applicable to predicting the probability of a fish being one species or another when there is *inadequate information* on the length-species relationship for the current year.
- **Current model** only uses data on length-species relationships from the current year, which is most applicable to predicting the probability of fish being one species or another when there is *adequate information* on the length-species relationship for the current year.

Length and migration timing data collected from a Vaki optical beam counter from River Tweed in 2014 were used to compare abundance estimates of salmon and trout generated from the two models. Main findings from this study were:

- **Length and migration timing was related to species identification**. The probability of being a salmon or trout depended on an individuals' length and migration date through the counter.
- **Estimates of salmon abundance were similar for both models**. The probability of being a salmon was summed across all individuals to estimate the total number of salmon. Estimates of salmon abundance were similar between both models, with 95% confidence intervals overlapping.
- **Estimates of trout abundance were similar for both models**. The probability of being a trout was summed across all individuals to estimate the total number of trout. Estimates of trout abundance were similar between both models, with 95% confidence intervals overlapping.

Chapter 4 – Operational Costs and Validation

Operational Costs

In this section, cost considerations for operating and maintaining all major types of counter technologies are reviewed and discussed. The costs considered represent typical budgets, but site-specific considerations are also discussed. Chapter 4 highlights the main cost considerations for operating fish counters, including:

- **Counter structure** – Structure type is one of the largest determinants of cost and varies greatly among counter setups.
- **Debris load** – The amount of debris (i.e., wood, bedload) that is transported downstream will affect the number and duration of site visits required to ensure proper counter operation.
- **Fish abundance** – High fish abundance (i.e., high number of fish events) can rapidly fill data storage for some counters (e.g., resistivity), requiring frequent downloads and higher costs.
- **Equipment malfunction** – Equipment malfunctions will increase in-season maintenance costs and can jepordize data quality. It is recommended to purchase backup equipment (high capital cost).
- **Power supply** – Power consumption and availability of mains power varies among counter equipment. Alternative power sources are more expensive but can also be more reliable.
- **Site access** – Remote sites are more costly than local sites due to increased travel costs and the need for alternative power supplies.

All operational costs reviewed are considerated in the decision and cost model.

Validation

Validation is critical for producing accurate population estimates; increased validation results in more certain abundance estimates. However, validation can be expensive and determining the appropriate amount of validation can be difficult. Our analysis evaluates the trade-off between validation effort (i.e., number of fish validated) and uncertainty in population estimates (i.e., accuracy, precision, and bias) to provide guidelines for how much to validate.

As validation effort increased, the value of additional fish counts being validated decreased. In other words, validating more fish when few counts had been validated was more important than when many counts had been validated. Our analysis also highlighted the different parameters that required a greater number of fish counts to be validated to achieve a given level of uncertainty:

- **Mean counter accuracy** – Lower counter accuracy required greater validation effort.
- **Counter accuracy variability** – More variable counter accuracy required greater validation effort.
- **Number of species** – More species required greater validation effort.

We found that the more complex the system the more validation was required, and that this depends on both counter and population characteristics.

Methods for incorporating validation data into uncertainty in population estimates are presented. Methods include using validation data and a beta binomial distribution to:

- **Estimate up and down counter accuracy**
- **Estimate species ratios of up and down counts**

Recommendations are made as to the minimum number of fish that need to be validated to produce abundance estimates within 5 and 10% relative error of the true abundance for three measures of uncertainty:

- **Accuracy** – A measure of how close an estimate is to the true abundance (a combination of precision and bias).
- **Precision** – A measure of how repeatable an estimate is.
- **Bias** – A measure of whether or not estimates are consistently higher or lower than the true abundance.

Methods for converting validation effort into validation time using migration duration and the mean abundance of a population are presented. Such a conversion is necessary because validation time is a more relevant metric for calculating the cost of validation than the number of fish to be validated. Validation cost estimates are included in the decision and cost model and based on the length of a migration, population size, number of species, counter accuracy, and consistency.

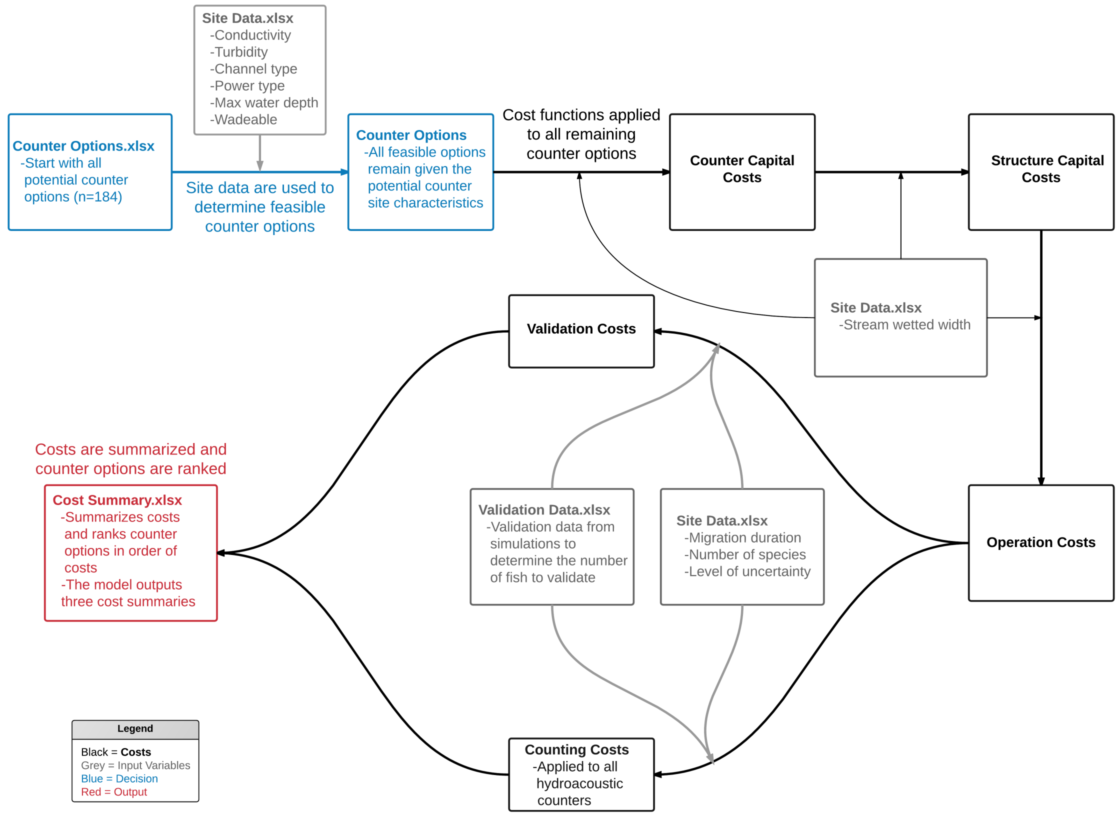
Chapter 5 – Counter Decision and Cost Model: Integrating Technological and Economic Considerations to Determine Choice of Counter Technology and Structure

In this section, the main deliverable of the report is presented as a decision model that incorporates information on technical limitations, and costs of installation and operation based on the characteristics of a potential site. This model is intended to aid MSS in determining the most cost-appropriate counter setup for a given site.

Based on an extensive literature review and IFR's professional experience, 10 site variables were determined to be important for the decision model and would be used as input variables:

- **River bankfull width** is the width of the river just before a river floods its banks. This variable is used to determine the cost of structures that scale with river width.
- **Conductivity** is a measure of the conductance of water. Resistivity counters are not suitable for rivers with conductivities < 20 µS during salmon migrations.
- **Turbidity** is a measure of the amount of light that can pass through water. Optical beam counters are not suitable for rivers with a turbidity > 90 NTU during salmon migrations. Video counters are not suitable for rivers with a turbidity > 30 NTU during salmon migrations.
- **Maximum water depth** can influence fish migration behavior and the performance of specific counters. Resistivity flat pad sensors are not suitable in locations with a water depth > 1.5 m during salmon migrations.
- **Minimum water depth** at the deepest point in a river's cross-section can influence the performance of specific counters. Hydroacoustic counters require water depths to be > 0.9 m to operate effectively.
- **Channel type** determines the type of structure needed, and is designated as either a fish pass or a river.
- **Power type** provides information about the type of existing power at the potential site and the preferred power if none exists.
- **Number of species** is the number of species that will be counted by the counter during salmon migrations.
- **Migration duration** is the number of days between the start and end of the salmon migration. This influences a number of cost functions that are based on time.
- **Mean population size** is the mean abundance for the population (use the previous 10 years). This influences the time required to validate a given number of fish.
- **Wadeability** refers to whether or not a moderately experienced person can safely wade across a river during the salmon migration.

Using these input variables, a decision model was developed to determine the technical feasibility of technologies and the costs of construction and operations of the equipment. The model evaluates 184 counter scenarios that vary in the technology, counter settings, sensors, structure, power options, and software. The model structure is shown in the flow diagram below.



Schematic of the counter decision and cost model.

We apply the decision and cost model to a range of sites located throughout Scotland. The model produces summaries of costs for all feasible counter scenarios and ranks each scenario in order of cost, from least to most expensive. These case studies illustrate how to use and interpret the model output of capital, 10-year operational and 10-year total costs. We discuss the output with regards to limitations in both capital and operational budgets.

Each case study outlines:

- **General watershed and site characteristics**
- **Population characteristics** – life history information, co-migrating species
- **Site visits by IFR**
- **Qualitative evaluation of sites** – General assessment of the site's benefits and limitations by IFR staff
- **Model evaluation of sites and counter options** – Ranked summary of counter options for each site

The collective finding from many case studies suggests there is no one clear counter setup but that many counter setups have potential. There were some potential counter sites, however, where only one counter setup was identified as feasible. Furthermore, for most counter setups the 10-year operational costs were much greater than the initial capital costs indicating that considering operational costs might be a priority.

Chapter 6 – Opportunities for Combining Technologies

Electronic counters can be paired with other technologies to improve counter estimates and provide additional biological information relevant to management. Examples of how to combine technologies with electronic counters are reviewed and discussed. Main topics discussed include:

- **Species identification** – Identifying species using fish counters can be challenging, but the use of other technologies can provide such information. For example, electronic telemetry tags can be used to determine the proportion of species migrating past counters.
- **Generating estimates for large watersheds** – Of course it can be difficult to deploy counters on the mainstem of a large watershed. Alternative approaches include combining high accuracy counters on smaller tributaries with telemetry tags to determine the proportion of fish in different reaches or tributaries of a large river. Collectively this information can be used to calculate a total abundance for the watershed.
- **Estimating population level survival** – Estimating survival of fish at the population level from individual-based telemetry studies is difficult. Pairing counters with telemetry can provide population level estimates of survival, which is rarely done.
- **Estimating age structure** – Age structure is important for fisheries management as it relates to population productivity and dynamics. This requires sampling of fish for ageing structures to determine ages. This information can be combined with counter data to determine the age-composition of populations.

Chapter 7 – Spatial Considerations for a Counter Network

While the technical and economic considerations are important for determining the suitability of sites, the development of a counter network requires the spatial coverage of counters to be considered. Spatial coverage refers to the percent of Scottish salmon populations for which a counter-based estimate of abundance is available. Because populations covary, a counter on one river could provide information (i.e., coverage) about the abundance of salmon on another, whereby the amount of information or coverage is equal to the covariance between the populations. A coverage index is described using Pearson’s correlation coefficients between rivers. Application of the coverage index is discussed in relation to:

- **No count data** – When no counter data are available, rod catch data can be used to estimate covariation between streams.
- **Comparing counter networks** – The counter coverage index can be used with costs and life history characteristics to compare different counter network designs.
- **Challenges using the coverage index** – Some of the main limitations of the counter coverage index is data quality and rivers with multiple populations.

Chapter 8 – Future Research and Recommendations

Future Research

- Investigate potential renewable power sources such as solar, wind, and hydropower generators for powering counters in remote areas.
- Further investigate Mark 12's hardware availability and software functionality. Mark 12 technology is currently not commercially available and information on the counter is extremely limited. Furthermore, its use has been limited to fish passes and small sensor units and has not been tested in free-flowing river channels.
- Further investigate SalmonSoft's FishTick software. Limited information on its time savings and effectiveness exists as a video counting software.
- Further investigation into the accuracy of length data generated by multibeam hydroacoustic counters operating at low resolution.
- Further investigation of how to acquire the raw data that make up Aquantic's graphical trace plots. Such data could be useful for manipulating the Logie 2100C's counting algorithm.
- Further investigate integrating remote sensing technologies (e.g., telemetry) with fish counters.
- Further develop the concept of a spatial coverage index for evaluating counter networks.
- Develop expertise throughout Scotland through training and knowledge exchanges with experienced personnel.

Recommendations

- Findings of this report emphasize the need for the validation of counter data. Validation should be completed for all counter technologies, including those that are not typically considered (e.g., hydroacoustic counters).
- Our decision and cost model provides real options for counter scenarios, but does not take into account the importance of site visits. We recommend a minimum of one year of monitoring at potential counter sites to collect the information needed to make an informed decision. Site-specific evaluations are needed to ensure the proper application of counter technology.

Acknowledgements

We would like to thank the steering group and Marine Scotland Science staff for their thoughtful and constructive feedback throughout the project (John Armstrong, Colin Bean, Ian Davies, Alistair Duguid, Ross Gardiner, Jeff Gibbons, Chris Hall, James Hunt, Bob Laughton, Julian Maclean, Iain Malcolm, James Orpwood, Brian Shaw, Ian Simpson). We would also like to thank Donna-Claire Hunter for coordinating the earlier part of the project and all the biologists and technicians that hosted IFR during site visits. We would also like to acknowledge Alastair Stephen, Magnus Thor Asgeirsson, Duncan Grey, Briony Hutton, Francisco Neira, Scott Walters, Jeff Fryer for providing valuable information on counter technologies. We are grateful to Brian Leaf, Keri Benner from Fisheries and Oceans Canada, and Dean Peard from the BC Ministry of Environment, for providing DIDSON datasets. Joel Harding provided valuable comments on earlier drafts of this report.

Dedication

This work is dedicated to Don McCubbing for his passion, knowledge, and creativity in fisheries. Don grew up and began his career in fisheries in Scotland, but it was in Canada where he became an expert in fish counter technologies. It is fitting that this work would merge the two countries that he called home. He will be forever missed.

Table of Contents

List of Tables

List of Figures

List of Appendices

Glossary of Terms and Abbreviations

2100C Graphics Program	Aquantic's proprietary software designed for collecting graphical trace data from the Logie 2100C resistivity counter.
2100C Windows Control Program	Aquantic's proprietary software designed for operating the Logie 2100C resistivity counter.
2100C Windows Graph Program	Aquantic's proprietary software designed for reading graphical trace data files collected from the Logie 2100C resistivity counter.
Accuracy	Measure of how close an estimate is to the true value (i.e., a combination of precision and bias).
Aquantic Ltd.	Manufacturer and supplier of Logie resistivity fish counters located in Thurso, Scotland.
Bias	Measure of how much estimates are consistently higher or lower than the true value.
Binomial beta distribution	Family of continuous probability distributions defined on the interval (0 = event will not occur, 1 = event is absolutely certain).
BioSonics	Manufacturer and supplier of a wide range of hydroacoustic echosounders including single and splitbeam echosounders (DT-X and MX). Located in Seattle, United States.
Box sensor	A type of resistivity counter sensor specifically designed for fish pass structures.
Crump weir	An in situ triangular structure used to measure discharge and aid in fish migration monitoring when operated in conjunction with a resistivity counter.
DIDSON 300	A dual frequency, multibeam sonar counter manufactured by Sound Metrics Corporation
DIDSON Display Control Software (DCS)	Sound Metrics Corp. proprietary software designed for the DIDSON counters.
DT-X Echosounder	Splitbeam echosounder used to assess fish populations, biomass and size distribution, manufactured by BioSonics.
EA Technology & Scotland Southern Energy	Manufacturer of the Mark 12 resistivity counter, located in Capenhurst, United Kingdom.
Echoview 6.1	Software package for hydroacoustic data processing, providing visualization and analysis capabilities. Developed by Echoview Software Pty Ltd. in Hobart, Australia.
FishCounter	An R package developed by InStream Fisheries Research for the management of Logie 2100C data, functions include data summaries and plots.
FishTick	A computerized video system (software) used to analyze fish passage data collected through video. Developed by SalmonSoft.

Flat pads	Terminal sensors designed for Logie resistivity counters.
Floating fence	Fence used to restrict fish movement to specific area.
HTI	Hydroacoustic Technology Inc. Manufacturer and distributor of hydroacoustic fisheries equipment, including splitbeam echosounders.
Large river	River with a bankfull width > 40 m.
Logie 2100C	Electronic fish counter based on the resistivity principle. Manufactured by Aquantic Ltd.
M900 Series	The M series of 2D multibeam sonar counters manufactured by Teledyne BlueView Inc.
Mark 12	Electronic fish counter based on the resistivity principle. Manufactured by EA Technology and Scottish and Southern Energy.
Medium river	River with a bankfull width of 21-40 m.
Passive integrated transponders (PIT)	A passive form of electronic telemetry tag.
Picket fence	Fence used to restrict fish movement to specific area.
Posterior distribution	Expected distribution of parameter values determined from a Bayesian analysis that is based on prior information about the parameter as well as data being directly used in the estimation.
Precision	Measure of how repeatable an estimate is.
Prior distribution	Expresses prior knowledge about the uncertainty in a parameter.
ProViewer 4.2	Latest version of the 2D sonar control and viewing software developed by Teledyne BlueView Inc.
Riverwatcher	Optical beam counter designed specifically for installation in fish passes, pools and traps. Manufactured by Vaki Aquaculture Systems Ltd.
SalmonSoft	Developer and distributor of FishTick software program in Portland, United States.
Small river	River with a bankfull width of 1-20 m.
Sound Metric Corporation	Manufacturer and distributor of dual frequency, multibeam sonars DIDSON and ARIS used in fish enumeration studies. Based in Bellevue, United States.
Teledyne BlueView Inc.	Manufacturer and distributor of 2D multibeam M900 series sonars, located in Bothell, United States.
Tubes	Terminal sensor designed specifically for Logie 2100C resistivity counter and fish passage structures.
Vaki	Manufacturer and distributor of optical beam counters (Riverwatcher) used in fish farming and river stock management. Company is based out of Kopavogur, Iceland.
Winari	Riverwatcher counter’s proprietary analysis software developed by Vaki. Used to analyze and present data.

1.0 Introduction

Atlantic salmon (*Salmo salar*) have significant ecological, cultural and economic importance in Scotland. In recent years, salmon have become the target of large conservation actions due to growing concerns about their population status and the potential impacts of human activities on their productivity. Accurate estimates of population sizes are needed to: (1) adequately assess the current and future status of salmon populations, and (2) comply with various legislative and policy requirements, such as the EU Water Framework Directive (Directive 2000/60/EC) and the Habitats Directive (Directive 92/43/EEC). Spawner abundance estimates are also important when assessing conservation limits (CLs), which represent the abundance of adult spawners required to fully populate a river with juveniles (ICES 2013). In Scotland, electronic fish counter technology has been the cornerstone to accurately assess salmon population sizes. Marine Scotland Science (MSS) seeks to expand the current distribution of counters to include new sites throughout Scotland. An expanded network will provide valuable information for salmon fisheries management, sustainable marine planning, the development of renewable energy, and the growth of aquaculture. Design, implementation and operation of a counter network, however, require significant knowledge and experience with counter technology and the associated economic costs. This report aims to fill a significant knowledge gap with regards to the technical, logistical and economic considerations for the development and implementation of a Scottish salmon counter network in MSS.

Accurate population estimates are critical for effective management and conservation. Dependable abundance estimates over time will allow the assessment of population trends and how they may respond to environmental change or anthropogenic stressors (Connors et al. 2014). Few rivers in Scotland have accurate, catch-independent estimates of adult spawners and juvenile recruitment; this represents a major challenge to Scotland’s ability to assess salmon populations with confidence.

Although there are a number of existing electronic counters in Scotland (Eatherley et al. 2005), additional counting sites are required to determine conservation limits at the national scale. Eatherly et al. (2005) assessed 29 counter sites, and discovered that only 12 of the counter sites produced reliable data. This study demonstrated the relatively low coverage of reliable adult spawner counts that currently exist in Scotland. Building from these existing sites, the development of a large-scale network of counting sites could provide improved data for estimating spawner abundance, establishing CLs and determining compliance with CLs over time. Given this context, the development of a national counter network has been identified as an important goal for MSS.

The cost and effectiveness of counter site locations are important considerations that can determine the success of a counter network.

Additional factors such as the selection of the counter technology, watershed, channel and population characteristics, and budgetary and management objectives can influence the cost and effectiveness of developing a counter site. No single counter technology will suit all sites and many counter technologies may be feasible in a single site; the trade-off between cost and effectiveness of a range of counter scenarios must be evaluated.

This report provides an extensive review of electronic counter technologies and their potential for implementation in Scotland's rivers. We consider all major types of proven counter technologies and software implemented by companies and government agencies worldwide. The overall objective of this report was to inform the future development of a fish counter network for Scotland. Specific objectives of this report were to:

1. Assess the technical benefits and limitations, and economic costs of deploying different counter technologies in different environmental settings, including a consideration of engineering requirements.
2. Assess the opportunities for automating signal processing and quality control associated with different counter technologies, considering existing processes and protocols where these can be identified.
3. Determine the costs of maintaining and validating the various counter options in the range of environmental contexts explored, including the costs of data processing and validation.
4. Combine data collated from Objectives 1-3 to produce an economic and technical optimization model to inform the choice of counter options in particular environments.

Following this section, Chapter 2 – Technical Considerations and Costs, provides an overview and discussion of the benefits and limitations of different counter technologies and their associated structures. We review each major counter technology in detail, providing associated cost estimates, and summaries of key structures commonly associated with electronic counters. Chapter 3 – Software: Automating Counts and Quality Control, provides a thorough review of new and existing software used to automate counts and evaluate data quality. We also provide an evaluation of Echoview, a third party software tailored for hydroacoustic counters, and review its cost and effectiveness for semi-automating counts. We also present a new R package, FishCounter, developed for Logie resistivity counter data that provides data management and quality control features such as error removal and creating a master dataset from individual download files. We also describe a model created to predict species using body length data collected from Vaki optical beam counters. In Chapter 4 – Operational Costs and Validation, we discuss general counter operations and associated costs for technology. Major topics include maintenance, field-based operations, data collection and validation, and producing population estimates with acceptable levels of uncertainty. Chapter 5 – Counter Decision and Cost Model: Integrating technological and economic considerations to determine choice of counter technology and structure, provides a synthesis of previous sections into a concise model, which is the major deliverable of this project. MSS can use this model as a tool to evaluate different counter scenarios to best fit the objective and budget for a proposed counter site. Chapter 6 – Opportunities for Combining Technology, discusses future opportunities for integrating electronic counters with other technologies to improve estimates of population size and other biological data such as migration timing and marine survival estimates for fish populations. Finally, Chapter 7 – Spatial Considerations for a Counter Network, outlines methods for integrating spatial considerations, including the proximity of existing counter sites and covariation in abundance among populations when developing an electronic counter network.

References

Connors, B.M., Cooper, A.B., Peterman, R.M., and Dulvy, N.K. 2014. The false classification of extinction risk in noisy environments. P Roy Soc B-Biol Sci 281: 20132935–20132935. doi: 10.1098/rspb.2013.2935.

Eatherley, D., Thorley, J.L., Stephen, AB, Simpson, I., MacLean, J.C., and Youngson, A. 2005. Trends in Atlantic salmon: the role of automatic fish counter data in their recording. *In* Scottish Natural Heritage Commissioned Report No. ROAME No. FNB.

ICES. 2013. Report of the Working Group on North Atlantic Salmon (WGNAS), 3-12 April 2013, Copenhagen, Denmark.

2.0 Technical Considerations and Capital Costs

2.1 Counter Technologies

There is a diversity of fish counter technologies and manufacturers (Fewings 1998), each with their own set of technical advantages and limitations (Eatherley et al. 2005). Common counter technologies used to enumerate salmonids in North America and the UK include multibeam sonar, resistivity, and optical beam counters. Less commonly used technologies also exist, including video and splitbeam sonar (see Section 2.2 for descriptions). Selecting the appropriate technology can pose challenges without the proper information to evaluate trade-offs between the strengths, limitations and costs of each technology. This section provides an in depth review of the most common fish counter technologies, along with their advantages and limitations. First we briefly review how each counter technology works, and their optimal working conditions. Each technology is also summarized in Section 2.2 and references from our literature review are provided in Appendix 1. All of the information discussed was used to inform the decision and cost model in Section 5 but is also useful for evaluating the appropriate counter application on its own.

2.1.1 Hydroacoustic Counters

Multibeam Sonar

Multibeam, or imaging sonars, function by emitting numerous small acoustic beams (i.e., sound pulses) at a fixed frequency from a transducer and converting the returning echoes into high quality images. Software applications interpret these images to generate a video-like image that can be played back using various types of software. Two primary manufacturers, Teledyne BlueView and Sound Metrics Corp., supply the sonar transducers and their associated software. Each manufacturer offers different models that range in cost and technical specifications. Through literature research and conversations with fisheries researchers that operate sonar equipment, we found that the most widely used and effective models are the DIDSON 300 produced by Sound Metrics Corp. and the M900 series from Teledyne BlueView. From here on we refer to these two models when we provide any specifications or details. The cost of these highly specialized units is generally high (i.e., between £20 000 and £52 000). Table 2.1 shows the approximate equipment costs for multibeam sonar. The costs presented in the tables were prices quoted to IFR by the manufacturer in US dollars. These prices were converted to British pounds using the conversion rate at the time of writing this document. A significant advantage of this type of technology is that limited mounting and diversion structures are required to operate the counter. The minimum equipment investment for this type of technology includes storage for all the equipment, the sonar transducer and mounting device, a data logger (i.e., personal computer along with operational software and hard drives), and onsite power. Additional accessories such as sonar lenses and lighting boards are recommended. Mounting the sonar transducer must be tailored to each site and can be designed and fabricated locally. The transducer mount can be fixed to a pre-existing structure (Baumgartner et al. 2006), or it can be free standing, such as an adjustable pole mount (Figure 2.1) or a modified stepladder (Figure 2.2) (see Enzenhofer and Cronkite 2005).

Figure 2.1. Sonar unit mounted on the bottom of a tripod at Spius Creek, held to the substrate by sandbags. This installation allows adjustment with a winch above water surface. Photo courtesy of H. Olynyk – DFO.

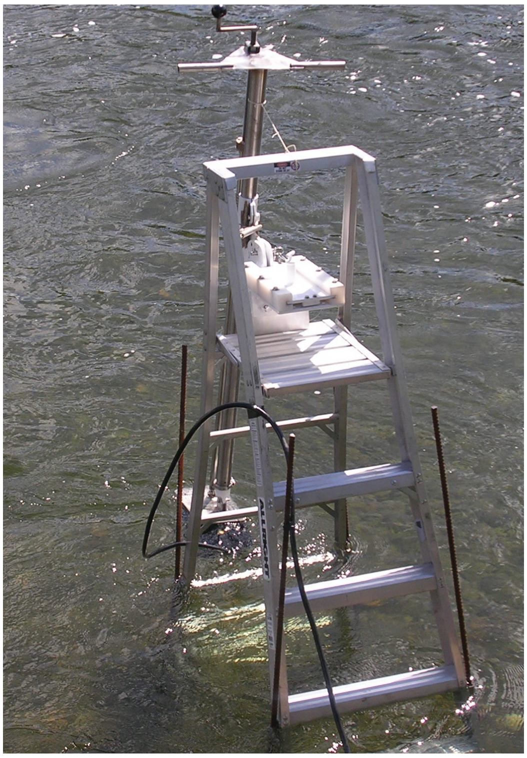


Figure 2.2. A simple stepladder mount for a DIDSON sensor. Photo courtesy of H. Enzenhofer.

Table 2.1. Equipment costs for all major types of counters. List may not be exhaustive, nor may all components be required at all site locations. Cost ranges encompass the base cost through to the highest cost likely to be incurred.

Technology	Counter	Sensor	Structure	Mounting bracket	Power supply	Computer	Data storage media	Equipment storage on site	Video validation	Remote access software
Multibeam sonar	£20 000 – £60 000	NA	Fence: £1000 – £50 000	£5000 – £8 000	£500 – £2000	£400 – £000	£50 – £500	£200 – £5000	NA	NA
Resistivity counters	£10 000 – £20 000	Crump weir: £20 000 – £750 000 Flat pad: £300/m Tube: £1000 Flume: £4000	Fence: £1000 – £50 000 Fish pass insert: £7 000 – £10 000	NA	£500 – £2000	NA	NA	£200 – £5000	£2000 – £10 000	£400 – £1500
Optical beam counters	£20 000 – £30 000[a]	NA[b]	Fence: £1000 – £50 000 Fish pass insert: £7 000 – £10 000	NA	£500 – £2000	NA	NA	£200 – £5000	NA	NA
Video counters	£1000 – £20 000	NA	Fence: £1000 – £50 000	£500 – £8 000	£500 – £2000	£400 – £1000	£50 – £500	£200 – £5000	NA	NA
Splitbeam sonar	£35 000 – £70 000	NA	Fence: £1000 – £20 000	£1000 – £5000	£500 – £2000	£400 – £1500	£50 – £500	£200 – £5 000	NA	NA

[a] Cost of a video validation box for optical beam counters have been included in the counter costs.

[b] Sensor costs for optical beam counters have been included in the counter costs locations.

Due to the nature of multibeam sonar, a blind spot is present directly in front of the transducer; the size of this blind spot is dependent on the type of sonar being used. Blind spots can range from a minimum of 0.83 m in DIDSON 300 or 2.0 m in M900 series. As all fish must pass through the sonar beam to be detected, a small diversion fence is often required behind the mount and beyond the blind spot on the downstream side of the equipment to prevent fish from passing behind the equipment or within the blind spot. The range of operation for each sonar device is different and is a function of the operation frequency. Single transducers have been used to enumerate fish in cross-sectional areas ranging from 2 to 35 m (Belcher 2004). In most cases, evaluation of fish passage beyond 20 to 25 m becomes increasingly problematic (see Case Study 1, Section 3.1.2). Due to these limitations, combining sonar counters with partial fences to constrain fish passage, or using two counters each on alternate riverbanks, can improve detection accuracy. Orientation of the sonar beam can also be problematic if water levels fluctuate during operations. These situations may require continuous realignment, which can be time consuming if water height fluctuations are common. In instances of high flow conditions a remote operable pan or tilt mount may be required for alignment. Passing objects through the beam can calibrate settings and check for blind spots. Validation methods to determine counter accuracy are restricted to clear, calm streams with laminar flow where fish passage can be visually assessed by an observer (H. Enzenhofer, pers. comm.). Other disadvantages of sonar counters include: (1) the inability of sonar to identify fish species, and (2) the high cost and portable nature of the equipment making it susceptible to theft, vandalism or loss in flood events. Careful selection of appropriate sites is also required to ensure the substrate or riverbed profile does not cause blind spots in the beam, that fish are not spawning in the beam area, and that fish are encouraged to pass through the beam one time rather than recycling through prior to spawning. In general, sonar counters do not function well in areas with high sound reverberation such as fish passes (Baumgartner 2006, Baumgartner et. al. 2012).

Data collection and storage is undertaken on a local computer hard drive using proprietary software, which requires a user to set up and maintain. Data storage demands are high (0.5 to 2 GB/hour), although current data storage media is relatively inexpensive to purchase. Power demands can also be high (up to 130 Ah/day, Pipal et al. 2010), so connecting to mains power is optimal. Some installations have been operated on large battery banks, solar panels or other types of electrical generators, but this reduces reliability and increases costs and labour.

Data analysis can occur through manual observation and can be reviewed in real time or at faster speeds. Teledyne BlueView and Sound Metrics Corp. offer playback software with the purchase of a counter. Third party software can also be used to automate the data analysis process and provide single fish traces or counts. Sound Metrics proprietary software is also capable of automating the process and producing counts. The Teledyne BlueView software is playback only. Echoview 6.1 is a third party software that can read and analyze hydroacoustic data, and perform a semi-automated process to clean, analyze and detect fish in data files. The efficiency of Echoview's analysis is dependent on data quality and provides time savings compared to manual analysis methods in most cases. Further overview of manufacturer and third party software can be found in Section 3.1 (Existing Methods).

Potential Engineering Requirements

Engineering costs for deployment of sonar counters are generally limited. Specific brackets, mounts or fence designs may be required, but in general these can be generated from existing designs at lower costs unless there is a specific engineer sign off requirement. Structural engineering is rarely required unless the project includes modifications to an engineered structure such as a fish pass, in which case the requirements would be very site specific.

M900 Series by Teledyne BlueView

BlueView Technologies, Inc. is a large company based out of Seattle, Washington, United States that focuses on creating high-resolution underwater acoustic measurement tools for navigation, monitoring, and detection. The company supplies the US Navy, Coast Guard and port authorities. BlueView do not specifically advertise their systems for fisheries management applications but the basic principles are similar to those of other multibeam systems and have been used to enumerate migrating salmonids (Cronkite et al. 2008, D. Ramos-Espinoza, unpublished data). The price for BlueView transducers range from £15 350 to £22 110.

Teledyne BlueView offers a variety of transducer models, however the P900-45 is the model that has been used in fisheries applications (Cronkite et al. 2008, D. Ramos-Espinoza, unpublished data). The P series of sonars have now been replaced by the M series of sonars and are the new generation of transducers from Teledyne BlueView. The technical specifications remain almost identical and thus from here on we refer to the specifications of the M series transducers. The M900-45 unit operates at a single frequency of 900 KHz and has an optimum detection range between 2 and 60 m. The M900-45 uses 256 beams (beam width of 1° horizontal by 20° vertical, spaced 0.18° apart) for a total 45° field of view.

Advantages for the M900 series are similar to those of the DIDSON. The equipment is very adaptable to various conditions and set up and operation is relatively simple and requires minimal training. Playback software is also intuitive and easy to use.

Due to the lower operating frequency of the M900-45, the quality of the video is not as high as the DIDSON and manual enumeration is not as quick and easy. The M900-45 has not been widely used by researchers and thus the level of accuracy for its sizing tool is unknown. Proprietary software does not have fish counting or tracking capabilities and third party software must be used to generate and analyze count or trace data. Through our own work we discovered that Echoview software was capable of analyzing M900-45 data and that data quality is similar to DIDSON on the low frequency setting (0.7

MHz). Teledyne BlueView has recently developed a new dual frequency model (M900-2250) that aims to increase the quality of output data when used at the high frequency (768 beams with a width of 1° horizontal [H] by 20° vertical [V], spaced 0.18° apart). Like the DIDSON at higher frequency, this unit produces higher quality images but has a similar operating range to that of the DIDSON at its high frequency setting (M900 = 8 m, DIDSON = 10 m).

DIDSON by Sound Metrics Corp.

The DIDSON is a multibeam sonar system that was developed by the Applied Physics Laboratory at the University of Washington in 1999. It is now manufactured and sold by Sound Metrics Corporation in Bellevue, Washington, United States, a large company specializing in hydroacoustic equipment for commercial applications.

Sound Metrics' sonars range from £48 030 to £51 236 depending on the unit in question. Data can be collected between 4-21 frames per second providing near video quality imaging once it is stitched together by the equipment's proprietary software. The DIDSON can operate at two frequencies which determine the detection range and video resolution. At high resolution (1.8 MHz), the DIDSON can be deployed between 0.42 to 26.1 m away from the target region, and detect fish in a target zone up to 10 m wide. At low resolution (0.7 MHz), it can be deployed between 0.83 to 52.3 m away from the target, and detect fish in a target zone up to 40 m wide (see Case Study 1, Section 3.1.2). Additional proprietary lenses can be used to enhance image quality. The high frequency mode uses 96 beams (beam width of 0.3° horizontal [H] by 14° vertical [V], spaced 0.3° apart) for a total field of view of 29° horizontal by 14° vertical; the low-frequency mode uses 48 beams (beam width of 0.4° H by 14° V, spaced 0.6° apart) for a total view of 29° horizontal by 14° vertical.

A major advantage of DIDSON counters is the high quality images produced by the small angle and spacing of the beams. In addition the DIDSON hardware and software are relatively intuitive to use and, the training involved for operating the equipment is minimal (see Section 3.1.1 for a review of DIDSON software). This equipment is very adaptable; applications of DIDSON can be used in different environments with the use of proprietary or third party accessories. At high resolution, manual enumeration of fish can be performed accurately, as image quality is high, although, sufficient time should be allocated to achieve high enumeration accuracy.

The DIDSON can be used to measure the length of individual fish but accuracy is variable depending on site conditions. Burwen et al. (2010) found that the length of manually measured fish is highly correlated to lengths measured by the DIDSON (R^2 = 0.90, Root mean square error = 5.76 m). It should be noted this study used the DIDSON LR, a model that was not advertised on the Sound Metrics website. Burwen et al. (2007) compared length estimates of tethered and free-swimming fish using a DIDSON 300. The study found that tethered fish were subject to positive bias that increased with range from the transducer (1.3 cm/m of range). Measurements of free-swimming fish had a slight positive bias for individuals under 68 cm and slight negative bias for those greater than 68 cm. One disadvantage with the DIDSON at low resolution is the probability of fish detection declines as distance from the DIDSON sonar increases (Burwen et al. 2010). In our experience, we found fish swimming beyond 18 m from the sonar head may have a lower probability of detection and length inaccuracies. Data generated in Case Study 1 suggested objects beyond 18 m from the sonar head may generate signal strengths below 80 dB; these objects were either undetected by the DIDSON counter or impossible to detect by both manual analysis and Echoview's software analysis (see Case Study 1, Section 3.1.2). Another major disadvantage with sonar technology is the large amount of data generated. The high resolution setting collects approximately 1 GB of data per hour. This means data typically needs to be uploaded daily unless a large databank is present onsite.

Splitbeam Sonar

Splitbeam sonars or echosounders have been used periodically in fish passage assessments (i.e., River Spey, Brotherston, C.E 2002). The principle behind all echosounders is that a pulse of high voltage energy is transmitted from the echosounder control unit to a transducer which in turn changes this to a sound pressure wave. This wave radiates spherically from the transducer into the water. If the wave impacts an object in the water with a different density than the water surrounding it, some of the wave energy is bounced back to the transducer. The transducer converts the returning pressure waves into electrical energy, which are magnified and filtered by the echosounder receiver. The receiver then provides an output signal, which can then be measured and assessed for additional information. Table 2.1 shows the approximate equipment costs for splitbeam sonar.

Two manufacturers, BioSonics and Hydroacoustic Technologies Inc. (HTI), market equipment that can be used for such applications. Equipment costs for a basic splitbeam echosounder and transducer range from £30 000 to £54 000 (as quoted by BioSonics Inc.). The sensor unit can be deployed on fixed concrete structures, fish passes, or mounted using a portable setup. Proprietary software and a data storage device are required, and all have to be present during data collection. In addition to the sensor equipment and computer, a mounting and deployment rig, power source, and diversion fence are required to operate at a particular location. Typical power consumption for the echosounder, not including a computer, is around 2.4 Ah.

The advantages of using splitbeam sonar are similar to those of multibeam sonars. A permanent structure is not required in the river, the equipment is relatively easy to use (plug and play), comes with its own logging software (potentially analysis software), and can be downloaded remotely. Unlike multibeam sonars, the file sizes are smaller reducing storage media requirements. Typically units require low maintenance although in some rivers such as the River Spey, where river discharge and debris can be substantial, this might not be the case. Limitations include the need for a specific riverbed profile that is gently sloping and triangular in cross-section. A bed profile with small substrate sizes is also required as it provides less “noise” or backscatter and helps to avoid fish passing undetected in the acoustic shadows. Other limitations include, software accuracy in tracking fish *versus* other debris and the need for additional hardware for remote operation and download (BioSonics DT-X Automated Monitoring System, price included in cost estimate). There is a need for a computer to run concurrently with the echosounder to collect data, thus power requirements are high enough to consider mains power as a requirement. Post processing of data with or without additional software is a time consuming endeavour.

Potential Engineering Requirements

Engineering costs for deployment of hydroacoustic counters are generally low. There may be the need for specific brackets, mounts or fence designs, but in general, these can be generated from existing designs and or fabricators at lower costs unless there is a specific engineer sign off requirement. Structural engineering is rarely required unless the project includes modifications to a fish pass.

2.1.2 Resistivity Counters

The Logie and Mark series resistivity counters are most commonly used in Europe and North America with one additional counter (the Pulsar) used in a few Canadian locations. These counters can be connected to multiple sensors comprised of electrode arrays. Sensor configurations include: Crump weirs, flat pads, boxes and tubes (see section 2.3 for descriptions). Advantages of these counters include low operational costs following installation, minimal annual maintenance and robust data collection (> 90% accuracy; McCubbing and Ignace 2000, Simpson 1978). This technology can also be designed to cover the full river widths which can avoid delays in fish migration caused by fences or other large structures (Aprahamian et al. 1996). The main disadvantage is that the initial installation costs can be high when a Crump weir is used as the sensor structure. Sensors also need to be validated (Dunkley and Shearer, 1982, Forbes et al. 1999) to determine accuracy under a range of environmental conditions (e.g., Bray 1997). Table 2.1 shows the approximate equipment costs for resistivity counters.

Required equipment includes a resistivity counter, electrode sensors, onsite power, lightning board, and onsite equipment storage. Power use is generally low, typically around 0.3 Ah per channel/pad deployed (for Logie 2100C). Resistivity counters also have the benefit in that they can be operated using mains power or battery banks. When the sensor electrodes are submersed in water, they create a resistive transducer (Aprahamian et al.1996). For a given water depth, temperature, and conductivity the resistance measured between a pair of electrodes will be constant. This is called bulk resistance and is independent of water velocity. Changes in water conductivity, and volume alter the measured bulk resistance, which generally decreases with increasing water depth and conductivity. Counter designs must be sure to avoid situations where inter-electrode resistance is low, which is typically the result of low water levels over the electrodes, high conductivity and/or long electrode lengths. Specialized computing equipment with data storage monitors the bulk resistance of electrode pairs and evaluates these changes against firmware algorithms to establish fish passage events. Data are stored internally for later retrieval, usually through an onsite laptop computer or through remote access software.

Potential Engineering Requirements

Engineering costs for deployment of resistivity counters can be limited or substantial if a full river span weir is proposed or requires modification. For the purposes of this report, we provide the costs of installing a resistivity counter in an existing fish pass, as a flat pad with or without a diversion fence and in conjunction with a full river span Crump weir. The latter option will require substantial engineering work including: scope and survey, design, permitting, construction oversight and sign off. Users should also be aware that the passage of objects, such as debris and ice, and changes in water depth over the electrodes as a result of wind or air entrainment, could cause temporary changes in the resistance between the electrodes. Counter design must account for these factors to avoid them being interpreted as fish movements and consequently causing false positive counts.

Logie Counter Series

The Logie 2100C was created in 1996 and is currently being manufactured by Aquantic Ltd. in Scotland. Note that there has not been a new hardware or software release since the early 2000s. The Logie 2100C is operated in conjunction with an electrode sensor to detect the upstream and downstream passage of fish as they pass over the sensors. Electrode sensors are manufactured by a third party and are comprised of three corrosion-resistant metal conductors placed in a parallel alignment to form an open array sensor configuration appropriate for weir, flat pad or closed tube configurations (Figure 2.3).

Figure 2.3. Logie resistivity counter setup with battery bank. Photo courtesy of InStream Fisheries Research.

An extremely important subsidiary function of the Logie fish counter is its capability to regularly measure factors affecting bulk resistance (every 30 minutes) and to automatically adjust the sensitivity of its signal-processing path to compensate for any changes. At sites where moderate to high water conductivity prevails and remains constant, the standard counter is not required to make these adjustments. At sites with low conductivity, these adjustments are made with the aid of more precise conductivity data from the optional environmental card and associated conductivity probe.

The Logie 2100C counter continuously monitors the bulk resistance between pairs of electrodes and from them derives a signal, which defines the instantaneous relative magnitude of one to the other. As a fish swims through the sensor array it displaces water. Because the body mass of the fish is considerably less resistive than the volume of water, which it displaces, this passage causes a temporary reduction in the resistance measured between an electrode pair. Fish direction is determined by the order in which the pairs of electrodes measure a change in resistance. Thus, the perturbation of the background signal by a fish swimming through the array allows the counter to detect its passage and direction.

Different relationships exist between the resistance a fish creates and its mass when passing over the counter electrodes, at varying bulk resistances. At bulk resistances below 100 ohms, there is little contrast between the resistances created by a 20 cm fish compared to one in excess of 1 m in length. However, as bulk resistance increases above 100 ohms, fish at a constant swim height will show significantly larger resistances as they increase in size. Thus, the counter can establish the direction of fish passage, and in some cases establish relative fish size based on the strength of resistance signals (McCubbing et al. 2000).

Data are collected using Logie's proprietary software (refer to Section 3.1.6). Each change in resistance is logged on a counter buffer file. This record includes the date, time, conductivity (if a conductivity board and probe are present), counter electrode pair (channel), direction of passage (or event) and estimated peak signal size (Table 2.2). The Logie counter can also produce a graphical data output. This is generated for all records if the counter is set up to capture this data, but is not recorded within the counter itself. Instead it is captured on a laptop or data logger through the printer port. Graphics data can be visually inspected using Aquantic's 2100C Graphics Program software for compliance with typical fish events and can be used as a form of pseudo-validation (see Section 4.2). An example of the graphical output is provided in Figure 2.4.

Table 2.2. Example of data output from Logie resistivity counter.

Date	Time	Conductivity	Channel	Direction	Peak signal size
04/29/1999	19:44:24	142	1	U	93
04/29/1999	19:46:32	142	1	U	43
04/29/1999	19:47:17	142	2	U	66

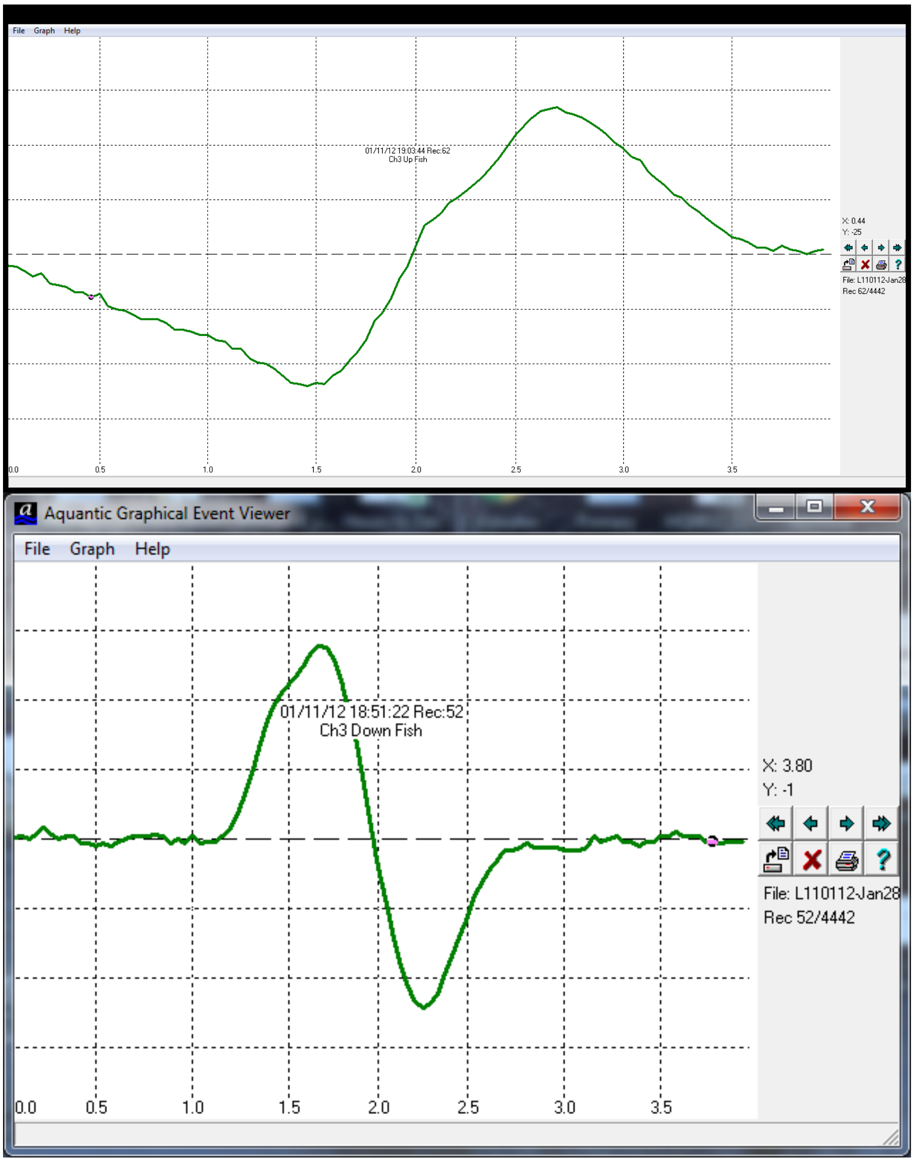


Figure 2.4. Example signal traces from graphics programs operated by the Logie 2100C resistivity fish counter with a flat pad sensor. The top plot shows the trace of a fish moving upstream over the counter and the bottom plot show the trace of a fish moving downstream over the counter.

Mark Counter Series

The Scottish and Southern Energy (SSE) counter was developed in the late 1940’s by Norman Lethlean for what used to be the North of Scotland Hydro-Electric Board. It was first operated at Clunie and Pitlochry salmon ladders in 1951 (R. Gardiner, pers. Comm.). Since its inception, the SSE counter has been subject to a number of upgrades and modifications. Commercial sale of these units has not occurred, so full specifications are not readily available. Use of these counters has been restricted to fish passes with limited passage areas such as the top cell of a Borland lift. It is capable of operating two sensor channels each 1 m wide. The Mark 12 (MK12) unit is most commonly used in fish passes. MK12 has removed the Wheatstone Bridge electrical circuit to measure changes in resistance and instead monitors the resistance across pairs of electrodes and not the resistance of the body of water above them. Briefly, as an ascending fish enters the downstream counting zone (between downstream and centre electrode) it causes the current flowing between the electrodes to increase. Once the current exceeds the minimum fish current (defined by user) the downstream yellow LED illuminates, indicating that a fish has entered the lower counting zone. As the fish proceeds upstream it moves away from the lower counting zone and enters the upper counting zone (between centre and upstream electrodes) and causes an increase in current between those electrodes. Once the current exceeds the minimum fish current the upstream green LED illuminates, indicating that the fish has entered the upper counting zone. If the fish continues to move upstream and leaves the counting zone within a user defined time period, an upstream count is recorded and both LEDs light up. For a fish moving downstream the above sequence is reversed. The MK12 counter now also has the ability to automatically compensate for changing conductivity. The new MK12 unit uses proprietary software to link image records to environmental and fish signal data, count records, and allow users to set the minimum current before a fish is detected. Linking all the various data together allows users to greatly reduce the amount of time needed for validation. Due to the limited width of each independent sensor, these counters are restricted to fish passage areas less than 1 m wide.

Pulsar Resistivity Counters

Pulsar resistivity fish counters have been used by the government of Canada for many years in the enumeration of sockeye salmon and other species. These counters use the Wheatstone Bridge principle similar to the Logie counter, but only work with a series of small (30 cm width) Perspex tunnels. While a few sites still utilize this older technology on Vancouver Island (Stamp River), most locations have moved to alternate more updated technologies that create digital records of fish passage. No current manufacturer of equipment could be sourced for these counters that historically were produced in British Columbia, Canada.

North West Marine Technologies

North West Marine Technologies (NWMT) produces an adult fish counter and sensor tube for its utilization. Information on the use of the adult fish counter has been very difficult to source and existing operational sites have not been located.

2.1.3 Optical Beam Counters

Optical beam counters use vertically arranged optical infrared beams to count fish as they pass through the counter (Figure 2.5). Due to the limited distance light can travel through water, the emitting diodes and receivers must be placed closely together (< 1 m) and thus usually require a fish pass or fence system to divert fish towards sensors. The pattern of disruptions to light beams enable the fish counter to calculate the shape, size, profile and direction of motion of a fish passing through the sensor (Figure 2.6). The equipment required for this type of installation includes the optical counter, onsite power, and a mounting structure. Additional structures such as a lightning board and onsite equipment storage are preferred. Power consumption is generally low, typically at 0.2 Ah per channel deployed. Advantages to using these counters include low cost operation following installation and robust data. The largest disadvantage is the initial installation costs, particularly if the sensors are to be placed in a new location where an existing diversion weir is not present but is required. Also, weekly maintenance may be required for debris removal. As this type of technology does not cover the full width of a river, it also has the potential to delay fish migration if it is used in conjunction with any type of diversion structures such as fences and weirs. Sensor units should be submerged at all times and air entrainment avoided if large quantities of noise-related events are to be avoided. Limited publications exist on the effectiveness of optical beam counters despite worldwide use. According to the manufacturer, the Riverwatcher can count fish at 98% accuracy and measure size with more than 95% accuracy. A study by Shardlow and Hyatt (2004) achieved > 90% accuracy with careful installation and operation of a Vaki Riverwatcher counter. Values can approach 100% in ideal conditions (low fish abundance and clear water) and decrease as conditions become more difficult (high fish abundance or debris load). Table 2.1 shows the approximate equipment costs for optical beam counters.

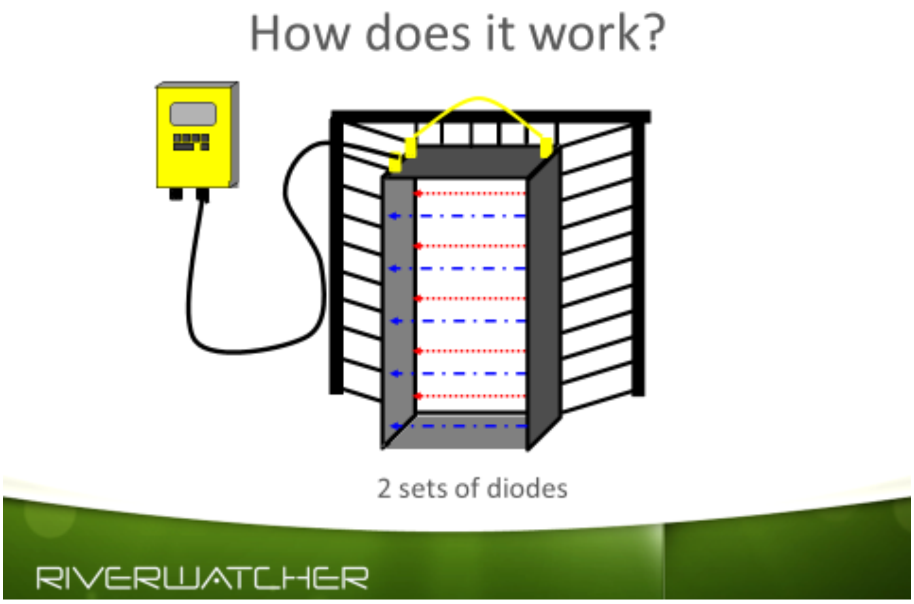


Figure 2.5. Virtual illustration of Vaki Riverwatcher’s migration corridor. Photo courtesy of Vaki.

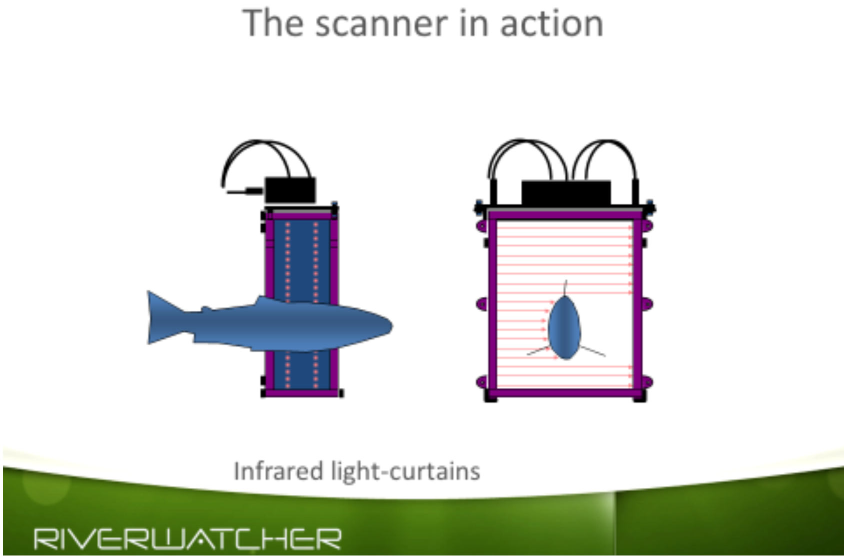


Figure 2.6. Virtual illustration of fish migrating through Vaki Riverwatcher. The left illustrates a side profile view of the counter. The right illustrates how a fish disrupts the optical beams. Photo courtesy of Vaki.

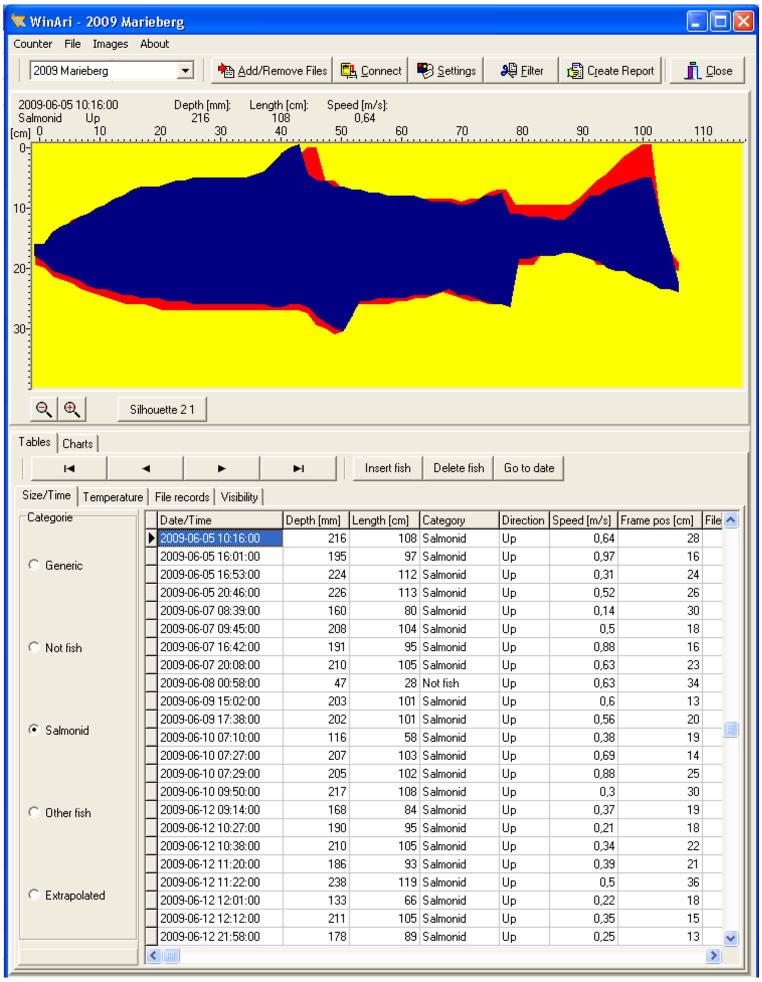
Potential Engineering Requirements

Engineering costs for deployment of optical beam counters is variable and mostly contingent on whether a diversion weir is proposed or requires modification. There may be the need for specific weir or fence designs and these would be very site specific. For the purposes of this report, we provide the costs of installing an optical beam counter in an existing fish pass and in conjunction with a full river span fence. Neither are likely to require substantial engineering work.

Vaki Counters

Vaki, based in Iceland, is the only commercial supplier of optical beam counters. Many of their designs are used in the fish farming industry. The Riverwatcher is specifically marketed for migrant fish enumeration and is extensively used in Iceland, Norway and Sweden, as well as many other countries worldwide. This model is an integrated infrared optical beam counter unit which, when combined with Vaki's proprietary monitoring computer and firmware, will generate fish abundance data, date and time of records, digital silhouettes of fish from the infrared lights, evaluation of fish *versus* non fish records (QA), species evaluation, direction of movement, and fish length. In addition, the Riverwatcher can be combined with a proprietary video light box to capture still or video images of fish movement (Figure 2.7). This information is tagged and appended to the counters output for operator review. Data is compiled and analyzed with the provided software and allows users to check individual fish records against images provided from the optical beam counter or, when the conditions are suitable and video is installed, from the video images (Figure 2.8). Refer to Section 3.1.4 for a detailed analysis of the Riverwatcher's proprietary software, Winari.

Figure 2.7. Vaki optical beam counter with double light box video recorder. Photo courtesy of Vaki.



2009-06-05 10:16:00
Salmonid Up
Depth [mm]: 216
Length [cm]: 108
Speed [m/s]: 0,64

Categorie
○ Generic
○ Not fish
● Salmonid
○ Other fish
○ Extrapolated

Date/Time	Depth [mm]	Length [cm]	Category	Direction	Speed [m/s]	Frame pos [cm]	File
2009-06-05 10:16:00	216	108	Salmonid	Up	0,64	28	
2009-06-05 16:01:00	195	97	Salmonid	Up	0,97	16	
2009-06-05 16:53:00	224	112	Salmonid	Up	0,31	24	
2009-06-05 20:46:00	226	113	Salmonid	Up	0,52	26	
2009-06-07 08:39:00	160	80	Salmonid	Up	0,14	30	
2009-06-07 09:45:00	208	104	Salmonid	Up	0,5	18	
2009-06-07 16:42:00	191	95	Salmonid	Up	0,88	16	
2009-06-07 20:08:00	210	105	Salmonid	Up	0,63	23	
2009-06-08 00:58:00	47	28	Not fish	Up	0,63	34	
2009-06-09 15:02:00	203	101	Salmonid	Up	0,6	13	
2009-06-09 17:38:00	202	101	Salmonid	Up	0,56	20	
2009-06-10 07:10:00	116	58	Salmonid	Up	0,38	19	
2009-06-10 07:27:00	207	103	Salmonid	Up	0,69	14	
2009-06-10 07:29:00	205	102	Salmonid	Up	0,88	25	
2009-06-10 09:50:00	217	108	Salmonid	Up	0,3	30	
2009-06-12 09:14:00	168	84	Salmonid	Up	0,37	19	
2009-06-12 10:27:00	190	95	Salmonid	Up	0,21	18	
2009-06-12 10:38:00	210	105	Salmonid	Up	0,34	22	
2009-06-12 11:20:00	186	93	Salmonid	Up	0,39	21	
2009-06-12 11:22:00	238	119	Salmonid	Up	0,5	36	
2009-06-12 12:01:00	133	66	Salmonid	Up	0,22	18	
2009-06-12 12:12:00	211	105	Salmonid	Up	0,35	15	
2009-06-12 21:58:00	178	89	Salmonid	Up	0,25	13	

Figure 2.8. Screenshot of Vaki's proprietary software for the Riverwatcher counter, Winari, with corresponding fish shadow from a specific fish event. Photo courtesy of Vaki.

2.1.4 Other Counter Technologies

Video

In general, rivers and streams in Scotland experience periods of high turbidity annually, usually associated with spate events and presumably movement of salmon and trout. For this reason, full river recordings of fish movement are limited. One current pilot study on the River Deveron (equipment supplied by Lamberg Bio Marin) did not have any available data at the time of writing this report. During a site visit by IFR staff in October 2014, the river was high and extremely turbid and the problems of capturing video images under these conditions were self-evident. Table 2.1 shows the approximate equipment costs for video counters.

Video cameras have been extensively used in fish ladder applications in the North West of the US for several decades as a way of verifying manual counts at observation windows (http://www.fpc.org/adultsalmon_home.html). A more recent evaluation of video only counters was undertaken by the UK Environment Agency (Washburn et al 2008b). In this review, the potential for capturing video images of fish with cameras and digital video recorders was reviewed, as well as the availability of motion-triggered recording and post-processing software. To summarize, video cameras used in fish passes and ladders do have utility on their own when enumerating migrant fish. Cameras were placed at a suitable location in the fish pass where fish do not hold and were typically operated both day and night. Light sources for night recording can include visible or infrared light. A flash board can be fixed to the wall or bed of a fish pass to flood the area with as much light as possible. The main advantages to this are readily available equipment that is low cost and easy to install. The disadvantages are that turbidity or light reflection can prevent collection of useable images. Cameras also need protection from flood events and images require manual processing or additional software to evaluate which is time consuming. Software such as FishTick can save time on data analysis and avoid operator error. This software has two main functions: it can remove segments of video that lack fish, and be set to record video when fish trigger the software. See Section 3.1.7 for a review of the FishTick software. A study by the UK Environment Agency found that FishTick could review 24 hours of data in 15 minutes, with a detection rate of 90% (Washburn et al. 2008a). Other preliminary reports suggest inaccuracy in enumerating high-density eel and American shad migrations. It is likely more suited to enumerate species with longer period migrations, where fish numbers are dispersed throughout the migration period. As with any other automated fish counting software, raw data quality is key to the efficiency and accuracy of the results. Turbid water and low lighting would make fish detection difficult. IFR staff have not had the opportunity to work with this software and suggest potential users consult FishTick and the UK Environment Agency report (Washburn et al. 2008b) for additional information.

The estimated cost of installing a fish pass video monitoring system is between £5 000 and £8 000 for equipment and labour. A digital video recorder (DVR) and weatherproof cameras are the minimum equipment required. Low power DVRs or computers fitted with DVR cards can be deployed depending on location and power availability at the site. If installed in conjunction with other fish counting technologies, one dedicated computer can be used to run both the DVR and counter.

Potential Engineering Requirements

Engineering costs for deployment of video counters are generally limited. Like sonar and hydroacoustic counters, there may be the need for specific brackets, mounts or fence designs, but in general, these can be generated from existing designs and/or fabricators at lower costs unless there is a specific engineer signoff requirement. Structural engineering is rarely required unless the project includes modifications to a fish pass.

2.2 Counter Technology Specification Sheets

Counter specification sheets summarize the details of the counters and the advantages and limitations presented in the previous section that provided a more comprehensive review of each technology. These sheets are designed to be a standalone section that will provide readers an “at a glance” comparison of each counter type. These specification sheets are formatted for printing.

2.2.1 Multibeam Sonar

Multibeam sonars function by emitting numerous small acoustic beams (sound pulses) and converting the returning echoes into high quality images. The images are stitched together by proprietary software, resulting in data that resembles a video format. The data can be processed by software or manually to produce counts. Most of the specifications are similar between the two manufactures, however specific differences are noted in the tables (BlueView = BV, Sound Metrics = SM).

Manufacturers and Models			
Manufacturer	Model	Cost	Company size
Teledyne BlueView	M900-90, M900-2250	£15 300 and £22 500	Large
Sound Metrics Corp.	DIDSON 300, ARIS Explorer 1800	£48 030 and £51 236	Large

Required Equipment		
Equipment	Source	Comments
Sonar/transducer	Manufacturer	SM: Included is 15 m cable, other lengths are extra BV: 1.5 m cable included, other lengths extra
Sonar/transducer mount	Manufacturer and third party fabrication	May include pan/tilt rotator
Sonar lenses	Manufacturer (Sound Metrics)	Concentrator, telephoto, or spreader lens dependent on site specific requirements
Logging device	Personal computer	
Download device	Personal computer	
Lighting board	Manufacturer or third party	
Onsite equipment storage	Third party fabrication	

Power Requirements		
Power source	Supply voltage	Power consumption
Mains	12 – 48 Volts	25 - 150 watts or 2.5 – 12.5 Ah
Battery	12 – 48 Volts	25 - 150 watts or 2.5 – 12.5 Ah

Data Management and Software		
Application	Software and source	Comments
Logging, downloading and setup	Both: Proprietary software	BV: File recorded in .SON format SM: File recorded in .DDF, and .ARIS format
Analysis	SM: Proprietary software or third party (e.g. Echoview, R) BV: third party software	Both: Counts not provided from raw data, post-processing required, using proprietary or third party software.
Data storage	Internal and personal computer	SM: DIDSON, up to 8 GB of internal storage (4hrs of recording) or personal computer BV: Requires personal computer

Operational Requirements		
Operation	Schedule	Comments
Sonar installation	Annually (user defined/site specific)	Permanent structure vs. temporary structure
Sonar setup	As conditions change	Site specific
Downloading	User defined, site specific	Dependent on files sizes, and data management requirements
Sonar maintenance	Manufacturer recommended (i.e., annually)	e.g., Recalibration, seal maintenance, cable maintenance
Calibration	User defined or internal calibration	

Sensor Unit Structure and Engineering			
Structures	Engineering	River position	Comments
Fixed concrete structure	Third party construction	In river anchored or mounted to a shore structure	SM: Max width 10 m at high frequency and 40 m at low frequency
Diversion fence	Third party fabrication of fence and supporting structures	In river	This is a common structure used in combination with multibeam counters
Portable mount	Manufacturer and third party fabrication	In river; aimed to scan sections of interest	This may require construction of diversion fences; maximum width limits are as discussed above

	Advantages	Limitations
Sonar	-Plug and play	-High cost for sonar transducer
Data management and software	-Potential for data backup -Software provided and able to provide count data	-Need personal computer running concurrent to log and store data -Post processing for count data- requires time -Lack of validation
Power requirements		High power requirements
Operational requirements	-Low sonar maintenance	-May require personnel to be on site to download data daily
Sensor unit structure and engineering	-Does not require permanent structures to be constructed	-SM: Limited to small and medium river sizes

2.2.2 Splitbeam Sonars

Echosounders function by transmitting a high voltage pulse to a transducer. The transducer converts the electrical energy to sound pressure, which radiates spherically from the transducer. The sound pressure wave (pulse) then travels through the water. If the wave impacts an object with a density different than that of the surrounding water, a certain amount of the pressure is reflected back and detected by the transducer. The transducer converts the reflected pressure wave into electrical energy that is amplified and filtered by the echo sound receiver. This receiver then creates an output signal that can be measured and further provide information on the target (object) that reflected the energy (pulse).

Manufacturers and Models			
Manufacturer	Model	Cost	Company size
BioSonics	DT-X Echosounder + Transducer	£35 492	Medium

Required Equipment		
Equipment	Source	Comments
Transducers unit	Manufacturer	Sell echosounder and transducer as kits
Logging device	Personal Computer	Remote sites require additional DT-X AMS system that automates logging and operation (cost - £17 261)
Download device	Personal computer	
Transducer mount/deployment	Manufacturer and third party fabrication.	User defined
Onsite equipment storage	Third party fabrication	

Power Requirements		
Power source	Supply voltage	Power consumption
Mains	11-14 V DC or 90-264 V AC	30 Watts, 2.5 Ah at 12 V
Battery	11-14 V DC or 90-264 V AC	30 Watts, 2.5 Ah at 12 V

Data Management and Software		
Application	Software and source	Comments
Logging, downloading and setup	Proprietary software	Included with counter
Analysis	Proprietary or user defined (e.g., Echoview)	Has two programs to analyze data VisAcq Auto Track and Visual Analyzer
Data storage	Personal computer	Data is stored on personal computers that operate the equipment

Operational Requirements		
Operation	Schedule	Comments
Transducer installation	User defined	Permanent vs. temporary structure
Echosounder setup	As conditions change	Site specific
Downloading	User defined, site specific	Data files are not very large – can be exported as .csv files
Transducer maintenance	Annually	Factory calibration
In Situ Calibration	User defined	completing a field calibration before and after a survey is recommended

Sensor Unit Structure and Engineering			
Structures	Engineering	River position	Comments
Fixed concrete structure	Third party construction	In river anchored or mounted to a shore structure	Max width is dependent on riverbed profile.
Fish pass	Manufacturer and third party fabrication of mount for sonar	In river; aimed to scan width of fish pass channel.	Position should take into account varying water levels.
Portable mount	Manufacturer and third party fabrication	In river; aimed to scan sections	Proper site required

	Advantages	Limitations
Echosounder, transducer	-Plug and play	-High cost for unit
Data management and software	-Automated counting and data storage -Potential for data backup -Potential for remote downloading -Software provided -Small file size and large storage capacity	-Need personal computer running concurrent -Proprietary software has limitations – third party software is expensive. -Post processing for count data maybe required
Power requirements		-High power requirements
Operational requirements	-Low counter maintenance	-May require a person to be on site at all times or purchase of expensive remote operation equipment
Sensor unit structure and engineering	-Does not require permanent structures to be constructed	-Requires ideal river profile conditions

2.2.3 Resistivity Counters

Resistivity counters function as resistivity transducers, measuring the bulk resistance of the water through a set of three electrodes. Resistivity counters rely on the body mass of a fish being considerably less resistive than the volume of water that it displaces. When a fish passes over the electrodes, a momentary reduction in resistance is detected and the counter assigns a direction to the movement. Resistivity counters are comprised of a counter box containing the instruments for measuring resistivity and an algorithm that translates changes in resistance into fish movement records, additional equipment is required for installation and use. Most of the specifications are similar between the two manufacturers, however specific differences are noted in the tables (Logie 2100C = LG, Mark 12 = MK).

Manufacturers and Models			
Manufacturer	Model	Cost	Company size
Aquantic	Logie 2100C	£10 000	Small
EA Tech and Scottish and Southern Energy	Mark 12	£20 000	Large

Required Equipment		
Equipment	Source	Comments
Sensor unit	Third party fabrication	See Sensor Unit Structure and Engineering section
Logging device	Not required	LG: Internal memory MK: Internal memory & Compact Flash card
Download device	Personal computer	MK: Can also have data transferred to Compact Flash card
Lighting board	Manufacturer	
Onsite equipment storage	Third party fabrication	

Power Requirements		
Power source	Supply voltage	Power consumption
Mains	LG: 24 V or 12 V DC MK: 15 V to 75 V DC	LG: 0.3 Ah per channel
Battery	24 V or 12 V DC battery bank	LG: 0.3 Ah per channel (e.g., 12 V 40 Ah battery life for is approximately 2.5 days)

Data Management and Software		
Application	Software and source	Comments
Logging, downloading and setup	Proprietary software	Included with counter
Analysis	User defined (e.g., Excel, R)	MK: has proprietary analysis software used for validation
Data storage	Internal and personal computer	LG: Stores data but personal computer required for additional backup of data; outputs .txt files < 100 kb per record MK: Compact Flash card and .txt files

Operational Requirements		
Operation	*Schedule*	*Comments*
Sensor installation	Once or annually	Permanent structure vs. temporary structure
Counter setup	As conditions change	Site specific
Downloading	User defined, site specific	Max storage in the 10's of thousands or records, remote download potential
Sensor maintenance	Site specific	E.g., removal of algal growth or debris
Counter maintenance	Annually and during installation	Check connections to sensor unit
Calibration	User defined or internal calibration	LG: Internal calibration occur every 30 mins. User may also calibrate conductivity probe.

Sensor Unit Structure and Engineering			
Structures	*Engineering*	*River position*	*Comments*
Crump weir	Fixed concrete structure	In river; up to full river width	LG: Max width 5 m per channel (max 4 channels per unit)
Fish pass (tube sensors or flat sensor pad)	Third party fabrication of insert or mount for sensors to fit into fish pass	In river; channel width	MK: Max width 1 m per channel (max 2 channels per unit)
Flat pad	Third party fabrication of sensor pad and anchors	In river; up to full river width	Max width 5 m per channel

	Advantages	Limitations
Counter	-Moderate cost for counter unit	-Can only function in waters with conductivity > 20 μS
Data management and software	-Automated counting & data storage -Potential for data backup -Potential for remote downloading -Software provided -Small file size and large storage capacity	-Need PC running concurrent to counter for data backup -LG: Software is limited in functionality. No analysis capability -LG: Poor stability at upper end of storage capacity.
Power requirements	-Low power requirements – good for use in remote locations	-Operating validation equipment will require more power
Operational requirements	-Low counter maintenance	
Sensor unit structure and engineering	-Wide range of sensor array can be used with counter and can be modified to suit river conditions	-Sensor units must be fabricated by third party (high costs, e.g., Crump). -Potentially high cost of installation -Limited to small and medium river sizes or in the case of Mark 12 a fish pass structure (max width of 1 m)

2.2.4 Optical Beam Counters

Optical beam counters emit beams of infrared light from one side of the counter and are received by sensor units on the opposite side. A fish count is created when a fish breaks the two vertical beams of light while swimming in either direction. The two-beam design enables the direction of detection and produces a trace that is recorded with every count. Optical beam counters come as a complete unit with sensor, counter, and software.

Manufacturers and Models			
Manufacturer	Model	Cost	Company size
Vaki	Riverwatcher with video validation box	£27 000	Medium

Required Equipment		
Equipment	Source	Comments
Sensor unit	Manufacturer	
Logging device	Manufacturer	
Download device	Personal computer	
Lightning board	Third party	
Mounting box or enclosure	Manufacturer	This is included as package with Riverwatcher model.
Onsite equipment storage	Third party fabrication	

Power Requirements		
Power source	Supply voltage	Power consumption
Mains	12 V DC	0.2 Ah
Battery	12 V DC battery bank	One channel (0.2 Ah) (e.g., 12 V 40 Ah battery life for is approximately 8 days)

Data Management and Software		
Application	Software and source	Comments
Logging, downloading and setup	Proprietary software	Included with counter
Analysis	Proprietary software or user defined (e.g., Excel, R)	Proprietary software can be used for validation and correcting counts but does not provide estimates of uncertainty
Data storage	Internal or web based server	Riverwatcher daily program can be used to upload data to server and real-time counts can be observed.

Operational Requirements		
Operation	Schedule	Comments
Sensor installation	Annually	Can be installed using a permanent or temporary structure
Counter setup	Annually	Site specific – length depth ratios for fish images can be set so the counter can identify species.
Downloading	User defined, site specific	Max storage in the 10's of thousands of records, remote download capable with all units
Sensor maintenance	Site specific	E.g., removal of algal growth or debris
Counter maintenance	Annually and during installation	Very little maintenance required
Calibration	No calibration needed	

Sensor Unit Structure and Engineering			
Structures	Engineering	River position	Comments
Fish pass	Third party fabrication of insert or mount for sensors to fit into fish pass	In river; channel width	This is the most common structure used to operate optical beam counters
Fence	Third party fabrication of fence and supporting structures	In river; up to full river width	This is a less common structure used to operate optical beam counters

	Advantages	Limitations
Counter	-Moderate cost for counter unit which includes sensor and validation camera	-Can only function in waters with turbidity <90 NTU
Data management and software	-Automated counting and data storage -Potential for data backup -Remote downloading included -Excellent software provided -Small file size and large storage capacity	
Power requirements	-Low power requirements – good for use in remote locations	
Operational requirements	-Low counter maintenance	
Sensor unit structure and engineering	-sensors are manufactured -Validation equipment can be added to sensor unit by manufacture.	-Sensor units are small and multiple units may be required for high migration rates. -Limited to small and medium river sizes and fish passes

2.3 Structures

In this section we briefly summarize the structures used to assist in the enumeration of fish through electronic counter technology. The structures do not count fish, but are used in conjunction with the equipment detailed in Section 2.1 to improve and facilitate the collection of data.

2.3.1 Fences

Fish fences are commonly used worldwide as a primary method for the capture and enumeration of salmon and trout. Fences generally include a full span barrier across a river or fish pass combined with a trap box or passageway into which migrating fish are directed. Upon capture, fish are often handled through netting or crowding so that abundance, species allocation and biological data can be collected. Structures used to construct fences may be temporary or permanent depending on migration timing, river characteristics and project budgets. Permanent impassable structures such as purpose-built concrete weirs, existing rock weirs, and dams with fish passage structures will also be discussed, along with fish pass box and tube counter enumeration methodologies.

Fences can be used in conjunction with remote sensing equipment (i.e., counters, tag readers, etc.) to effectively enumerate migrating populations of salmonids (Rand et al. 2007). Two common examples of temporary diversion fences are picket fences and Alaskan floating fences, both intending to restrict fish movement to a specific area (Figure 2.9). Both fence types can be interchangeable or may be suited to specific river types and conditions. Collection areas can range from tens of meters in width to < 1 m, and are dependent on the type of technology employed. Sonar or flat pad resistivity counters, for example, can span larger sections of the river, whereas Vaki or resistivity tube counters cover only small sections of the river (< 2 m).

Figure 2.9. Alaskan floating fence used on the Stanislaus River, United States. Panels are 20 ft. long and incorporate a Vaki counter unit. Photo courtesy of Vaki.

Picket Fences

Picket fences are structures composed of vertical pickets that are held together by aluminum rails, connected horizontally between metal tripods (Figure 2.10). Tripods are placed perpendicular to the riverbed or at an angle to improve fish passage or debris collection, and are typically weighted down with rocks or sandbags. Pickets made from steel or aluminum pipe are pushed down through the holes in the rails and into the river substrate, completing the barrier effect. Such fences can be used in high flow rivers provided debris loading is low and installation is completed during low flows (Figure 2.11). Increased maintenance costs can be incurred with cleaning and is dependent on the amount of leaf litter and other floating debris present in the system.

Figure 2.10. A single panel 10 ft high picket fence with mounting tripod and three rails. Photo courtesy of InStream Fisheries Research.

Advantages of picket fences include the low cost of fabrication and installation, as well as the portable nature of the units. Disadvantages include the risk of fence breach, daily maintenance for debris removal, picket removal, and risk of blow out or fence loss from high flows.

Figure 2.11. Seton River picket fence with trap box. River width approximately 30 m, discharge 30 m^3/s, depth 1 m. Photo courtesy of InStream Fisheries Research.

Floating Fences

Alaskan floating fences use a combination of air-filled watertight PVC pipes held at equal spacing by a metal frame to form panels (McCubbing and Ward 2007, 2008). Each panel receives additional floatation by the addition of a planer board attached to the downstream end of the panel. This board, typically made from buoyant materials such as plywood or insulation foam, is attached by a hinge at one end under the panel and by adjustable chains at the other. By adjusting the chains, the angle of the panel can be determined by the operator. Panels are attached together and held in place on the riverbed by a wire running through cleats attached to the panels' upstream end (Figure 2.12). The wire is fixed to a mooring point on the riverbed. Panels can be 3 to 10 m in length and should float at an upward angle from the upstream to downstream direction. As water depth and velocity increases, the panels run the risk of sinking. The planer boards provide additional lift over and above the buoyancy of the PVC pipes, thus preventing the fence from sinking.

Advantages of Alaskan floating fences include low maintenance and installation costs, as well as the semi-portable nature of the units. Disadvantages include the risk of fence sinking when too much debris builds up on the fence, the need for a mounting structure on the riverbed, and the risk of damage to PVC pickets in debris laden flood events.

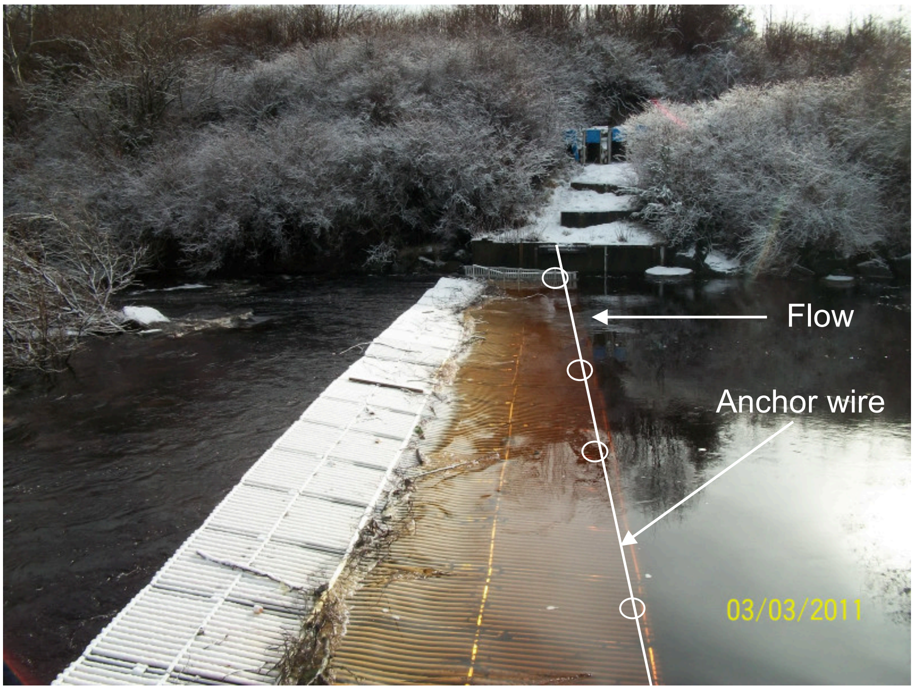


Figure 2.12. Keogh River Alaskan floating fence with 3 m long panels and trap box located on the far riverbank. Photo courtesy of InStream Fisheries Research.

Fence Installation Costs

The cost of manufacturing picket and Alaskan floating fences is highly dependent on the cost of raw materials and local machine shop labor. The primary cost is in aluminum, which varies greatly depending on purchasing time. Thus, any direction provided on the cost per meter of fence construction is subject to change. The market cost of any fence installation would need to be verified if it is to be compared with alternate technologies.

2.3.2 Resistivity Sensor Structures

Crump Weir

A Crump weir is a triangular structure with a 1:2 sloping front face and a 1:5 sloping back face (McCubbing and Ignance 2000) (Figure 2.13). Crump weirs were originally used as measuring structures in open flow channels to predict discharge and change flow characteristics in rivers. Since the Crump weir is fixed in the river, water flows over the weir without the downstream level being below the weir crest. Thus, Crump weirs have the advantage of producing a constant discharge coefficient over a wide range of natural discharge conditions. Crump (1952) developed the original design, with further investigations completed by White (1971). The application of Crump weirs in fish migration monitoring was first evaluated in the 1960’s and 1970’s in the UK by Simpson (1978). By pairing them with sensor units attached to a resistivity fish counter, the combination of the weir structure and sensor modified fish behaviour (i.e., fish swam at a constant height above sensors) and improved counter accuracy. Fish counts resulted in accuracies greater than 90% for validated upstream migrating salmonids (McCubbing and Ignance 2000). Crump weirs are the most common structures used to deploy resistivity counter sensors (Figure 2.13). Sensor units made from a pad of non-conductive materials (e.g., high-density polyethylene or fibreglass) are placed on the 1:5 sloping downstream face of the weir where fish passage is generally close to the weir face. Electrodes made from a non-corrosive material such as stainless steel are set into the pad to avoid damage by debris. Spacing between the electrodes is dependent on the size of the target species. Mounting methods and sidewalls must be insulated to avoid electric conductance with sensor electrodes.

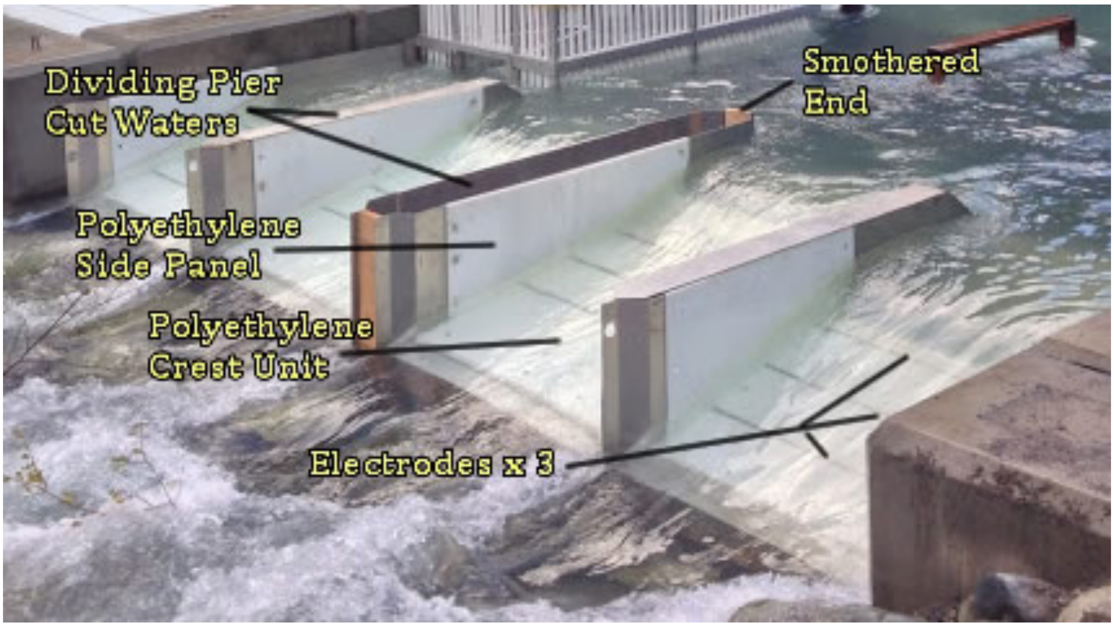


Figure 2.13. A four channel Crump weir with resistivity counter sensors installed. Photo courtesy of InStream Fisheries Research.

Crump weirs can take two forms: a mass concrete structure (Figure 2.14; see McCubbing and Ward 2007, 2008), or a combination of prefabricated weirs made from concrete, aluminum, fibreglass, or wood that are attached to a solid sill (Figure 2.15; see McCubbing et al. 2014). Sills are partially buried in the riverbed and can also be made from a number of materials, including a mass concrete pour, concrete lock blocks tied together with a thin pour sill, gabion baskets, or a metal substructure. Local engineering requirements, river substrate and discharge, site width and construction access would likely influence the type of Crump weir to be constructed. Life expectancy of these weirs is in the range of 15 to 20 years, after which maintenance and upgrades can be substantial.

The cost of installing a Crump weir, without sensor electrodes, can vary from £20 000 for a small stream to £750 000 depending on site characteristics. Most of this cost variance is determined by the size of the river.

Figure 2.14. Helmsdale resistivity fish counter weir with four channels at low flow. Photo courtesy of InStream Fisheries Research.

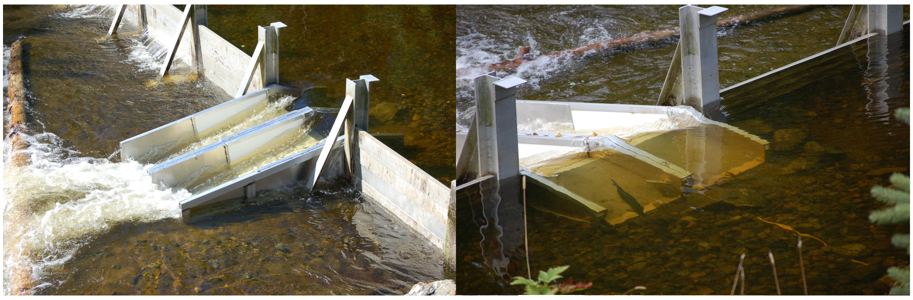


Figure 2.15. Glendale spawning channel (British Columbia, Canada) with a hybrid Crump weir and diversion fence. Photo courtesy of InStream Fisheries Research.

Flat pads

IFR has designed a number of modular flat pad sensors that can be directly placed on the riverbed with very low impact (McCubbing and Lingard 2013, D. Ramos-Espinoza unpublished data). Flat pad sensors can be used in situations where water depths at the enumeration site remain relatively low (< 0.5 m max depth). Pad frames are made from non-conductive materials and provide a mounting location for the electrodes. Structural strength is provided by non-conductive grommets with the frames open between electrodes to avoid surfing (i.e., raising of pads from riverbed). Pads can be used in series to provide multiple channels covering the desired width of the enumeration site (Figures 2.16 and 2.17).

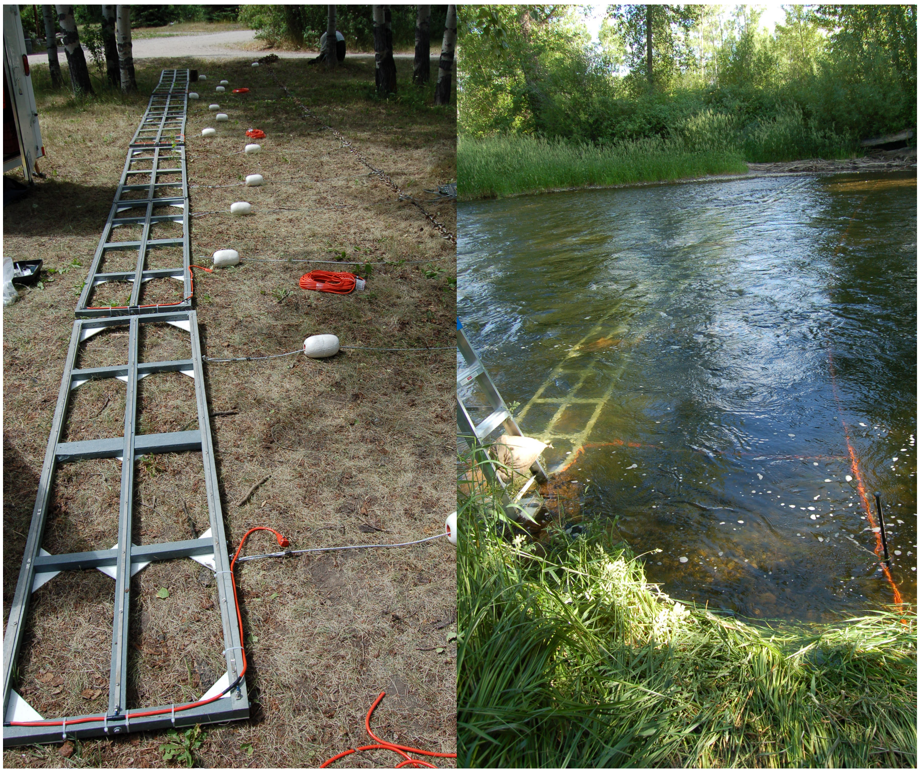


Figure 2.16. Chilcotin River flat pad sensor prior to (left) and after installation (right). River width approximately 24 m. Photo courtesy of InStream Fisheries Research.

Figure 2.17. Crawford Creek flat pad counter. Channel width approximately 10 m. Photo courtesy of InStream Fisheries Research.

The cost of building and installing flat pads are generally low. The equipment and supplies can be purchased for approximately £300 per 1 m section.

Fabrication can be undertaken by anyone with power tool experience and IFR has developed assembly plans for this. The units can be held in place on the riverbed by a heavy-duty chain ballast, duckbill anchors or something similar.

Box Sensors

Box sensors have been developed for specific applications in fish passes where an already restricted area is available for fish passage (Figure 2.18). As with other sensor types, the essential elements of design include electrodes set into a non-conductive base, non-conductive sidewalls (e.g., fibreglass, plastic) and a maximum water depth of 1 m. All conductive elements must be at least 1.5 times the distance between electrode pairs to avoid signal leakage.

These units are specialized and are hard to assess for budgeting purposes. Each site is unique and thus requires a configuration that fits the location. A minimum of £5000 is likely required for small fish pass sites, but this could rise substantially on larger, more complex, locations.

Figure 2.18. Box sensor unit awaiting deployment. Photo courtesy of InStream Fisheries Research.

Tube Counters

The placement of electrodes in counting tubes has been common practice for many years (e.g., Tummel fish pass, Pitlochry, UK). The design of the tube sensors involves installing the circular electrodes at suitable spacing within the non-conductive interior of the tube. More recently, tube counters have been used in Canada where high fish passage rates (i.e., up to 8 000 fish per day) have resulted in 'banks' of up to eight sensors being used in conjunction with a separation grid to provide accurate counts (McCubbing 2012, Ladell and McCubbing 2013a, 2013b, Casselman et. al. 2014). Tubes can be large in orifice (> 1 m; Tummel and Pitlochry Rivers, Scotland, UK) or smaller (~0.35 m; Seton Dam, Lillooet, BC; Figures 2.19 and 2.20). Smaller tubes are used when fish need to be in close proximity to electrodes to produce accurate counts.

These units are like a specialized box sensor and are also hard to assess for budgeting purposes. Each site is somewhat unique and thus requires a configuration that fits the location. A minimum of £4000 is likely required for small fish pass sites, and this could rise substantially on larger, more complex, locations, where multiple tubes and large separation grids are required.

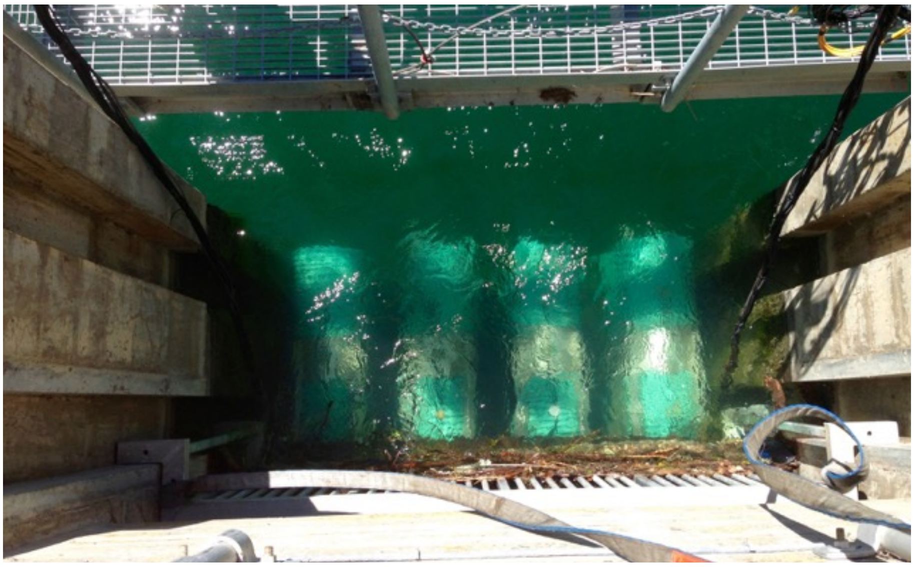


Figure 2.19. Seton Dam fish pass counter with eight sensor units. Note that only the top four tubes are visible. Photo courtesy of InStream Fisheries Research.

Figure 2.20. Seton Dam fish pass sensor units prior to installation in a separation grid. Photo courtesy of InStream Fisheries Research.

References

Alaska Department of Fish and Game. 2015. Alaska Fisheries Sonar. Juneau, Alaska, United States. Available from http://www.adfg.alaska.gov/index.cfm?adfg=sonar.didson.

Aprahamian, M., Nicholson, S., McCubbing, D. and Davidson, I. 1996. The use of resistivity fish counters in fish stock assessment. *In*: Stock Assessment in Inland Fisheries, I.G. Cowx (ed). Fishing News Books, Oxford, 27-43.

Aquantic Ltd. 1998. 2100C Logie Fish Counter – Operating and Technical Manual.

Baumgartner, L. J.; Reynoldson, N.; Cameron, L.; Stanger, J., 2006: Assessment of a dual-frequency identification sonar (DIDSON) for application in fish migration studies. Fisheries Final Report Series No. 84, NSW Department of Primary Industries.

Baumgartner, L. J., Bettanin, M., McPherson, J., Jones, M., Zampatti, B. and Beyer, K. (2012), Influence of turbidity and passage rate on the efficiency of an infrared counter to enumerate and measure riverine fish. Journal of Applied Ichthyology, 28: 531–536.

Belcher, E.O. 2004, Case Study: Alaska Department of Fish and Game Uses DIDSON to Count Salmon Swimming Up-River to Spawn. Sound Metrics Corp. Bellevue, Washington, United States. 4 p.

Casselman, M.T., N.J. Burnett, N.N. Bett, C.T. Middleton, E.G. Martins, D.C. Braun, D. McCubbing, and S.G. Hinch. 2014. BRGMON-14 Effectiveness of Cayoosh flow dilution, dam operation, and fishway passage on delay and survival of upstream migration of salmon in the Seton-Anderson watershed. Annual Report – 2013. Report prepared for St’át’imc Government Services and BC Hydro. The University of British Columbia, Vancouver, BC. 66 p. + 2 Apps.

Cronkite, G.M., Enzenhofer, H.J., Ridley, T., Holmes, J., Lilja, J., and Benner, K.. 2006. Use of high-frequency imaging sonar to estimate adult sockeye salmon escapement in the Horsefly River. Can. Tech. Rep. Fish. Aquat. Sci. 2647.

Cronkite, G.M., Enzenhofer, H.J., and Holmes, J.A. 2008. Evaluation of the BlueView ProViewer 900 Imaging Sonar as a tool for counting adult sockeye salmon in the Adams River, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 2798.

Crump, E.S. 1952. A new method of gauging stream flow with little afflux by means of submerged weir of triangular profile. Proc. Inst. Civil Engrs. Part 1, Vol. 1. 223-242 pp.

EA Technology Ltd. 2006. Fish Counter System – User Guide Version 1.4, Guide produced for Scottish and Southern Energy.

Ladell, J., and McCubbing, D. 2013a. Fish counter enumeration of steelhead and rainbow trout on the Bonaparte River in 2011. Report submitted to Ministry of Environment, Fisheries Branch, Kamloops, BC. 25 p.

Ladell, J., and McCubbing, D. 2013b. Fish counter enumeration of steelhead and rainbow trout on the Bonaparte River in 2012. Report submitted to Ministry of Environment, Fisheries Branch, Kamloops, BC. 29 p.

McCubbing, D., and Ignace, D. 2000. Salmonid escapement estimates on the Deadman River, resistivity counter video validation and escapement estimates. MEOLP Project Report Number 2000, Vancouver, Canada.

McCubbing , D.J.F., Ward, B., and Burroughs, L. 2000. Salmonid escapement on the Keogh River: a demonstration of a resistivity counter in British Columbia. Province of British Columbia Fisheries Technical Circular no. 104, 25 pp.

McCubbing, D., and Ward, B. 2007. Adult steelhead trout and salmonid smolt migration at the Keogh River, B.C., during winter and spring 2007. Report prepared for Habitat Conservation Trust Fund. Contract #CBIO4051.

McCubbing, D., and Ward, B. 2008. Adult steelhead trout and salmonid smolt migration at the Keogh River, B.C., during winter and spring 2008. Report prepared for Habitat Conservation Trust Fund. 41 p.

McCubbing, D. 2010. Fish counter enumeration of steelhead and rainbow trout on the Bonaparte River in 2009. Report submitted to Ministry of Environment, Fisheries Branch, Kamloops, BC. 30 p.

McCubbing, D., and Lingard, S. 2013. Coho salmon adult spawner escapement estimates for the Lemieux River based on resistivity counts, 2012. Technical report prepared for Fisheries and Oceans Canada, Kamloops. 24 p.

McCubbing, D., Melville, C., Wilson, LJ, and Ramos-Espinoza, D. 2014. Lower Bridge River adult salmon and steelhead enumeration 2013. Report prepared for BC Hydro. 57 p. + 1 App.

Rakowitz, G. 2009. Didson counting - manual or automatic? Proceedings of the underwater acoustic measurements: technologies and results. Nafplion, Greece, 6pp.

Simpson, D. 1978. Electrical resistivity fish counters. *In* Rhythmic Activity of Fishes, J.E. Thorpe, ed., pp. 259-268. London: Academic Press.

Sound Metrics Corp. 2015. DIDSON Sonars. Bellevue, Washington, United States. Available from http://www.soundmetrics.com/products/didson-sonars/Software.

White, W.R. 1971. The performance of two-dimensional and flat-V triangular profile weirs. Proc. Inst. Civil Engrs. Suppl. (ii) Paper 7350 S. 48 pp.

Washburn, E., Gregory, J., and Clabburn, P. 2008a. Development of a fish counting system for fish passes. Environmental Agency Internal Report.

Washburn, E., Gregory, J., and Clabburn, P. 2008b. Using video images for fisheries monitoring. Environmental Agency Internal Report.

3.0 Software: Automating Counts and Quality Control

3.1 Existing Software

3.1.1 DIDSON Software

Sound Metric Corporation – DIDSON 300: DIDSON Display and Control Software

The DIDSON Display and Control Software (DCS) is Sound Metric’s proprietary software for the DIDSON line of multibeam sonar systems. This Windows-based software functions as the main control module and data processing software for the DIDSON. Along with a computer, DCS is required in the daily operation and data collection of sonar files (.ddf) from the DIDSON. The software is included with the purchase of a sonar unit; DIDSON purchasers can obtain future software upgrades at no additional cost.

Data Collection

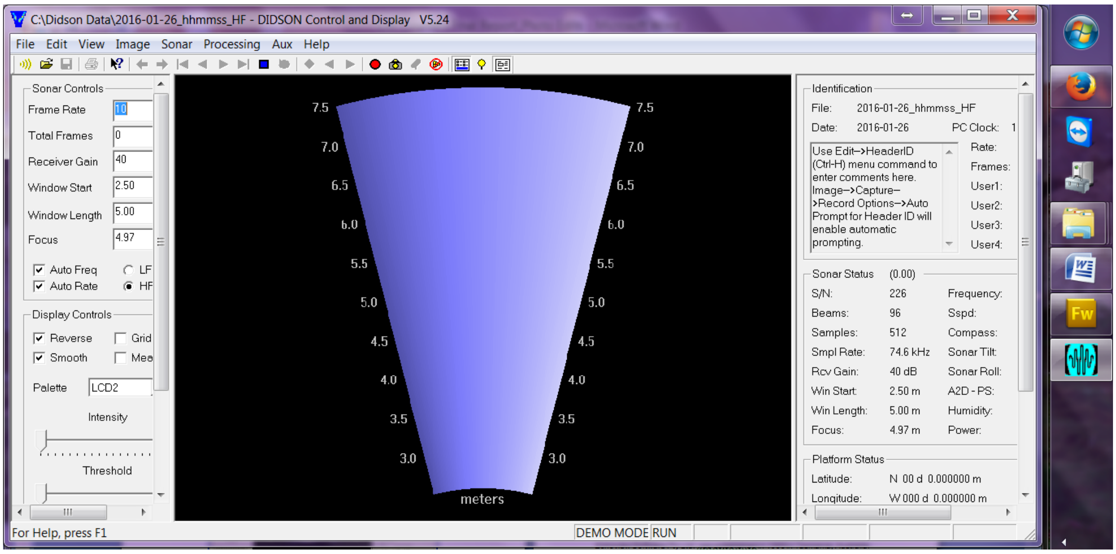
DCS can control the frequency, ping rate, duration, schedule of collection and the file size of the data collected (Martignac et al. 2014). Changing the frequency and ping rate allows for a range of image qualities. The duration and file size settings provide options for collecting smaller, more frequent, data files providing easier transfer and manipulation of data. While file corruption rarely occurs, less information is lost if the data files are small. The record scheduling setting provides users with options in subsampling. In systems where target population sizes are large, the DIDSON can be controlled by DCS to automatically collect data according to a set schedule (Maxwell and Gove 2004).

Data Processing

DCS provides the user with various tools to streamline and optimize data processing. Figure 3.1 provides a preview of the software’s interface. Below are descriptions of the notable functions:

- Background subtraction: Static repeating background is removed with this function. After the function is applied, only signals of moving objects theoretically remain, aiding in the efficiency of fish detection.
- Convolved samples over threshold (CSOT) tool: Periods of inactivity within the collected data are removed with this function. With the function applied, only periods with fish passage remain. Another function with CSOT is a size threshold (in cm^2). Once this threshold is set, objects smaller than the threshold are filtered out which enables the targeting of specific species.
- Correct transmission loss: Differences in fish echo intensity in relation to their distance from the sonar head is equalized with this function. This increases the image quality of objects at far range.

- Display echogram mode: Converts the swath-mapping (fan) display into an echogram, where the central beam is plotted in relation to distance from the sonar head in a time series.
- Mark fish: Fish length is determined automatically for a particular object selected by the user. Once selected, the data can be exported to a separate text file.
- Measure: Fish length, width and distance can be measured manually with this function.
- Playback: This function is very similar to video players. Data can be played continuously, frame by frame, in reverse, and paused. In addition, the frame rate can be adjusted to accelerate viewing speed.
- Rectangular display: Stretches the swath-mapping (fan) display into a rectangular display.
- Zoom: Magnifies the ensonified image of the users selected region.



Frame Rate 10
Total Frames 0
Receiver Gain 40
Window Start 2.50
Window Length 5.00
Focus 4.97
☑ Auto Freq ○ LF
☑ Auto Rate ● HF
☑ Reverse ☐ Grid
☑ Smooth ☐ Mea
Palette LCD2

File: 2016-01-26_hhmmss_HF
Date: 2016-01-26 PC Clock: 1
Use Edit–>HeaderID (Ctrl-H) menu command to enter comments here. Image–>Capture–>Record Options–>Auto Prompt for Header ID will enable automatic prompting.
Rate:
Frames:
User1:
User2:
User3:
User4:

Sonar Status (0.00)
S/N: 226 Frequency:
Beams: 96 Sspd:
Samples: 512 Compass:
Smpl Rate: 74.6 kHz Sonar Tilt:
Rcv Gain: 40 dB Sonar Roll:
Win Start: 2.50 m A2D - PS:
Win Length: 5.00 m Humidity:
Focus: 4.97 m Power:

Latitude: N 00 d 0.000000 m
Longitude: W 000 d 0.000000 m

Figure 3.1. DIDSON DCS interface depicting the sonar’s ensonification region.

Data Export and Analysis

Apart from the ability to export the lengths of manually selected fish, the DCS does not have the ability to automatically detect fish and export the data (Rakowitz 2009). A user is required to watch and enumerate objects that resemble fish manually using a counter (e.g., tally wacker) (Cronkite 2006). DCS’s CSOT function provides significant time savings by eliminating data with no activity. Although this function sounds beneficial in theory, we have not tested its accuracy. There have been reported cases of the CSOT eliminating data files containing target fish (H. Enzenhofer, pers. comm.; F. Martens, pers. comm.; D. Peard, pers. comm.). To the best of our knowledge, the DIDSON DCS also does not have additional analysis functions for displaying data in a graphical format.

Recommendations

Although the DIDSON DCS provides time saving functions for the enumeration of fish, the lack of an automated fish detection feature requires a large time investment for manual analysis. Third party software such as Echoview is recommended to save analysis time.

3.1.2 Echoview Software

Sonar data is typically collected in a proprietary video format developed by each manufacturer. Traditionally, the data is analyzed manually by an operator watching and identifying ensonified images or by the equipment's proprietary software. There are many advantages in using the human eye for manual enumeration of fish. The ability to discretionally recognize specific images and patterns, combined with background knowledge, enables operators to identify errors during manual analysis that may not be recognized by automated software. This must be balanced against the significant time investments required to conduct manual counting, particularly when fish migration is over an extended period of time. Software analysis of sonar data varies depending on the program being used, but in general they all share the same advantages. Software can process large amounts of data very quickly, detect anomalies the human eye cannot see, automate analysis, and offer objective results. Combining both human and automated analysis methods can generate confident estimates.

Echoview Software Pty Ltd: Echoview 6.1

Echoview Software Pty Ltd. was established in 1995 in Tasmania, Australia. Echoview 6.1 is a third party Windows-based program used for visualization and analysis of hydroacoustic data. Version 6.1 of the software was released in January 2015; a new iteration of the software is scheduled to be released in 2016. Echoview is an industry standard software package with the ability to read ensonified data in multiple proprietary sonar recording file formats such as the Simrad (EK60, ES70, EK80 and ME70), BioSonics (DT-X), HTI (Models 241 and 244), Sound Metrics (DIDSON and ARIS), Kongsberg Mesotech (M3, SM20 and EM Series), Reson (SeaBat T20, 6K, 7K and 8K Series), Furuno (FQ80, ETR-30N and FCV-30), BlueView (2D imaging sonar), RDI ADCP (Workhorse series) and ASL AZFP. For the purpose of our analysis, we evaluated Echoview using data collected by DIDSON multibeam sonars.

Template Creation in Echoview

Multibeam sonars emit sound waves directionally in a fan-like shape, collecting data that is visualized within a swath. Echoview software operates by applying virtual algorithm variables in sequential steps to yield various processing effects. An example of the data manipulation flowchart used in our analysis is shown in Figure 3.2. A data manipulation template can be created using a data file over a short time period. After the template is fine-tuned and perfected, the template can be applied to multiple data files to perform the same actions on the whole dataset, thus saving a significant amount of processing time for the user.

When a DIDSON data file is imported into Echoview, the multibeam data is displayed as a virtual echogram, where the ensonified images are stitched together into a video-like format. Ensonified objects are plotted in relation to the angle of beams and distance to the sonar head. Repeating background objects are removed using the “Multibeam Background Removal” variable (Figure 3.2). The remaining echoes are amplified using the “Beam Dilation Filter 3 x 3” variable. Next, clusters of objects in each data frame (referred to as pings by Echoview) are identified as fish by the “Multibeam Target Detection” variable. Size classes are then removed using the “Length Filter” variable. Next, the multibeam data (angle of beams vs. range to sonar) is converted into a time series of single beam data (ping vs. range to sonar) by applying the “Target Conversion” variable. This display enables Echoview to group detected clusters together into fish tracks. Lengths are colour coded in relation to time as a quality control variable using “TS Substitution Length Review”, and direction of travel is detected in relation to time using “TS Substitution Angle Review”. Creating and applying the data manipulation flowcharts is not an intuitive process. For our analysis, this was only possible after initial training (see the “Echoview training” section for an overview of time used in training). We analyzed data from two different DIDSON configurations in our case studies: Kitwanga River using a low resolution (0.7 MHz) setup, and Mitchell River using a high resolution (1.8 MHz) setup. Creating and fine tuning of the procedures described in Figure 3.2 for low resolution data took approximately 6 hours (refer to Case Study 1, Section 3.1.2) and creating and fine tuning of the flowchart for high resolution data took approximately 5 hours (see Case Study 2, Section 3.1.2).

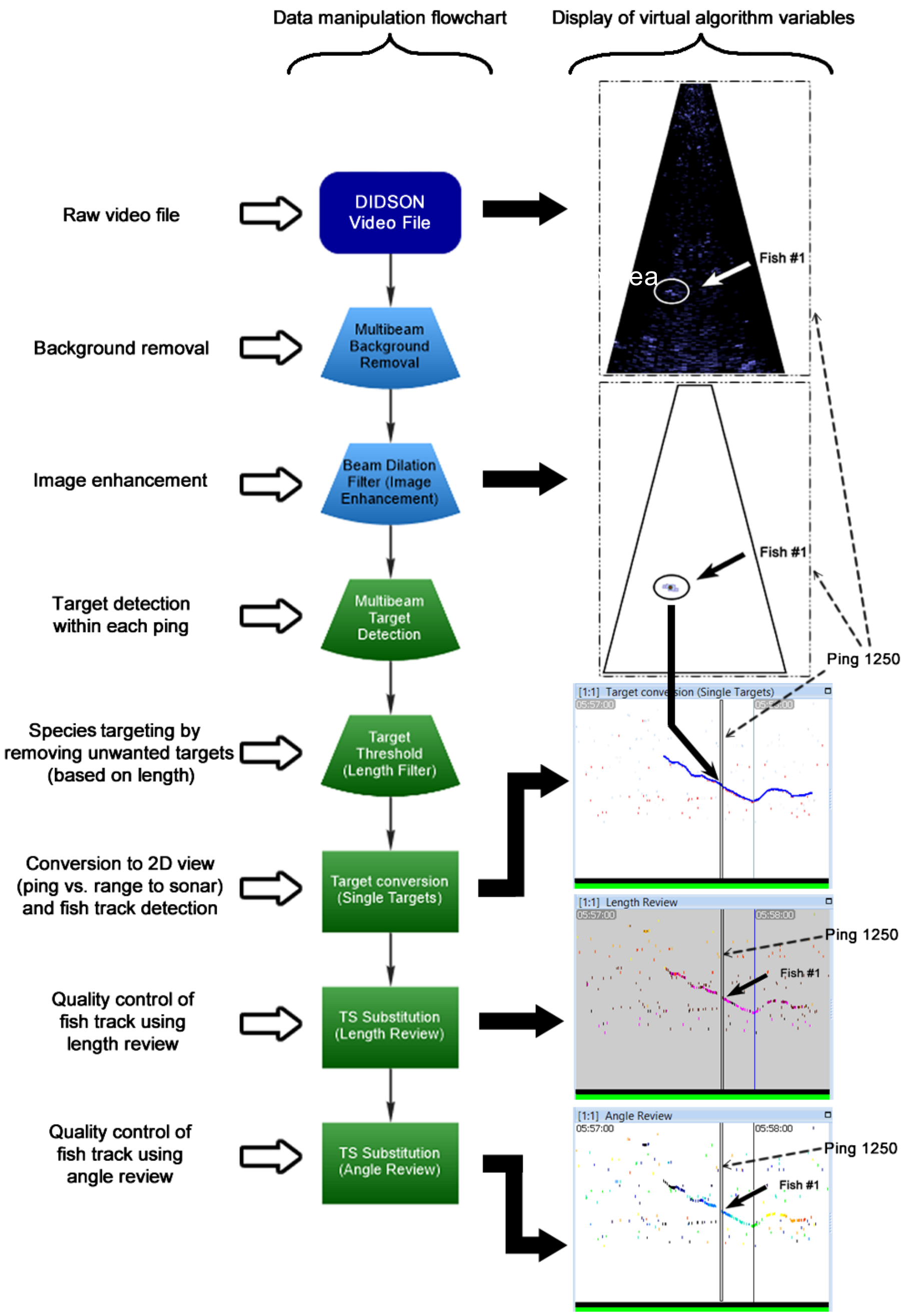


Figure 3.2. Echoview's data manipulation flowchart used in Case Study 1. (a) A single echogram ping of DIDSON data, with an image of Fish #1 ensonified. (b) Same image as (a) but with the background removed and beam dilation filters applied. Fish #1 is the only object remaining after the variables are applied. (c) Virtual echogram converted into a time series of single beam data, with each ping displayed next to one another. Ping 1250 from (a) and (b) are displayed within the thin rectangular box. The fish tracking setting is applied, showing a trace of Fish #1 in the water column in relation to time (blue line). (d) Time series of single beam data, displaying the length of each ensonified object in relation to time. The same coloration indicates objects with similar lengths. Fish #1 is shown as the purple line, and ping 1250 is displayed within the thin rectangular box. (e) Time series of single beam data, displaying the angle of each ensonified object in relation to the sonar head through time. The

full rainbow coloration indicates a track of movement from one edge of the ensonified region to the next. Fish #1 is shown as the rainbow line, and ping 1250 is displayed within the thin rectangular box.

Automating Data Analysis using Scripts

After the creation of a data manipulation flowchart, a user is required to apply the template for the detection of fish track data. Although there are already significant time savings yielded by automated analysis of the multibeam data (e.g., in contrast to watching the files in real time), the process of opening a file, applying a template and exporting fish tracks for every DIDSON data file is time consuming. Raw DIDSON data from Case Study 1 was split into 184 files (31 hours of data, 10 min each file). Data from Case Study 2 was split into 48 files (16 hours of data, 20 min each file). Applying templates for every file becomes extremely time consuming. Fortunately Echoview has the ability to automate this process by using scripts.

Echoview supports various forms of scripting language, such as: Visual Basic, Visual Basic for Applications, R, Matlab, JScript, Java script, Borland C++ Builder, Delphi, Visual C++, C# and Visual J++. By creating a script in any of the above languages, data files can be analyzed by Echoview automatically with the push of a button. The script opens each data file, applies the template, and exports the fish tracks into a .csv file without human supervision. Although the time savings of using a script for one file is trivial, it becomes significant when it is applied to many data files. In our analysis, we were able to modify an existing Microsoft Visual Basic script provided by Echoview after our initial training (see the “Echoview training” section for an overview of time used in training). Four hours were required to understand and modify the script for our case studies (refer to Case Studies 1 and 2). We were then able to pre-process data overnight without supervision. Fish tracks for Case Study 1 were completed in 116 min, and fish tracks for Case Study 2 were completed in 41 min. Time requirements for this automated analysis will vary with the processing speed of the computer.

Verification of Echoview Data

The last step of analysis is verification by the user. This step is necessary to identify whether the software’s fish track detections are true or not. Depending on the quality of the collected video data and template parameters set by the user, the efficiency of this process can vary considerably. After the verification process, the data is exported into a .csv file for further analysis. Timestamps, fish length, positioning data and many other variables can be generated and exported automatically. Although the initial template setup and this verification process are extensive, significant time savings remain as a result of using the software to perform the bulk of the analysis. With the low-resolution data (see Case Study 1), the verification averaged 1 min per fish (Table 3.1). With the high-resolution data (see Case Study 2), verification averaged around 0.5 min per fish (Table 3.2). For a comparison of Echoview to manual analysis, see section “Cost and effectiveness of Echoview analysis to manual analysis” in addition to Case Studies 1 and 2.

Table 3.1. Summary of time requirements and number of fish enumerated from Case Study 1: Kitwanga River Steelhead enumeration using low-resolution DIDSON data using Echoview.

Kitwanga River Analysis	1	2	3	4	Total
Total amount of data (hrs)	8.33	7.17	7.33	7.83	30.67
Echoview analysis					
Verification time-Echoview (hrs)	2.00	2.00	4.33	5.50	13.83
Number of fish detected-Echoview	94	96	288	322	800
Average processing time per fish (min)	1.28	1.25	0.90	1.03	1.04
Manual analysis					
Total analysis time-Manual (hrs)	4	4	4	4	16
Time savings (%)	50%	50%	-8%	-37.5%	13%

Table 3.2. Summary of time requirements and number of fish enumerated from Case Study 2: Mitchell River Sockeye migration estimation using high-resolution DIDSON data using Echoview

Mitchell River File #	1 to 24	25 to 48	Total
Total amount of video (hrs)	8	8	16
Echoview analysis			
Verification time-Echoview (hrs)	2.3	2.6	4.9
Number of fish detected-Echoview	296	395	691
Average processing time per fish (min)	0.47	0.40	0.43
Manual analysis			
Total analysis time-Manual (hrs)	3	3	6
Time savings (%)	23%	13%	18%

Total Time Estimation in a Typical Analysis

Table 3.3 depicts a summation of the total time required for fish enumeration analysis using DIDSON data. After completing our initial training (refer to "Echoview Training" section), the flowchart template and script modification were relatively simple to complete. Manual verification for both analyses required the most time. Compared to the Kitwanga River analysis (Case Study 1), the reduction in time of the Mitchell analysis (Case Study 2) was due to increased data quality and resolution.

Table 3.3. Summary of total time requirements for DIDSON data analysis using Echoview. Verification is the average time of all fish analyzed.

Case Study	Data Resolution	Flowchart Template Creation	Script Creation	Verification
Kitwanga River	Low (0.7 MHz)	6 hrs	4 hrs	Average 1 min per fish
Mitchell River	High (1.8 MHz)	5 hrs	4 hrs	Average 0.4 min per fish

Echoview Training

Since analyzing stationary multibeam sonar data is very specific, information on training time requirements is lacking. Depending on the level of sonar knowledge and scripting experience the user has, training time will vary. In our analyses, we did not have any previous sonar or scripting knowledge. We were provided with an Echoview license, DIDSON video data, and manually enumerated DIDSON data. Training was complete when we were able to replicate the information from the manually enumerated counts. Time requirements and accuracy of our results from Echoview were compared to manually enumerated data in the following case studies. An estimated cost of training for a MSS biologist is shown in Table 3.4. Note that Echoview offers a three-day training course at a rate of £575. We cannot speak to the effectiveness of this training course. Learning how to use Echoview software is broken into the following steps:

Basic Understanding – 17 hours

This step involved general familiarity with Echoview, navigating the software, reading and loading raw files, understanding echograms and interpreting virtual variables. Echoview's self-education manuals were used to facilitate this learning process.

Intricate Understanding – Additional 75 hours

This involved tasks such as adjusting filters, removing background noise, enhancing signals, detecting fish tracks, counting fish, exporting data and QA/QC of exported data. Echoview's self-education manuals, YouTube channels, a user forum and scientific literature were used to facilitate this learning process. A one-year technical support service was included with our lease of Echoview which we used extensively to facilitate the learning process.

Scripting and Automating Analysis – Additional 25 hours

This stage involved learning how to update existing Microsoft Visual Basic Scripts to enable automation of Echoview. Echoview staff provided an example script which we modified for use in both case studies.

Table 3.4. Estimation of training cost in relation to the hourly rate of a MSS biologist.

Task	Hours required for training	Cost to MSS (£50/hour)
Basic Understanding	17	£850
Intricate Understanding	75	£3,750
Scripting Knowledge	21	£1,050
Total	113	£5,650

Software Cost

Echoview is separated into 13 specific modules that can be purchased or leased separately to answer specific questions. In our analyses, six modules were required: base, bathymetric, fish tracking, stationary sonar, scripting and analysis export (see Table 3.5 for a cost summary). With the lease or purchase of a new license, Echoview includes a free 12-month maintenance and support contract (Echoview Upgrade & Support Agreement – EUSA). We found the EUSA to be invaluable and Echoview's staff were very willing to offer assistance.

Table 3.5. Cost summary of Echoview software modules used in analysis.

Modules	4-week lease cost (minimum lease period) (£)	Cost (£)
Base	206.80	1654.40
Bathymetric	206.80	1654.40
Analysis Export	523.60	4188.80
Fish Tracking	265.11	2120.96
Stationary Sonar	356.33	2850.56
Scripting	211.53	1692.16
Total	£1770.16	£14 161.28

Cost and Effectiveness of Echoview Analysis Compared to Manual Analysis

In our analyses, we found the amount of time required for Echoview's verification process to be highly variable. With the low-resolution data, the verification averaged 1 min per fish (Table 3.1). With the high-resolution data, verification averaged approximately 0.5 min per fish (Table 3.2). Data quality significantly enhanced Echoview's ability to detect fish tracks and reduced the amount of manual verification.

Manual analysis times were provided by the Ministry of Environment British Columbia (MOE) for Case Study 1; and by the Department of Fisheries and Oceans Canada (DFO) for Case Study 2 (Tables 3.1 and 3.2). Manual time estimates also included extra time used to perform quality assurance and control, and record physical data. Manual data analyses were viewed in fast-forward, ranging from 5 to 12 times the speed of normal data collection in order to save time. It should be noted that the analysis times are an estimated average, which could vary depending on the accuracy requirements and extra data (length estimates, timestamps, and signal strengths) of specific projects.

There are two main constraints operators face when manually analyzing multibeam sonar data: budget and time considerations, and effectiveness of analysis (Figure 3.3). Budget and time constraints force users to increase viewing speed of the DIDSON data in order to complete the analysis on time. This typically results in reductions in the effectiveness of fish counts resulting in missed or misidentified fish (refer to Case Study 1). Increased effectiveness is achieved by reductions in viewing speed, resulting in additional time and costs (refer to Case Study 2). From our analyses, Echoview balances the trade-off between these two constraints by providing objective results in a relatively short period of time.

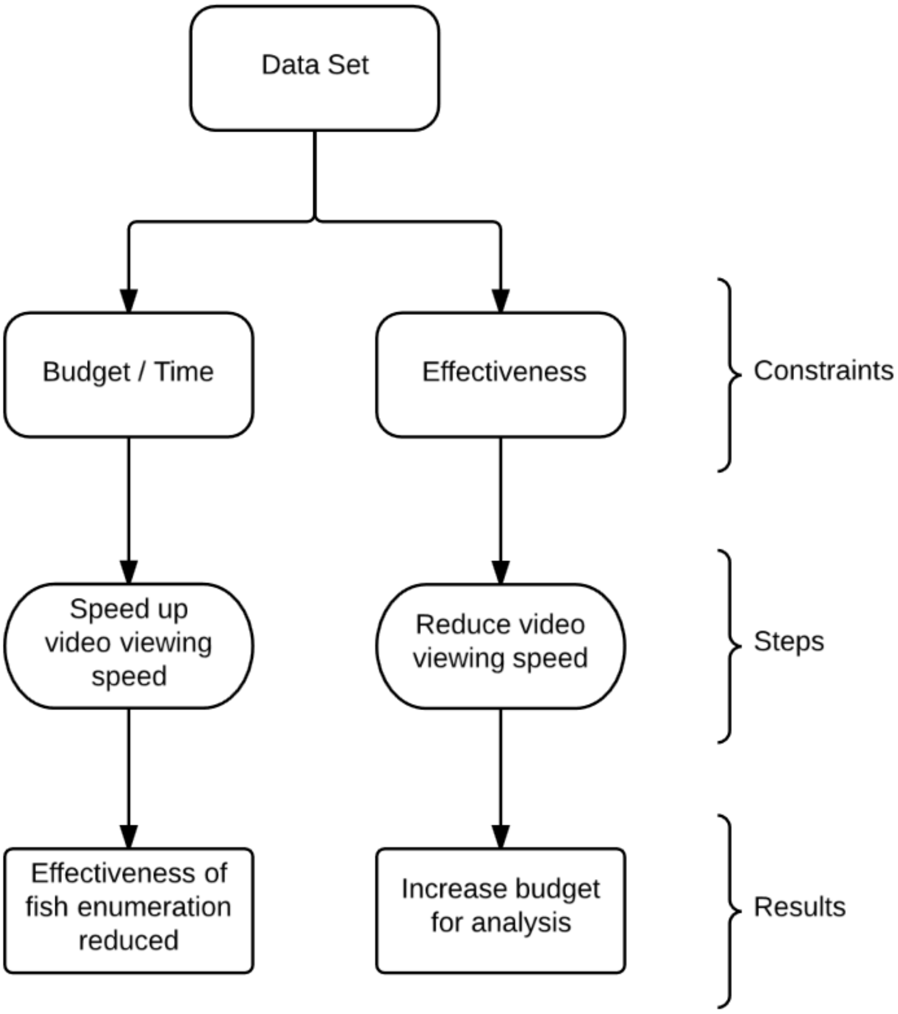


Figure 3.3. Flowchart illustrating budget and effectiveness trade-off in manual analysis.

Echoview Advantages

Echoview has the ability to apply templates to data in subsequent years or data from similar sites. Since sonar deployment sites are typically stationary, the physical characteristics of a site are similar every year. Thus, applying a set template to similar data is relatively easy and requires only minor modifications. Compared to manual methods, the use of Echoview also integrates an objective method into analyses. Since manual analysis of a DIDSON dataset would require multiple people, additional error could be incorporated into estimates as a result of different interpretations of the data. Once an Echoview template and script are created, it is relatively easy for a trained Echoview user to instruct a naïve user to perform manual verification. This eliminates the need to fully train all staff in the use of Echoview. Echoview also has the ability to interpret fish tracks that are impossible to detect by the naked eye with low-resolution DIDSON data. This aspect is further explored in Case Study 1.

Echoview Disadvantages

There are some disadvantages in the use of Echoview. The initial investment in Echoview is relatively high. The amount of cost savings after the initial investment is dependent on the duration and number of projects the software can be applied to. While the software has the ability to identify and determine the lengths of moving objects in hydroacoustic data, it becomes problematic when the migration density of fish is high (Case Study 2). Fish that are too close together are often ensonified as one object; while teasing apart the fish signal is possible, it is a time consuming task. The additional time required to perform this task may not be as efficient compared to manually analyzing the data. Moreover, the length estimates from these fish may be inaccurate as the signals are mixed together and difficult to separate. In Case Study 1, we found the DIDSON lacks the ability to detect smaller fish at distances further than 15 m. Due to the decreased signal sizes at long ranges, fish sizing seemed to be inaccurate under long range detection. While this may not be a fault in Echoview, it should be noted that Echoview's results are completely dependent on the quality of the raw DIDSON data.

3.1.2.1 Case Study 1 – Kitwanga River Steelhead Enumeration Using Low Resolution (0.7 MHz) DIDSON Data

Introduction

Ministry of Environment of British Columbia (MOE) collected abundance data for summer steelhead (*Oncorhynchus mykiss*) using a DIDSON hydroacoustic system. Such data is important for management purposes, however, the cost of analyzing the DIDSON data from the Kitwanga River are prohibitive due to the high number of person hours required to interpret data. Enumerating the migration of steelhead in the river requires manual analysis of the DIDSON data, where an operator watches the DIDSON video and counts the fish observed. Every fish in the video are interpreted and measured to determine the species and other physical data, and requires the operator to watch the video in real time. Time constraints do not make it practical to perform a manual analysis on an annual basis. Therefore, Echoview software was tested to determine the feasibility of using it as a cost-effective tool for the data analysis component. The goal of this study is to compare the effectiveness and efficiency of manual enumeration to semi-automated enumeration using Echoview. The efficiency analysis is reported in Section 3.1.2; the accuracy analysis is reported below. The DIDSON raw data and manually-derived results were provided by MOE.

Methods

Study Site

The Kitwanga River is a fifth-order river in the lower Skeena watershed in the North West region of British Columbia, Canada. Kitwanga is a small but biologically-rich river system, with a total mainstem length of 59 km and a drainage area of approximately 83 000 hectares (Cleveland, 2000). The Kitwanga River supports six species of Pacific salmon, including Chinook salmon (*O. tshawytscha*), chum salmon (*O. keta*), coho salmon (*O. kisutch*), sockeye salmon (*O. nerka*), pink salmon (*O. gorbuscha*), kokanee salmon (*O. nerka*) and steelhead (*O. mykiss*). Resident rainbow trout (*O. mykiss*), cutthroat trout (*O. clarki*), Dolly Varden (*Salvelinus malma*), bull trout (*S. confluentus*), mountain whitefish (*Prosopium williamsoni*) and various other species of coarse fish also reside in the river (Grieve and Webb, 1997). Kitwanga summer-run steelhead typically commence their spawning migration into Kitwanga River from mid-April until the end of May, during freshet flows.

DIDSON Installation

All raw data was collected by MOE from 20 April to 30 May 2013 using a DIDSON 300 sonar unit (Sound Metrics Corp.). River substrate consists of cobble to small boulders, with no large woody debris at the sample site. Water velocity averaged around 1.5 m/s during peak flows. Hydraulic conditions at the DIDSON site were laminar and unidirectional. The river cross sectional wetted width was approximately 26 m, with an average water depth ranging 0.05 to 0.5 m, and maximum depth of 1.2 m at peak freshet. Water clarity was variable, with clarity decreasing significantly during freshet flows. The counter was mounted on a specially designed metal frame, anchored to the river bottom, angled to ensonify the water column from bank to bank. Data was collected on the low frequency setting (0.7 MHz) with a capture range of 0.83 to 40 m in front of the sonar head. A 1.5 m diversion fence was mounted perpendicular to the river channel to divert steelhead a minimum of 1 m from the DIDSON to ensure steelhead migrate within the field of view. The fence was located approximately 0.4 m downstream of the DIDSON counter, anchored to concrete lock blocks on river left. A concentration lens was attached to the DIDSON to focus the beams into the appropriate water depth for the site of the counter, providing a data capture angle of 29° horizontal by 3° vertical (pers. comm. D. Peard). DIDSON data was collected using Sound Metric Corp's proprietary Display and Control Software (DCS). The DIDSON DCS was set to record a new file every 10 minutes. 184 files collected between 20 April to 26 April 2013 were used in IFR's comparative analysis. This subset of data was chosen by IFR staff because it represented a range of daily steelhead migration rates (10 to 280 fish per day).

Manual Analysis

The manual enumeration of steelhead was completed by biologists. 184 DIDSON data files were analyzed by watching each file using DIDSON DCS. For the purpose of enumerating steelhead, only fish greater than 83 cm in length were identified as steelhead and included in the escapement estimate. All fish measured as less than 83 cm in the DCS software were intentionally untracked and not recorded. The biologist manually measured each fish that migrated past the sonar beam and determined its length, using the measurement tool provided by the software. If the fish was deemed longer than 83 cm, a timestamp, fish length, distance from sonar head, and direction of travel were recorded. The total amount of time estimated to analyze the data manually was recorded for comparison (See Section 3.1.2).

Echoview Analysis

Echoview (Version 6.1, Echoview Software Pty Ltd.) was used for the semi-automated enumeration of steelhead. Following the steps described in Section 3.1.2 - “template creation in Echoview”, “automating data analysis using scripts”, and “manual verification of Echoview data”, the same 184 DIDSON data files used in the manual analysis were evaluated. Timestamps, lengths, distance from sonar head, and direction of travel of all fish seen by Echoview were exported into Microsoft Excel, and no size cut-offs for steelhead were used in the Echoview analysis.

Comparative Analysis

Using the timestamps and distance from sonar head, fish identified in the manual analysis were matched with fish identified in the Echoview analysis. Graphs of fish identified by the two methods were plotted using R (R Development Core Team 2009). Fish lengths and signal strength data plotted were determined by Echoview. Note that all fish identified through the manual enumeration method were identified by Echoview, suggesting that Echoview was at least as efficient as manual enumeration in detecting fish.

Results and Discussion

Fish Length and Distance from Sonar

Fish detected by the manual analysis were all determined to be greater than 83 cm, while length estimates generated by Echoview show the determined targets vary above or below 83 cm (Figure 3.4). Only fish greater than 40 cm (determined by Echoview) were plotted in our analysis, as virtually all fish below 40 cm were not tracked in the manual analysis. This suggests fish below 40 cm were purposely untracked as they did not resemble the target species (steelhead, if > 83 cm). Between 0.83 to 9 m from the sonar (near-bank), a number of fish determined by Echoview to be only above 40 cm were detected by manual analysis as greater than 83 cm. Between 9 to 18 m from the sonar (mid-river), and 18 to 26 m from the sonar (far-bank), manual detection appeared to decrease in comparison to Echoview’s detections. In general, there was also a decrease in the variance of fish size as distance from the sonar head increased; this was shown by a general lack of fish in the far-bank section below 50 cm and above 80 cm in length observed by Echoview. These results were likely due to a reduction of signal strength with increasing distance from sonar, leading to a lower detection probability (Figure

3.6). The decrease in signal strength may lead to a reduction in image quality, potentially causing length inaccuracies that lead to target species misidentification.

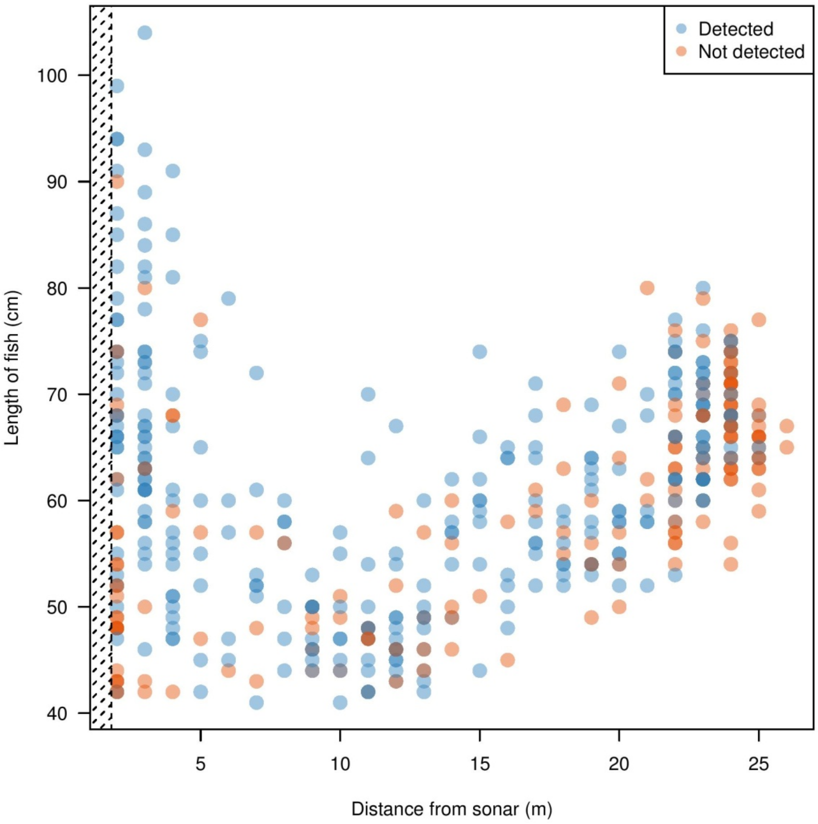


Figure 3.4. Estimated fish lengths using Echoview in relation to distance from sonar. The variance in Echoview-measured fish sizes decrease as the distance from the sonar increases. Blue points are fish detected by Echoview and identified as the target species (steelhead, > 83 cm) by manual analysis. Note the high number of blue points measured to be < 83 cm by Echoview, suggesting that the manual estimates of size differ in comparison to Echoview estimates of size. Orange points are all other fish detected by Echoview, and represent fish that are either missed by manual counts, or assumed to be < 83 cm during manual analysis and therefore not tracked. The hashed area illustrates an area not ensonified by the DIDSON, located between 0-0.83 m from the sonar head. A 1.5 m diversion fence diverts fish at a minimum of 1 m to ensure migration is within the field of view. Only fish > 40 cm determined by Echoview are plotted, as fish < 40 cm were purposely not tracked in the manual method since they were not the target species.

Signal Strength and Fish Length

Figure 3.5 further illustrates the difference of the 83 cm fish size cut-off generated by the manual analysis; the length estimates generated by both methods were significantly different. Using data from Echoview, fish length was not a determining factor of signal strength, as signal strength generally ranged between 80 to 90 decibels (dB) across all lengths of fish. Signal strength indicated that 90 dB was the maximum strength that can be attained by any size of fish. Most fish with high signal strength seemed to have a higher probability of detection in the manual analysis, as it translated to a better quality image. The lack of fish detected with signal strengths less than 80 dB suggested that any objects or fish below this threshold were undetected by both the manual and Echoview analyses, or were not ensonified by the DIDSON counter.

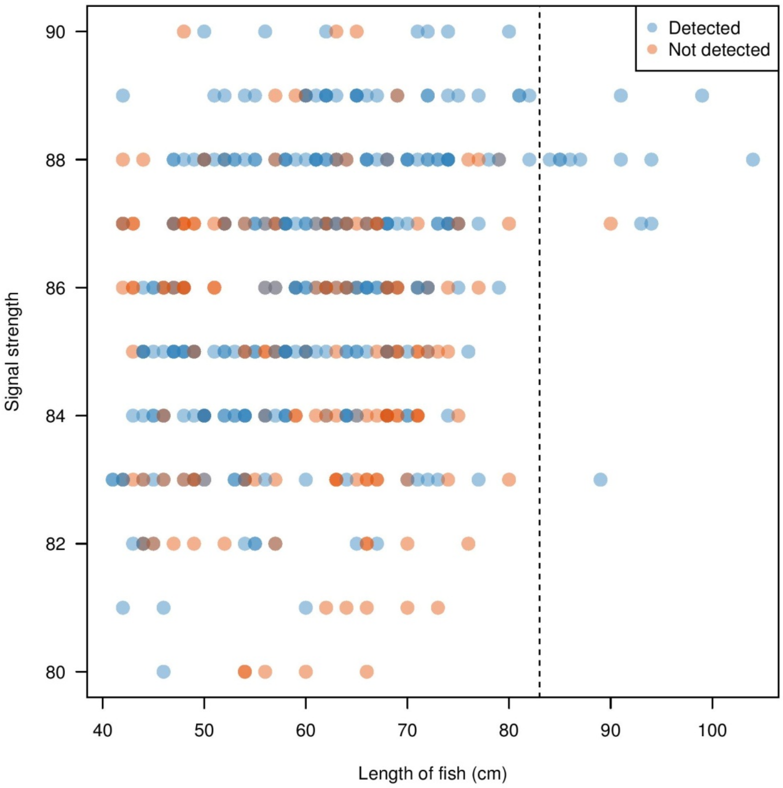


Figure 3.5. Signal strength in relation to fish length as determined by Echoview. Blue points are fish detected by Echoview and identified as the target species (steelhead, > 83 cm) by manual analysis. Orange points are all other fish detected by Echoview, and represent fish that are either missed by manual counts, or assumed to be < 83 cm during manual analysis and therefore not tracked. The dotted line illustrates the established 83 cm fish size cut-off for manual analysis. note the high number of blue points measured to be < 83 cm by Echoview, suggesting manual estimates of size differ in comparison to Echoview estimates of size. Only fish > 40 cm determined by Echoview are plotted, as fish < 40 cm were purposely not tracked in the manual method since they were not the target species.

Signal Strength, Fish Length, and Distance from Sonar Head

Figure 3.6 reiterates the trends shown in Figure 3.5, but separates the detection by distance from sonar. Data generated by Echoview show fish migrating 0 to 9 m from the sonar head (Figure 3.6a) had a signal strength range of 83-90 dB. Fish migrating between 9 to 18 m and 18 to 26 m (Figure 3.6b and c, respectively) had a signal range of 80-90 dB. For manual analysis, there was a decrease in detection probability as distance from sonar increased.

Signal strength was consistently high for all lengths of fish and did not increase with fish length in the 0 to 9 m section (Figure 3.6a). High signal strength typically provided a clearly ensonified video image, which translated into a high proportion of fish detected for both methods of enumeration. For fish above 80 cm, migration only occurred between 0 and 9 m from the beam, however this may have been an artifact of the low frequency data collected. Signal strength started to decline from the upper threshold at 9 to 18 m away from the sonar (Figure 3.6b) and continued to decline at 18 to 26 m away from the sonar (Figure 3.6c). Due to the signal strength's positive correlation with a high image quality, it is evident that fish with lower signal strengths were not detected during the manual analysis. There is a possibility that fish in the far end of the ensonified region may have appeared shorter during the manual analysis due to images not fully ensonifying. This may have resulted in an under representation in length, causing the fish to appear less than 83 cm and not tracked as a steelhead. Steelhead (> 83 cm) could still be moving in the far-bank, but their length measurements may simply be inaccurate.

Manual Count Effectiveness, Signal Strength and Distance from Sonar

The probability of a fish being detected through manual analysis increased with greater signal strength (Figure 3.7). Through IFR's own visual observations, Echoview's detection of increase in signal strength typically translated to a clearer image of fish in the DIDSON data. This could explain why there was an increase in proportion of counts detected during the manual analysis in relation to stronger signal strengths. Manual detection probability decreased with an increase in distance from the sonar (Figure 3.8). The inability to see fish during the manual analysis, or fish appearing to be smaller than target size due to low signal strengths, could explain the decrease in proportion of counts detected at farther distances from the sonar (Figure 3.9).

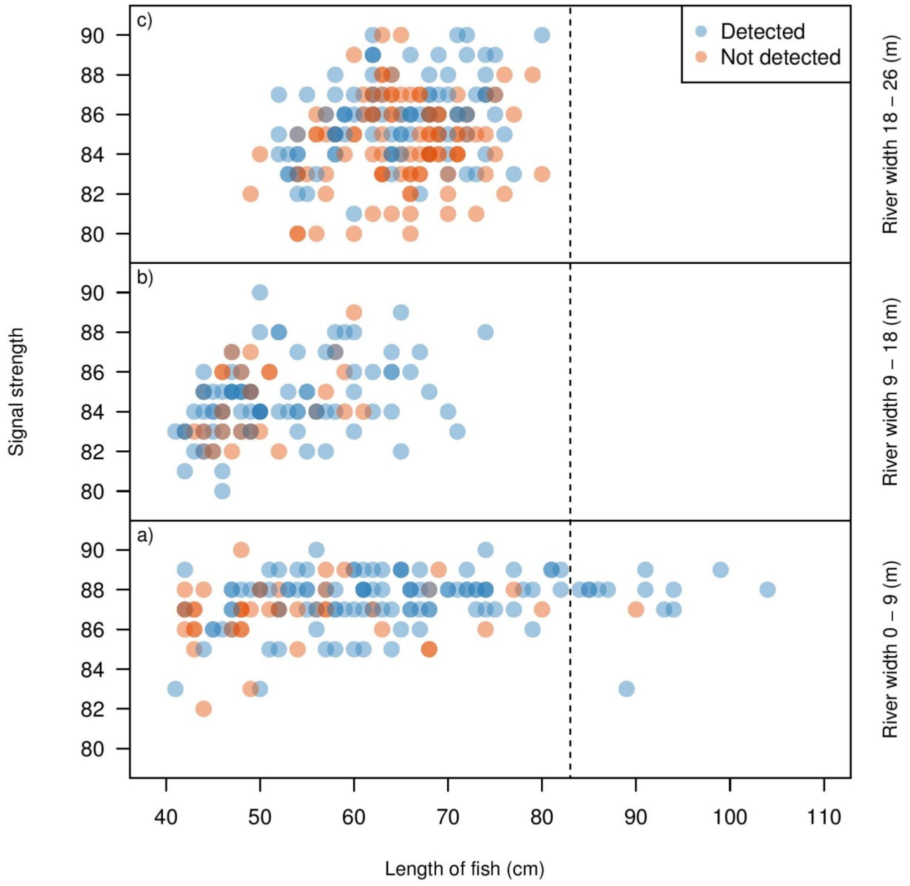


Figure 3.6. Signal strength in relation to estimated length as determined by Echoview. The variance in Echoview measured fish sizes decrease as the distance from the sonar increases. Blue points are fish detected by Echoview and identified as the target species (steelhead > 83 cm) by manual analysis. Note the high number of blue points measured as < 83 cm by Echoview, suggesting manual estimates of size differ greatly in comparison to in comparison to Echoview estimates of size. Orange points are all other fish detected by Echoview, and represent fish that are either missed by manual counts, or assumed to be < 83 cm during manual analysis and therefore not tracked. Only fish > 40 cm determined by Echoview are plotted, as fish < 40 cm were purposely not tracked in the manual method since they were not the target species.

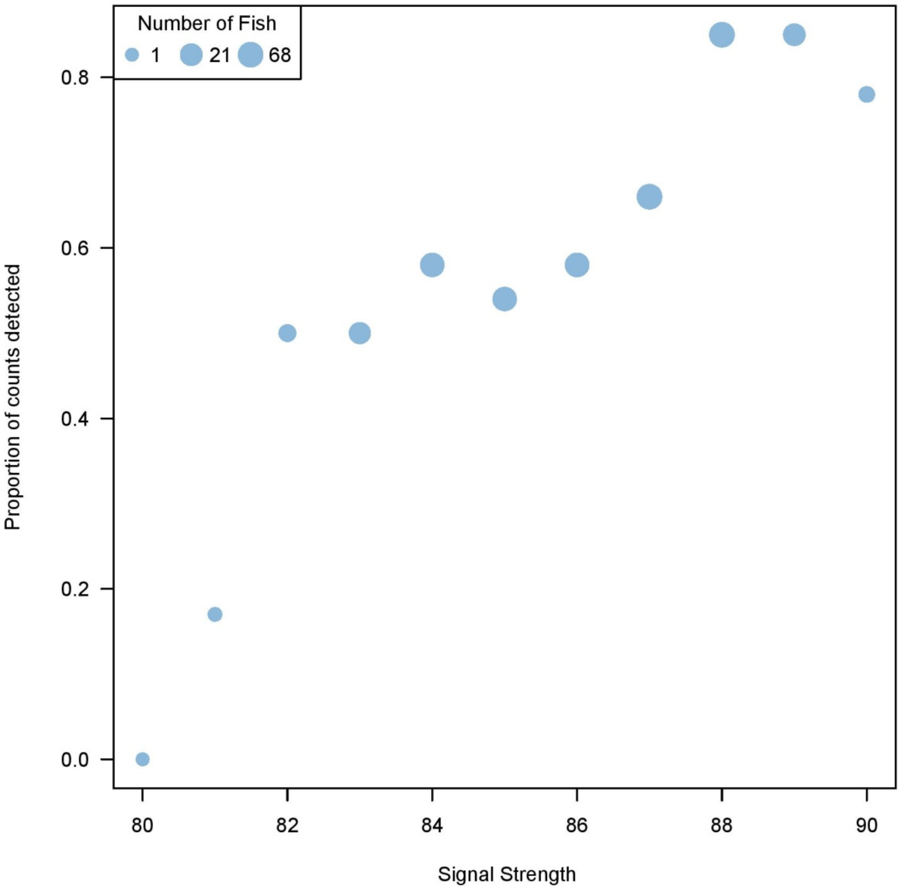


Figure 3.7. Proportions of counts detected in manual analysis increase relative to signal strengths, as determined by Echoview. Only fish > 40 cm determined by Echoview are plotted, as fish < 40 cm were purposely not tracked in the manual method since they were not the target species.

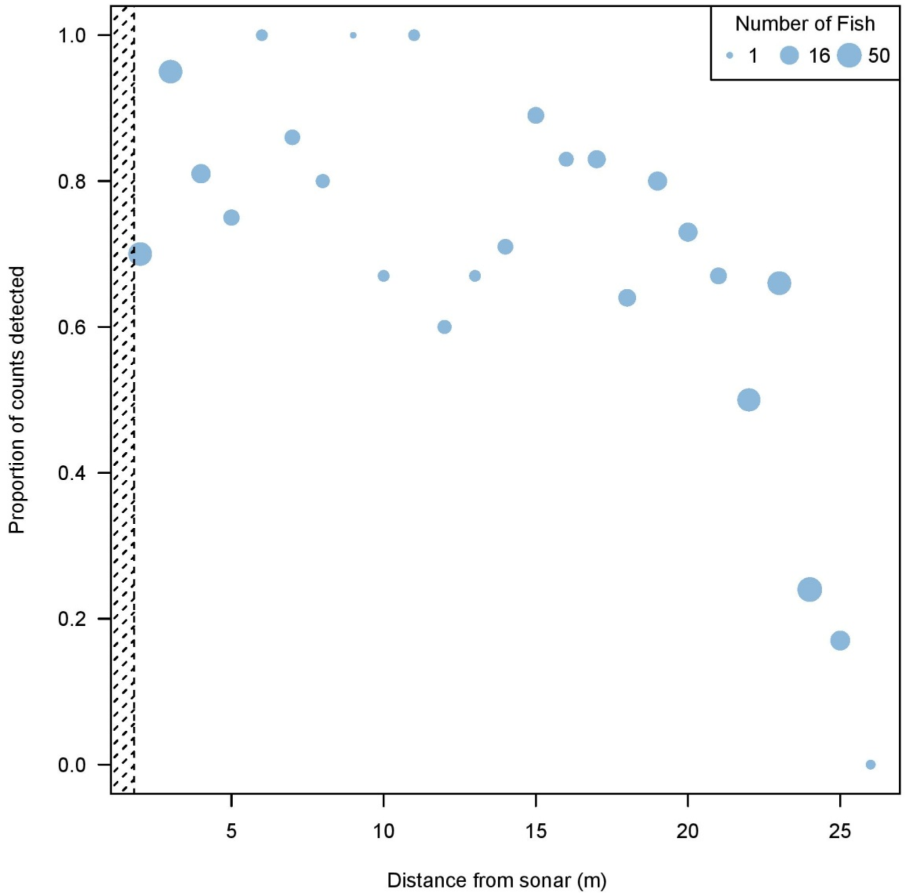


Figure 3.8. Proportion of counts detected in manual analysis decrease relative to an increase in distance from sonar. The hashed area illustrates an area not ensonified by the DIDSON, located between 0-0.83 m from the sonar head. A 1.5 m diversion fence diverts fish at a minimum of 1 meter to ensure migration is within the field of view. Only fish > 40 cm determined by Echoview are plotted, as fish < 40 cm were purposely not tracked in the manual method since they were not the target species.

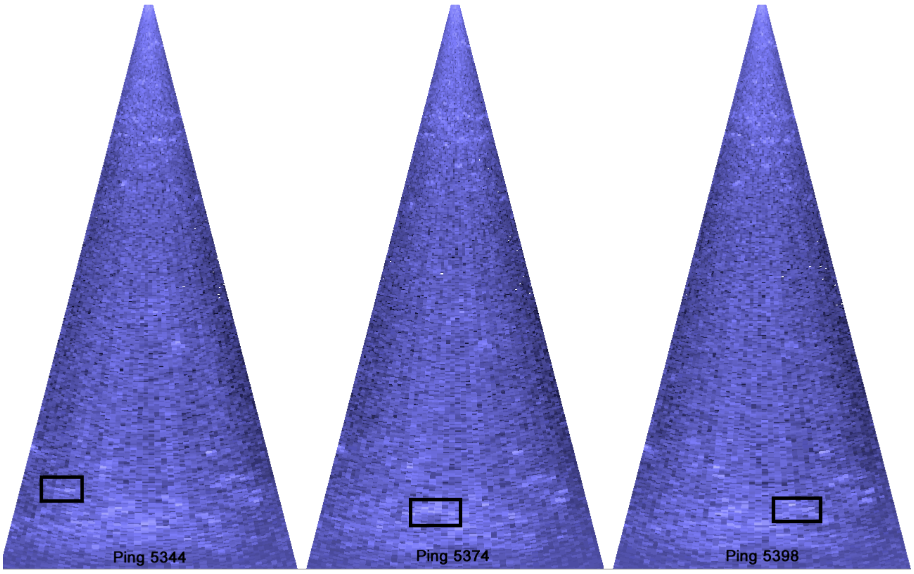


Figure 3.9. Sequential frames showing a fish migrating through the DIDSON imaging region at an average of 25 m away from the sonar head. Plots illustrate the difficulty of identifying fish manually at greater distances from equipment.

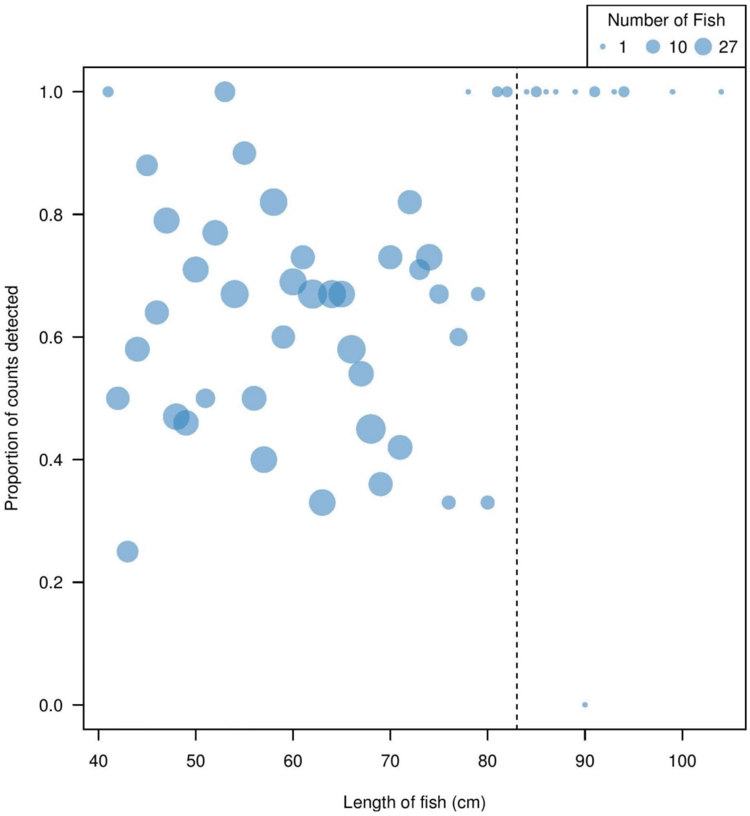


Figure 3.10. Proportion of counts detected in manual analysis increase relative to greater fish length, as determined by Echoview. The dotted line illustrates the established 83 cm fish size cut-off for manual analysis in enumerating Steelhead. Only fish > 40 cm determined by Echoview are plotted, as fish < 40 cm were purposely not tracked in the manual method since they were not the target species.

Manual Count Effectiveness and Fish Length

Fish determined to be above 80 cm by Echoview had a high proportion of counts detected as > 83 cm in manual analysis. The detection was likely high because fish determined to be > 80 cm by Echoview looked significantly larger on the DIDSON display (Figure 3.10); it was unlikely they would be missed. For fish determined to be 40 to 80 cm by Echoview, a portion of the fish were considered to be > 83 cm by manual analysis while the rest were considered to be below. This inconsistency in sizing was likely due to the inability of the human eye to decipher small differences in length.

Conclusions

We found various inconsistencies in fish length determination between the two methods of analysis using low resolution DIDSON data. Since we do not have true lengths of fish data collected, length accuracy of both analysis cannot be validated. We can only conclude that there was a difference of lengths generated between the two methods. Although there are shortcomings in the software's ability to analyze fish data (e.g., low signal strengths translated to potentially inaccurate length analysis), we felt that Echoview provided an objective and automated approach in determining length. There was a reduction in effort and increase in objectivity in the results when Echoview was used. It should be noted for the most part, Kitwanga River steelhead move in a single file pattern and the Echoview software functions optimally with this type of data. If the migration pattern changed into a cluster-like formation, the efficiency of Echoview's fish detection algorithm can change significantly (see Case Study 2 below).

3.1.2.2 Case Study 2 – Mitchell River Sockeye Enumeration Using High Resolution (1.8 MHz) DIDSON Data

Introduction

The Mitchell River is one of three major spawning areas for sockeye salmon (*Oncorhynchus nerka*) of the Quesnel River system in British Columbia, Canada. The river is a sixth-order stream located in the Cariboo Mountains Wilderness Park, east of Quesnel in central British Columbia. The Mitchell River supports five species of Pacific salmon, including Chinook (*O. tshawytscha*), coho (*O. kisutch*), sockeye (*O. nerka*) and steelhead (*O. mykiss*). Resident rainbow trout (*O. mykiss*), Dolly Varden (*Salvelinus malma*), bull trout (*S. confluentus*), mountain whitefish (*Prosopium williamsoni*) and various other species of coarse fish are reported in Fish Inventories Data Queries (accessed 20 June 2015). Sockeye salmon typically migrate from late August to late September. While sockeye typically move in a single file formation in this system, there are some instances where clusters of fish move past the sonar head at once. In 2009, a DIDSON hydroacoustic sonar was used to collect migration data on this population. Data were manually enumerated, where DIDSON data was reviewed to enumerate the number of fish that swam past the sonar head. For the purpose of this report, we analyzed the same DIDSON data using Echoview to determine the accuracy and efficiency of the software program. Raw data and manual count results were provided by Fisheries and Oceans Canada (DFO). The efficiency of using Echoview as a data analysis tool is reported in Section 3.1.2.

Methods

Site Characteristics and DIDSON Installation

The DIDSON unit was deployed approximately 1 km downstream of spawning grounds and 7 km upstream of Quesnel Lake (UTM: 10 U 648388 5853209). River substrate consisted of silt to large gravel with some large woody debris and in-stream vegetation on the left bank. Water velocity ranged between 1.0-2.0 m/s with a gradient of < 1%. Flow pattern at the DIDSON site was laminar and unidirectional with no obvious turbulence and a water depth of 1.5 m through the ensonified area. The stream cross section was planar, with a wetted width of approximately 35 m. Two weirs were installed on each bank to limit the fish migration corridor to 10 m in width. Water clarity was generally high, but turbidity increased during high rain events. Data was collected using a DIDSON 300 sonar unit (Sound Metrics Corp.). The unit was deployed using a modified ladder and adjustable pole mount (Enzenhofer and Cronkite 2005) and angled approximately -10° to -12°. By reducing the migration corridor to 10 m, the DIDSON could be deployed at the high frequency setting (1.8 MHz) to collect high-resolution images collected at 4 frames per second (fps). Forty-eight data files, each 20 minutes in duration, were collected on 1 and 2 September 2009 and used in IFR's comparative analysis (one 20 min file from every hour over 48 hours). Manual sockeye enumeration was completed by DFO, and enumeration using Echoview was conducted by IFR.

Manual Enumeration

A modified manual fish counting method described in Cronkite et al. (2005) was used by DFO. Fish were counted using a hand held counter (e.g., tally whacker) and both upstream and downstream counts were entered into a Microsoft Excel spreadsheet. Fish that moved towards, and crossed, the upstream edge of the ensonified area were counted upstream, whereas fish that crossed the downstream edge of the ensonified area were counted downstream. At the discretion of the operator, fish that visually appeared to be the correct species were enumerated. Files were analyzed at 60 to 80 fps (fast forward) during low migration periods, and the fps rate was lowered during periods of high migration. Of the 48 data files analyzed, 20 files were re-analyzed at random to determine operator accuracy; if these counts were different, an average of enumerated numbers was used. Time required to manually enumerate fish was provided by DFO. All data files were analyzed using the DIDSON display and control software (DCS) provided by Sound Metrics Corp. The following features available in the software package were used in the analysis (Cronkite et al. 2005):

- Background subtraction
- Transmission loss correction

- Echogram
- Mark fish
- Measure
- Rectangular display
- Zoom

Software Enumeration

Echoview was used for this analysis. Following the steps described in Section 3.1.2, IFR analyzed the same 48 data files used in the manual enumeration. Timestamps, lengths, distance from sonar head and direction of fish travel were exported into Microsoft Excel. The total amount of time required to analyze the data was logged for comparison.

Comparative Analysis

Due to the low number of co-migrant species and high number of sockeye salmon, timestamp, length, and distance from sonar data were not collected. Fish from both analyses could not be paired up for a direct comparison. Only the total number of fish from each analysis was compared.

Results and Discussion

The total number of manually counted up and down fish were 627 and 110, respectively. The total number of Echoview counted up and down fish were 623 and 68, respectively. The difference in the number of observed up counts ranged between 0 and 9, while differences between down counts ranged between 0 and 14 for the two methods. Manual and Echoview comparisons are presented in Table 3.6 and Figures 3.11 and 3.12.

Table 3.6. Comparison of fish counts in manual and Echoview analysis files.

File #	Length (min)	UP			DOWN		
		Manual enumeration	Echoview enumeration	Difference	Manual enumeration	Echoview enumeration	Difference
1	20	21	25	-4	5	2	3
2	20	24	25	-1	5	3	2
3	20	34	32	2	4	3	1
4	20	20	21	-1	2	1	1
5	20	22	24	-2	1	0	1
6	20	12	12	0	4	1	3
7	20	7	10	-3	0	0	0
8	20	0	1	-1	0	0	0
9	20	0	0	0	0	0	0
10	20	0	1	-1	0	0	0
11	20	0	3	-3	0	0	0
12	20	0	0	0	0	0	0
13	20	0	0	0	0	0	0
14	20	0	0	0	0	0	0
15	20	0	0	0	0	0	0
16	20	0	0	0	0	0	0
17	20	0	0	0	0	0	0
18	20	0	0	0	0	0	0
19	20	0	0	0	0	0	0
20	20	0	0	0	0	0	0
21	20	0	1	-1	0	0	0
22	20	43	43	0	10	5	5
23	20	44	41	3	19	5	14
24	20	33	34	-1	2	3	-1
25	20	26	17	9	6	4	2
26	20	34	30	4	0	3	-3
27	20	31	22	9	2	6	-4
28	20	19	14	5	4	1	3
29	20	17	12	5	0	0	0
30	20	28	22	6	3	7	-4
31	20	6	7	-1	3	1	2
32	20	25	24	1	2	2	0
33	20	1	6	-5	0	0	0
34	20	0	3	-3	0	0	0
35	20	0	4	-4	0	0	0
36	20	0	2	-2	0	0	0
37	20	0	1	-1	0	0	0
38	20	0	0	0	0	0	0
39	20	1	1	0	0	0	0
40	20	20	20	0	0	0	0
41	20	0	0	0	0	0	0
42	20	0	0	0	0	0	0
43	20	0	0	0	0	0	0
44	20	0	0	0	0	0	0
45	20	10	14	-4	3	3	0
46	20	85	82	3	22	8	14
47	20	32	34	-2	8	8	0
48	20	32	35	-3	6	2	4
Sum	960	627	623	4	110	68	42

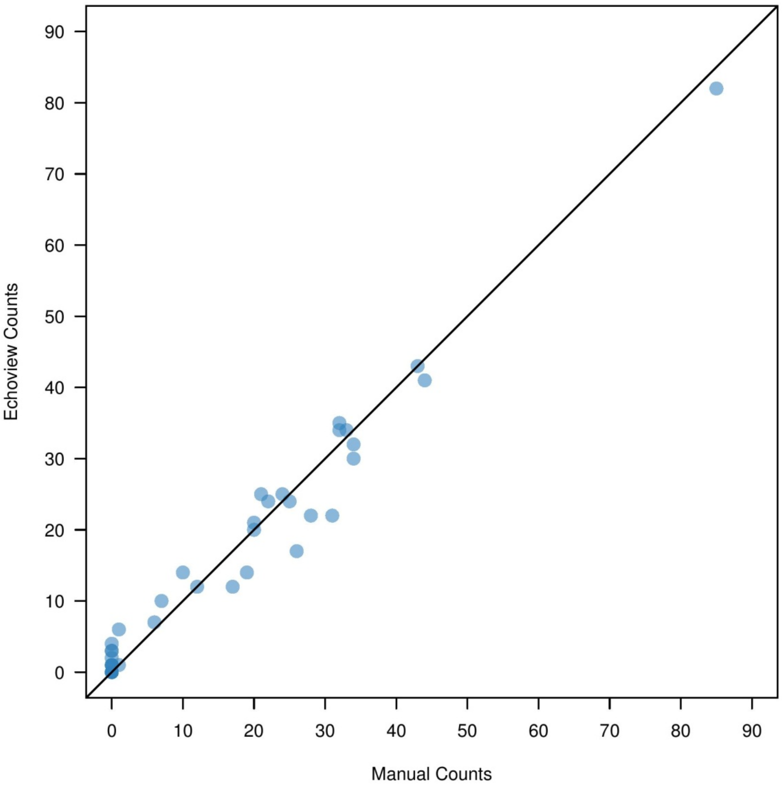


Figure 3.11. Comparison of up count fish between Echoview and manual analysis. Each point represents a separate analysis file.

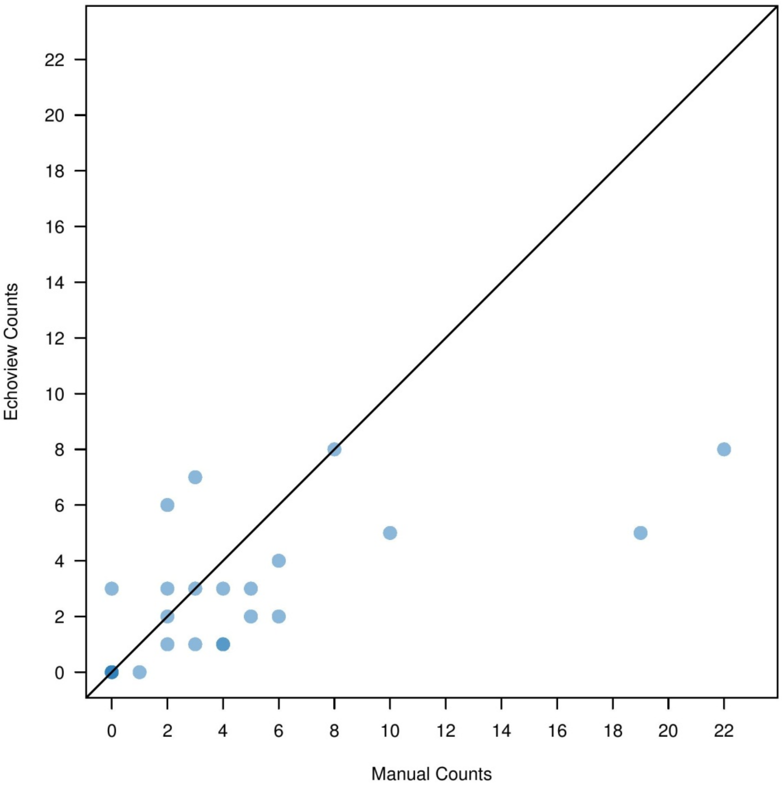


Figure 3.12. Comparison of down count fish between Echoview and manual analysis. Each point represents a separate analysis file.

It is difficult to determine the exact reason for the count discrepancies between the two methods. Assumptions made by the DFO operator performing manual counts could have generated the observed difference in fish numbers. Since species identification was determined visually by estimating fish size, misidentification would result in different numbers of fish detections in the manual analysis. By watching the data at 60-80 fps manually, fish could have been overlooked during periods of low migration. The averaging of counts for files that were re-analyzed during the manual enumeration may also explain differences in fish numbers. High migration periods caused both methods to have difficulty determining fish numbers within a moving cluster (Figure 3.13). For manual counts, the number of detected fish in these clusters could be subjective based on the operator's ability to track every fish (Figure 3.13). In Echoview, it was equally difficult to determine the number of fish in clusters (e.g., ≥ 5 migrating). By watching the raw video while analyzing fish tracks, we had enough information to tease apart the majority of fish signals, but this was very time consuming and also somewhat subjective. In general, difficulty increased when individuals passed through the ensonified region in a cluster.

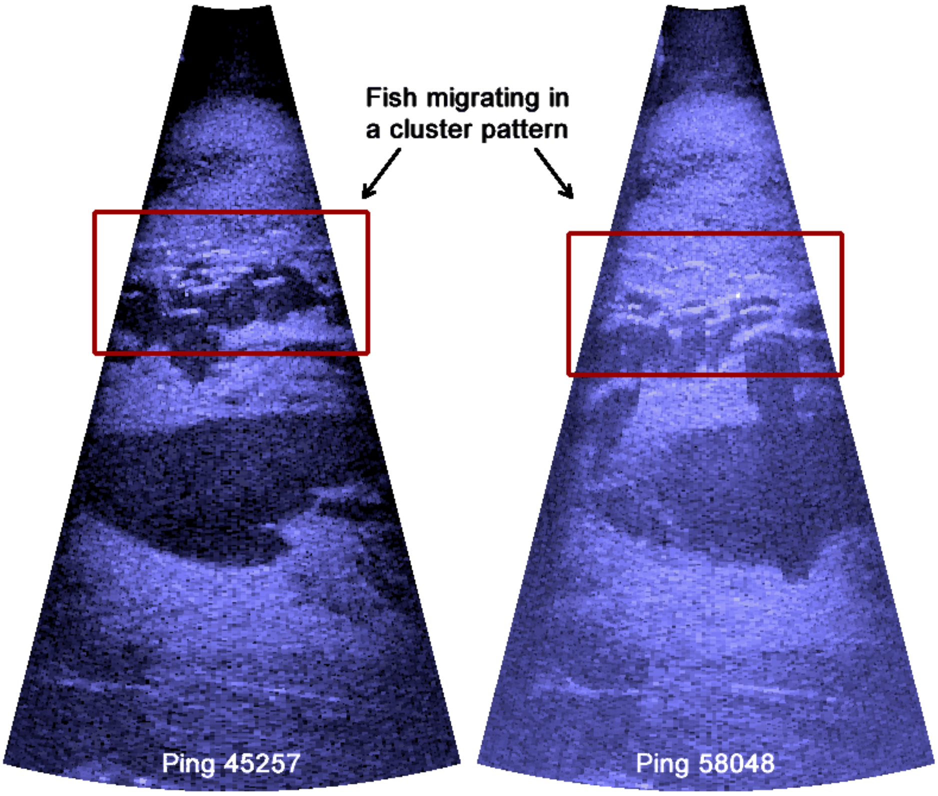


Figure 3.13. Raw DIDSON data during high migration periods, where sockeye salmon moved in a cluster formation. Both images show the difficulty in determining exact numbers of fish within the cluster.

Conclusions

Echoview provided similar counts to manual enumeration. For periods of low or single-file migration, the software was able to determine fish length and numbers with ease. Compared to Case Study 1, the high-resolution image quality enabled us to verify each fish faster. A comparison of estimated fish lengths between the two methods could not be made, as fish were not measured during the manual analysis. Accurate counts for clusters of fish were difficult for both methods.

3.1.3 BlueView

Teledyne BlueView Inc. – BlueView: ProViewer 4.2

ProViewer is a Windows-based program designed to view and record live imagery from imaging sonar and sonar data files (.son). This software is provided by the manufacturer as a free download from their website, or a CD provided with the purchase of a transducer. ProViewer provides basic features to set up and operate the sonar units, and allows users to record, open and view saved .son files.

System Requirements:

- Windows XP (Service Pack 3), Windows 7
- Dual-core CPU or better
- 1 GB or more of RAM
- 100 MB or more of free space
- .NET Framework installed
- Internet access
- Dedicated Ethernet port

Setup

Setup of the system is straightforward. Comprehensive reference documents (Software Handbook provided by BlueView) guide users through the process. Once the software has been connected to the sonar, users have the ability to adjust various settings to suit their data recording needs, which include:

- Range controls: Controls range to which sonar will image.
- Image rotation: Rotates sonar imagery to an angle defined by the user, dependent on mounting of sonar.
- Record: Save sonar data in proprietary file format (.son). The sonar data can be accessed at a later date and exported to a variety of standard formats such as .avi.

In previous software versions, users were not able to automate and control the recording times or file sizes. Users also had to manually start and stop the recording. If left recording for extended periods of time, one large file was created, increasing the risk of data corruption and loss. The current version (4.2) still does not support pre-set recording times, but does enable users to set the maximum sonar file size that can be recorded. Once this size is reached, the current file is saved and a new file will be created.

Play-Back

When a .son file is loaded through the software, users have various controls to view the recording. By default, range arcs and labels are superimposed on the recorded images. These provide a visual indication of how far objects or fish are from the sonar head, and can be toggled off if desired. Controls include:

- Play and Pause
- Next ping: Allows users to advance one ping at a time.
- Previous ping: Allows users to reverse one ping at a time.
- Fast Forward and Fast Reverse: Users can playback at faster rates. Four levels of speed in each direction are available.

Data Processing and Analysis

ProViewer does not offer any data analysis or processing capabilities. During playback of a file, users can modify the display options to fine tune video resolution:

- Sound speed: Depending on environmental conditions, the speed of sound value may need to be adjusted to attain better sonar imagery.
- Color map: This refers to the colours used to display the sonar image. Different colour maps have different characteristics to suit various operations. Some offer high image definition but low contrast, and vice versa.
- Sensitivity: Image sensitivity can be adjusted to improve image quality. For example, lowering the intensity will allow more of the background to be displayed, while increasing it will suppress background noise and increase the contrast of the image.
- Intensity: Intensity controls the brightness of the image.
- Gamma: This feature allows users to control the intensity or brightness at which the various colour maps are displayed.
- Measurement tool: A simple length measurement tool allows users to measure the distance between two user-defined points.
- ProViewer provides users options for exporting previously saved sonar data into several formats. Export options include screenshots, subset (range of pings) and video (range of pings in an AVI movie file).

Recommendations

Overall, ProViewer should only be considered as a viewing and operating software as it does not give the user the capability of automatically counting or tracking individual fish. For more detailed data analysis and processing, third party software is recommended.

3.1.4 Vaki

VAKI – Riverwatcher Counter: Winari Software

Winari is VAKI's proprietary Windows-based software designed to analyze and present data recorded with a Riverwatcher fish counter. Winari has three main functions: transfer data from the Riverwatcher unit, store and manage data retrieved from the unit and present the data in an organized format for the user. Winari is not required in the daily operations and data collection of the Riverwatcher; it is purely used as a data retrieval and analysis tool. Winari is free to download from the VAKI website.

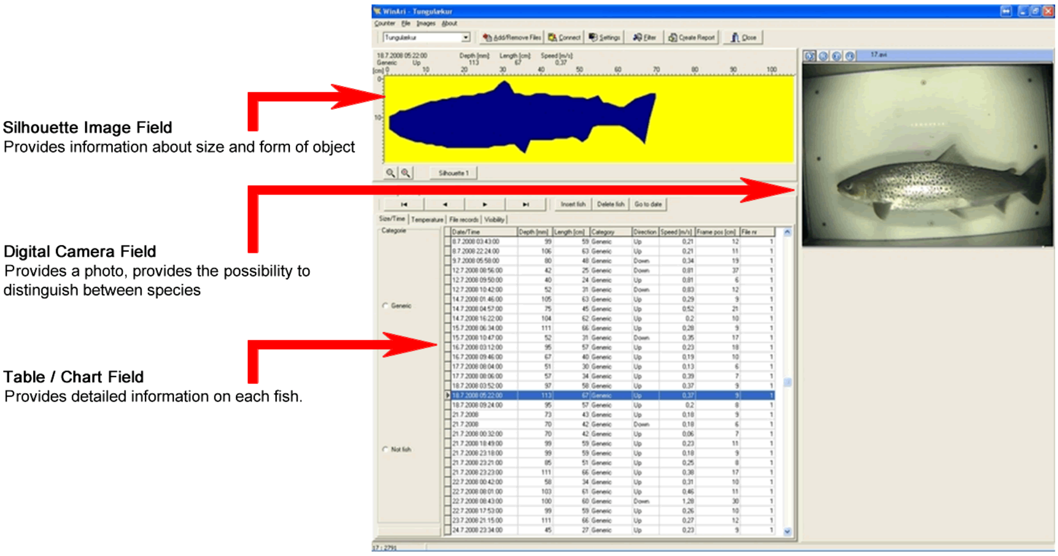
Setup

Setup of Winari is straightforward with comprehensive reference documents provided by VAKI (Riverwatcher Software Manual). Installation requires a download and install of Winari from the VAKI website, an install of VideoLAN VLC Media Player and installation of a USB-to-Serial converter into the host PC computer.

Functionality

Understanding the functionality of Winari through the reference documents was challenging due to several inaccurate translations in the English manual. Winari can manage multiple counters; each counter can be named specifically and accessed separately. Data can be downloaded onsite by direct connection or remotely using a landline or GSM mobile phone. Unlike hydroacoustic counters, fish data is only collected when an object breaks the optical beam in the counter. Continuous images are not collected to imitate a video, however the sensitivity of the counter to trigger the video recording can be adjusted to reduce the number of potential false negative counts. All data files collected are synchronized for each potential fish in the Winari software. A user can scroll through each proposed fish to verify whether the software's interpretation is correct. Figure 3.14 provides a preview of the Winari software environment. Under the user's discretion, data can be separated further in Winari depending on project requirements. Riverwatcher collects multiple data types that can be analyzed by Winari:

- .ARV files: Fish size, direction of travel, timestamp and positioning data is collected.
- .IMG files: Silhouette images of each fish are collected providing the user with a verification image for each ARV file. Silhouettes can be exported for further analysis.
- .VSB files: The functionality of light emitting diodes (LED) in the Riverwatcher is recorded.
- .TDT files: Records temperature every three hours.
- Photo files: Real-time photos of each fish that trigger the Riverwatcher are collected. This file type is optional, but provides the user with the potential to verify species, sex or any other factors.



Date/Time	Depth [mm]	Length [cm]	Category	Direction	Speed [m/s]	Frame pos [cm]	File nr
8.7.2008 03:43:00	99	59	Generic	Up	0,21	12	1
8.7.2008 22:24:00	106	63	Generic	Up	0,21	11	1
9.7.2008 05:58:00	80	48	Generic	Down	0,34	19	1
12.7.2008 08:56:00	42	25	Generic	Down	0,81	37	1
12.7.2008 09:50:00	40	24	Generic	Up	0,81	6	1
12.7.2008 10:42:00	52	31	Generic	Down	0,83	12	1
14.7.2008 01:46:00	105	63	Generic	Up	0,29	9	1
14.7.2008 04:57:00	75	45	Generic	Up	0,52	21	1
14.7.2008 16:22:00	104	62	Generic	Up	0,2	10	1
15.7.2008 06:34:00	111	66	Generic	Up	0,28	9	1
15.7.2008 10:47:00	52	31	Generic	Down	0,35	17	1
16.7.2008 03:12:00	95	57	Generic	Up	0,23	18	1
16.7.2008 09:46:00	67	40	Generic	Up	0,19	10	1
17.7.2008 08:04:00	51	30	Generic	Up	0,13	6	1
17.7.2008 08:06:00	57	34	Generic	Up	0,39	7	1
18.7.2008 03:52:00	97	58	Generic	Up	0,37	9	1
18.7.2008 05:22:00	113	67	Generic	Up	0,37	9	1
18.7.2008 09:24:00	95	57	Generic	Up	0,2	8	1
21.7.2008	73	43	Generic	Up	0,18	9	1
21.7.2008	70	42	Generic	Down	0,18	6	1
21.7.2008 00:32:00	70	42	Generic	Up	0,06	7	1
21.7.2008 18:49:00	99	59	Generic	Up	0,23	11	1
21.7.2008 23:18:00	99	59	Generic	Up	0,18	9	1
21.7.2008 23:21:00	85	51	Generic	Up	0,25	8	1
21.7.2008 23:23:00	111	66	Generic	Up	0,38	17	1
22.7.2008 00:42:00	58	34	Generic	Up	0,31	10	1
22.7.2008 08:01:00	103	61	Generic	Up	0,46	11	1
22.7.2008 08:43:00	100	60	Generic	Down	1,28	30	1
22.7.2008 17:53:00	99	59	Generic	Up	0,26	10	1
23.7.2008 21:15:00	111	66	Generic	Up	0,27	12	1
24.7.2008 23:34:00	45	27	Generic	Up	0,23	9	1

Figure 3.14. Winari's interface displaying data. An .ARV file (fish physical data) is paired with .IMG (fish silhouette) and photo data (digital image) to provide an overview of each object detected. Photo courtesy of Vaki.

Data Export and Analysis

Winari provides the user with the ability to export all data files above for each verified fish. Fish length, size, timestamp, visibility, temperature and other fish data can be exported separately or synchronized. Basic graphical analysis can also be performed using Winari, such as migration pattern in relation to time or fish lengths in relation to time.

Recommendations

Overall, Winari provides the user with a multitude of verification options to optimize data quality control. The automated fish detection feature eliminates the need of manual verification of lengthy video data, and the basic graphical outputs provide a simple and quick analysis for users.

3.1.5 Mark 12

EA Technology Limited and Scottish and Southern Energy – Mark counter: No software

There is no proprietary software required for operating the Mark 12 (MK12) counter. A Mark 12 operates through a text-based menu system and can be accessed from any text-based terminal application such as HyperTerminal (Windows XP and older) and PuTTY (Windows Vista and newer). Connection to the counter can be achieved in two ways:

1. Direct connection through a null modem cable (RS232) to a laptop or PC.
2. PSTN phone line via a modem plugged into COM2.

Once a connection is established, the user is presented with the main menu that contains a set of numbered options. Selecting a number will access another menu or modify a value. To make any adjustments, the user must be well versed on principles of how resistivity counters function. Some of the modifications users can make are, but not limited to, the following (EA Fish Counter User Guide):

- Site name and details: User can modify site name and add any other important information.
- Digital input activation: User can enable or disable the digital inputs from environmental monitoring equipment.
- Environmental transducers: User can enable or disable any of the environmental transducers (i.e., cameras, conductivity probes).
- Environmental monitoring logging period: User can modify the time (in minutes) between logging environmental inputs to file.
- Camera activation: User can enable or disable the cameras connected to the counter.
- Camera ‘On’ delay: Allows users to modify the length of time (in milliseconds) from when the fish triggers the first electrode to when the picture is taken.
- Camera modes: Allows users to toggle between the three camera trigger options. Each mode refers to the first LED for a fish event that will trigger a picture to be taken.
- Channel Activation: Allows the user to toggle each counting channel on or off.
- Minimum Electrode Current: Adjust level of current (in units of 0.016 mA) needed before channels can be active.
- Minimum Fish Current: Allows users to modify the minimum current before a fish is detected. Three options are available: automatic, static conductivity and static minimum fish current.
- Modify Counts: Allows users to modify all count variables for water drive card.
- Minimum Counts: Modify the delay between current exceeding minimum fish current and initiating fish detection.
- Maximum Counts per Fish: Allows user to set the maximum amount of time for a fish to complete passage over electrodes.
- Maximum Single Lamp Counts: Allows users to modify the time delay before an LED is extinguished when only one LED is on.
- Exit Delay Counts: Users can modify the delay between detecting a fish and conforming a fish event.
- Start Delay Counts: Users can adjust the delay between when an electrode is triggered (exceeds the minimum electrode current) and the channel becoming enabled.
- View Compact Flash Information: Allows users to view information about the file storage system. Details of both internal and external storage can be viewed.
- Reset Total Fish Counts: Allows users to reset the total number of fish. The daily totals will not be affected.

Overall, MK12 counters are data-logging devices that store data and allow users to retrieve that information. Although operating software is not required to run the MK12, the multitude of data that is produced by the counter can be viewed on MK's proprietary analysis software for further analysis and validation. Alternatively, data can be exported as .txt files and analysed by user-defined software. Files created by the counter are as follows:

- Fish Movements: File that holds the details of all fish movements for that week.
- Fish Signals: File written weekly that contains the fish signals that correspond to the fish movements.
- Daily Summary: File that displays all up and down counts of functioning channels.
- Events: Weekly file that contains information for any designated counter events, such as an error with the power supply.
- Pictures: If cameras are enabled, pictures are taken for each event. A corresponding picture (.jpeg) file is created to match all event data and is available for download.

We have not had the chance to view or review MK's proprietary analysis software, but through personal communication with MK12 operators, we believe the software will become invaluable, as it allows users to link all the corresponding fish events or partial events data from each of the files, thereby facilitating the validation process.

3.1.6 Logie Software

Aquantic Ltd – 2100C Logie Fish Counter: 2100C PC Control Program

Software provided by Aquantic is strictly controlling software enabling users to set up and control a counter. There are two versions of this software: a Windows-based version with more intuitive controls and a simpler DOS-based version for use with newer versions of Windows (7 or 10). Both of these programs are included with the purchase of a counter (pre-loaded on CD), can be downloaded for free from the Aquantic website, or at the request from the manufacturer (Brown 1998).

Through our experience, the Windows-based 2100C PC control program does not function or is unreliable with Windows versions newer than Windows 7. For Windows 7 and 8, the new DOS-based program is more reliable.

Functionality

With this software the user can set and display various parameters on the counter to suit specific requirements.

- Continuous display of status: If the counter is connected to a PC, the user can choose to have status information sent to the PC at regular intervals and on the occurrence of any change in status. It is primarily intended as a "front panel" for the counter when the PC/Palmtop is left permanently connected to the control port. The information displayed includes number of events, up/down counts, date and time and version number.

- Status dump: Every 30 minutes, the counter performs self-calibration which includes a conductivity reading. Users can select to have the counter send a status dump to the printer following calibration.
- Thresholds: The user is prompted to enter the channel number (1-4) upon which the current values for the up and down thresholds are displayed followed by a request to enter new values.
- Reset counts: After confirmation, the totals of all up and down counts are reset to zero.
- Insert Dummy fish: Allows the insertion of a “standard” fish signal into any of the four channels, as either an upstream or downstream “fish”. This allows the user to test whether or not the counter is functioning properly.
- Enable/disable: Individual channels may be enabled or disabled as required.
- Event relay/Up relay/Down relay: The instrument is fit with a total of eight single-pole normally open relays and four single pole changeover relays. These may be assigned using the above commands to particular channels.
- Printer: The counter may, at the user’s discretion, print information on each count as it occurs. The data printed consists of the date, time, conductivity at the time of the most recent calibration, channel, upstream or downstream movement and peak signal size, which is the highest peak recorded by the counter as the fish passes over the sensor. The peak signal size can be reported as a percentage from 0% to 99% or as a value from 0 to 127 (see 2100C Graphics Program section). If enabled, a printer, a computer, or text-capturing device (RX Reader) with an RS232 serial connection should be attached to the PRINTER port on the rear panel of the counter and set to the correct baud rate (9600), parity (even) and number of stop bits (one). In addition, the user can select whether the pseudo-graph output is enabled: see 2100C Graphics Programme details below.
- Pseudo-graph output: A pseudographical output has been made available via the printer port to be able to show fish waveforms on a PC display (Figure 2.4, Section 2). The user may select pseudographical output on a per-channel basis, although if any channel has this form of output enabled, all other channels have their normal printer output suppressed. The output takes the form of pairs of characters, representing the encoded value of the channel number and the signal value measured by the counter at its normal sampling rate. See section below for information on the *2100C Graphics Programme*.
- Events: It is possible for a signal to be detected that exceeds the pre-set thresholds, but does not pass internal checks that determine whether or not it is a fish. The signal may, if the user desires, trigger the event relay, and generate a trace on the chart recorder output. This command enables or disables this occurrence. In addition, the user may choose to have the event relay operate as soon as an event is detected, rather than after the signal is processed. This would be useful for triggering still cameras. Users may also choose to log these signals or not, as required.

- Baud rates: Allow the user to individually configure the serial ports to operate at one of the following baud rates: 300, 600, 1200, 2400, 4800, 9600 and 19200.
- Re-calibrate counter: If this command is chosen, then the counter will perform its calibration procedure, which normally occurs automatically every thirty minutes.
- Conductivity calibration: The conductivity probe may be calibrated, to compensate for cable capacitance.
- Show conductivity: The current value of conductivity, as read by the probe, can be continuously displayed.
- Change algorithm (fast/slow): The fish discrimination algorithm built-in to the counter can take two forms: (1) a fast version that can count fish passing at a rate up to one fish every 0.5 s but which is more susceptible to false counts due to wind and waves, and (2) a slow version that can only count fish passing at a rate of no more than one fish every two seconds, but is more dependable at rejecting false counts.
- Channel length/depth: Electrode length and normal water depth for each channel may be entered.
- Length and conductivity compensation: Length and conductivity compensation factors may be entered.
- Maximum size: The range of values allocated to fish sizes may be set to 0-99% or 0-127.
- Datalog buffer format: The buffer holding the logged counts and/or events may be set to either Linear (stops logging once full) or Circular mode (starts overwriting data once full), or cleared (deletes data once full).
- Length compensation: The user is prompted for a length compensation factor (in % per m). This is used, along with the electrode length, to calculate a gain compensation factor for different sizes of weir sections

Data Management

Although the Logie PC control program does not have any data processing or analysis capabilities, the data stored within the counter can be downloaded by the user. This is done through the “Show/download the information logged in the counter” menu. This allows the user to display the events stored in the datalog on the screen or download them to a file (location specified by user). By default, the counter creates an .lg2 file that can be read as a .txt file by simply changing the extension name manually to .txt.

Users can also choose to download and display a specific number of records. This is done through the “show the last 100 records” option. This will download the specified number of records starting from the last recorded event.

2100C Graphics Programme

This program is designed specifically for recording pseudo-graphical information from the counter to a personal computer. The computer should be connected through a RS232 serial connection attached to the PRINTER port on the rear panel of the counter. Like the 2100 PC control Program, this program is strictly an operating/controlling program with no data analysis capabilities. *2100C Graphics Programme* is available for download from the Aquantic website. Note that once the program has been downloaded from the website, the associated “GRPH.config” file should always be saved in the same folder as the program. Upon start up, the program looks for this file to establish connection. The GRPH.config file enables users to set the preferences for communication between the computer and counter.

2100C Options are as follows:

- Port: Allows users to input what communications port the counter is connected to (i.e., COM1, or COM2).
- Baud: Allows users to set the communications baud rate - this should always be set to 9600.
- Logfile: Default file name created by the program - this should be left as “grph.log”

Once the program is open there are various options available. Key options include:

- Set baud rate: Once connected, the user has the option to change the baud rate. Note that this is not recommended.
- Record data from counter in a file: Opens a file to record any graphical data sent to the computer via RS232 serial connection. The user has the option to name the file to suit their needs. The file, by default, is saved to the location where the program is located (e.g., Desktop). If the user does not assign a file name, then the data is saved to the default GRPH.log file.

The output takes the form of pairs of characters, representing the encoded value of the channel number and the signal value measured by the counter at its normal sampling rate. A small example of a typical output is:

```
S 19/03/97 23:11:54 150 1 D 050
D @@PP``pp@@PP``pp@@PP``pp@@PP``pp@@PP``pp@@PP``pp@@
D pp@@PP``pp@@PP``pp@@PP``pp@@PP``pp@@PP``pp@@PP``pp
F 1
```

The start of a fish record is indicated by the S, which is in the same format as the normal logged or printed data, except for the preceding S. The ensuing D records are the blocks of encoded data. The end of the output is indicated by the F record. To view the fish trace or waveform on a PC, the appropriate logging software is required.

2100B/C Windows Graph Programme with Video Capture

The 2100B/C Windows Graph Programme is designed specifically to view the Logie counters graphical output files. This is a Windows-based program that can open any .log file to view individual record/event traces. This program is designed specifically to view data and offers no analysis capabilities. The user simply loads the appropriate data file and scrolls through each individual trace (either an event or record) to verify the correct identification of the record by the counter algorithm.

3.1.7 SalmonSoft: FishTick Software

The FishTick software is third party video motion detection software developed by SalmonSoft. FishTick aims to remove periods without fish from digital video recordings to limit the amount of video a user has to analyze. The software has two components: a video-capture program (FishCap) and a video-review program (FishRev). FishTick is available in two versions: “Lite” with restricted features and “Standard” with full features. The software can work in conjunction with an external computer or can be loaded directly onto a digital video recorder (DVR). It can be purchased as standalone software or with an entire counting system. Cost is dependent on the exact specifications of the software, ranging from £1938 to £4200. A report by the Environment Agency found FishTick can analyze 24 hours of video data in 15 minutes with a detection rate of 90% (Washburn et al. 2008b).

System Requirements – Video Capture Program:

- Windows XP, 7 or 8
- Dual core CPU at 2.0 GHz with a suitable video capture device
- Minimum 2 GB of RAM
- Installation of video device, Avid Dazzle recommended.
- Video from Firewire (IEEE-1394) adapters or MPEG or AVI files also accepted

System Requirements – Video Review Program:

- Windows XP, 7 or 8
- Dual core CPU at 2.0 GHz with a suitable video capture device
- 2 GB of RAM Minimum
- Microsoft Excel installed
- 19” monitor recommended

Software Setup

The current version of FishTick functions best when it is operated through an onsite computer. Future versions of the software will work best with video files downloaded off of DVRs. For a comprehensive list of DVRs that work with FishTick, contact the manufacturer directly.

Functionality

FishCap: Has an extensive list of parameters that can be modified. FishCap has two main functions. Firstly, the program can re-write recorded videos to separate segments with fish and segments without fish, limiting the amount of video the user has to review. Secondly, FishCap can be deployed in real time to only record fish videos when fish are present. Cameras can be activated to record only if a switch or tripwire is triggered.

FishRev: Allows the user to scan through video files with fish created by FishCap. Videos can be viewed at 1/6th to 60 fps. Users can tally fish species using mouse or keyboard shortcuts, and the data can be automatically stored in Microsoft Excel files by date and time.

Recommendations

Overall, FishTick provides the user with features that can aid in the analysis of DVR recordings. If the program performs as intended, it can save valuable time by significantly reducing the amount of data.

3.2 New Methods

3.2.1 FishCounter R package

The FishCounter R package is an open source software that uses R code to automate the management and visual exploration of Logie counter data. The package has two main data management functions and six data exploration plotting functions described below. All functions were developed based on Logie counter user's experience within IFR and Marine Scotland Science (I. Simpson, pers. comm.).

How to use FishCounter

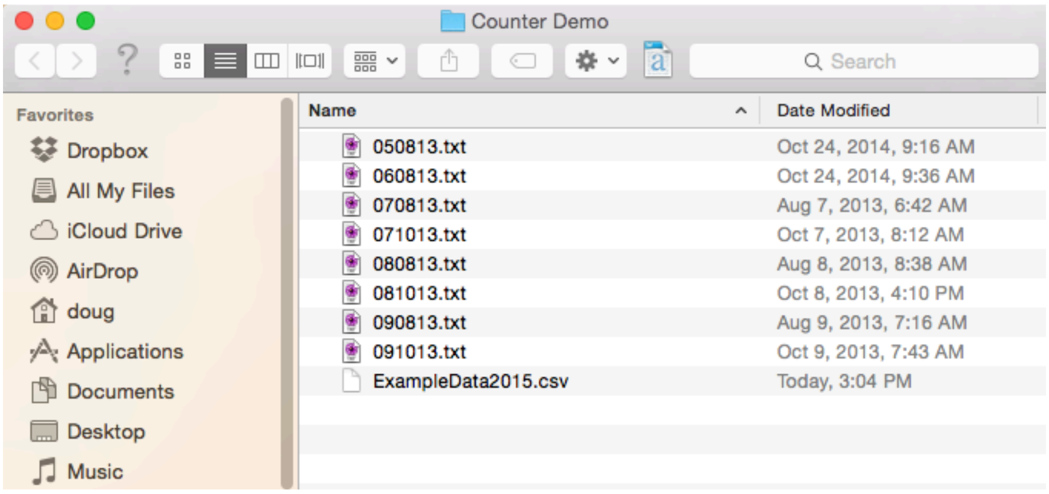
The FishCounter package is simple enough to be used by beginner R users. R statistical software is an open-source software based on the R language (Ihaka and Gentleman 1996), and can be downloaded for free at http://www.r-project.org/. R software contains a number of base functions, however the real power of R is the ability for additional functions to be written and compiled into packages. Additional packages can be downloaded from CRAN using the R console, and can also be downloaded from individual repositories such as GitHub. For example, the FishCounter package can be downloaded from GitHub by installing the *devtools* package (ref) and using the install_github function.

Using the FishCounter package requires the user to know how to set a working directory, install packages, execute functions and specify simple arguments for R functions. Once the package is installed, the user has access to help documentation that defines all of the functions and arguments.

Data Management

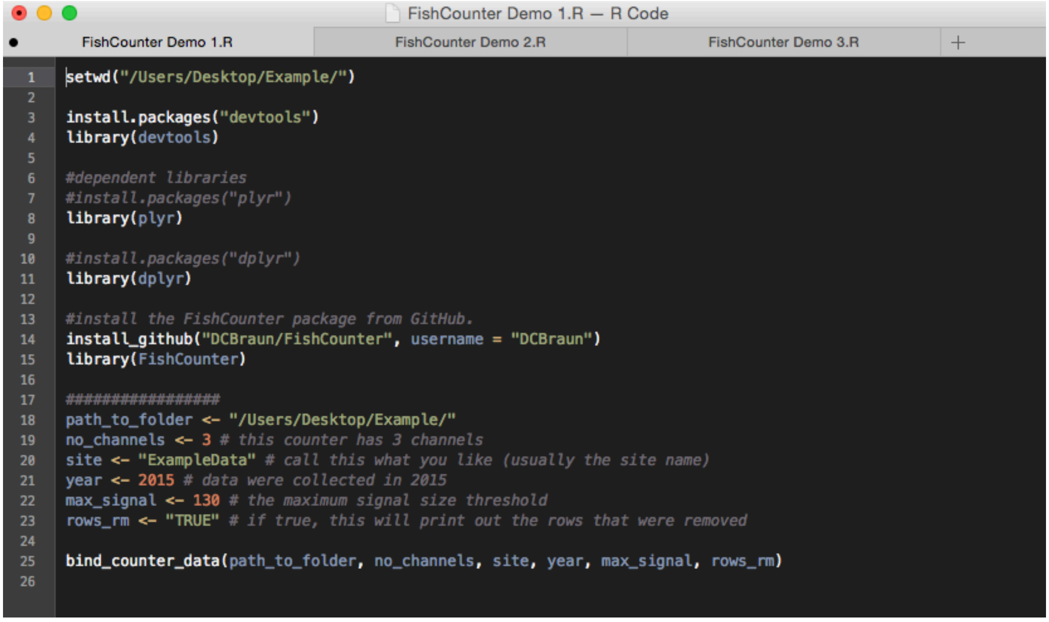
There are no built-in data management capabilities in the Logie software. The counter stores data until it is deleted, and unless the counter data is deleted, each successive download will contain previously downloaded data. This requires additional work by the user to sort and extract the unique data records. Furthermore, the counter data can contain errors that must be manually removed. FishCounter's *bind_counter_data* function automates the management of Logie counter data by binding individual download files together and producing a single master dataset (Figure 3.15). *Bind_counter_data* requires that all Logie files are converted to .txt files and placed into a single folder. Within the *bind_counter_data* function there are a set of internal functions that "clean" the data by removing errors, counter status reports and redundant data. Removing errors is particularly important for the counter data since it is prone to producing irregular records (1-2% of all records are irregular). Note that there is an optional argument to print out all rows removed and the reason for their removal. Sample code is provided to demonstrate the installation of the FishCounter package and the running of the *bind_counter_data* function (Figure 3.16). Once the master dataset has been generated, it must be read back into R (see Figure 3.17).

Logie's 2100C Graphics Programme can be used as backup source of data. This can be stored on a computer or on a small, low power secure digital data logger. Data produced by this stream does not have the same issues of downloading duplicate data and can be used to observe the change in resistance (i.e., the fish trace) for pseudo-validation. However, these data still suffer from errors (much lower error rate than the counter data, < 1%) and data are not managed. To graphically observe the data or to extract the original counter records, the user needs to sort and extract the relevant data. FishCounter's *bind_signal_data* function performs similar actions to the *bind_counter_data* function and will provide a single clean master dataset that can be used in place of the datasets directly downloaded from the counter.



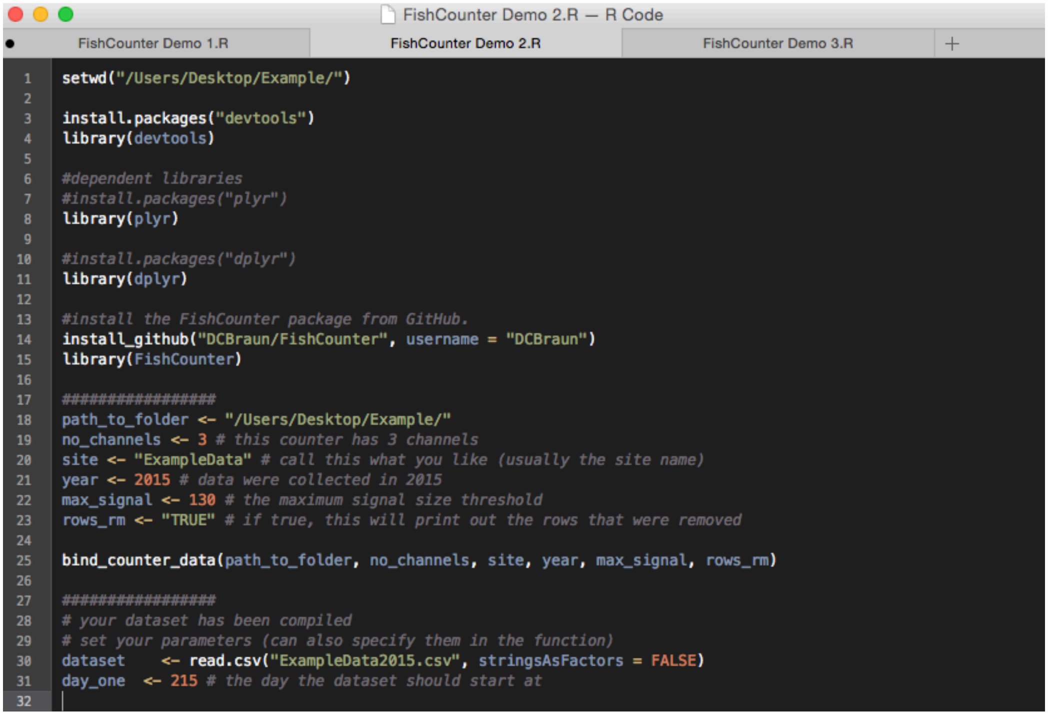
Name	Date Modified
050813.txt	Oct 24, 2014, 9:16 AM
060813.txt	Oct 24, 2014, 9:36 AM
070813.txt	Aug 7, 2013, 6:42 AM
071013.txt	Oct 7, 2013, 8:12 AM
080813.txt	Aug 8, 2013, 8:38 AM
081013.txt	Oct 8, 2013, 4:10 PM
090813.txt	Aug 9, 2013, 7:16 AM
091013.txt	Oct 9, 2013, 7:43 AM
ExampleData2015.csv	Today, 3:04 PM

Figure 3.15. Screen shot of example folder containing individual files (e.g., 050813.txt) and master data file produced by the *bind_counter_data* function (ExampleData2015.csv).



```r
setwd("/Users/Desktop/Example/")

install.packages("devtools")
library(devtools)

#dependent libraries
#install.packages("plyr")
library(plyr)

#install.packages("dplyr")
library(dplyr)

#install the FishCounter package from GitHub.
install_github("DCBraun/FishCounter", username = "DCBraun")
library(FishCounter)

#################
path_to_folder <- "/Users/Desktop/Example/"
no_channels <- 3 # this counter has 3 channels
site <- "ExampleData" # call this what you like (usually the site name)
year <- 2015 # data were collected in 2015
max_signal <- 130 # the maximum signal size threshold
rows_rm <- "TRUE" # if true, this will print out the rows that were removed

bind_counter_data(path_to_folder, no_channels, site, year, max_signal, rows_rm)

```

Figure 3.16. Screen shot of sample R code that demonstrates how to install the FishCounter package and use the *bind_counter_data function*.

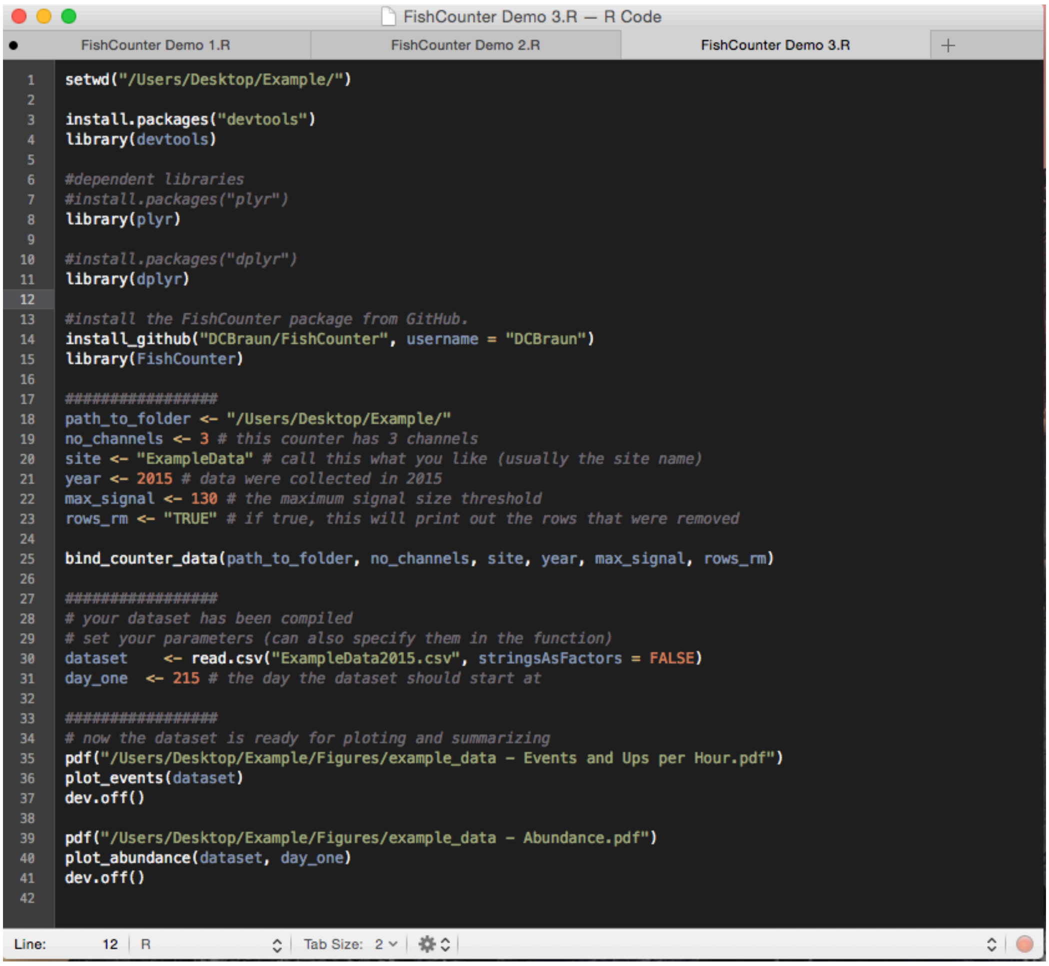


```r
setwd("/Users/Desktop/Example/")

install.packages("devtools")
library(devtools)

#dependent libraries
#install.packages("plyr")
library(plyr)

#install.packages("dplyr")
library(dplyr)

#install the FishCounter package from GitHub.
install_github("DCBraun/FishCounter", username = "DCBraun")
library(FishCounter)

#################
path_to_folder <- "/Users/Desktop/Example/"
no_channels <- 3 # this counter has 3 channels
site <- "ExampleData" # call this what you like (usually the site name)
year <- 2015 # data were collected in 2015
max_signal <- 130 # the maximum signal size threshold
rows_rm <- "TRUE" # if true, this will print out the rows that were removed

bind_counter_data(path_to_folder, no_channels, site, year, max_signal, rows_rm)

#################
# your dataset has been compiled
# set your parameters (can also specify them in the function)
dataset    <- read.csv("ExampleData2015.csv", stringsAsFactors = FALSE)
day_one  <- 215 # the day the dataset should start at

```

Figure 3.17. Screen shot of sample R code that demonstrates how to read in the new master dataset produced by the *bind_counter_data function*. It also shows how to set the *first_day* parameter, which determines the day the dataset should begin.

Data Visualization

Data visualizations can be used to asses a counter's efficacy and to visualize migration timing. We developed a number of functions to produce plots commonly used by IFR staff to inspect in-season data. This helps staff identify and troubleshoot counter problems. Each plot function produces the visualization in a new plotting window or can be saved as a .pdf (or other image format) for reports and presentations (Figure 3.18).



```
setwd("/Users/Desktop/Example/")

install.packages("devtools")
library(devtools)

#dependent libraries
#install.packages("plyr")
library(plyr)

#install.packages("dplyr")
library(dplyr)

#install the FishCounter package from GitHub.
install_github("DCBraun/FishCounter", username = "DCBraun")
library(FishCounter)

#################
path_to_folder <- "/Users/Desktop/Example/"
no_channels <- 3 # this counter has 3 channels
site <- "ExampleData" # call this what you like (usually the site name)
year <- 2015 # data were collected in 2015
max_signal <- 130 # the maximum signal size threshold
rows_rm <- "TRUE" # if true, this will print out the rows that were removed

bind_counter_data(path_to_folder, no_channels, site, year, max_signal, rows_rm)

#################
# your dataset has been compiled
# set your parameters (can also specify them in the function)
dataset    <- read.csv("ExampleData2015.csv", stringsAsFactors = FALSE)
day_one  <- 215 # the day the dataset should start at

#################
# now the dataset is ready for ploting and summarizing
pdf("/Users/Desktop/Example/Figures/example_data - Events and Ups per Hour.pdf")
plot_events(dataset)
dev.off()

pdf("/Users/Desktop/Example/Figures/example_data - Abundance.pdf")
plot_abundance(dataset, day_one)
dev.off()
```

Figure 3.18. Screen shot of sample R code that demonstrates how to create .pdf files of output from two plotting functions.

hist_records – This function plots histograms of the distribution of peak signal sizes (PSS) for up counts, down counts and events, which are user specified (Figure 3.19). PSS can be a reliable indicator of relative fish mass. Determining species using indicators of fish mass is important for Scottish rivers and will require some information about species size relationships.

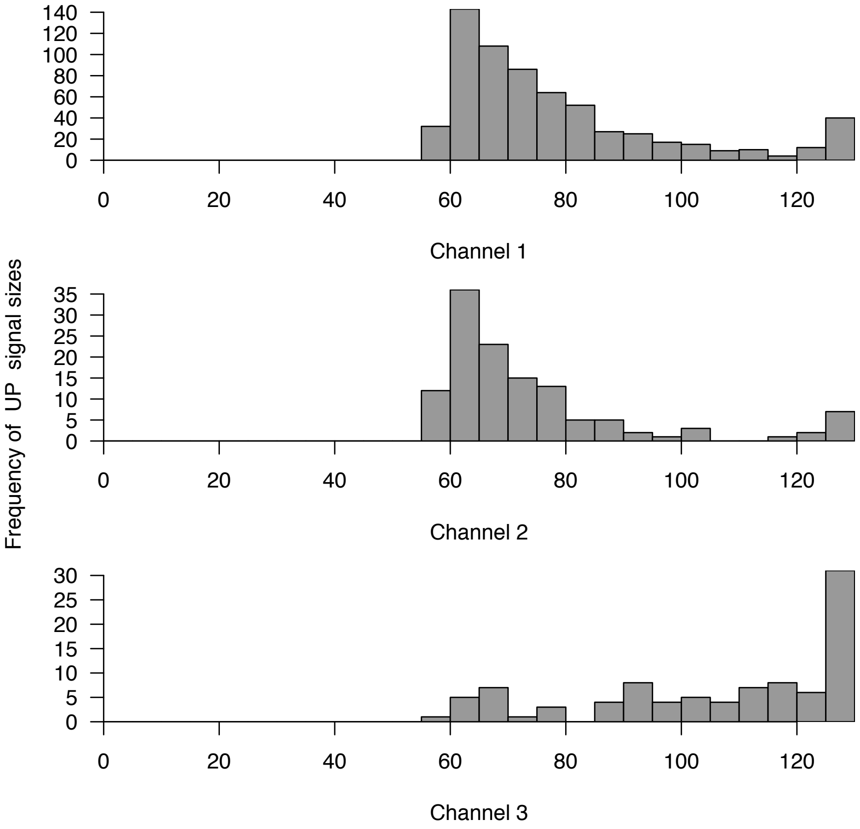


Figure 3.19. Plots of histograms of up count PSS values for Channels 1 to 3.

hist_records recognizes how many channels the counter uses and plots each channel. The user examines the distribution of signal sizes and can make comparisons among channels. This helps the user identify channels that are not operating properly and unusual fish behaviour. If the counter user expects fish will migrate through all channels, for example, the PSS distributions among channels should look similar. Differences in the distributions may suggest that the electrodes are not working or attached correctly. This series of plots requires some knowledge of how the counter operates in a given watershed and will be most useful to experienced counter users.

plot_events – This function plots time series of the mean number of events per hour for all channels, the number of events for each channel per hour, and the number of up counts per hour for each channel. An event is recorded (instead of an up count or down count) when changes in resistance do not meet the criteria for the record to be classified as an up or down count. This can happen when a fish attempts to cross over the electrodes but turns back before swimming completely over the counter sensor. Events can also occur due to low water levels over the electrodes, wind action, and other animals moving over the sensor units. Events commonly occur, but the baseline rate for each counter will differ. For each channel the events per hour can be compared to the mean events per hour for all channels, which provides a baseline value. Events are more common when there are higher upstream passage rates. The number of up counts per hour are plotted which allows the user to identify high event rates that do not coincide with high up count passage rates (Figure 3.20). This series of plots require some knowledge of how the counter operates in a given watershed and will be most useful to experienced counter users.

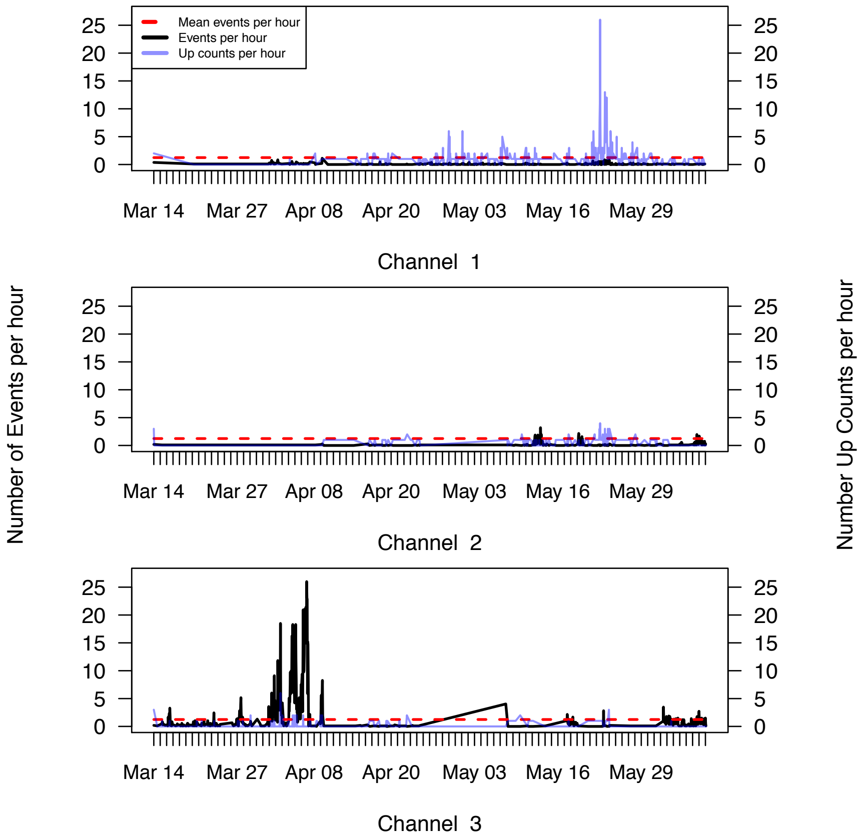


Figure 3.20. Plots showing the number of events per hour by date. Each plot represents the events for a given channel. Black lines are the number of events per hour, blue lines are the number of up counts per hour, and the horizontal dashed red line is the mean number of events per hour for all channels. This provides a baseline for the typical number of events per hour and can be used as a benchmark for when there may be counter problems.

plot_pss_date – This function plots a time series of raw and daily mean up count PSS values for each channel, which are user defined (Figure 3.21). PSS can be a reliable indicator of relative fish mass. This plot highlights changes in the distribution of PSS values through time, which, in some cases, can be used to identify changes in species (trout vs. salmon) or life history (one-sea-winter vs. multi-sea-winter in adult salmon).

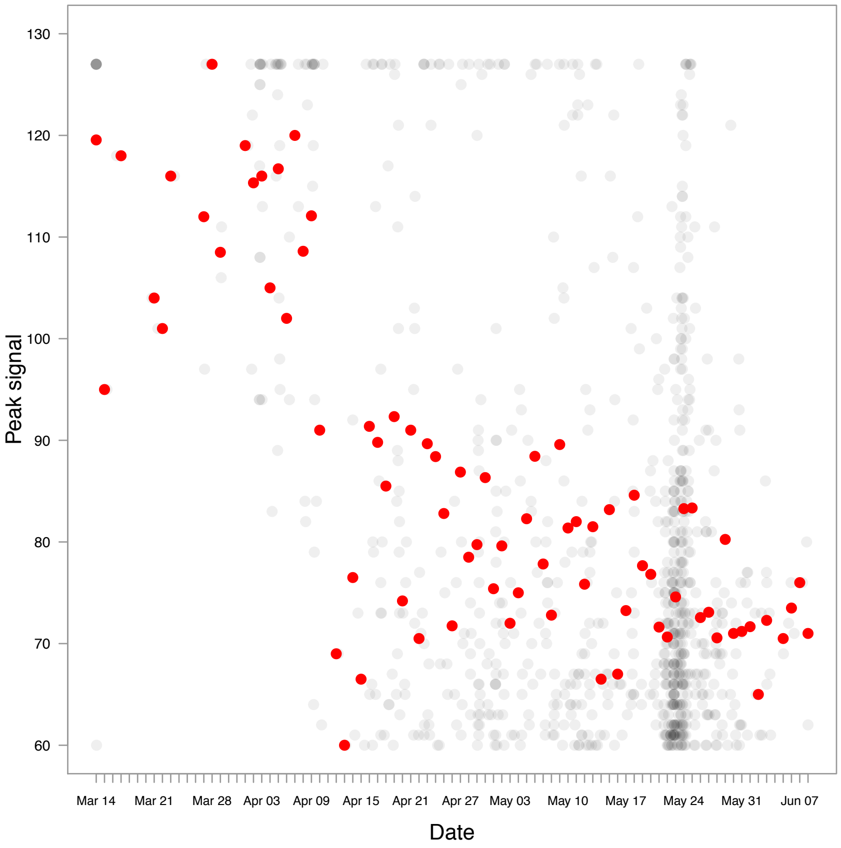


Figure 3.21. Plot produced by *plot_pss_date* function. Grey points show the raw up count peak signal size values and the red points indicate the daily mean up count PSS values. PSS is an indicator of fish size. Note the declining PSS values from mid March to early April, depicting the switch from anadromous to resident *Oncorhynchus mykiss*.

plot_pss_hour – This function plots the up count PSS values by time of day (Figure 3.22). The upper plot shows the total number of up counts per hour and the lower plot shows the raw PSS values by hour of the day. The upper plot allows the user to identify peak migration times in the day. The lower plot allows the user to identify differences in the PSS among hours. This information could be used to target trapping efforts, counter validation, or for identifying general fish behaviour.

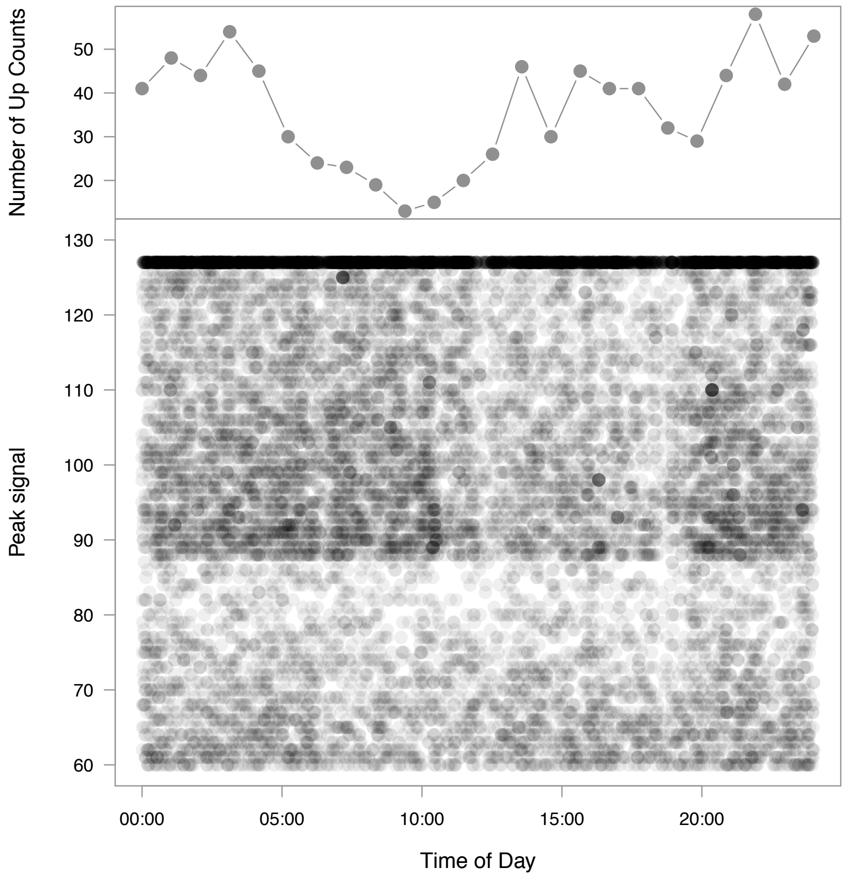


Figure 3.22. The top plot shows the number of up counts by time of day, and the bottom plot shows the peak signal size by time of day.

plot_abundance – This function plots time series of daily and cumulative up counts (Figure 3.23). This highlights the daily migration rates and how they relate to the total number of fish that have migrated upstream over the counter.

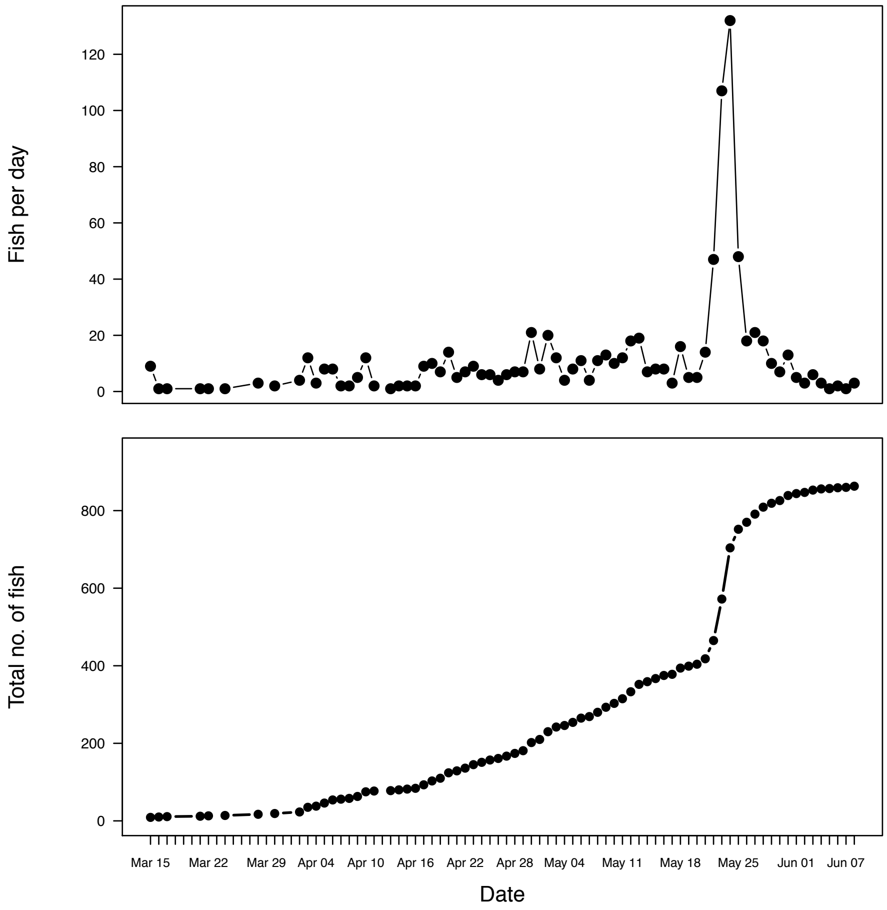


Figure 3.23. Plot produced by *plot_abundance* function. The top plot shows the daily number of fish passing through the counter. The bottom plot shows the cumulative abundance by day. This function plots the raw number of up counts and should not be used as a definitive count but as a minimum count.

3.2.2 Species Identification Models

Introduction

In many UK rivers, salmon (*Salmo salar*) and trout (*S. trutta*) migrate upstream to spawn at similar times. These species can migrate in similar abundances and, in some situations, overlap in size, complicating the enumeration of adult spawners by electronic fish counters. On some rivers there may also be other migratory fish species present that require consideration. Data on species identification is important for producing accurate species-specific estimates of abundance, conducting long-term monitoring, and setting conservation limits. While species identification is possible with video validation, in most cases it is not possible to identify all fish or may not be cost-effective; therefore, the species identification of many fish remains unknown. Development of methods that allocate unidentified fish to different species will help to improve the accuracy of fish counter estimates that will help to inform management decisions.

Counters can readily record metrics that are useful for identifying species such as length. For example, Vaki's Riverwatcher counters calculate the length of all recorded traces. Echoview software can provide length estimates from sonar images, and peak signal size from some resistivity counter setups can be used as an index of fish length. A simplistic approach to species allocation is to use minimum and maximum cut-off lengths that species are most likely to occur within. However, distinguishing species using length cut-offs relies on distinct species-length relationships (i.e., one species is consistently longer than the other), which is often not the case for salmon and trout in the UK. This approach also bins fish into two broad length categories, which is an unrealistic assumption. A more accurate approach is to apply proportions of each identified species within a size interval (~ 5 cm) to the numbers of unidentified fish in the same length interval. But, this also ignores the continuous nature of size data and requires a representative sample of identified fish for each length interval. Furthermore, neither approach provides estimates of uncertainty.

The previous length-interval approach, however, can be modified and an average proportion of each species within each length interval can be calculated using data from multiple years. This option usually results in a representative sample of identified fish for each length interval but averages all the variation in size-species relationships among years and ignores non-stationary in length-species relationships. For example, the average length of salmon returning from the sea increases throughout a year, while the average length of trout changes from month-to-month and often consists of a bimodal distribution of smaller brown trout and larger sea trout. There is also some variation in the species-length distributions of both species from year-to-year and there are normally different population components to consider that are linked to run timing and the length of time fish spend at sea. Models that account for seasonal and inter-annual variations in length-species relationships need to be developed to produce accurate species-specific abundance estimates. Gurney et al. (2014) provide methods for discriminating species using length and age distributions. While their methods provide accurate estimates of abundance for species by age, it requires both length and age data. Length data, or some measure of size, can easily be obtained using electronic fish counters, but age data requires fish be handled and sampled in the field. Different ages of salmon and trout migrate at different times of the year; therefore migration date might aid in species identification (Bacon et al. 2009) when age data are not available.

We used the Gala Water, a small tributary of the Tweed River, UK, as a case study to illustrate this model. The Tweed has annual migrations of both salmon and trout throughout the year, with the majority of salmon migrating between September and November. Trout migration consists of sea trout which typically spend one or two years at sea, and brown trout that are a resident form of trout that make annual spawning migrations to smaller tributaries. Fish are enumerated with a Vaki counter located at the bottom of a fish pass near the confluence of the Gala Water and Tweed. Due to high turbidity events, which are a common occurrence in UK Rivers, identification rates by video validation are variable, ranging from 34 to 59%. Since 2006, the Tweed Foundation has used the Vaki counter to generate a database of over 45 000 fish records that include calculated length, of which over 15 000 individuals have been identified to species using video validation.

We used a generalized linear modeling (GLM) approach to determine the species of unidentified fish counts using length distributions. For each month, we estimated the probability a fish was either a salmon or trout based on length using data from the year of analysis (current method). We also tested a second method for years when validation data was limited which uses length distributions for each month from previous years (historical method), accounting for annual variation in the length distributions using a generalized linear mixed-effects model (GLMM). Our analysis also accounts for uncertainty in our species-specific estimates of abundance.

Methods

Study Site and Counter

The Tweed catchment area is nearly 5000 km^2 and contains approximately 15% of the water used by salmon in Scotland. A Vaki counter was installed in 2006 to enumerate adult salmon and trout migrating upstream in the Gala River, which has a catchment area of 207 km^2 (Figure 3.24). The counter is located in the lower part of the catchment at the Skinworks Cauld fish pass (Figure 3.25). Each fish passing through the Vaki counter produces a silhouette that is used to measure the depth of each fish from which the length is estimated, as well as the direction of movement. A Vaki Riverwatcher model was used with Vaki's colour video camera attachment and light tunnel to control the position of each fish and provide illumination (Figure 3.26).

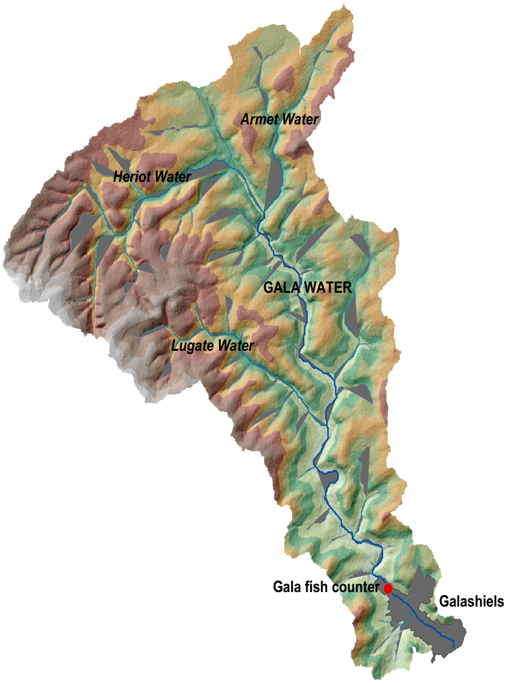


Figure 3.24. Map of the Gala Watershed. The red dot indicates the location of the Skinworks Cauld fish pass and the Vaki fish counter at Gala. Grid reference: NT 487 367. Map courtesy of James Hunt.

Figure 3.25. Photo of the Skinworks Cauld fish pass and counter site. Photo courtesy of James Hunt.

Figure 3.26. Photo of the Vaki counter and colour video camera installation at the Skinworks Cauld fish pass. Fish enter the counter at the top of the photo and exit at the bottom. The triangular section of the counter box on the right side of the photo is the colour camera and viewing window. Photo courtesy of James Hunt.

Data

All fish passing through the Vaki counter were enumerated and had lengths estimated using a standard depth to length ratio. Lengths are measured to the nearest centimeter and are reported to be up to 90% accurate (http://www.vaki.com/Products/RiverwatcherFishCounter/). The species for all fish that were sufficiently visible was determined using colour video images (Figure 3.27). Species that were not salmon or trout were removed from the dataset because they only represent a small fraction of the total number of fish enumerated each year. This included one grayling, 11 rainbow trout, and

1533 records that were determined not to be fish (i.e., otter). We excluded data from January to May 2014 because there were no fish to predict species during these months.

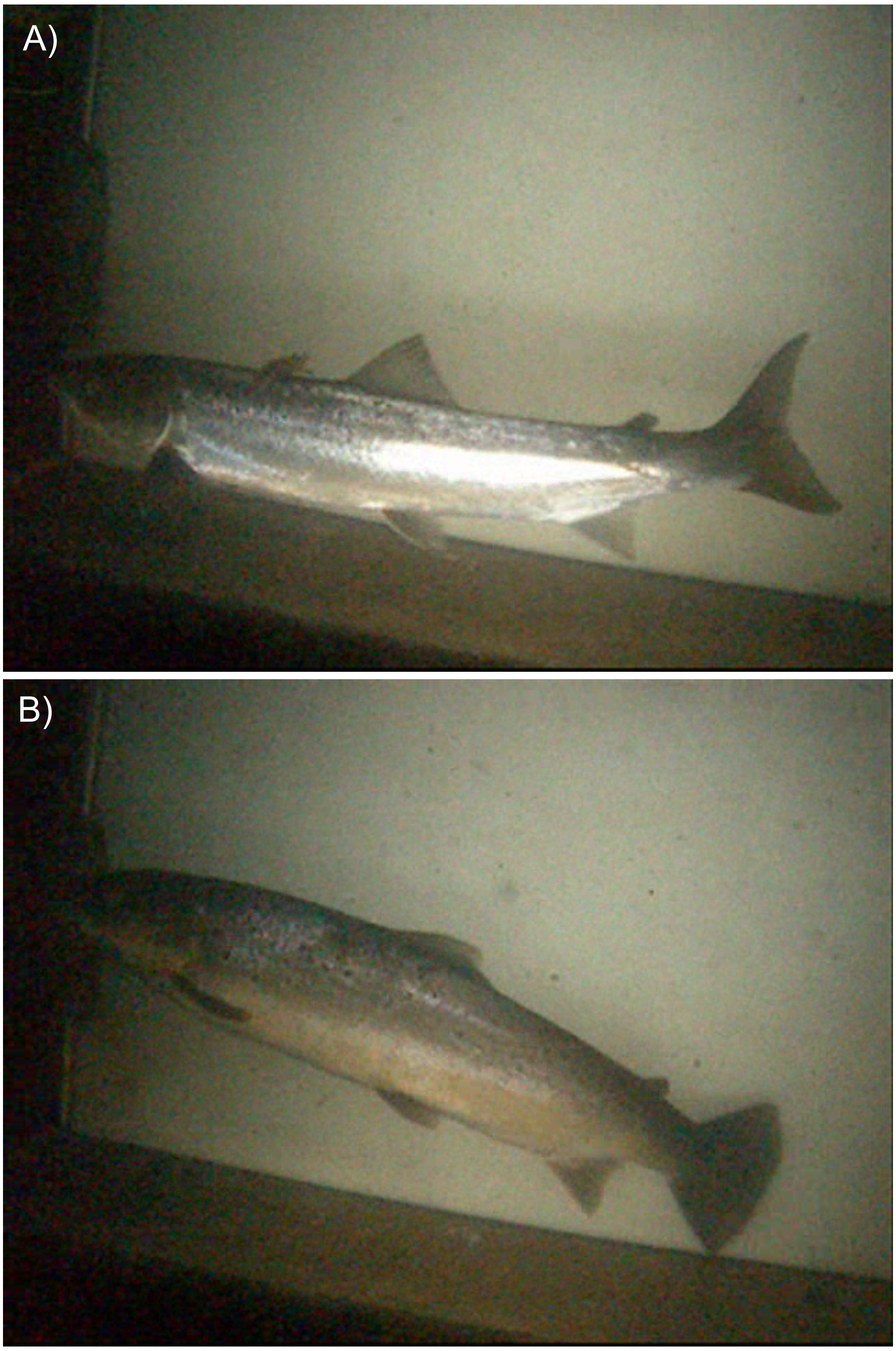


Figure 3.27. Screen shot of A) salmon and B) trout swimming through the Vaki counter. Photo courtesy of James Hunt.

<u>Model</u>

We used a GLM to relate the length of individual fish to species identification (salmon [1] or trout [0]) based on species data that was video validated by observing fish pass through the counter. We evaluated two model forms: (1) a historical model that uses data from previous years of sampling, and (2) an in-season model that only uses data from the current year (2014 as an example). The historical model can be used when the number of validated fish in a given month is too few to confidently estimate the species distribution based on fish size. The current model can be used to fit months or years when the number of records with length data is sufficient to get confident estimates of species proportions.

Current Model

We fit a GLM to the 2014 data using the ‘stats’ package (family: binomial) in R (R Development Core Team 2012). We included length and month as explanatory variables. The model is as follows:

$$Y_{i,j} \sim Bin(1, p_i)$$
$$logit(p_i) = \alpha + \beta_1 L_i + \beta_2 Jun + \beta_3 Jul + \beta_4 Aug + \beta_5 Sep + \beta_6 Nov + \beta_7 Dec$$

where, $Y_{i,j}$ is either salmon [1] or trout [0] for fish *i*, β_1 is the effect of length (L). The effects of months June to December are described by coefficients β_2 to β_7, with October as the reference month (i.e., α); it is common practice to assign the factor level with the most data as the reference level when creating dummy variables. Each year the model is fit to a different dataset and the months included in each model will depend on the available data. If fish were only observed migrating from September to November, for example, then the model would only contain those months as predictors. Alternatively, if fish were observed migrating all months of the year, the model would contain all months as predictors.

Historical Model

We fit a GLMM to all available data (2006 - 2014) using the ‘glmmADMB’ package (Bolker et al. 2012) with a binomial distribution. We included fixed effects for length and month. To take advantage of all years of data, we included year as a random effect, which allows for variation among years in the relationship between fish length and species. The historical model is as follows:

$$Y_{i,j} \sim Bin\left(1, p_{ij}\right)$$
$$logit\left(p_{ij}\right) = \alpha + \beta_1 L_{ij} + \beta_2 Jun_j + \beta_3 Jul_j + \beta_4 Aug_j + \beta_5 Sep_j + \beta_6 Nov_j + \beta_7 Dec_j + a_j$$
$$a_j \sim N(0, \sigma_a^2)$$

The random intercept of year is a_j with a mean of 0 and variance.

For both current and historical models, we estimated the number of fish that were salmon by summing the predicted probabilities of being a salmon (between 0 and 1) for each fish. To estimate the number of trout, we summed the predicted probabilities of being a trout for each fish. We present the estimated probabilities for each month with 95% confidence intervals. Note that the confidence intervals for the historical model only include error in the fixed-effects and not the random effect of year. Therefore, estimates of uncertainty are biased low, which can be significant if there is large variation between years. The approximate method was used to calculate the 95% confidence intervals. We illustrate the current and historical models by producing estimates of salmon and trout for 2014.

Results

Salmon and trout co-migrate through the Gala fish counter from July to December, although co-migration is limited to fewer months in some years (Figure 3.28). Salmon had longer bodies than trout on average, but there is substantial overlap in their length distributions (Figure 3.28). Between June and December 2014, 672 salmon and 1705 trout were visually identified by Tweed staff moving upstream through the counter. A total of 2439 fish were not identified due to water clarity issues. Using the current GLM, we predicted that of the 2439 unidentified fish, 947 (95% CI 841 – 1083) were salmon and 1492 (95% CI 1356 – 1598) were trout. Using the historical GLMM, we predicted 1070 salmon (95% CI 900 – 1246) and 1369 trout (95% CI 1193 – 1539).

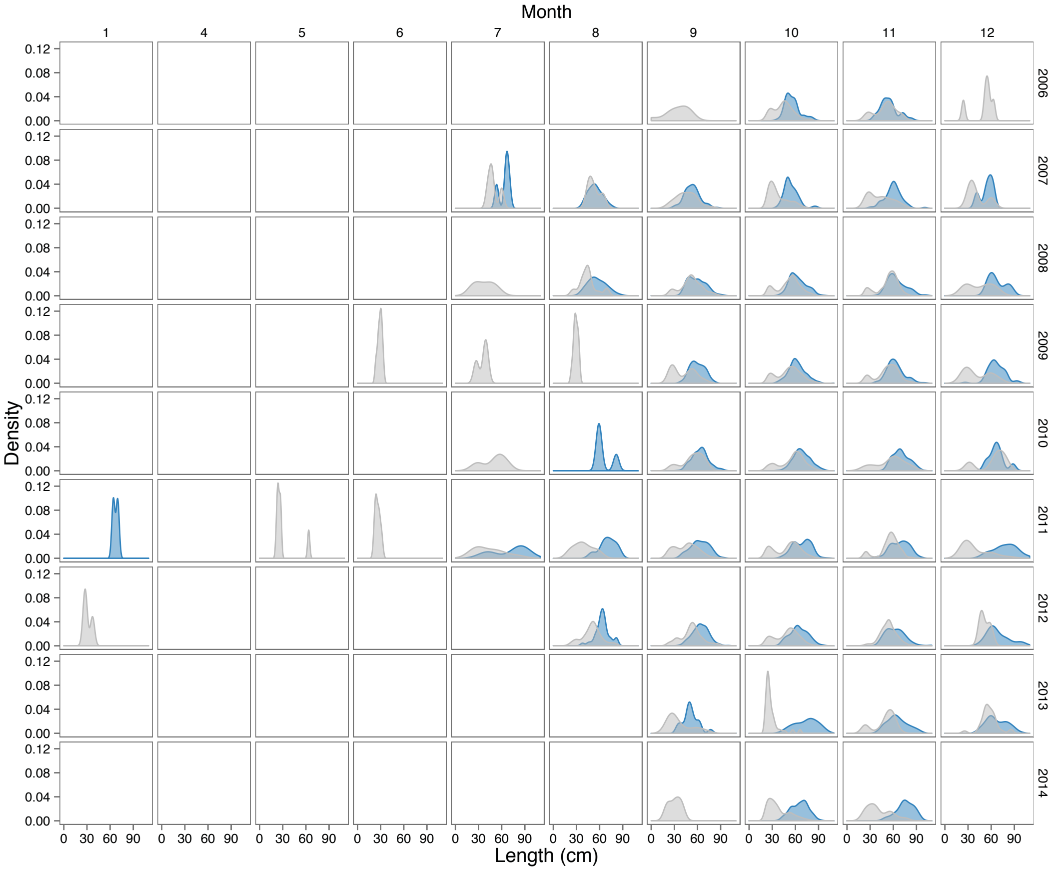


Figure 3.28. Length distributions for salmon (blue) and trout (grey) by month and year.

The uncertainty for both models overlap within species, but there is a greater difference between the number of salmon and trout estimated by the current model when compared to estimates for the historical model (Figure 3.29). The current model has the benefit of using length-species relationships from the current year. However, it tends to produce uncertain and uninformative estimates for most months and sizes except October and November in 2014 (Figure 3.30) The historical model produces more certain estimates over a longer time period (e.g., August to December 2014; Figure 3.31), because it draws on a much larger sample size (historical *n* = 15 252, current *n* = 2377) for all months by incorporating all years of data.

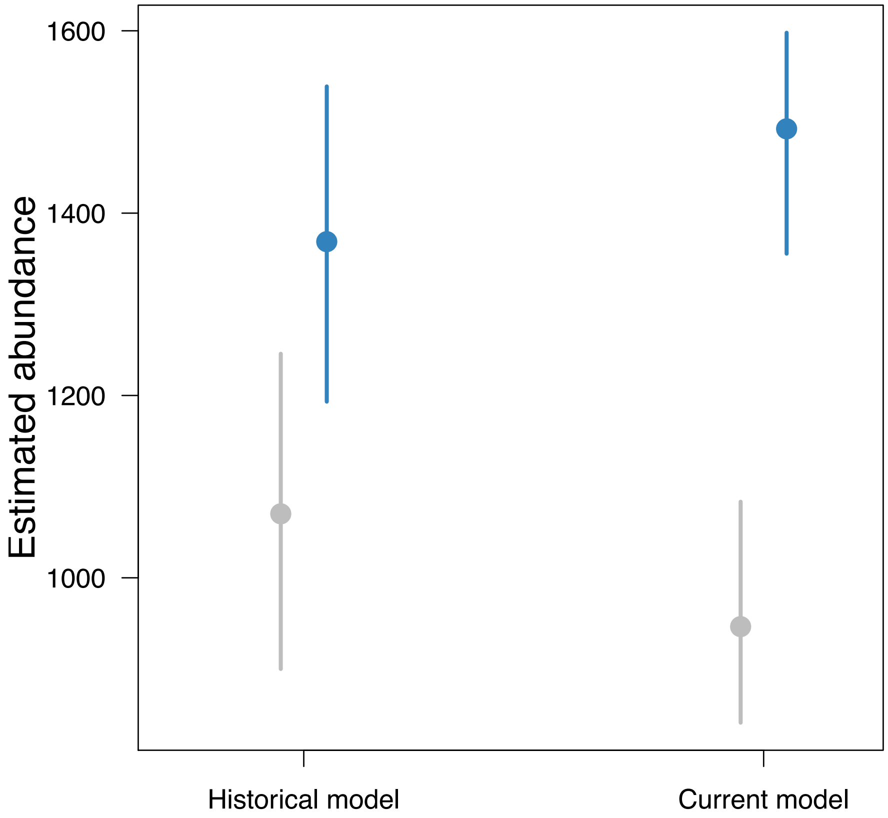


Figure 3.29. Estimated abundance for salmon (blue) and trout (grey) for 2014 using the historical and current models. The dots represent the mean estimate and the bars are the 95% confidence intervals surrounding the mean estimates.

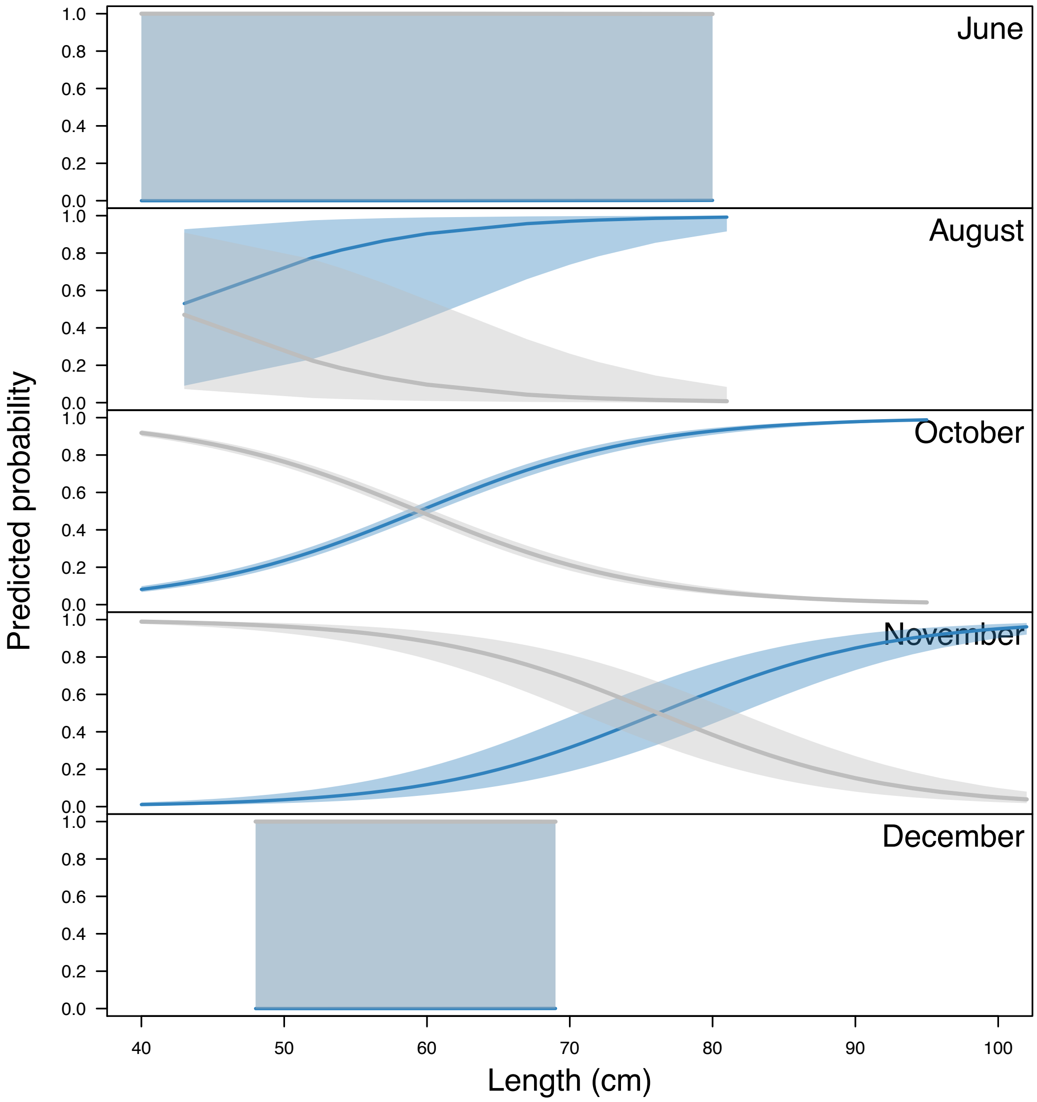


Figure 3.30. Plots showing predicted probabilities of being a salmon (blue) and trout (grey) by month using the current model (GLM, family: binomial). Length and month are the explanatory variables. The solid line is the mean predicted probability for a given fish length and shaded areas are the 95% confidence limits on the predicted probabilities.

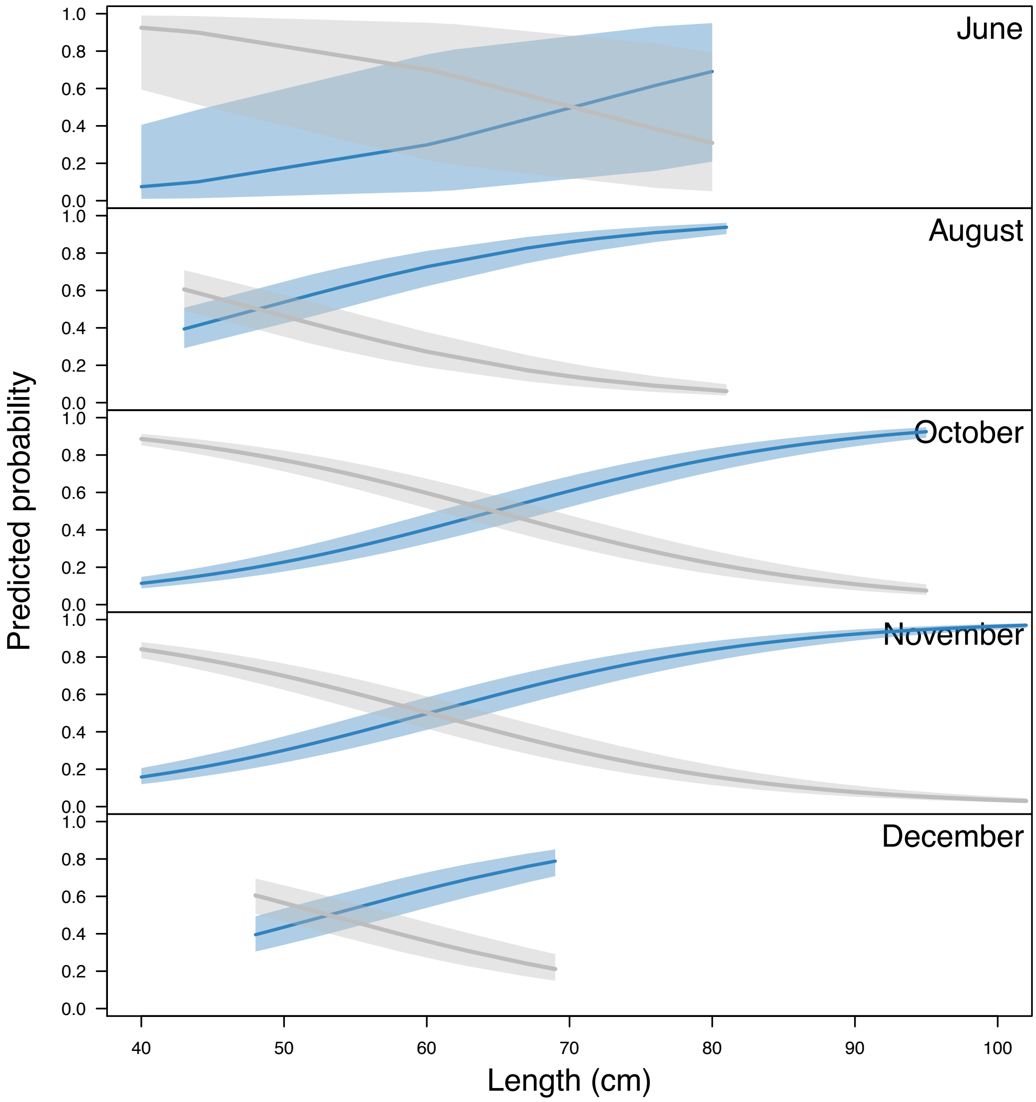


Figure 3.31. Predicted probabilities of being a salmon (blue) and trout (grey) by month using the historical model (GLMM, family: binomial). Length and month are explanatory variables, and year has been set as a random effect. The solid line is the mean predicted probability for a given fish length and shaded areas are the 95% confidence limits on the predicted probabilities. Note that the 95% confidence intervals are only for the fixed-effects and underestimate the total uncertainty (fixed-effects + random effects).

Discussion

We used a generalized linear modeling approach to predict the species migrating through a Vaki counter in 2014 based on fish length. We applied two different types of generalized linear models, which used either the current years data (2014, current model) or all historical data (2006-2014, historical model). The two models predicted different numbers of salmon and trout, but in many cases the 95% confidence intervals overlapped.

The historical model has high statistical power because of the high sample size (*n* = 15 252 identified salmon and trout between June and December).

The biggest advantage of the historical model is that it draws on information from other years, which is particularly helpful when there have been few fish identified to species in the year of concern. Differences in uncertainty between the current and historical models during months with low sample sizes are illustrated by comparing the uncertainty in predicted probabilities for August (Figures 3.30 and 3.31). The main difference between the two models is that the historical model uses the average relationship between fish length and species, whereas the current model uses the specific relationship for the current year. This is an important difference to consider if in the year being predicted fish size distributions contrast greatly from the historical average. In years or months when this is the case, the current model will generate more accurate estimates. However, if year-to-year variability is relatively low, the historical method is favorable.

In our example, we compared the predicted probability of being a salmon or trout from June to December between two models (current and historical); alternatively, one could use the current and historical models together within a given year. For example, in October and November when there are typically a large number of fish validated to species, the current model will produce certain estimates that are probably more accurate than the historical model. In most other months, however, validated samples sizes are sufficiently low that most predicted probabilities within a month are uncertain. Although this combined method may improve estimates of abundance, the majority of fish migrate through the fish counter between October and November and are well represented by the validation data, making up the vast majority of the total abundance annually. Species length cut-offs could also be applied to reduce uncertainty. For example, if it is known that fish < 40 cm are always trout and fish > 100 cm are always salmon, this information could be used to determine species above and below these length cut-offs with greater certainty than the model. This could be incorporated using prior distributions in a Bayesian framework.

Although these methods are general, they rely on relatively large quantities of accurate length data and a length-species relationship. Therefore, applications of these models to other types of fish counters and sites with small sample sizes are likely limited. For example, resistivity counters provide rough approximations of fish length using peak signal size and would likely provide uncertain predicted probabilities of species unless there was a length cut-off between species. It is important to assess the quality of data and strength of the length-species relationship before applying these models to other fish counter data. The modeling approach presented herein can be used to determine the species identification of salmon and trout using length data. A combined modeling approach could be explored further. In addition, cross-validation of the models' predictions would also provide an estimate of the predicted error of the model.

References

Alaska Department of Fish and Game (ADFG). 2015. Alaska Fisheries Sonar, Sonar Tools: Imaging Sonar. Available from http://www.adfg.alaska.gov/index.cfm?adfg=sonar.didson (assessed May 2015)

Aquantic Ltd. 1998. 2100C Logie Fish Counter – Operating and Technical Manual.

Bacon, P.J., Palmer, S.C.F., MacLean, J.C., Smith, G.W., Whyte, B.D.M., Gurney, W.S.C., and Youngson, A.F. 2009. Empirical analyses of the length, weight and condition of adult Atlantic Salmon on return to the Scottish coast between 1963 and 2006. ICES Journal of Marine Science 66:844–859.

BlueView Technologies, Inc. 2007. ProViewer Software Handbook. Part Number 201334-01

BlueView Technologies, Inc. ©2003-2007. ProViewer High Definition Imaging Sonar User’s Handbook. PN 201310-02B.

Cronkite, G.M.W., Enzenhofer, H.J., Ridley, T., Holmes, J., Lilja, J., and Benner, K. 2006. Use of High-Frequency Imaging Sonar to Estimate Adult Sockeye Salmon Escapement in the Horsefly River, British Columbia, iv+47 pp.

EA Technology Ltd. 2006. Fish Counter System – User Guide Version 1.4, Guide produced for Scottish and Southern Energy.

Gurney, W.S.C., Brennan, L.O., Bacon, P.J., Whelan, K.F., O’Grady, M., Dillane, E., and McGinnity, P. 2014. Objectively assigning species and ages to salmonid length data from dual-frequency identification sonar. Transactions of the American Fisheries Society 143:573-585.

Holmes, J.A., Cronkite, G.M.W., and Enzenhofer, H.J. 2005. Feasibility of deploying a dual frequency identification sonar (DIDSON) system to estimate salmon spawning ground escapement in major tributary systems of the Fraser River, British Columbia. Canadian technical report of fisheries and aquatic sciences 2592: xii + 51 p.

Ihaka, R., and Gentleman, R. 1996. R: A language for data analysis and graphics. Journal of Computational and Graphical Statistics 5: 299–314.

Rakowitz, G. (2009) Didson counting - manual or automatic?. (Proceedings of the Underwater Acoustic Measurements: Technologies and Results, Nafplion, Greece, 2009), 6 pp.

Sound Metrics Corp. 2015. DIDSON Sonars. Bellevue, Washington, United States. Available from http://www.soundmetrics.com/products/didson-sonars/Software.

VAKI Aquaculture Systems Ltd. 2015. Riverwatcher Fish Counter User Manual

VAKI Aquaculture Systems Ltd. 2015. Riverwatcher Software User Manual, Winari Software.

4.0 Operational Costs and Validation

4.1 Operation and Maintenance

In this section we discuss general cost considerations for operating and maintaining all major types of counter technologies, with more specific information below. Cost estimates were based on an extensive literature review (Appendix 1), data from questionaires sent to current counter operators (Appendix 2), and from IFR's 25-year experience with various counters. These costs represent typical budgets, but as each site is unique, this can vary greatly depending on the following:

Counter Structure

Structure type is one of the largest determinants of cost. Crump weirs and flat pads, for example, are low maintenance and require infrequent debris removal, whereas partial diversions and fish passes require moderate maintenance and require periodic monitoring and cleaning. Full river span picket fences require a high level of maintenance in-season. Most picket fence sites are inspected daily to several times per week for debris, holes, or other issues that may compromise operation. High water levels can limit fence access due to safety issues with wading in fast deep water and can also overturn fences. In these cases, complete in-season rebuilds are common. Alaskan floating fences are generally lower maintenance than traditional picket fences, as they are self cleaning and much less likely to be "blown out" during a high water event.

Debris Loads

The amount of debris (i.e., wood, bedload) that is transported downstream will affect the number and duration of site visits required to ensure proper counter operation. The frequency of visits will increase, and take longer, with higher debris loads and more frequent discharge fluctuations.

Fish Abundance

High fish abundance (i.e., high number of fish events) can rapidly fill data storage for some counters (e.g., resistivity), subsequently requiring more frequent downloading. This will require more site visits, especially if the counter does not have remote download capabilities.

Equipment Malfunction

Equipment malfunctions increase in-season mainanence costs. While some repairs can occur in the field, other instances require the equipment to be sent to the manufacturer, resulting in potential data gaps. This should be avoided since data gaps reduce data reliability which requires additional analyses. If consistent data collection is the highest priority, it is recommended to purchase backup equipment (high capital cost). Another option, which can reduce costs but is less reliable, is an assurance from the supplier that loan or lease of equipment is available in the event of equipment malfunction.

Power Supply

Power consumption varies among counter equipment. Mains power is most reliable and only susceptible to power outages, which can be mitigated by having a backup battery supply. Unfortunately, it is not always available and could be costly to install in remote sites. When on mains power, the site requires infrequent weekly visits if no remote communication is available, and less frequently if counter operation can be monitored remotely. It is important to keep in mind that power outages can damage equipment.

Alternative power supplies (i.e., batteries, solar) will moderately increase maintenance costs; the cost of batteries and other infrastructure (if installing a solar-powered system) can vary depending on the location. Site visits should occur weekly at minimum if using alternative power supplies to change batteries and ensure proper functioning. Temperature and cloud cover will influence the discharge rate of batteries and recharge rate of solar pannels, respectively. In some cases, battery or solar power can be more reliable than mains power when power outages are frequent. Solar and wind power generation can be paired with batteries to increase the time between battery changes and in some cases can be used to eliminate battery changes.

Site Access

Site access can cause costs to vary considerably. If a site is close to the operators workbase and easily accessed by vehicle, costs will be low. Conversely, if a site is farther away and poses accessibility challenges (i.e., no vehicle access), time and travel costs will increase accordingly. Here we provide a breakdown of operation and maintenance costs for all major types of counter technologies. Refer to Table 4.1 for a summary of this information.

Table 4.1. Maintenance and operation costs associated with optical beam, hydroacoustic, resistivity and video counters.

Type of counter	**Typical application and channel type**	**Maintenance**		**Operations**			
		Annual costs	In-season costs	Remote downloading capabilities	Power supply	Equipment servicing	Debris load and structure
Optical beam counters	Fish pass	Installation: 2-4 ppl for 1 day Removal: 2-4 ppl for 1 day	Moderate	Supported by manufacturer and available for all models	12 V 40 Ah battery will last 8 days	Manufacturer: Out of country High shipping costs, long transport time Backup cost: High (£27 000)	Periodic removal required
	Full-river fences	Installation: 2-4 ppl for 2 days Removal: 2-4 ppl for 1 day	High	Supported by manufacturer and available for all models	12 V 40 Ah battery will last 8 days	Manufacturer: Out of country High shipping costs, long transport time Backup cost: High (£27 000)	Up to daily removal required
Hydroacoustic counters	Diversion fence	Installation: 2-4 ppl for 2 days Removal: 2-4 ppl for 1 day	High	Limited to no capability due to large data files	2.5-12.5 Ah	Manufacturer: Out of country High shipping costs, long transport time Backup cost: High (£22 000-48 000)	Up to daily removal required

	No structure	Installation: 2 ppl for 1 day Removal: 2 ppl for 1 day	Low	Limited to no capability due to large data files	2.5-12.5 Ah	Manufacturer: Out of country High shipping costs, long transport time Backup cost: High (£22 000-48 000))	Little to no removal required
Resistivity counters	Crump weir	Installation: 2 ppl for 1 day Removal: 2 ppl for 1 day	Low	Capable with third party software and hardware	24 V 40 Ah battery will last 5 days	Manufacturer: Scotland-based Low shipping costs, short transport time Backup cost: Low (£10 000-20 000)	Little to no removal required
	Flat pad sensor	Installation: 2 ppl for 2 days Removal: 2 ppl for 1 day	Low	Capable with third party software and hardware	24 V 40 Ah battery will last 5 days	Manufacturer: Scotland-based Low shipping costs, short transport time Backup cost: Low (£10 000-20 000)	Little to no removal required
	Tube sensor in fish pass	Installation: 2-4 ppl for 1 day Removal: 2-4 ppl for 1 day	Moderate	Capable with third party software and hardware	24 V 40 Ah battery will last 5 days	Manufacturer: Scotland-based Low shipping costs, short transport time Backup cost: Low (£10 000-20 000)	Periodic removal required

	Flume sensor in fish pass	Installation: 2-4 ppl for 1 day Removal: 2-4 ppl for 1 day	Moderate	Capable with third party software and hardware	24 V 40 Ah battery will last 5 days	Manufacturer: Scotland-based Low shipping costs, short transport time Backup cost: Low (£10 000-20 000)	Periodic removal required
Video counters	Fish pass	Installation: 2 ppl for 1 day Removal: 2 ppl for 1 day	Moderate	Limited to no capability due to large data files	Mains power	Replacement in-season Backup cost: Low (£5000)	Periodic removal required
	Diversion fence	Installation: 2-4 ppl for 2 days Removal: 2-4 ppl for 1 day	High	Limited to no capability due to large data files	Mains power	Replacement in-season Backup cost: Low (£5000)	Up to daily removal required

Notes. All sites were assumed to be 20 m wide, have road access for installation and removal, and have a 10 m-long diversion fence (where applicable). In-season maintenance costs are related to the debris load and structure: Low (little to no removal required), Moderate (periodic removal required) and High (up to daily removal required). Installation and removal time are in people days (ppl).

4.1.1 Optical Beam Counters

Maintenance

Vaki Riverwatcher fish counters are usually associated with fish passes or fish fences, and generally require minimal to moderate maintenance once installed.

Annual Costs

Equipment is typically installed prior to fish migration periods, and removed during periods of fish absence to avoid damage when not in use. Installation and removal normally takes 2 to 4 people one day. A typical installation scenario for Riverwatcher counters would be at a fish pass with good road access. Pre-built sensor units are installed in the fish pass using a crane truck. Depending on the location (easy access *versus* remote access) and complexity of the site (small fish pass *versus* full span fence), installation could take one to several days and will be site-specific. Counters, sensors and fences will also require maintenance and repair periodically (i.e., annually) to ensure that equipment is in good working order for the following season. Costs vary depending on the level of maintenance required and the location of the manufacturer. Vaki, for example, is located in Iceland, while Aquantic and SSE are located in Scotland. Costs of shipping equipment can be substantial (up to £300) and should not be overlooked.

Operational and In-season Cost Considerations

Vaki Riverwatcher counters typically require weekly visits to ensure proper operation, check for debris issues and to collect data and video validation data if there is no remote access. Depending on location, safety issues and access can require 1 to 2 technicians for half of a day.

In-season maintenance may be required if sensors and fence panels are damaged by debris. Risk of vandalism can also be high in more populated sites. Operators who responded to the questionnaire indicated costs ranging between £3000 to £10 000 annually to install, operate, download and review data from optical beam counters (Appendix 2). The highest cost was associated with labour, followed by equipment and travel. Respondents identified ongoing maintenance as the greatest cost by task. Larger budgets were associated where high debris loads required regular removal. The following sections present cost and reliability considerations applicable to Vaki counters:

Remote Downloading

Vaki counters can be monitored, and have data downloaded, remotely. This reduces the need for more frequent site visits and increases the reliability of counter operation. Costs associated with remote downloading are low compared to weekly site visits despite an initial investment in communication equipment. Additional data transfer costs can vary (i.e., cell phone or hard wired internet access) but are relatively inexpensive.

Power Supply

Two power supplies are used for Vaki counters: mains and battery power. Mains power is the lower, and more reliable, cost option. Mains power eliminates the need for regular site visits, especially if coupled with remote downloading capabilities. Conversely, batteries require an upfront equipment cost and weekly site visits to change batteries. Vaki counters typically require 0.2 Ah per channel to operate and a 12 V 40 Ah battery would operate the counter for approximatley 8 days. Batteries need to be replaced every 2 to 3 years.

Equipment Malfunction

If counter or sensor failures occur, Riverwatcher counters must be returned to the manufacturer in Iceland for repair. This can incur high costs and result in considerable data gaps. Several respondents to the questionaire found the high cost of repairs and the need to ship equipment to Iceland problematic. One strategy is to purchase an after-sales service contract offered by Vaki; the cost of the service contract is dependent on distance from Iceland and what level of service is required by the operator. A basic service contract included with Riverwatcher is £850. Data gaps can be prevented by purchasing backup counter and sensor equipment (£27 000) on-site.

4.1.2 Hydroacoustic Counters

Maintenance

Multibeam (e.g., DIDSON 300, or BlueView M900-2250) and splitbeam sonar counters (e.g., DTX-Echosounder) have similar maintenance requirements. Depending on the site, hydroacoustic counters can be used with or without a structure. Multibeam sonars are generally used in conjuction with a diversion fence that forces fish to migrate through a constrained portion of channel rather than the entire streamwidth. A typical multibeam installation would include a diversion fence (e.g., purpose built picket fence across a portion of the stream width). Assuming the site had road access, we estimate it would take 2 to 4 people approximately 2 days to install. Depending on the location, road access and site characteristics (i.e., streamwidth, expected discharge and debris loads), installation could take several more days with the same number of staff. Splitbeam counters have a longer range than multibeam and may not need a diversion fence, but require a specific stream profile (i.e., a consistent angled bed profile).

Annual Costs

Hydroacoustic counters are typically installed prior to the migration period and removed when fish are not migrating. After removal, equipment should be cleaned and allowed to dry before storing in a dry location. Maintenance can be done during the lowest migration period if migrations are year round. Sonar counters may require maintenance and repair annually during the off-season which can require the user to return equipment to the manufacturer. This may be impracticable due to costs and time constraints and is at the discretion of the user. All hydroacoustic counter manufacturers are located in the United States. Diversion fences will also require annual maintenance during the off-season to ensure structures are in good working order for the next season.

Operational and In-season Cost Considerations

Operation costs for hydroacoustic counters vary depending on the requirements of the operator, but are generally higher than optical beam or resistivity counters. Depending on location, safety issues and site, operators will typically have 1 to 2 technicians on site daily for a half day to maintain equipment and collect data.

In-season maintenance requirements are generally low. Multibeam sonar counters have lenses that must be cleaned periodically depending on sediment loads. Splitbeam sonar counters may require cleaning or replacing of transducers. Other common requirements include changing the trajectory due to water-level fluctuations and debris removal from partial diversion fences, however this can be incorporated into daily site visits. Operators who responded to the questionaire indicated expenses ranging from £50 000 to £80 000 annually to install, operate, and download and review data for sonar counters (Appendix 2). The highest cost was associated with labour, followed by equipment and travel. Respondents identified data collection and processing as the greatest cost by task. Backup equipment, in the case of equipment malfulction, can cost £22 000 for BlueView P900-2250 and £48 000 for a DIDSON 300. The following sections present cost and reliability considerations applicable to hydroacounstic counters:

Remote Downloading

Sonar counters have an external computer that communicates operational settings and stores recorded data. Data files are large (0.5-1 GB per hour) and downloading remotely is not a cost-effective method given that daily visits are required and there is little additional benefit.

Power Supply

Two power supplies are typically used for hydroacoustic counters which have high power requirements (2.5-12.5 Ah). Mains power or battery banks charged by generator, solar or micro-hydro generator are used. Mains power is more reliable and requires less maintenance by staff. Systems relying on battery require upfront setup and equipment costs, and regular site visits to ensure operation. Batteries need to be replaced every 2 to 3 years.

Debris Load

Sonar counters are typically used with diversion fences that require frequent visits by staff to remove debris. As the majority of operators are visiting the site daily to retrieve data, debris removal is not neccesarily an extra expense. High discharges and sediment load can also interfere with the effectiveness of sonar counters, but this is something that is beyond the operators' control.

4.1.3 Restivity Counters

Maintenance

Resistivity counters (Logie 2100C, Mark 12 counter) are usually associated with Crump weirs, tubes, flat pads or flume sensor structures which all require minimal maintenance once installed.

Annual Costs

Annual maintenance is contingent on the site. If a Crump weir (high initial capital cost) is installed at the start of a project, annual maintenance is quite minimal and consists up to 1 day of work for 1 to 2 people testing wiring, examining electrodes and other in-river equipment for damage. Generally this equipment is quite durable and should not require major repairs or replacement for at least 10 years if properly designed and installed.

If a tube or flat pad is used, it is typically installed just prior to the migration period of the fish being enumerated and removed during periods of fish absence to avoid damage when not in use. Installation and removal for both tubes and flatbeds should take 2 to 4 people one day. A typical install scenario for a flat pad would be in a small- to medium-sized river with vehicle access (max width 25 m and uniform depth of 1 m) where pre-built equipment would be installed and anchored to the stream bottom. Tube sensors are typically installed at the top of a fish pass using a crane truck; also requiring good road access. Depending on the location (remote access) and complexity of the site, installation could take several days longer and will be site-specific.

Operational and In-season Cost Considerations

Resistivity counters typically require weekly site visits to evaluate proper counter operation, check for debris issues, retrieve images, and download data if there is not remote download capabilitites. Depending on location, safety issues and access, site visits require 1 to 2 people for half of a day.

Wiring from the counter to the Crump weir electrodes can be damaged by debris during flood events and electrodes can also be displaced. These events can be expensive to repair (£3000), resulting in lost operational time. The cost would be much less to repair the same damage for flat pads and tube sensors because they can be removed from the river or fish pass (£1000). There is also the risk of counter failure in-season due to power outages, lightning strikes, and data overloading the counter. It is recommened that backup equipment is available or an assurance from the manufacturer that replacement or loan equipment will be made available during repairs.Operators who responded to our questionaire indicated expenses ranged from £3000 and £10 000 annually to install, operate, and download and review data from resistivity counters. The highest cost was associated with labour, followed by equipment and travel. Respondents identified counter ongoing maintenance as the greatest cost by task. The following sections present cost and reliability considerations applicable to resistivity counters:

Remote Downloading

Resistivity counters can be monitored, and have data downloaded, remotely, reducing the need for site visits and increasing counter reliability. Costs associated with remote downloading are low compared to weekly visits. There is an initial investment in communication equipment, and ongoing costs that are dependent on what communication platform is used (i.e., cell phone or hard wired internet access).

Power Supply

Two power supplies are used for resistivity counters: mains and battery. Mains power is the lower cost option and more reliable. Mains power eliminates the need for regular site visits, especially when coupled with remote downloading capability. Conversely, batteries require an upfront equipment cost and, at minimum, weekly site visits to change batteries. Resistivity counters typically require 0.3 Ah per channel to operate (i.e., a 12 V 40 Ah battery would last approximatley 2.5 days). Batteries need to be replaced every 2 to 3 years.

Equipment Malfunction

If counter or sensor failures occur, certain repairs can occur without shipping to manufacturer. Circuit boards and wiring within the counter can be replaced onsite with support from the manufacturer. Sensors and wiring can also be repaired as they are usually built by a local third party with common materials. Having backup counters (£10 000 for Logie, £20 000 for Mark 12) and sensor equipment on-site can avoid compromised data when failure occurs.

Debris Load

Resistivity counters are typically used with Crump weirs, flat pads, or in conjunction with fish passes where debris do not typically accumulate. Thus, site visits to address this issue are infrequent.

4.1.4 Video Counters

Maintenance

Video counters generally require a moderate level of maintenance compared to the other counter technologies. Depending on the site, video counters can be used with or without a structure, but are typically used in conjuction with a diversion fence or fish pass that constrains fish migration through a smaller channel area. A typical install of a purpose-built picket fence across a portion of stream width at a site with road access would take 2 to 4 people approximately 1 to 2 days. Conversely, depending on the location (remote access) and complexity of the site (i.e., streamwidth, expected discharge, debris loads, etc.), installation could take several days longer and will be site-specific.

Annual Costs

Video counters are typically installed prior to fish migration periods and removed when fish are not present. After removal, equipment must be cleaned and allowed to dry before storing in a dry location. Video counters may require periodical replacement, maintenance or repair. Generally, video equipment is inexpensive compared to other counter technologies; digital video recorders are £100-500 (can record video from up to 8 cameras at a time) and video cameras are £50-500 (per camera) depending on desired camera mounting locations (underwater *versus* above the channel). Repair is usually not an economical option due to the low price of equipment favoring full replacement. Diversion fences will also require periodic maintenance and repair (i.e., annually) to ensure structures are in good working order for the following season. These costs are variable and difficult to estimate.

Operational and In-season Cost Considerations

Operational costs for video counters vary depending on requirements of the operator, but are generally similar to optical beam and resistivity counters. Depending on location, safety issues and access, site visits require 1-2 technicians on site weekly for a half day to maintain equipment and retrieve data. In-season maintenance requirements are generally low. Most requirements are cleaning or replacing cameras, adjusting camera angles due to water-level fluctuations, removing debris from in front of lenses, cleaning flash boards, and cleaning and maintaining diversion fences. As with all counter technologies, there is the risk of video counter failure in-season. Backup equipment is recommended; this is a feasible option for most budgets due to the low cost of this equipment. Operators who responded to the questionnaire indicated expenses between £20 000 and £50 000 annually to install, operate, and download and review data from video counters. The highest cost was associated with labour, followed by equipment and travel. Respondents identified analysis as the greatest cost by task. This specifically refers to the cost associated with reviewing all video footage in order to count fish. The following sections present cost and reliability considerations applicable to video counters:

Remote Downloading

Video counters typically store recordings directly on digital video recorders (DVR) with removeable hard drives. Data files are large (typically 3 to 9 GB per day) and remote downloading is not an efficent option. Remote downloading is not cost-effective and given the high storage capacity of most DVR units (up to 4 TB) is not necessary.

Power Supply

The same power supply options are available for video counters: mains and battery. Mains power is more reliable and requires less maintenance by staff. Batteries require an upfront equipment cost and require regular site visits to change batteries, at minimum, every second day. Batteries need to be replaced every 2 to 3 years.

Equipment Malfunction

If equipment failure occurs, video equipment can be replaced in-season at a low cost compared to other technologies. Therefore, backup equipment should be an integral part of the budget, minimizing the risk of data loss.

Debris Loads

Video counters are used in conjunction with two structures: diversion fences and fish passes. A diversion fence requires frequent visits by staff to ensure that debris load is not affecting the counter operation. Diversion fences require more frequent visits, every 1-2 days, and therefore increase cost of operations accordingly. High discharge and sediment load can also influence the effectiveness of video counters, but this is something that is beyond the operators' control.

4.2 Validation Costs

Validation of data is key to assessing counter performance. More specifically, validation can be used to evaluate the accuracy, precision, bias and uncertainty in abundance estimates generated by a counter. One of the major challenges to validation is the number of person hours required. We use simulations to examine the trade-off between validation effort and the uncertainty in population estimates. We then show how validation data can be used to achieve acceptable levels of uncertainty in population estimates. Finally, we provide recommendations on validation requirements given different levels of uncertainty.

Introduction

Validation is essential when assessing the quality of data produced by fish counters. Unfortunately it is uncommon, where 3 out of 7 of our survey respondents reported annual validation efforts (Appendix 2). Validation involves quantifying the error rates in counter classification. These error rates are comprised of two important sources; sensor accuracy and species identification. Sensor accuracy is important for all counters and is calculated using type one (false positive) and type two (false negative) error rates. The accuracy of determining species identification is separate from sensor accuracy and is only required when two or more species overlap in their migration timing.

There are a wide variety of validation techniques, the gold standard being cross comparisons of count data to video observations of the number and species of fish. This is a true form of validation because it is independent of the counter, and can provide information on the true abundance and species composition of fish. Limitations of this technique include the requirement of high water clarity to view all fish and the ability to collect video at night, both of which can be challenging. Pseudo-validation refers to a method that does not represent the actual process being counted, or methods that are not independent of the counter. This includes methods such as dragging a dummy fish over the electrodes of a resistivity counter to interpret signal traces. This will trigger a signal for most counters but the dummy fish may differ, albeit only slightly, from a real fish migrating over the counter. Signal traces from Logie counters can also be used to validate counts but are a form of pseudo-validation because they are not independent of the counter and cannot detect false negatives (i.e., a fish passed through the counter but was not detected). Nonetheless, most pseudo-validation methods can provide adequate assessments of counter performance.

Other counters can also be used to validate the counter of interest. Although this is another form of pseudo-validation, it may be necessary due to river conditions that prohibit the use of video validation. For example, IFR used BlueView multibeam sonar to validate a flat pad resistivity counter in a remote location of British Columbia. The river was too wide and water clarity was too low to consider video validation. The main concern was that both counters may have missed fish, however it was assumed that the occurrence of missed events by both counters would have been extremely low. One of the major challenges is determining appropriate validation requirements. For example, increasing validation effort will decrease the uncertainty of abundance estimates but will also cost more time and money.

Here we used a series of simulation studies examining the effect of sensor accuracy and species composition to evaluate the trade-off between validation effort (i.e., cost) and uncertainty in abundance estimates. We simulated three counter scenarios: (1) a single species model with consistent counter accuracies of 70%, 80% and 90%, (2) a single species model with variable counter accuracies (50% or 80%), and (3) a two species model with both consistent and variable counter accuracies. We characterized validation effort as the number of fish validated (e.g., the number of fish observed on video) and assessed uncertainty in abundance estimates using three performance metrics; accuracy, precision, and bias.

Methods

For all simulations, we started with a known number of fish that moved up and down over the counter; this represents the true abundance of the population (up fish minus down fish). To put this into a validation context, this would be the number of fish observed on a video had video of the entire migration been reviewed. We termed this column of data video, where each up and down count was a row with a value of 1. We then specified the counter accuracy (e.g., consistent accuracy where 80% of the fish were correctly detected by the counter; variable accuracy: where 50% or 80% of the fish were correctly detected by the counter). We did not consider false positive up counts because these are typically rare for a well-sited counter and therefore would have little influence on the recommended validation effort. The counter accuracy was applied to the known, true abundance to back calculate the number of counts correctly recorded. A column named counter contained these data, where a value of 1 was given to a fish that was correctly counted by the counter and 0 if it was missed. A species ratio was applied to all records (observed and not observed by the counter) to divide the counts into two species. Under the column species, a value of 1 was assigned to the target species and 0 for other species. Table 4.2 provides an example of a typical validation dataset sampled to determine the relationship between validation effort and uncertainty.

To simulate the effects of different efforts on the uncertainty estimates derived from validation data, we randomly subsampled the validation dataset and calculated abundance estimates which were compared to the true abundance. Validation effort is the number of fish drawn from the population to estimate the counter accuracy and ranged from 50 to 1000 fish in increments of 50. Validation in the simulations is the equivalent to comparing the number of fish observed by video passing over the counter to the number of up counts observed by the counter. We did not validate more than 1000 fish due to extremely low error rates beyond this validation effort (i.e., < 3%). For each subsample (i.e., sample for each validation effort) we estimated the counter accuracy and species ratio by drawing from a binomial beta distribution using Monte Carlo simulations. We used a binomial beta distribution because the validation data were made up of 1's and 0's (binomial distribution component - 1's were given to fish observed and 0's were given when fish were not observed) and were used to estimate the proportion of counts (beta distribution component) that were correctly classified. We used the mean values and the posterior distributions of estimated counter accuracies and species ratios to calculate mean abundance estimates and levels of uncertainty.

Table 4.2. Example of a validation dataset. Date_time is a record of when a fish passed through the counter, channel is the channel it passed through, direction is the direction of fish movement (U=up, D=down), counter is whether or not the counter recorded the fish (1=recorded, 0=missed), video is whether or not each record was observed as a fish on the video (1=fish, 0=no fish), and species is whether or not the fish was the target species (1=target species, 0=other species). Note that date_time and channel were not used in simulations; these variables are presented to illustrate a typical validation dataset.

date_time	channel	direction	counter	video	species
13-08-01 19:54	2	U	1	1	1
13-08-01 19:54	2	U	1	1	1
13-08-01 20:01	3	U	1	1	0
13-08-01 20:01	3	U	1	1	1
13-08-01 20:03	1	U	0	1	1
13-08-01 20:04	2	D	1	1	1
13-08-01 20:04	2	D	1	1	1
13-08-01 20:04	3	U	1	1	1
13-08-01 20:04	3	U	1	1	1
13-08-01 20:04	2	U	1	1	0

Single Species Model – Constant Accuracy Scenario

The simplest scenario included three single species scenarios that differed in up count accuracy (70%, 80%, and 90%). We simulated only one population and used a down count accuracy of 80% for all scenarios. We determined the accuracy by subtracting the estimated values from the known abundance for each random sample for all validation sample sizes and calculated the root mean squared error. Accuracy is a measure of how close an estimate is to the true abundance (i.e., a combination of precision and bias). Precision was determined by subtracting the estimated values from the mean of all estimated values and calculating the root mean squared error. Precision is a measure of how repeatable an estimate is. Bias was calculated as the raw error (i.e., subtracting the known abundance from the estimated abundance). Bias is a measure of whether or not estimates are consistently higher or lower than the true abundance. All plots present the mean percent relative errors and 1 standard deviation.

Single Species Model – Variable Accuracy Scenario

To evaluate a more complex scenario, we allowed the accuracy to vary throughout the migration. To do this we simulated a population with a migration timing distribution, which was based on the migration characteristics of the North Esk (data provided by I. Simpson, MSS). When daily migration rates were within 25% of the maximum fish migration rate observed, the accuracy of the counter decreased from 80 to 50%. Although we used migration rate to alter counter accuracy, this scenario is representative of many other factors (e.g., changes in water depth) that may affect counter accuracies. We simulated this scenario 100 times (i.e., we created 100 populations). This allowed us to incorporate the stochasticity of variable accuracies because the population and migration characteristics changed with each simulation.

Two Species Model – Variable Accuracy Scenario

To further increase complexity, we explored a two species model with variable accuracy. This is the most likely scenario for salmon-bearing rivers in Scotland. The methods were identical to single species – variable accuracy simulations, except we altered the species proportion to reflect a two species system. We applied a known target species proportion of 0.8.

Results

All simulation scenarios showed that there are diminishing returns on increased validation effort. In other words, as more fish are validated the corresponding uncertainty of population estimates decreased at a slower rate.

Single Species Model – Constant Accuracy

Lower accuracy counters require more validation than higher accuracy counters to achieve the same percent relative error in the accuracy and precision of abundance estimates. Uncertainty for all three metrics can be high at low validation sample sizes and for lower up count counter accuracies (Figure 4.1). Fish abundances were always slightly overestimated, as indicated by positive and low percent relative bias values (mean estimate always < 4%).

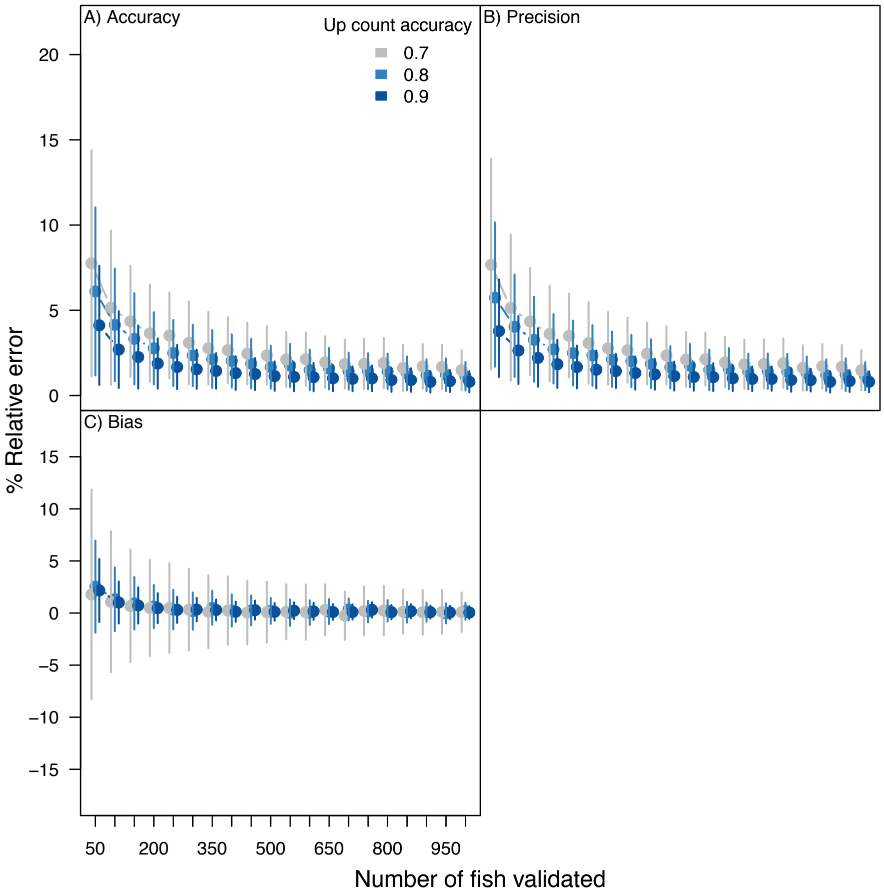


Figure 4.1. Plots showing the trade-off between validation effort (the number of fish validated) and error in abundance estimates for a single species at a constant accuracy (70% - grey, 80% - blue, 90% - dark blue). Error in abundance estimates are reported as the percent relative error in a) accuracy, b) precision and c) bias. Accuracy is a measure of how close an estimate is to the true abundance (i.e., a combination of precision and bias). Precision is a measure of how repeatable an estimate is. Bias is a measure of whether or not estimates are consistently higher or lower than the true abundance. Points indicate mean values and vertical bars represent the standard deviation.

Single Species Model – Variable Accuracy

The variable accuracy scenarios require more validation to achieve the same level of certainty as the 80% constant accuracy scenario (Figure 4.2). Although the mean accuracy of the variable scenario is approximately 0.7, the uncertainty is much higher than the constant 0.8 accuracy.

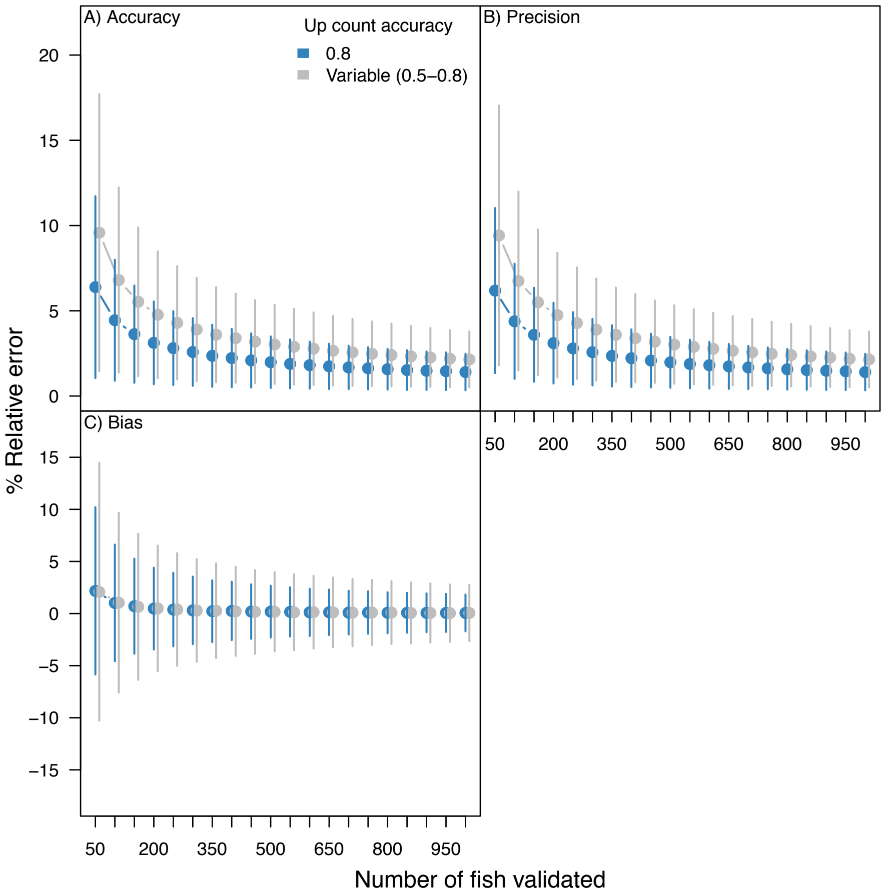


Figure 4.2. Plots showing the trade-off between validation effort (the number of fish validated) and error in abundance estimates for a single species - variable accuracy (80% - grey) and variable accuracy (50-80% - blue). Error in abundance estimates are reported as the percent relative error in a) accuracy, b) precision, and c) bias. Accuracy is a measure of how close an estimate is to the true abundance (i.e., a combination of precision and bias). Precision is a measure of how repeatable an estimate is. Bias is a measure of whether or not estimates are consistently higher or lower than the true abundance. Points indicate mean values and vertical bars represent the standard deviation.

Two Species Model – Variable Accuracy

There is an increase in the mean percent relative error and variance for accuracy and precision when two species are validated for both scenarios (Figure 4.3). The difference between the two scenarios is consistent with the single species versions, which suggests that adding a species to the model has the same impact on uncertainty in both cases. The percent relative bias tends to be slightly less negative for the variable scenario compared to the consistent scenario.

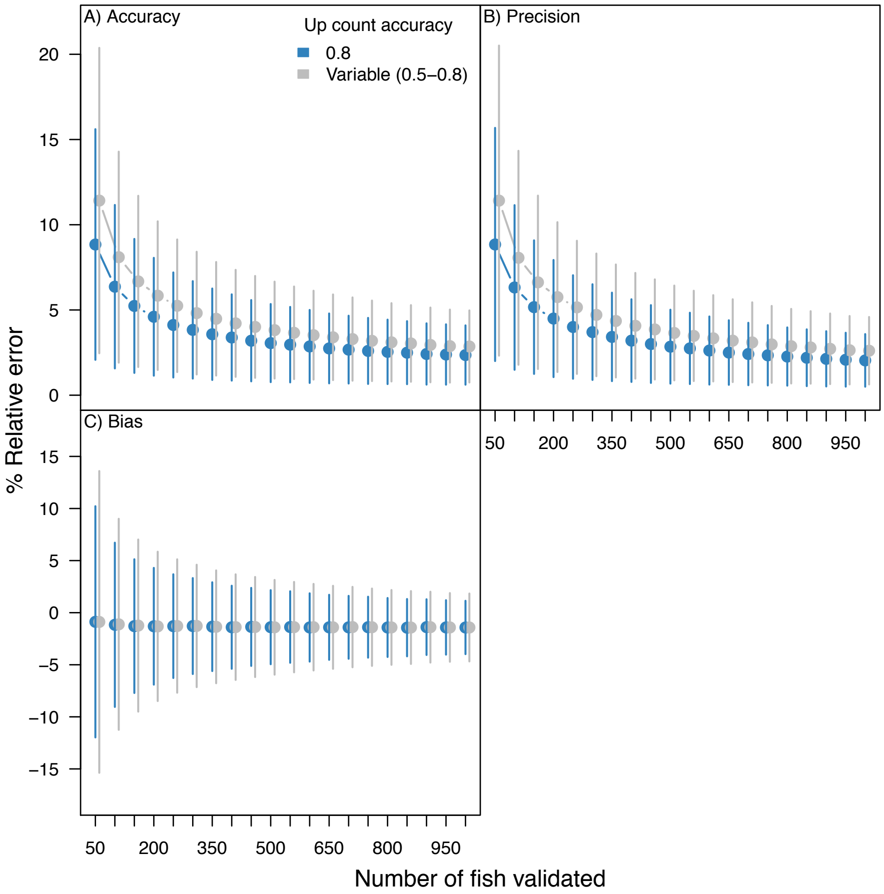


Figure 4.3. Plots showing the trade-off between validation effort (the number of fish validated) and error in abundance estimates for a two species - constant accuracy (80% - grey) and variable accuracy (50-80% - blue) scenario. Error in abundance estimates is reported as the percent relative error in a) accuracy, b) precision, and c) bias. Accuracy is a measure of how close an estimate is to the true abundance (i.e., a combination of precision and bias). Precision is a measure of how repeatable an estimate is. Bias is a measure of whether or not estimates are consistently higher or lower than the true abundance. Points indicate mean values and vertical bars represent 1 standard deviation.

Discussion

We used simulations to explore the trade-off between validation effort and multiple metrics of uncertainty in abundance estimates for different counter scenarios. Simulation scenarios range in complexity from a single species – constant counter accuracy model to two species with variable counter accuracy. We found diminishing returns in reductions of uncertainty with increased validation effort across all simulation scenarios. Using this information, we provide recommendations about the number of fish that should be validated given a suite of counter-population characteristics.

There was a decreasing non-linear relationship between validation effort *versus* both accuracy and precision. In other words, doubling validation effort will not reduce the accuracy of population estimates by a half. We also observed a similar relationship between validation effort and bias except that bias was nearly zero in all cases once 200 fish had been validated. These diminishing returns can help identify an optimal validation effort for a given set of counter conditions. The number of fish validated may be driven by cost in which case our results provide general guidelines for the expected level of uncertainty in abundance estimates. However, if a target level of uncertainty is identified, our results can determine the number of fish to be validated.

The main differences among scenarios were increases in the mean and variation of accuracy and precision as complexity increased. This could be due to the fact that variable accuracy scenarios were conducted over many populations (i.e., 100), whereas the constant counter accuracy scenario represented a single population. We ran the variable accuracy scenarios 100 times due to the high variability in accuracy estimates from one simulation to the next. For example, each simulation produced a unique run timing and migration rate (fish per day) that influenced counter accuracy; higher migration rates led to lower counter accuracy and lower migration rates resulted in higher accuracy. The lower and upper counter accuracy values were set *a priori* to be 50 and 80%, respectively. This additional variability was observed in the variation around the mean estimates for both variable counter accuracy scenarios (Figure 4.2 and 4.3). This highlights that the variability in counter accuracy is as important as the mean counter accuracy.

One of the key points from meetings and site visits in Scotland is that simple simulations (i.e., single species – constant accuracy) would not capture the complexity of salmon populations in Scotland. For instance, the assumption that counter accuracy is constant during a migration is not valid for many counters. The accuracy of flat pad and Crump weir resistivity counter setups shift with water depth, whereby deeper water tends to reduce accuracy. Hydroacoustic applications are also susceptible to changes in water levels. These counters are setup to operate at a given water level and need to be adjusted when water levels change. However, there are many counters where constant accuracy models could be applied, such as a resistivity counter with tube sensors or a Vaki Riverwatcher counter. Both of these counter setups can have extremely high and stable accuracies, even at high migration rates. Also, these setups are typically used in fish passage structures or controlled waterways and need to be submerged so accuracies are not often affected by discharge. We assume that the standard deviations for most counter applications will be greater than the standard deviations we report for the constant accuracy simulations and that they are an over simplification of actual uncertainty. While we address this issue by increasing the complexity of the simulation models, it is important to note that our results are likely minimum estimates of uncertainty for a given number of fish validated. Furthermore, the presence of more than one species requires increased validation effort to achieve the same level of uncertainty. This is intuitive because the number of target fish validated is reduced (from the total number of fish) when there are other species present. For this, we assumed that species proportions were consistent throughout the migration, which is likely an invalid assumption.

4.3 Population Estimates with Uncertainty

Assessing uncertainty of population abundance estimates is crucial for effective fisheries management. This requires knowledge of the different sources of counting error, which were discussed and quantified in the previous section (Chapter 4.2 Validation Costs). Here we describe novel methods for incorporating different sources of counter error into estimates of population abundance. For instance, fish passage abundance estimates are often calculated by expanding the number of net up counts by the estimated accuracy of the counter. For example, if a counter produces 120 fish counts (110 up counts – 10 down counts = 100 net up counts) and it has been estimated that the counter detects 90% of the fish moving in both directions, then the total number of fish upstream of the counter is estimated to be 111. Although the estimated counter accuracy is high, the true accuracy of the counter is unknown and can only be determined by validating all fish passage events (Chapter 4.2 Validation Costs). Validating all fish passing over a counter, however, is seldom done and is not cost-effective.

Calculations of fish passage abundance rarely account for uncertainty in counter accuracy estimates. The goal of this analysis was to account for uncertainty in estimating fish passage numbers. We used Monte Carlo simulation methods to account for uncertainty in up and down count accuracy and the accuracy of identifying proportions of target species that pass over counter sensors. This procedure simulates the uncertainty in counter sensor accuracy and species proportion given information about counter accuracy derived from the previous validation data. The more fish passage events that are validated, the narrower the distribution of accuracies and the more certain the estimate. We illustrate this analysis using simulation data from the previous section (Chapter 4.2 Validation Costs).

We used Monte Carlo simulations to create probability distributions to account for error in counter accuracy and species identification. Validation data were composed of 1’s (correctly counted fish or target species 1) and 0’s (not counted or other species); therefore samples were drawn from a binomial beta distribution:

Equation 4.3.1

$$\pi \sim \mathrm{B}(\alpha, \beta)$$

where, π is the proportion of records correctly counted, *B* is the binomial beta distribution, α and β are the alpha and beta parameters, respectively. Prior distributions can be used to inform sampling by specifying the alpha and beta parameters; otherwise both parameters are set to 1 for an uninformative prior, which is what we used for all simulations. Posterior distributions were simulated in R statistical software (R Development Core Team, 2012) using the MCbinomialbeta function in the ‘MCMCpack package’(Martin et al. 2013). Each posterior was comprised of 500 samples drawn from the binomial beta distribution.

We used the posterior distributions to calculate abundance estimates and uncertainty. First, the number of up counts for the target species was calculated as:

Equation 4.3.2

$$U_1^* = \frac{U_{1,2} - \overbrace{V_u A_u^* S_u^*}^{\text{Up counts}}}{A_u} - \frac{D_{1,2} - \overbrace{V_d A_d^* S_d^*}^{\text{Down counts}}}{A_d}$$

where, U_1^* is the posterior distribution for net up counts that are target species, $U_{1,2}$ is the total number of up counts for both the target species (1) and non-target species (2), V_u is the number of target species up counts validated,A_u^* is the posterior distribution of the up count accuracy, and S_u^* is the proportion of counts that are the target species. The total number of down counts for species 1 are calculated using the same methods as the total species 1 up count estimates and are subtracted from the total species 1 up counts to get the net up counts for species 1.

We present the posterior distributions for counter accuracies, species proportions and abundance estimates for species 1. We also present the 2.5 and 97.5% credible intervals for the posterior distribution of abundance estimates. Figure 4.4 shows the posterior distributions for counter accuracy of simulated populations (A-B), species proportions (C-D), and abundance (E) using data from Chapter 4.2 (Validation Costs). The estimated distributions (Figure 4.4A-D) are used to calculate the distribution of estimated fish passage numbers (Figure 4.4E).

This method allows the calculation of common estimates of uncertainty such as 95% credible intervals and standard deviations. Another major advantage of this method is that prior information can be used to inform counter accuracy and species ratios. While the use of priors can be problematic and depend on the information being used to determine the prior (Gelman 2002, Kuhnert et al. 2010), they can be extremely valuable when specific counter accuracy information is lacking in a given year or a given site. In some systems, for example, it is difficult to validate a large number of fish moving downstream. Estimates of down count accuracy from small sample sizes can be misleading and have a large influence on population estimates when the ratio of down counts relative to up counts is high. Using prior information about how a counter setup should operate can provide more reliable estimates of counter accuracy in the absence of abundant validation data. It is important to note that the uncertainty this method incorporates may not account for all uncertainty and will always be an underestimate.

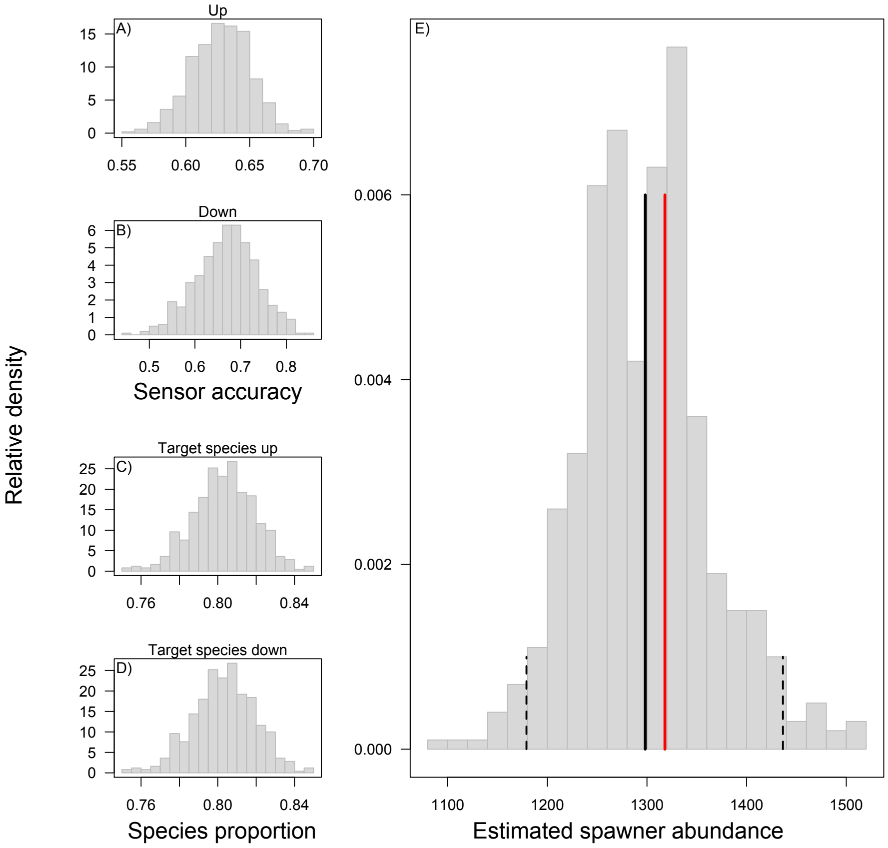


Figure 4.4. Posterior distributions of A) counter up and B) down accuracy, C) species proportions moving upstream and d) downstream, and E) estimated spawner abundance. Uniform prior distributions were used for A-D. The estimated spawner abundance represents the number of fish that passed over the counter while accounting for uncertainty in counter accuracy and the proportion of fish that were identified as the target species. The red line is the true abundance and the solid black line is the mean estimated spawner abundance. The broken black lines indicate the upper and lower bounds of the 2.5 and 97.5% credible interval.

Recommendations and Costs

One consideration not addressed in these simulations is how to sample video to ensure a particular number of fish will be validated. We suggest a stratified random sampling method whereby a fixed number of hours of video are viewed each day, which is divided into 5-10 random samples for each day. For example, an hour of video was reviewed each day; it could be divided into 6 randomly selected 10 min sections. This sampling method works well because it distributes the number of validated fish according to the run timing distribution. For example, during the peak migration rates, the largest number of fish will be validated, resulting in estimates of counter accuracy and species proportions when the largest number of fish are passing over the counter. This method works best for fish passage rates > 1 fish per hour but may not work with low passage rates < 1 fish per hour because the time it would take to observe the required number of fish may be excessive.

Our simulation study can be used to produce guidelines on validation requirements under a given set of conditions and for a desired level of uncertainty. However, associated cost estimates require specific information on the total number of fish that need to be validated (based on counter-population conditions) and the amount of time it will take to review these fish on video. We estimated validation time as follows:

Equation 4.3.3

$$h_v = C \cdot v \left(\frac{h_m}{a} \right)$$

where, h_v is the time to validate in hours, v is the known number of fish to be validated, a is the abundance of the population, and h_m is the number of hours from the beginning to the end of the migration in hours. C is a constant applied to the hours of video footage which accounts for setting up video footage, measuring fish lengths (where applicable), and entering data. We estimate this constant to be approximately 1.1 based on average fish passage rates of 1-3 fish per hour.

Our estimate of validation time makes a number of assumptions that could be altered based on the characteristics of the population being validated. For example, average fish passage rate (per day) may not be applicable to all populations because some fish species, or populations, may migrate predominately at night. Video review could focus on nighttime hours and could reduce h_m by half. C should be larger for higher fish passage rates to account for the additional time required to record fish. Identifying the number of fish to validate also depends on the level of uncertainty a manager is willing to accept. For example, Table 4.3 shows minimum validation samples sizes required to achieve population estimates that are within 5 and 10% of the true abundance. If we consider a counter scenario with variable accuracy (0.5 or 0.8) and one species, the number of fish requiring validation to achieve < 5% relative error in the accuracy of abundance estimates is four times that of number required to achieve < 10% relative error. Acceptable levels of uncertainty are important considerations determining annual validation costs.

Table 4.3. The minimum sample size and validation time required to attain < 5% and < 10% relative error for accuracy, precision and bias. Validation time is calculated using Equation 4.3.3 with a migration period of 4 months, a population abundance of 2000 fish, and a video constant of 1.1.

Metric	% relative error	Counter accuracy	Number of Species	Minimum sample size (Mean and (1SD)	Minimum time (hrs) (Mean and (1SD)
a) Accuracy	5	0.7	1	150 (350)	115 (267)
	5	0.8	1	100 (200)	76 (153)
	5	0.9	1	50 (100)	38 (76)
	5	0.5, 0.8	1	200 (600)	153 (458)
	5	0.5, 0.8	2	300 (1000)	229 (764)
	10	0.7	1	50 (100)	38 (76)
	10	0.8	1	50 (100)	38 (76)

	10	0.9	1	50 (50)	38 (38)
	10	0.5, 0.8	1	50 (150)	38 (115)
	10	0.5, 0.8	2	100 (250)	76 (191)
b) Precision	5	0.7	1	150 (350)	115 (267)
	5	0.8	1	100 (200)	76 (153)
	5	0.9	1	50 (100)	38 (76)
	5	0.5, 0.8	1	200 (600)	153 (458)
	5	0.5, 0.8		300 (850)	229 (649)
	10	0.7	1	50 (100)	38 (76)
	10	0.8	1	50 (100)	38 (76)
	10	0.9	1	50 (50)	38 (38)
	10	0.5, 0.8	1	50 (150)	38 (115)
	10	0.5, 0.8	2	100 (250)	76 (191)
c) Bias	5	0.7	1	50 (250)	38 (191)
	5	0.8	1	50 (150)	38 (115)
	5	0.9	1	50 (100)	38 (76)
	5	0.5, 0.8	1	50 (350)	38 (267)
	5	0.5, 0.8	2	50 (300)	38 (229)
	10	0.7	1	50 (100)	38 (76)
	10	0.8	1	50 (50)	38 (38)
	10	0.9	1	50 (50)	38 (38)
	10	0.5, 0.8	1	50 (100)	38 (76)
	10	0.5, 0.8	2	50 (100)	38 (76)

References

Gelman, A. 2002. Prior distribution. *In* Encyclopedia of Environmetrics. *Edited by* A.H. El-Shaarawi and W.W. Piegorsh. Chichester. pp. 1634–1637.

Kuhnert, P.M., Martin, T.G., and Griffiths, S.P. 2010. A guide to eliciting and using expert knowledge in Bayesian ecological models. Ecology Letters 13(7): 900–914. doi: 10.1111/j.1461-0248.2010.01477.x.

Martin, A.D., Quinn, K.M., and Park, J.H. 2013. Package “MCMCpack.” R Statistical Package: 1–162.

R Development Core Team. 2012. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. http://www.R-project.org/.

5.0 Counter Decision and Cost Model: Integrating Technological and Economic Considerations to Determine Choice of Counter Technology and Structure

Determining the appropriate technology, structure and operations that best fit the objectives and budget of a proposed counter can be difficult. This requires information on site characteristics, the costs of each counter scenario and how effective each scenario is at enumerating fish. Here we describe a decision and cost model that integrates information considered in Chapters 2 to 4, provides counter scenarios that are technologically feasible, and provides their implementation and operational costs for a given counter site. First, we outline the general model framework and discuss how it determines the feasibility of different counter scenarios. Finally, we present case studies that illustrate the application of the model and interpretation of its cost output and ranking of feasible counter scenarios for sites visited by IFR in October 2014. The model was written in the R language and is hosted on GitHub: https://github.com/InStreamFisheries/Counter_Decision_Cost_Model.git

5.1 Decision Cost Model Framework

The decision model consists of two main components (Figure 5.1). The first component is a series of decisions that determine whether each counter scenario is suitable for a potential counter site given its characteristics. This decision process uses data collected from the potential site in addition to information about the management objectives. Table 5.1 presents site data collected during IFR site visits to Scottish rivers that were chosen to represent a range of different watershed and site characteristics. Detailed variable descriptions are in Table 5.2. These data, along with a series of logical functions (see below), are used to query a master list of all potential counter scenarios (see Table 5.3 for all counter options and Table 5.4 for variable descriptions) to determine which ones are feasible given the characteristics of the potential site. For example, resistivity technology does not operate effectively when water conductivity is below 20 µS. Therefore the model does not consider resistivity counters at sites where conductivity is below this cut-off. To do this, the model uses the conductivity value that is entered into the site data in a logic function that provides a value of 'True' or 'False'. If true, scenarios with resistivity technology are removed. If False, no scenarios are removed and the same list of scenarios are queried in the next step. This process is iterative until all remaining counter scenarios are technologically feasible given the site's characteristics. The logical function is described as:

1. Optical beam counters do not function in turbid water (i.e., turbidity > 90 NTU)

a. If **max_turbidity_optical** > 90 NTU then,
    – remove scenarios where **technology** equals "Optical Beam"
b. If **max_turbidity_optical** < 90 NTU then,
    – all scenarios remain

2. Resistivity counters do not function well in low conductivity water (i.e., < 20 µS)

a. If water **min_conductivity** < 20 µS then,

– remove scenarios where **technology** equals “Resistivity”
b. If water **min_conductivity** > 20 µS then,
– all scenarios remain

3. Costs are different for counters deployed in fish passes *versus* rivers.
a. If site **channel_type** = fish pass then,
– remove scenarios where **channel_type** is a “river”
b. If site **channel_type** = river then,
– remove scenarios where **channel_type** is a “fish pass”

4. Costs are different depending on the presence or absence of mains power. If mains power is present, there are different costs for mains *versus* battery power.
a. If **existing_power_type** = “mains” then,
– remove scenarios where **power_type** is “battery”
b. If **existing_power_type** = none&**preferred_power_tyep** = “mains” then,
– remove all scenarios where **power_type** is “battery”
c. If **existing_power_type** = none&**preferred_power_tyep** = “battery” then,
– remove all scenarios where **power_type** is “mains”

5. Flat pad sensors are inaccurate in high water (i.e., > 1 m)
a. If **max_water_depth** is > 1 m then,
– remove all scenarios where sensor is “flat pad”
b. If **max_water_depth** is < 1 m then,
– all scenarios remain

6. Streams must be safely wadeable under all conditions for some structures to be installed and maintained (e.g., cleaning debris) throughout salmon migration.
a. If the site is deemed **wadeable** then,
– all scenarios remain
b. If the site is deemed **unwadeable** then,
– remove all scenarios where **structure** is “picket fence” or sensor is “flat pad”

7. Hydroacoustic counters do not work effectively in shallow water. They require that the minimum water depth, observed during the salmon migration period, for the deepest part of the channel to be > 90 cm.
a. If **min_water_depth** is < 90cm then,
– remove all scenarios where technology is “hydroacoustic”
b. If **min_water_depth** is > 90 cm then,
– all scenarios remain

8. Video counters do not function in moderately turbid water (i.e., turbidity > 30 NTU)
a. If **max_turbidity_video** > 30 NTU then,
– remove scenarios where **technology** equals “video”
b. If **max_turbidity_video** < 30 NTU then,
– all scenarios remain

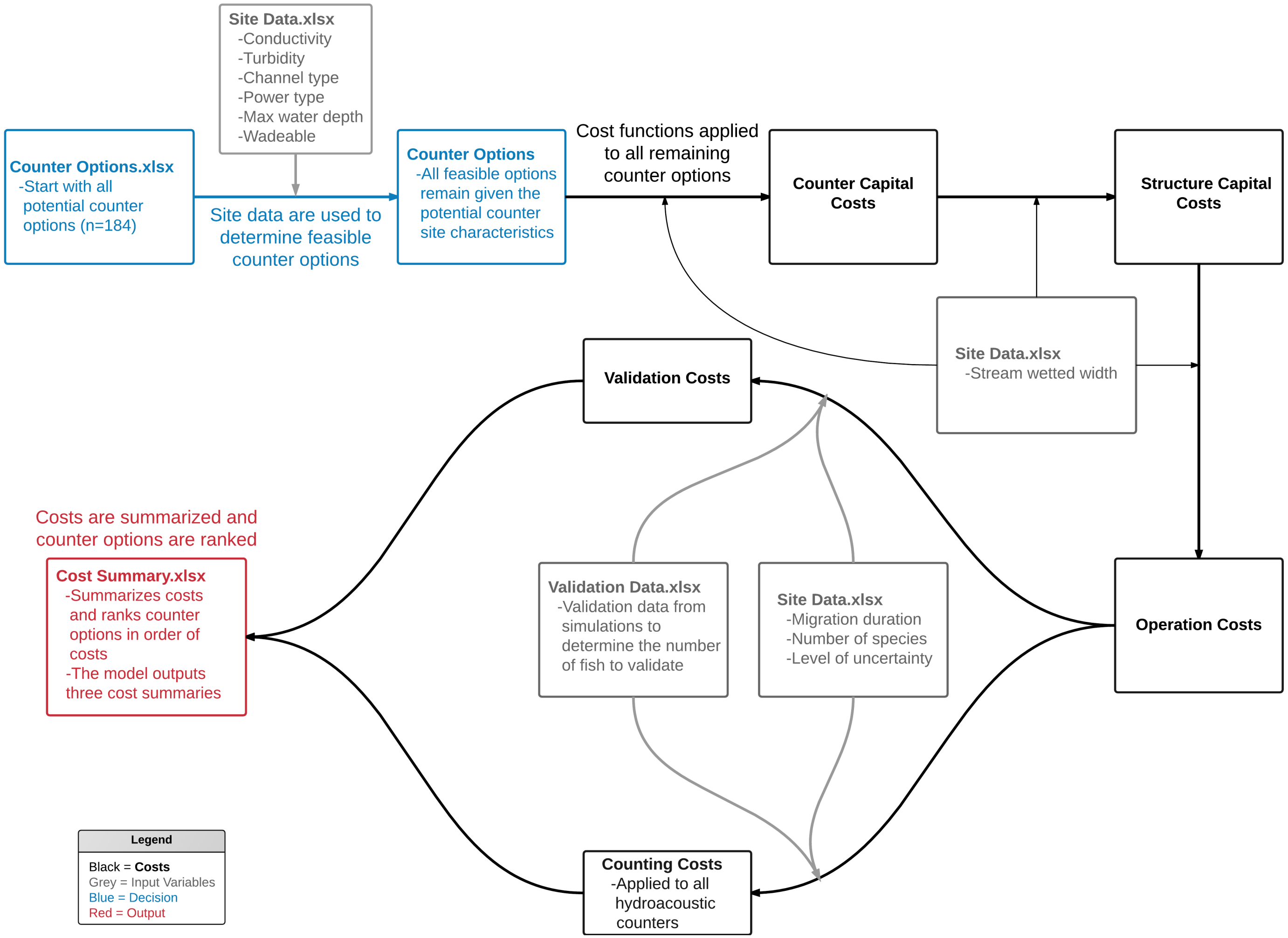


Figure 5.1. Flow diagram of the decision and cost model.

Table 5.1. Site Data.csv is available to download at http://dx.doi.org/10.7489/1689-1. Data were collected by IFR during site visits in October 2014. Description of variables can be found in Table 5.2.

Table 5.1. Descriptions of variables in Site Data.cvs file.

Variable	**Description**
bfw	Maximum river wetted width before a river floods, or width of a fish pass, in meters (m) during the migration at the potential counter site. Possible inputs can be any value greater than 0.
conductivity	Lowest conductivity in micro Siemens (μS) observed during the migration in the past 10 years. Possible inputs can be any value greater than 0. If historical data does not exist, a minimum of one year of continuous monitor should be conducted.
turbidity	Highest turbidity in Nephelometric Turbidity Units (NTU) observed during the migration in the past 10 years. If historical data does not exist, a minimum of one year of continuous monitor should be conducted.
max_depth	Maximum depth in meters (m) of a potential counter site during the migration. Possible inputs can be any value greater than 0.
channel_type	Type of channel the counter will be placed in – i.e., whether or not it is a fish pass or normal river channel. Possible inputs can be “fish pass” or “river”.
existing_power_type	What is the existing power type at the potential counter site? Possible inputs can be “mains” or “none”.
preferred_power_type	What is the preferred power type if there is no existing power at the potential counter site? Possible inputs can be “mains”, “battery” or “either”.
no_species	Number of species present during the migration that overlap in size. Possible inputs are any integer value equal to or greater than 1.
migration_length_day	Number of days from the start to the end of the migration. Possible inputs are any integer value equal to or greater than 1.
population_size_mean	Mean population size over the past 10 years. Possible inputs are any integer value equal to or greater than 1.
security_shed_present	Is a security shed (or related structure) at the potential counter site to place the counter and associated components? Possible inputs are “yes” or “no”.

cellular_network	Is there a mobile phone reception within 50 m of the potential counter site? Possible inputs can be “yes” or “no”.
uncertainty_metric	Metric used to determine the acceptable level of uncertainty. For example, if the acceptable level of uncertainty was for the mean estimated abundance to be within 5% of the true abundance, then the data input would be “mean”. Alternatively, if the acceptable level of uncertainty was for estimates within ± 1 standard deviation from the mean to be within 5% of the true abundance, then the data input would be “sd”. Possible inputs can be “mean” or “sd”.
relative_error	Acceptable level of relative error in abundance estimates. For example, if the acceptable level of uncertainty was for the mean estimated abundance to be within 5% of the true abundance, then the data input would be “5”. Possible inputs can be 5 or 10.
performance_metric	Metric used to characterize uncertainty. Possible inputs can be “accuracy”, “precision”, or “bias”.
counter_accuracy	Is the counter accuracy predicted to be constant or variable? This is a function of water depth variability over or through the counter and the type of counter, and only applies to resistivity counters. Possible inputs can be “constant” or “variable”.
counter_backup	Is a backup counter going to be purchased? Possible inputs can be “yes” or “no”.
land_cost	What is the estimated cost of acquiring the land for the potential counter site? Possible inputs can be any value equal to or greater than 0.
wadeable	Is the average person able to safely wade across the river at any time during the migration? Possible inputs can be “yes” or no”.

Table 5.3. Counter Option.csv is available to download at http://dx.doi.org/10.7489/1689-1, and represents all counter options considered by the decision and cost model.

Table 5.2. Descriptions of variables in Counter Option.csv file.

Variable	Description
option	Used to track the different options presented in the Counter Option.xlsx.
technology	Technology used to count or observe fish. Technologies considered are optical beam, hydroacoustic, and resistivity.
company	Company that manufactures counters.
company_risk	Risk level associated with the long-term persistence of a company and is proportional to company size (i.e., number of staff and infrastructure to support research, development, and support of their products). Low risk companies have ≥ 21 staff and large infrastructure; moderate risk companies have between 6 and 20 staff and moderate infrastructure; high risk companies have < 5 staff and little infrastructure. We considered EA Tech and SSE’s Mark 12 counter to be moderate risk because EA Tech is contracted to make counters for SSE and there have been little to no sales or support of counters to groups outside of SSE.
counter	Specific manufacturer and model of counter. May also specify specific settings and the number of counters. We include only the most cost-effective counter models for simplicity. All models included have been extensively studied and used for stock assessment of salmonids. Note that this variable is used to track the different counter options in the model.
no_counter	Number of counters to be purchased and deployed. Extra counters here are not to be used for backup, but rather to extend the area or cross-section of the river monitored. If backup counters are required, this can be specified in the site data.
counter_cost	Cost of purchasing the counter and/or sensor in 2015. For counters originally quoted in USD, (DIDSON 300 and BlueView M900-2250) a conversion of 1.64 USD to 1 GBP was used. For equipment sourced from the US, the price of any additional accessories needed, shipping, import duty and VAT would need to be added.
sensor	Type of sensor used with the counter. Potential sensor types are optical beam, multibeam, splitbeam, video, Crump weir, flat pad, flumes, and tubes. Resistivity counters rely on third party built sensor units (e.g., Crump weir, flat pad, tubes, and flumes). Cost of third party sensor units must be added to the counter cost (see sensor_cost_m variable). For other counter types that include the sensor unit (e.g., DIDSON 300, BlueView M900-2250, Riverwatcher, DTX-Echosounder and Video), the sensor units are included in the cost of the

	counter. Note that a Crump weir is also considered a structure (see structure variable), but it is useful to also consider it a sensor because it contains the electrodes for a resistivity counter.
channel_type	Type of channel the counter will be placed in. Important distinction is whether or not it is a fish pass or normal river channel. This will determine the type of structures available to install the counter.
structure	Type of structure to be used with the counter – may be required to fix the counter or sensor units into the river or fish pass (e.g., fish pass insert), or to improve counter accuracy by reducing the counting area of the river (e.g., picket fence or floating fence). Some structures contain the counter sensors (e.g., resistivity Crump weir, see sensor variable).
structure_risk	Level of risk of a structure failing or malfunctioning during the migration. All picket fences (i.e., diversion and full river spanning) are considered high risk because they are usually not permanent structures and are susceptible to high flows and debris. All floating fences are moderate risk because they can function well in high flows and debris, but still require a technician to monitor and clean the fence (much less frequently than a picket fence). Crump weirs and fish pass inserts are low risk because they are fixed into the river or fish pass. Having no structure is also low risk. Variable is not used in the model but is reported in the cost summary to help aid decisions.
counter_accuracy	Estimated counter accuracy (as a proportion of correctly counted records) for the technology, counter and structure used to deploy the counter. Estimates are based on IFR experience and the literature. Values for hydroacoustic technologies are set to zero because the counts are not automated and they are extremely difficult to validate.
structure_cost_fixed	Minimum cost of a structure. Mainly applies to the fish pass insert as it is a fixed cost and does not vary per meter like other structures. Also applies to a floating fence since it requires the construction of sidewalls regardless of fence width.
structure_cost	Per meter cost of a structure. Structure size is determined by the maximum bankfull width of the river during the migration, which is provided in Site Data.xlsx. If the cost per meter is linear, the per-meter cost is provided under the structure_cost_m variable (e.g., picket fence, floating fence). If the cost per meter is non-linear, a cost function is applied, which is embedded in the R code for the model. Cost function for the Crump weir is: $y = 173.27 \cdot x^2 + 7390.7 \cdot x + 3636.6$ Where *y* is the total cost for the Crump weir and *x* is the width (in meters) of the Crump weir required.
structure_pad	Denotes whether or not a concrete sill or chain ballast is to be used with a particular structure. For example, a concrete

	sill is a permanent structure that can be used to anchor a floating fence. A chain ballast is a semi-permanent structure that can anchor a floating fence. If no pad structure is to be used, the value is “none”.
structure_pad_cost	Cost for a pad structure. Pad structure size is determined by the maximum bankfull width of the river during the migration, which is provided in Site_Data.xlsx. If the cost per meter is non-linear (concrete sill), a cost function is applied, which is embedded in the R code for the model. Cost function for the concrete sill is: $y = 278.08 \cdot x^2 + 1739.5 \cdot x + 15215$ Where *y* is the total cost and *x* is the width (in meters) of the concrete sill required. If the structure pad is a chain ballast, then the cost is fixed.
sensor_cost_fixed	Minimum cost of a sensor unit. This only applies to counters that require third party built sensor units (i.e., resistivity counters). See sensor for further discussion.
sensor_cost_m	Per meter cost for a sensor unit. Sensor size is determined by the maximum bankfull width of the river during the migration, which is provided in the Site_Data.xlsx. This only applies to flat pad resistivity sensors and the cost increases linearly per meter.
optimal_ww_sensor	Optimal sensor width in meters for a sensor unit to count fish. Value is used to determine the size of a picket or floating fence when it is being used as a diversion structure.
annual_install_bio_days	Number of biologist days required to install the counter and/or sensor unit each year. Annual cost that only applies to semi-permanent counters (items removed annually), sensors, and/or structures such as fences, sensor units in fish passes and flat pad sensors. For permanent structures, the removal cost is included in the structure_cost_fixed and the structure_cost_m is only applied once. Model assumes a day rate for a biologist to be £300.
annual_install_tech_days	Number of technician days to install the counter and/or sensor unit each year. Annual cost that only applies to semi-permanent counters (items installed annually), sensors, and/or structures such as fences, sensor units in fish passes and flat pad sensors. For permanent structures, the installation cost is included in the structure_cost_fixed and the structure_cost_m is only applied once. Model assumes a day rate for a technician to be £200.
annual_removal_bio_days	Number of biologist days required to remove the counter and/or sensor unit each year. Annual cost that only applies to semi-permanent counters (items removed annually), sensors, and/or structures such as fences, sensor units in fish passes and flat pad sensors. For permanent structures, the installation cost is included in the structure_cost_fixed and the structure_cost_m is only applied once. Model assumes a day rate for a biologist to be £300.
annual_remov	Number of technician days to install and remove the counter

al_tech_days	and/or sensor unit each year. Annual cost that only applies to semi-permanent counters (items removed annually), sensors, and/or structures such as fences, sensor units in fish passes and flat pad sensors. For permanent structures, the installation cost is included in the structure_cost_fixed and the structure_cost_m is only applied once. Model assumes a day rate for a technician to be £200.
mounting_bracket_cost	A bracket that is used to mount hydroacoustic or video cameras in place. There are a wide range of options and costs, from inexpensive portable third party built units (£500) to expensive proprietary panning and tilting mounts that are fixed to lock blocks on the stream bank (£9500). We used the highest cost because it could be used at any counter site and under all water levels, whereas less expensive mounts will likely be site and water level specific in their application.
counter_service_cost_year	Cost for servicing the counter and/or sensor unit each year. Cost is applied annually and includes shipping costs. Costs are based on information gathered from direct communication with counter users or from manufacturers. Costs can vary greatly from year to year but these provide appropriate values when budgeting for maintenance.
computer_cost	Cost of a personal computer for operating all hydroacoustic counters. All other counters do not require a computer for operation.
data_storage_cost	Cost of four 4 TB hard drives. For most hydroacoustic and video applications, this is sufficient storage for one migration season. Hard drives can be traded out and data transferred to a server during the season.
downloading_freq_week	Number of days per week that a counter should be downloaded and the counter equipment checked during the migration. Frequency follows best practices.
power_type	Type of power available at the site. This removes counter options that do not match the existing_power_type specified in Site Data.xlsx. If no power options exist on site, the preferred_power_type entered in Site Data.xlsx is used to cost the installation of power.
no_battery	If the power_type is batteries, this provides the typical number of batteries that would be required to operate a counter setup for at least 7 days and the same number of backup batteries so that they can be switched out. We do not provide an estimate of the number of batteries for hydroacoustic counters because of their large power demands. Instead, a fixed cost of a generator is provided under power_install_cost.
battery_cost	Cost of one 12 V 40 Ah battery (£75) or one 12 V 80 Ah battery (£150).
power_install_cost	Cost of installing mains power or a generator at a site. Cost of installing mains power will be highly variable depending on the proximity of power. We used a rough estimate of £1000 for mains power.

remote_access_software_annual_cost	Annual cost of a remote download software program (e.g., Team Viewer). Software allows users to connect remotely to a computer in the field as long as there is cellular reception.
cell_plan_cost_month	Cost of a monthly cellular data plan with 1 GB of data.
cell_booster_cost	Cost of purchasing a cellular booster if there is not a cellular network.
site_visit_week_tech	Number of days per week a technician would visit a counter site to download data, check equipment, and clean counting structures and sensors. In all cases, we assume that two technicians will be visiting counter sites to ensure safe working conditions around water. If the value for this variable is one day, two technicians will visit the site for half a day.
permit_cost	This is the cost of permit applications to place a structure in a stream, see Appendix 3 for details.
permit_day	This is the number of days an engineer requires to complete all permit applications, which is estimate to be four.
counting_software	Software required for the counter to count fish. Optical beam and resistivity counters are automated and do not need additional software or people to count fish. Hydroacoustic technology produce images that either have to be viewed by a technician to count fish (“none”) or processed through a program such as Echoview (“Echoview”).
counting_software_cost	One time cost of software that can be used for data management, data processing and count automation.
counting_effort	Amount of effort required to count fish using Echoview or counting manually. Units are provided in counting_effort_units and are either “fish per minute”, “hours per day” or “none”. Manual counts do not total a full day because footage is reviewed at 3 times more frames per second than it is recorded (i.e., footage is sped up).
security_shed_cost	One time cost of a steel security shed that can house counter equipment (length - 2.7 m x width - 1.5 m x height - 2.0 m).
validation_type	Typical type of validation associated with each counter. Only the Logie 2100C typically uses true validation through continuous video. Allows for estimates of abundance to represent the absolute abundance. Riverwatcher and Mark 12 use pseudo-validation through triggered video. This type of validation in most cases allows for estimates of abundance to represent the absolute abundance. DIDSON 300, BlueView M900-2250 and D-TX Echosounder are typically not validated because their typical application is in turbid rivers and it is difficult to impossible to validate. Lack of validation does not allow for absolute estimates of abundance; at best an index of abundance can be estimated.
validation_method	Typical method of validation for each counter (see validation_type).
validation_risk	Risk associated with not accounting for all sources of error in estimating counter accuracy from validation data. High

	validation risk is when there is not validation performed. Error rates cannot be estimated and the uncertainties in abundance estimates are unknown.
validation_equipment	Cost of video validation equipment (if required). For counters that include video validation equipment (e.g., Riverwatcher), the cost is included in the cost of the counter. Cost is for 4 underwater video cameras and 1 DVR.
validation_effort	Level of validation effort is the number of fish that can be validated per unit minute. This applies to optical beam and the Mark 12 resistivity counters, and is fixed at 6 fish per minute. Validation effort for the Logie 2100C resistivity counter is determined by the equation found in Section 4.2 Validation Costs (Equation 2). Hydroacoustic counters are not typically validated and therefore validation effort is not determined.
validation_effort_units	These are the units for validation effort (fish per minute).

5.2 Cost Functions

The next step in the model is to calculate the costs for each remaining scenario. Costs are in the British Pound and were estimated using the 2015 Spon's Civil Engineering and Highway Works Price Book, and where prices were quoted in USD or CAD, conversions were applied (see Table 5.4). A series of cost functions are applied to each of the cost variables in the counter scenario. Many of the cost functions scale with the bankfull width of the potential site. For example, the cost of building a Crump weir for a resistivity counter, or a diversion fence to accompany a hydroacoustic counter, increases in cost for every additional meter of bankfull width. While the diversion fence increases at a linear rate, the Crump weir is a more complex non-linear function. Costs for validation are calculated using the validation data from simulations in Section 4.2, the number of fish to be validated based on counter, site, and management objectives can be found in Table 5.5. All cost functions are described in the variable descriptions in Table 5.4. The model outputs cost summaries including capital costs, 1-year operational costs, 1-year total costs (capital costs + 1-year operational costs), 10-year capital costs, 10-year operational costs and 10-year total (10-year capital costs + 10-year operational costs). For each of the case studies we present and evaluate the capital costs, 10-year operational costs, and the 10-year total costs.

Table 5.5 Validation Data.csv is available to download at http://dx.doi.org/10.7489/1689-1. These are the validation data used to determine the number of fish that should be validated.

5.3 Case Studies

In October 2014, IFR staff visited a number of potential counter sites throughout Scotland that serve as case studies to illustrate how the decision and cost model can be used. We present case studies of seven rivers that IFR visited (Figure 5.2). Potential sites were any sites identified and suggested by MSS staff (or fisheries board or trusts biologists) based on their knowledge of counter technologies and the river. If sites did not meet the criteria to be considered a counter site, they were eliminated from a full assessment. Sites and rivers were also eliminated if there was insufficient information collected during the site visit; these sites are discussed in the respective river's case study.

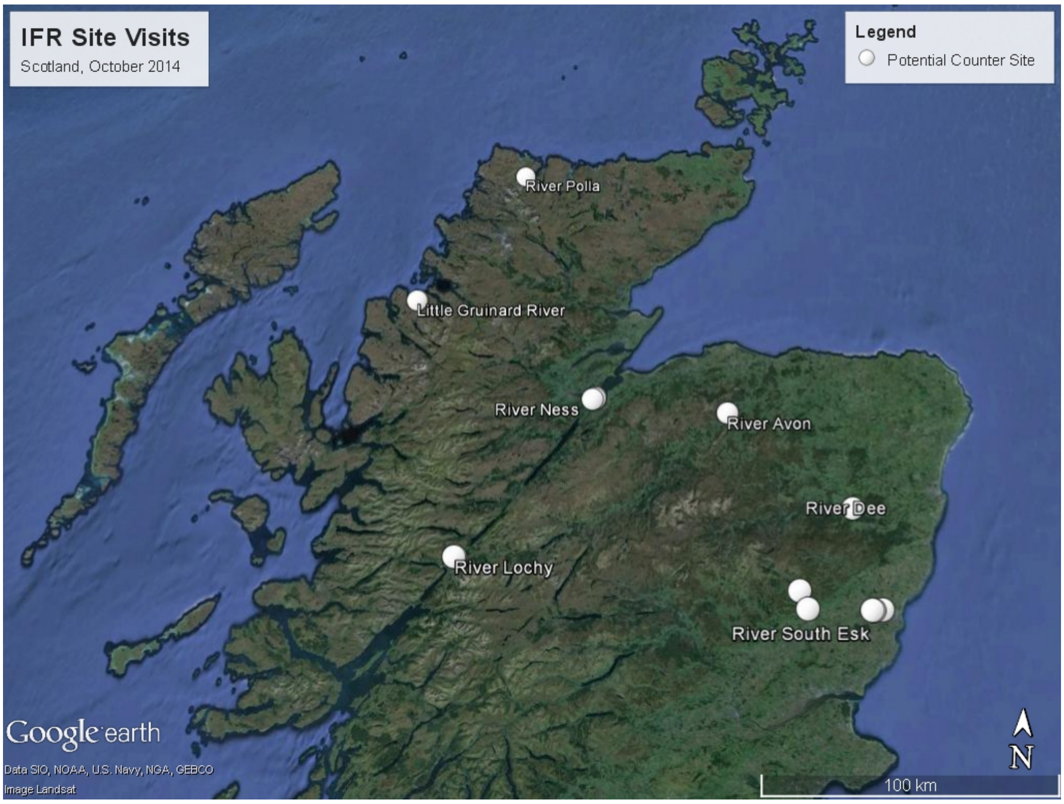


Figure 5.2. Map of Scottish rivers visited by IFR in October 2014.

Site visits were extremely successful and provided valuable information about the rivers and their populations of salmon, and a Scottish context for the development of the decision and cost model. Most visits consisted of an initial meeting with the fishery board or trust biologists, followed by one or more site visits. During the meetings and site visits, information about the watershed and populations were gleaned from staff members. One caveat to the information collected during the site visits is that most rivers in Scotland, including the majority of the rivers visited by IFR, were under extremely high flows. Consequently, this meant that most site assessments captured extreme conditions, which in some rivers made it difficult to assess site characteristics such as substrate composition. However, these extreme conditions demonstrate the inherent variability in environmental conditions (e.g., discharge, stage height, turbidity, and conductivity) that can be observed in a river, and highlights the importance of selecting counter setups that can operate effectively under even the most extreme conditions.

Data collected by IFR during site visits represents rough estimates and snapshots of the channel morphology and conditions at a site. Many of the variables were not measured accurately and assumptions were made, which are outlined here. IFR collected conductivity at each site but this was just a single measurement and is likely to change throughout the year and with changes in precipitation. IFR staff did not collect turbidity data during the site visits but instead made a qualitative visual assessment of water clarity. For example, water clarity was either clear or turbid. All clear rivers were given a value of 30 NTU and turbid rivers a value of 100 NTU since quantitative data are required for the model to assess different counter technologies. Depths of the specific site were not measured during the site visits and instead estimated based on the river channel characteristics and information gathered from local biologists.

Some variables are determined by the user considerations with regards to logistics and management objectives. For example, whether or not mains power or battery power should be used. In most sites mains power can be built into the site, while batteries could be used at all sites. For the case studies we assumed that mains power would be installed at all sites. If battery power was used it would change the absolute costs but they would likely maintain the same rank order for all cost summaries. For all case studies we included the cost of a backup counter. IFR highly recommends this especially since there is very little “off-season” for rivers in Scotland. We also assumed the same management assumptions for all case studies. Changing the level of acceptable uncertainty or the uncertainty metrics, however, would alter the costs since these variables are linked to the amount of validation required to achieve the specified level of uncertainty. We assumed land costs to be approximately £2000 to £5000, and used different values for some sites to test that the changes were being integrated into the costs.

Data were collected to provide some context for how to apply the counter decision and cost model to a potential site, and are not to be used as the actual site assessment. For accurate site assessments, IFR recommends collecting at least one year of data for environmental variables such as conductivity, turbidity, and stage height. We emphasize the importance of this step, as the model uses these parameters to determine the feasibility of technologies and structures. Furthermore, detailed cross-sectional surveys of channel morphology and substrate should also be conducted. Other important biological information to consider for a potential counter site are species composition, life history diversity, and overlap in length distributions and run timing. These factors can significantly alter the amount of time required for validation. This data collection will provide the necessary information for the model to be applied appropriately.

For each case study, we provide some basic information about the watershed, site and population characteristics, detailed site data used by the decision and cost model can be found in Table 5.1, and a summary in Table 5.6. Catchment area and discharge data presented herein were obtained from National River Flow Archive (NRFA) gauging stations. We present the 50th percentile (Q50) discharge, as well as the range from the 5th percentile (Q95) to the 90th percentile (Q10) in text as Q50 (Q95 – Q10) (National River Flow Archive 2015). We then provide a qualitative assessment of the site based on IFR’s professional experience with siting, installing, and operating fish counters. Finally, we assess the output of the decision and cost model, which includes making comparisons among feasible counter options based on the ranked order of counter scenarios with regards to capital costs, and 10-year operational and 10-year total costs. This is followed by a detailed description of the sites visited along with an assessment of the advantages and disadvantages of each site with regards to its potential as a counter site. Finally, the cost model output is discussed in the context of limited capital and operational budgets. Each case study ends with a recommendation about the best counter solutions based on the costs and IFR’s professional experience.

Table 5.3. Summary of characteristics of potential counter sites visited by IFR staff in October 2014.

Watershed	Site	Coordinates	Bankfull width (m)	Minimum depth (m)	Maximum depth (m)	Conductivity (μS)	Mains power	Species present	Run timing
River Avon	1	57°24'58"N 3°22'38"W	40	0.5	0.8	40	No	1	Spring, Summer, Fall
River Ness	1	57°28'02"N 4°13'44"W	60	0.3	1.5	25	No	2	Spring, Summer, Fall
	2	57°27'46"N 4°13'60"W	35	1.5	3	25	No	2	Spring, Summer, Fall
	3	57°27'32"N 4°15'5"W	30	1.5	3	25	No	2	Spring, Summer, Fall
Little Gruinard River	1	57°50'57"N 5°28'2"W	6	0.3	1	40	No	2	Spring, Summer, Fall
	2	57°51'4"N 5°27'40"W	8	0.9	1.5	40	Yes	2	Spring, Summer, Fall
River South-Esk	1	56°46'30"N 3°1'40"W	25	0.6	1.5	40	Yes	2	Spring, Summer, Fall
	2	56°42'55"N 2°59'24"W	15	0.3	1.8	30	No	2	Spring, Summer, Fall
	3	56°42'59"N 2°33'9"W	40	0.3	1.5	150	No	2	Spring, Summer, Fall
	4	56°42'53"N 2°36'45"W	3	0.3	0.6	150	No	2	Spring, Summer, Fall
	5	56°42'48"N 2°36'9"W	30	0.6	1.5	150	No	2	Spring, Summer, Fall
River Lochy	1	56°51'37"N 5°3'58"W	10	1.5	2	40	No	2	Spring, Summer, Fall
	2	56°51'31"N 5°4'21"W	50	0.9	1.5	40	No	2	Spring, Summer, Fall
River Dee	1	57°3'52"N 2°38'57"W	50	0.6	1.8	40	No	2	Spring, Summer, Fall
River Polla	1	58°27'4"N 4°45'36"W	20	0.3	0.6	40	No	2	Summer, Fall

5.3.1 River Avon

Watershed and Site Characteristics

River Avon is 30 km long, and has a catchment area of 543 km^2 and a discharge of 11 m^{3}s^{-1} (4-28 m^{3}s^{-1}) at the Avon at Delnashaugh NRFA station (No. 8004) (Figure 5.3).

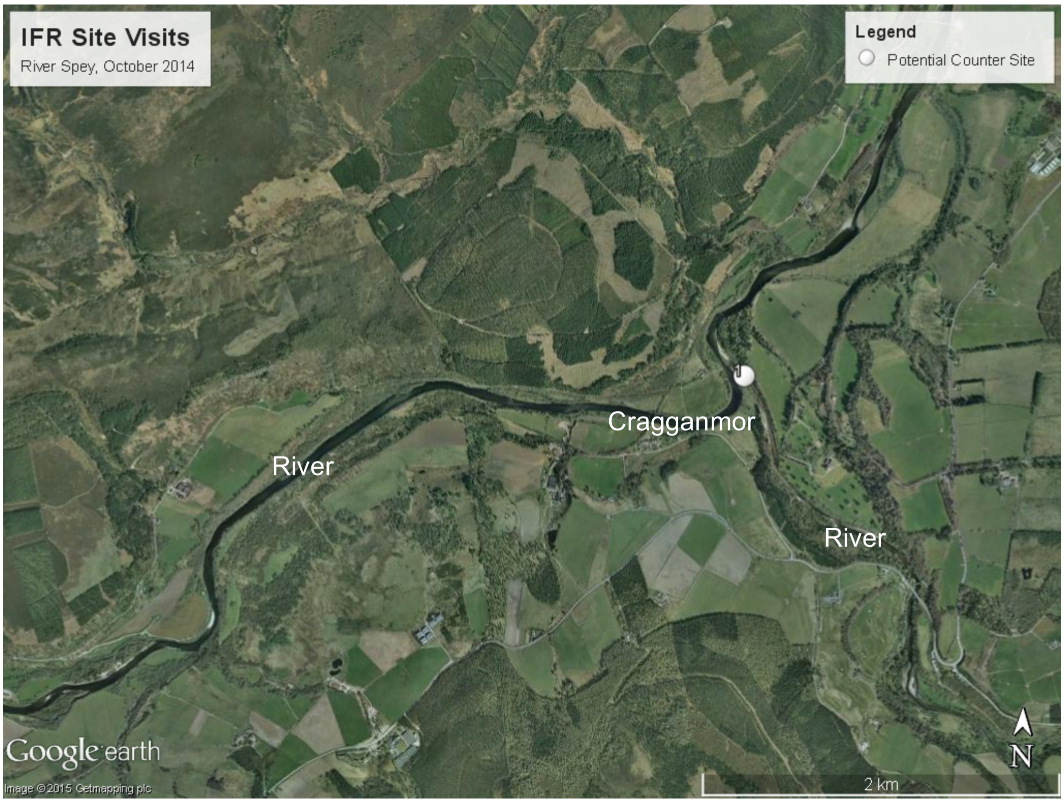


Figure 5.3. Potential counter site visited by IFR on River Avon, a major tributary of the River Spey.

Species and Run Timing

The River Spey and its tributaries supports one of the largest salmon populations in Scotland, where rod catches in 2014 totaled 4563 salmon (Spey Fishery Board 2015). River Spey also supports large populations of trout (sea trout rod catch of 2511 in 2014), which have overlapping size distributions and run timing (spring to fall) with salmon. The Spey Fishery Board (SFB) biologists suggested that there were low numbers of brown trout in the River Avon. The species composition, life history diversity, and overlap in length distributions and migration timing are important considerations when selecting a counter. The species and run timing characteristics of the Avon (i.e., mainly one species) make validation relatively simple because species identification will not be a large component and thus the amount of time required for validation will be reduced. Notably, River Spey and its tributaries is a Special Area of Conservation (SAC), with salmon spawning throughout the watershed.

IFR Site Visit

IFR visited River Avon with members of the Spey Fishery Board on 7 October 2014. The River Avon is a medium-sized river with low gradient at Site 1 (Table 5.6) (Figure 5.4). Spey Fishery Board biologists identified one potential counter site near the confluence with the River Spey (Figure 5.3). While the site was under extremely high flows during the site visit, the general channel characteristics appeared to be suitable for a counter setup. The site was also below the lower extent of spawning which means the entire population would be counted in this location. One disadvantage of this site was that there was no mains power available, but it is close to houses and existing power lines and mains power could be added. Access to the site was good with a well-kept road that led directly to the counter site.

Model Output and Counter Evaluation for River Avon – Spey Confluence

The decision and cost model retained one technologically and logistically feasible counter scenario out of a possible 184 for the River Avon – River Spey confluence site (Table 5.7). The turbidity variable removed all counter scenarios that used optical beam and video counters because the turbidity values for the site were above both 90 and 30 NTU thresholds, respectively. The channel_type variable removed all counter scenarios where channel_type = “fish pass”. Although there is no mains power at the site, mains power is possible and would be the preferred power_type. Thus, all counter scenarios with power_type = “battery” were removed. Max_depth variable removed all resistivity counters with flat pad sensors. The site is not always wadeable, and therefore the model removed all picket fence structure and resistivity flat pad sensor options. The variable used to remove the majority of the counter options was min_depth (> 90 cm min_depth required for hydroacoustic counters); this removed all counter options that used hydroacoustic technology.

A resistivity counter with a Crump weir was the only technologically and logistically feasible option, with capital, 10-year operational and 10-year total costs of £408 924, £123 684 and £532 607, respectively (Table 5.7). While IFR agrees with the model output of a resistivity Crump weir counter setup, coarse site visit data may be the reason for only one feasible counter option at the River Avon. A more detailed site assessment that would include monitoring water conditions over time and more accurate depth measurements may reveal additional counter options.

Figure 5.4. A potential counter site on the River Avon, October 2014. Photo courtesy of InStream Fisheries Research.

Table 5.4. Decision and cost model output for the River Spey confluence site on the River Avon. Options are ranked by 10-year total cost, from least to most expensive. Costs are provided in GBP, and cost rankings are provided in parentheses. Res. represents resolution.

Option	Technology	Company	Res.	Counter	No. counters	Sensor	Structure	Structure pad	Counting software	Capital cost	10-year operational cost	10-year total cost
93	resistivity	Aquantic	NA	Logie 2100C	1	NA	Crump weir	none	automated	408924 (1)	123684 (1)	532607 (1)

5.3.2 River Ness

Watershed and Site Characteristics

River Ness is 20 km long, and has a catchment area of 1839 km^2 and a discharge of 67 m^{3}s^{-1} (20-183 m^{3}s^{-1}) at the Ness-side NRFA station (No. 6007) (Figure 5.5). Discharge data from the Ness-side gauge station is applicable to the three potential counter sites visited by IFR staff.

Figure 5.5. Potential counter sites visited by IFR on River Ness.

Species and Run Timing

Ness watershed supports modest numbers of salmon (~1000 rod caught salmon per year), as well as populations of brown trout, which have overlapping size distributions and run timing (spring to fall) with salmon. Loch Ness also supports ferox trout, which are cannibalistic brown trout that reach large sizes. This life history form can drop out from the loch into the River Ness and may complicate counts. Populations of Arctic char reside in Loch Ness but have not been found to use the River Ness for spawning (Ness District Fisheries Management Plan). Pike are also present in the Ness watershed and have been found in many of the lochs and rivers including River Ness. These large-bodied fish would be difficult to discriminate from salmon due to their size overlap, however the population of pike is believed to be very small. The species composition, life history diversity, and overlap in length distributions and migration timing are important considerations when selecting a counter. These characteristics can make it difficult to determine species identification throughout the salmon migration and it is important to select a counter scenario that allows for validation of species identification.

IFR Site Visit

IFR visited the three potential counter sites on River Ness with members of the Ness Fishery Trust staff on 8 October 2014 (Figure 5.5). Site 1 was the Bught Park parking lot, Site 2 was the Gennel's Well footbridge, and Site 3 was the rock weir located approximately 1 km upstream of Site 2. Site 3 would require extensive changes to the rock weir to ensure fish are unable to pass during high flows; these costs are beyond the scope of the model and for this reason Site 3 was not considered further.

Figure 5.6. A potential counter site on the River Ness, October 2014. Photo courtesy of InStream Fisheries Research.

The main advantage of sites on the River Ness is that turbidity is extremely low all year round, because the turbidity is buffered by Loch Ness; this is a key characteristic for effective year-round video validation. A disadvantage of sites in the River Ness is its large bankfull width (Figure 5.6). Installing a counter at Site 1 is feasible, but this site has a very large bankfull width and would likely only be operable as a counter site by using two mulitbeam sonar counters and a diversion fence, or a split beam counter and a diversion fence. Site 2 also has potential as a counter site but may be problematic because this site has two channels as the river splits just upstream of the footbridge. One option would be to operate two counters, one on each channel; the model was not able to deal with the two channels in one costing but could be applied to each channel separately and the costs summed. This approach would ignore a number of operational cost savings and would likely lead to overestimating operation costs. An alternative solution would be to operate one counter and tag fish downstream and use telemetry to estimate the proportion of fish that migrate up the channel without a counter. We did not apply the model to Site 2 for the aforementioned reasons. While this approach introduces other logistical and potential economic challenges that cannot be accounted for in the model, it would provide additional biological data that could be useful for understanding salmon behavior. Another major disadvantage of the River Ness sites are their exposure to the public and the associated security risk to equipment. Both Site 1 and 2 can be easily accessed by the public; this should be a major consideration when making decisions about a site.

Model Output and Counter Evaluation for River Ness – Bught Park

The decision and cost model retained 44 technologically and logistically feasible counter scenarios out of a possible 184 for the River Ness Bught Park site (Table 5.8). The channel_type variable removed all counter scenarios where channel_type = “fish pass”. Additionally there is mains power at the site, so all counter scenarios with power_type = “battery” were removed. The max_depth variable removed all scenarios with sensor as a “flat pad” since the maximum depth of the site is greater than 1 m. The river is not wadeable, so sensors that were flat pad were removed along with structures that were “picket fence”. Finally, any counter scenarios that had a maximum sensor width less than the bankfull width of the site and did not have a fence structure were removed. Fences allow the counter width to be expanded and therefore can be used in large rivers.

Limited Capital Budgets

The five least expensive options include hydroacoustic and video counters, varying in the types of structures and manufacturers. Video counter scenarios offer the least expensive capital costs starting at £57 730, followed by hydroacoustic D-TX Echosounder at £89 557 (Table 5.8). Options 3 to 5 included hydroacoustic counters Teledyne BlueView and BioSonics, and ranged from £89 707 to £97 806. Video is not recommended for this site because of the inherent challenges with regards to capturing the entire cross-section of such a large river. Although the third to fifth scenarios with the least expensive capital cost are feasible, we do not recommend these counter scenarios because they have only one counter. For this site, the two hydroacoustic (e.g., DIDSON 300 or BlueView M900-2250) units are required when operating the unit under low resolution. This would reduce the amount of fence required and minimize risk. The scenario with the second least expensive capital cost is the D-TX Echosounder, which has an exceptional optimal sensor range (100 m), but little research has been conducted on the effectiveness of this counter. The least expensive counter scenario with two hydroacoustic counters is the BlueView M900-2250 with a floating fence, but no Echoview software to perform semi-automated counts at £102 854. A similar scenario, but instead with a DIDSON 300 counter, would cost £186 853. Counter scenarios ranked six through 44 ranged in capital costs from £101 453 to £1 326 728. Exceptionally high capital costs are associated with building a concrete sill, which is > £1 million. Due to the large bankfull width of the River Ness, many of the counter scenarios would perform less than optimal and the amount of fence required would be logistically difficult and have a high risk of failure. This case study highlights the limitation of the model in that it performs poorly with large sites. Most large sites (i.e., bankfull width > 50 m) would benefit from additional assessment.

Limited Operations Budgets

The five least expensive options over a 10-year operational period include hydroacoustic BlueView M900-2250 and optical beam Riverwatcher (Table 5.8). Despite their low operational costs, Riverwatcher counters are not well suited for this site and therefore we focus our assessment of operational costs on the variation in hydroacoustic counter operation costs. The most viable hydroacoustic counter scenarios with regards to operation costs all include Echoview software that semi-automates counting fish. The operational costs for counter scenarios without Echoview are 3-fold higher; operational costs for all hydroacoustic counters without Echoview ranged from £1 836 150 to £1 846 150. Echoview greatly reduces the time required to review hydroacoustic data and count fish.

The total cost over 10-years (including capital and 10-year operational costs) ranged from £734 337 to £849 205 for the top-ten ranked hydroacoustic counter scenarios, with scenarios ranked 11 through 38 having a total cost ranging from £1 853 010 to £3 148 898 (Table 5.8). We recommend that hydroacoustic counter scenarios that include two counters and Echoview software be considered for Site 1 – the Bught Park site on the River Ness.

Table 5.5. Decision and cost model output for the Bught Park site on the River Ness. Options are ranked by 10-year total cost, from least to most expensive. Costs are provided in GBP, and cost rankings are provided in parentheses. Res. represents resolution.

Option no.	Technology	Company	Res.	Counter	No. counters	Sensor	Structure	Structure pad	Counting software	Capital cost	10-year operational cost	10-year total cost
108	optical beam	Vaki	NA	Riverwatcher	1	NA	floating fence	chain ballast	automated	101453 (6)	**133552 (1)**	**235005 (1)**
116	optical beam	Vaki	NA	Riverwatcher	2	NA	floating fence	chain ballast	automated	128453 (14)	**133552 (2)**	**262005 (2)**
32	hydroacoustic	Teledyne BlueView	low	BlueView	1	NA	floating fence	chain ballast	Echoview	102187 (8)	**642650 (5)**	**734337 (3)**
40	hydroacoustic	Teledyne BlueView	high	BlueView	1	NA	floating fence	chain ballast	Echoview	109286 (11)	642650 (6)	**741436 (4)**
13	hydroacoustic	BioSonics	low	D-TX	1	NA	none	none	Echoview	102037 (7)	650650 (17)	**741737 (5)**
16	hydroacoustic	BioSonics	low	D-TX	1	NA	floating fence	chain ballast	Echoview	104037 (10)	652650 (18)	745737 (6)
48	hydroacoustic	Teledyne BlueView	low	BlueView	2	NA	floating fence	chain ballast	Echoview	115334 (12)	642650 (7)	746484 (7)
56	hydroacoustic	Teledyne BlueView	high	BlueView	2	NA	floating fence	chain ballast	Echoview	131532 (15)	642650 (8)	762682 (8)
4	video	various	NA	various	1	NA	floating fence	chain ballast	none	**57730 (1)**	721864 (24)	778694 (9)
124	hydroacoustic	Sound Metrics	low	DIDSON 300	1	NA	floating fence	chain ballast	Echoview	157148 (18)	647650 (13)	794298 (10)
132	hydroacoustic	Sound Metrics	high	DIDSON 300	1	NA	floating fence	chain ballast	Echoview	161509 (19)	647650 (14)	798659 (11)
140	hydroacoustic	Sound Metrics	low	DIDSON 300	2	NA	floating fence	chain ballast	Echoview	199333 (22)	652650 (19)	840483 (12)
148	hydroacoustic	Sound Metrics	high	DIDSON 300	2	NA	floating fence	chain ballast	Echoview	208055 (23)	652650 (20)	849205 (13)
107	optical beam	Vaki	NA	Riverwatcher	1	NA	floating fence	concrete sill	automated	1220126 (28)	**133552 (3)**	1353678 (14)
115	optical beam	Vaki	NA	Riverwatcher	2	NA	floating fence	concrete sill	automated	1247126 (35)	**133552 (4)**	1380678 (15)
31	hydroacoustic	Teledyne BlueView	low	BlueView	1	NA	floating fence	concrete sill	Echoview	1220860 (29)	642650 (9)	1853010 (16)
39	hydroacoustic	Teledyne	high	BlueView	1	NA	floating	concrete	Echoview	1227959	642650 (10)	1860109

		BlueView					fence	sill		(32)		(17)
15	hydroacoustic	BioSonics	low	D-TX	1	NA	floating fence	concrete sill	Echoview	1222710 (31)	652650 (21)	1864410 (18)
47	hydroacoustic	Teledyne BlueView	low	BlueView	2	NA	floating fence	concrete sill	Echoview	1234007 (33)	642650 (11)	1865157 (19)
55	hydroacoustic	Teledyne BlueView	high	BlueView	2	NA	floating fence	concrete sill	Echoview	1250205 (36)	642650 (12)	1881355 (20)
3	video	various	NA	various	1	NA	floating fence	concrete sill	none	1176403 (24)	721864 (25)	1897367 (21)
123	hydroacoustic	Sound Metrics	low	DIDSON 300	1	NA	floating fence	concrete sill	Echoview	1275821 (39)	647650 (15)	1912971 (22)
64	hydroacoustic	Teledyne BlueView	low	BlueView	1	NA	floating fence	chain ballast	none	**89707 (3)**	1836150 (26)	1915357 (23)
131	hydroacoustic	Sound Metrics	high	DIDSON 300	1	NA	floating fence	concrete sill	Echoview	1280182 (40)	647650 (16)	1917332 (24)
21	hydroacoustic	BioSonics	low	D-TX	1	NA	none	none	none	**89557 (2)**	1844150 (38)	1922757 (25)
72	hydroacoustic	Teledyne BlueView	high	BlueView	1	NA	floating fence	chain ballast	none	**97806 (5)**	1836150 (27)	1923456 (26)
24	hydroacoustic	BioSonics	low	D-TX	1	NA	floating fence	chain ballast	none	**91557 (4)**	1846150 (39)	1926757 (27)
80	hydroacoustic	Teledyne BlueView	low	BlueView	2	NA	floating fence	chain ballast	none	102854 (9)	1836150 (28)	1927504 (28)
88	hydroacoustic	Teledyne BlueView	high	BlueView	2	NA	floating fence	chain ballast	none	119052 (13)	1836150 (29)	1943702 (29)
139	hydroacoustic	Sound Metrics	low	DIDSON 300	2	NA	floating fence	concrete sill	Echoview	1318006 (43)	652650 (22)	1959156 (30)
147	hydroacoustic	Sound Metrics	high	DIDSON 300	2	NA	floating fence	concrete sill	Echoview	1326728 (44)	652650 (23)	1967878 (31)
156	hydroacoustic	Sound Metrics	low	DIDSON 300	1	NA	floating fence	chain ballast	none	144668 (16)	1841150 (34)	1975318 (32)
164	hydroacoustic	Sound Metrics	high	DIDSON 300	1	NA	floating fence	chain ballast	none	149029 (17)	1841150 (35)	1979679 (33)
172	hydroacoustic	Sound Metrics	low	DIDSON 300	2	NA	floating fence	chain ballast	none	186853 (20)	1846150 (40)	2021503 (34)
180	hydroacoustic	Sound Metrics	high	DIDSON 300	2	NA	floating fence	chain ballast	none	195575 (21)	1846150 (41)	2030225 (35)
63	hydroacoustic	Teledyne BlueView	low	BlueView	1	NA	floating fence	concrete sill	none	1208380 (25)	1836150 (30)	3034030 (36)

71	hydroacoustic	Teledyne BlueView	high	BlueView	1	NA	floating fence	concrete sill	none	1216479 (27)	1836150 (31)	3042129 (37)
23	hydroacoustic	BioSonics	low	D-TX	1	NA	floating fence	concrete sill	none	1210230 (26)	1846150 (42)	3045430 (38)
79	hydroacoustic	Teledyne BlueView	low	BlueView	2	NA	floating fence	concrete sill	none	1221527 (30)	1836150 (32)	3046177 (39)
87	hydroacoustic	Teledyne BlueView	high	BlueView	2	NA	floating fence	concrete sill	none	1237725 (34)	1836150 (33)	3062375 (40)
155	hydroacoustic	Sound Metrics	low	DIDSON 300	1	NA	floating fence	concrete sill	none	1263341 (37)	1841150 (36)	3093991 (41)
163	hydroacoustic	Sound Metrics	high	DIDSON 300	1	NA	floating fence	concrete sill	none	1267702 (38)	1841150 (37)	3098352 (42)
171	hydroacoustic	Sound Metrics	low	DIDSON 300	2	NA	floating fence	concrete sill	none	1305526 (41)	1846150 (43)	3140176 (43)
179	hydroacoustic	Sound Metrics	high	DIDSON 300	2	NA	floating fence	concrete sill	none	1314248 (42)	1846150 (44)	3148898 (44)

5.3.3 Little Gruinard River

Watershed and Site Characteristics

Little Gruinard River is a small river; it has a catchment area of 81 km^2, is fed by a series of large lochs, and has low levels of species diversity and productivity (Figure 5.7). Currently, there are no SEPA gauging stations on the Little Gruinard River.

Figure 5.7. Potential counter sites visited by IFR on Little Gruinard River.

Species and Run Timing

Little Gruinard River supports salmon and trout, which have overlapping size distributions and run timing (spring to fall). Salmon returns in the Little Gruinard River total approximately 100 fish annually. The Little Gruinard River is a SAC for salmon, where the population is predominantly grilse with some two sea-winter adults present. The species composition, life history diversity, and overlap in length distributions and migration timing are important considerations when selecting a counter. These characteristics can make it difficult to determine species identification throughout the salmon migration and it is important to select a counter scenario that allows for validation of species identification.

IFR Site Visit

IFR staff visited two potential counter sites on Little Gruinard. For this site visit, Donna-Claire Hunter, the project coordinator for Marine Scotland Science, hosted IFR on the Little Gruinard River and little information was available on run timing and species composition. Site 1 was located at a bridge on Highway A832, and Site 2 was < 50 m upstream of Gruinard Bay (Figure 5.7).

Site 1 was a high gradient, boulder section of the river that would make the operation of a counter difficult given the substrate (Figure 5.8). Old bridge posts on both sides of the river, however, may provide a constrained and consistent cross-section of the river for sonar to be operated. Mains power would also need to be installed. Although this site has potential as a counter site, Site 2 was much better suited and Site 1 was not considered further.

Figure 5.8. A potential counter site on the Little Gruinard River (Site 1), October 2014. Photo courtesy of InStream Fisheries Research.

Site 2 was a lower gradient, cobble and bolder section of the river that would be highly suitable for a counter setup (Figure 5.9). Main advantages of this site were the small channel width, availability of mains power, location relative to spawning and site access. Channel morphology is relatively uniform, and shallow with a narrow bankfull width. Such channel characteristics make it easy to install and operate counters, including operation of a diversion fence if one were required. Site 2 is located on a property with mains power and is below the lowest extent of spawning, with good access. Security for this site would likely not be an issue. IFR was able to drive vehicles close to the site and access it along the property owner’s road, reducing the time and challenge of carrying gear into the site, checking the counter and potential security issues. Access to this site makes batteries a viable option in the absence of mains power, however the remote location would add substantial travel time if staff were not local.

Figure 5.9. A potential counter site on the Little Gruinard River (Site 2), October 2014. Photo courtesy of InStream Fisheries Research.

Model Output and Counter Evaluation for Little Gruinard - Ocean Confluence

The model retained nine technologically and logistically feasible counter scenarios out of a possible 184 for the ocean confluence site on Little Gruinard River (Table 5.9). The channel_type variable removed all counter scenarios where channel_type = “fish pass”. Additionally there is mains power at the site, so all counter scenarios with power_type = “battery” were removed. The main variable use to remove the majority of the counter options was min_depth (> 90 cm min_depth required for hydroacoustic counters); this removed all counter options that used hydroacoustic technology.

Limited Capital Budgets

The five least expensive options include resistivity, optical beam and video counters, varying in the types of structures and sensor units. Video counter scenarios offer the least expensive capital costs starting at £25 580, followed by resistivity counters with flat pad sensors at £29 623 and £30 303 for the 2nd and 3rd ranked options (Table 5.9). Although the optical beam counter is ranked fourth, the capital cost is 2.8- and 2.3-fold greater than video counters and resistivity, respectively. The reason for this large difference in capital cost is due to the large cost of the Vaki Riverwatcher counter unit. From a capital cost perspective, the model results indicate that video and resistivity technologies would be the most cost-effective options.

Limited Operational Budgets

The five least expensive options over a 10-year operational period include resistivity and optical beam counters (Table 5.9). The large cost of operating video counters, attributable to the cost of reviewing video footage to count fish, lead to the worst cost rankings over a 10-year operational period and are typically 5-fold higher than the operational costs associated with the optical beam and resistivity counter setups.

The total cost over 10-years (including capital and 10-year operational costs) ranged from £123 666 to £252 258 for the top seven ranked scenarios, with scenarios ranked eight through nine having a total cost > £534 905 (Table 5.9). Scenarios ranked eight through nine all use video technology and the high cost over 10 years is attributable to the high cost of reviewing video to count fish. We recommend that the top seven ranked scenarios be considered for Site 2 – the ocean confluence site on the Little Gruinard River.

Table 5.6. Decision and cost model output for the ocean confluence site on Little Gruinard River. Options are ranked by 10-year total cost, from least to most expensive. Costs are provided in GBP, and cost rankings are provided in parentheses. Res. represents resolution.

Option no.	**Technology**	**Company**	**Res.**	**Counter**	**No. counters**	**Sensor**	**Structure**	**Structure pad**	**Counting software**	**Capital cost**	**10-year operational cost**	**10-year total cost**
95	resistivity	Aquantic	NA	Logie 2100C	1	flat pad	none	none	automated	**29623 (2)**	**94043 (2)**	**123666 (1)**
97	resistivity	Aquantic	NA	Logie 2100C	1	flat pad	picket fence	none	automated	**30303 (3)**	102499 (7)	**132802 (2)**
108	optical beam	Vaki	NA	Riverwatcher	1	NA	floating fence	chain ballast	automated	**69303 (4)**	**97538 (3)**	**166840 (3)**
116	optical beam	Vaki	NA	Riverwatcher	2	NA	floating fence	chain ballast	automated	96303 (6)	**97538 (4)**	**193840 (4)**
93	resistivity	Aquantic	NA	Logie 2100C	1	NA	Crump weir	none	automated	121494 (7)	**90680 (1)**	**212174 (5)**
107	optical beam	Vaki	NA	Riverwatcher	1	NA	floating fence	concrete sill	automated	127721 (8)	**97538 (5)**	225258 (6)
115	optical beam	Vaki	NA	Riverwatcher	2	NA	floating fence	concrete sill	automated	154721 (9)	97538 (6)	252258 (7)
4	video	various	NA	various	1	NA	floating fence	chain ballast	none	**25580 (1)**	510225 (8)	534905 (8)
3	video	various	NA	various	1	NA	floating fence	concrete sill	none	**83998 (5)**	510225 (9)	593323 (9)

5.3.4 River South Esk

Watershed and Site Characteristics

River South Esk at the Gella Bridge NRFA station (No. 13012) has a catchment area of 130 km^2 and a discharge of 3 m^{3}s^{-1} (1-12 m^{3}s^{-1}) (Figure 5.10). Discharge data from Gella Bridge is applicable to the Clova Bridge site (Site 1) on River South Esk visited by IFR staff.

River South Esk at the Prosen Bridge NRFA station (No. 13004) has a catchment area of 104 km^2 and a discharge of 2 m^{3}s^{-1} (0.7-7 m^{3}s^{-1}) (Figure 5.10).

River South Esk at the Brechin NRFA station (No. 13008) has a catchment area of 488 km^2 and a discharge of 9 m^{3}s^{-1} (2-27 m^{3}s^{-1}) (Figure 5.10). Discharge data from Brechin is applicable to the South Esk Bridge of Dun (Site 3), weir (Site 4) and footbridge (Site 5) sites visited by IFR staff.

Figure 5.10. Potential counter sites visited by IFR on River South Esk.

Species and Run Timing

River South Esk supports salmon and trout, which have overlapping size distributions and run timing (spring to fall). Subpopulations of spring and summer salmon, and grilse are all present in River South Esk. River South Esk is a SAC for salmon. Rod catches for salmon and sea trout in 2013 were approximately 500 fish for both species (Esk Rivers and Fisheries Trust 2014). Historically, rod catches have been between 500 and 3000, and 100 and 1500 for salmon and sea trout, respectively.

IFR Site Visit

IFR staff visited five potential sites in the River South Esk watershed – Site 1 the Clova Bridge (Figure 5.11 and 5.12), Site 2 the Prosen Bridge (Figure 5.13 and 5.14), Site 3 the Dun Bridge, Site 4 the River South Esk weir (Figure 5.15), and Site 5 the River South Esk footbridge (Figure 5.16). All sites except Site 3 could be potential counter sites, but varied in their channel characteristics significantly. Site 3 was tidal, which would be too difficult because of changing water levels and conductivity and therefore was not considered further.

Site 1 at the Clova Bridge was a lower gradient section of river with boulder substrate downstream of the bridge and gravel upstream of the bridge (Figure 5.11 and 5.12). The medium-sized channel width at Site 1 was appropriate for a range of counter designs. During the site visit the water was turbid, which could make video validation difficult. There is no mains power but the site is in close proximity to power lines. Access to the site was good. The main disadvantage of the Site 1 is the exposure to the public and associated security risk to equipment. The public can easily access Site 1 as it is located next to a car park and a frequently used road bridge; this should be a major consideration when making decisions about a site. Access to this site makes batteries a viable option in the absence of mains power.

Figure 5.11. Clova Bridge, a potential counter site on River South Esk. This picture shows the river upstream of the bridge. Photo courtesy of InStream Fisheries Research.

Figure 5.12. Clova Bridge, a potential counter site on River South Esk. This picture shows the river downstream of the bridge. Photo courtesy of InStream Fisheries Research.

Site 2 at the Prosen Bridge is a higher gradient section of the Prosen Water, which is a tributary of the River South Esk (Figure 5.13 and 5.14). The small channel size makes it an appropriate site for various counter scenarios, although the low conductivity IFR measured during site visit (30 µS) is cause for concern with regards to resistivity counters but is still greater than the threshold value of 20 µS. Year-round measurements of conductivity would have to be conducted if this site was to be assessed further. One major disadvantage of Site 2 is the exposure to the public and associated security risk to equipment. The public can easily access Site 1; this should be a major consideration when making decisions about a site. Site 2 also lacks access to mains power, but given its proximity to power lines, mains power could be easily installed. Access to this site makes batteries a viable option in the absence of mains power.

Figure 5.13. Prosen Bridge, a higher gradient section of the Prosen Water, a potential counter site for River South Esk. This picture shows upstream of the bridge. Photo courtesy of InStream Fisheries Research.

Figure 5.14. Prosen Bridge, a higher gradient section of the Prosen Water. A potential counter site for River South Esk. This picture shows downstream of the bridge. Photo courtesy of InStream Fisheries Research.

Site 4 at the River South Esk weir is a small fish pass in the middle of the fish weir and is a viable counter site (Figure 5.15). The fish pass provides a controlled environment for fish to pass through and would likely produce highly accurate estimates. Assess is easy, and although the site is accessible to the public, it is not in plain sight. One major advantage of this site is that it is near the lower extent of spawning and a counter in this location would all but a few fish that spawn in the 600 m between the weir and the footbridge downstream. One major disadvantage of this site is that the fish pass is in the middle of the weir and access could be challenging. This is a concern because the South Esk Trust staff indicated that high debris events are common on the river and would likely obstruct the fish pass and counter. In addition, there is no mains power at this site. Access to this site makes batteries a viable option in the absence of mains power.

Figure 5.15. South Esk weir, a potential counter site for River South Esk. A small fish pass exists in the middle of the fish weir. Photo courtesy of InStream Fisheries Research.

Site 5 at the footbridge 600 m downstream of the weir is a potential counter site due to its relatively narrow channel, uniform channel shape and low gradient (Figure 5.16). With the exception of the channel characteristics, the site is similar to Site 3 with regards to good access, high debris potential, and the lack of mains power. This site is below the lower extent of spawning and would enumerate the entire population of salmon. Access to this site makes batteries a viable option in the absence of mains power.

Figure 5.16. South Esk footbridge, a potential counter site for River South Esk. A footbridge downstream of the South Esk weir site. Photo courtesy of InStream Fisheries Research.

Model Output and Counter Evaluation for Sites on River South Esk

Site 1 – Clova Bridge

The decision and cost model retained one technologically and logistically feasible counter scenario out of a possible 184 for the Clova Bridge site on River South Esk (Table 5.10). High turbidity (> 90 NTU) at Clova Bridge at the time of the IFR site visit removed all counter scenarios where technology = "optical beam". Video counters (technology = "video") were removed as the turbidity at Clova Bridge was > 30 NTU. The channel_type variable removed all counter scenarios where channel_type = "fish pass". Although there is no mains power at the site, mains power is possible and would be the preferred power_type. All counter scenarios with power_type = "battery" were removed. Min_depth removed the majority of the counter options (> 90 cm min_depth required for hydroacoustic counters); this removed all counter options that used hydroacoustic technology.

A resistivity counter with a Crump weir was the only technologically and logistically feasible option, with capital, 10-year operational and 10-year total costs of £327 321, £154 239 and £481 560, respectively (Table 5.10). While IFR agrees with the model output of a resistivity Crump weir counter setup, coarse site visit data may be the reason for only one feasible counter option at Clova Bridge. A more detailed site assessment that would include monitoring water conditions over time and more accurate depth measurements may reveal additional counter options.

Site 2 – Prosen Bridge

The decision and cost model retained one technologically and logistically feasible counter scenario out of a possible 184 for the Prosen Bridge site on River South Esk (Table 5.11). High turbidity (> 90 NTU) at Prosen Bridge at the time of the IFR site visit removed all counter scenarios where technology = “optical beam”. Video counters (technology = “video”) were removed as the turbidity at Prosen Bridge was > 30 NTU. The channel_type variable removed all counter scenarios where channel_type = “fish pass”. Prosen Bridge could acquire access to mains power, so all counter scenarios with power_type = “battery” were removed. Min_depth removed the majority of the counter options (> 90 cm min_depth required for hydroacoustic counters); this removed all counter options that used hydroacoustic technology.

A resistivity counter with a Crump weir was the only technologically and logistically feasible option, with capital, 10-year operational and 10-year total costs of £184 106, £154 239 and £338 345, respectively (Table 5.11). While IFR agrees with the model output of a resistivity Crump weir counter setup, coarse site visit data may be the reason for only one feasible counter option at Prosen Bridge. A more detailed site assessment that would include monitoring water conditions over time and more accurate depth measurements may reveal additional counter options.

Site 4 – Weir

The decision and cost model retained three technologically and logistically feasible counter scenarios out of a possible 184 for Site 4 on River South Esk (Table 5.12). High turbidity (> 90 NTU) at Site 4 at the time of the IFR site visit removed all counter scenarios where technology = “optical beam”. Video counters (technology = “video”) were removed as the turbidity at the weir site was > 30 NTU. The channel_type variable removed all counter scenarios where channel_type = “river”. The weir site could acquire access to mains power, so all counter scenarios with power_type = “battery” were removed. Min_depth removed the majority of the counter options (> 90 cm min_depth required for hydroacoustic counters); this removed all counter options that used hydroacoustic technology.

Limited Capital Budgets

All three counter scenarios involve resistivity counters with a fish pass insert, with costs varying slightly with the type of resistivity counter (i.e., £10 000 for a Logie 2100C vs. £20 000 for a Mark 12) and sensor type (i.e., tube vs. flume). For budgets limited by capital cost, a Logie 2100C resistivity counter with a fish pass insert and tube sensor had the lowest capital cost of £73 436 (Option 99), followed by a Logie 2100C resistivity counter with a fish pass insert and flume sensor (Option 101, £76 436) and a Mark 12 resistivity counter with a fish pass insert and flume sensor (Option 103, £96 436) (Table 5.12).

Limited Operational Budgets

All three counter scenarios had the same 10-year operational cost (£158 239) (Table 5.12). Such a finding highlights the stability of resistivity counters when used in a fish pass and the relatively low cost required to operate a counter setup at a pre-existing fish pass.

The total cost over 10-years (including capital and 10-year operational costs) ranged from £197 300 to £220 300, with Option 103 having a higher cost due to the use of a Mark 12 resistivity counter and flume sensor (Table 5.12).

Site 5 – Footbridge

The decision and cost model retained one technologically and logistically feasible counter scenario out of a possible 184 for Site 5 on River South Esk (Table 5.13). High turbidity (> 90 NTU) at the footbridge on River South Esk at the time of the IFR site visit removed all counter scenarios where technology = “optical beam”. Video counters (technology = “video”) were removed as the turbidity at the footbridge was > 30 NTU. The channel_type variable removed all counter scenarios where channel_type = “fish pass”. The footbridge site could acquire access to mains power, so all counter scenarios with power_type = “battery” were removed. Min_depth removed the majority of the counter options (< 90 cm threshold required for hydroacoustic counters); this removed all counter options that used hydroacoustic technology.

A resistivity counter with a Crump weir was the only technologically and logistically feasible option, with capital, 10-year operational and 10-year total costs of £411 924, £154 239 and £566 163, respectively (Table 5.13). While IFR agrees with the model output of a resistivity Crump weir counter setup, coarse site visit data may be the reason for only one feasible counter option at the footbridge site. A more detailed site assessment that would include monitoring water conditions over time and more accurate depth measurements may reveal additional counter options.

Table 5.7. Decision and cost model output for the Clova Bridge site on the River South Esk. Options are ranked by 10-year total cost, from least to most expensive. Costs are provided in GBP, and cost rankings are provided in parentheses. Res. represents resolution.

Option no.	Technology	Company	Res	Counter	No. counters	Sensor	Structure	Structure pad	Counting software	Capital cost	10-year operational cost	10-year total cost
93	resistivity	Aquantic	NA	Logie 2100C	1	NA	Crump weir	none	automated	327321 (1)	154239 (1)	481560 (1)

Table 5.8. Decision and cost model output for the Prosen Bridge site on the River South Esk. Options are ranked by 10-year total cost, from least to most expensive. Costs are provided in GBP, and cost rankings are provided in parentheses. Res. represents resolution.

Option no.	Technology	Company	Res	Counter	No. counters	Sensor	Structure	Structure pad	Counting software	Capital cost	10-year operational cost	10-year total cost
93	resistivity	Aquantic	NA	Logie 2100C	1	NA	Crump weir	none	automated	184106 (1)	154239 (1)	338345 (1)

Table 5.9. Decision and cost model output for the weir site on the River South Esk. Options are ranked by 10-year total cost, from least to most expensive. Costs are provided in GBP, and cost rankings are provided in parentheses. Res. represents resolution.

Option no.	Technology	Company	Res.	Counter	No. counters	Sensor	Structure	Structure pad	Counting software	Capital cost	10-year operational cost	10-year total cost
99	resistivity	Aquantic	NA	Logie 2100C	1	tube	fishway insert	none	automated	39061 (1)	158239 (1)	197300 (1)
101	resistivity	Aquantic	NA	Logie 2100C	1	flume	fishway insert	none	automated	42061 (2)	158239 (2)	200300 (2)
103	resistivity	SSE	NA	Mark 12	1	flume	fishway insert	none	automated	62061 (3)	158239 (3)	220300 (3)

Table 5.10. Decision and cost model output for the footbridge site on the River South Esk. Options are ranked by 10-year total cost, from least to most expensive. Costs are provided in GBP, and cost rankings are provided in parentheses. Res. represents resolution.

Option no.	Technology	Company	Res.	Counter	No. counters	Sensor	Structure	Structure pad	Counting software	Capital cost	10-year operational cost	10-year total cost
93	resistivity	Aquantic	NA	Logie 2100C	1	NA	Crump weir	none	automated	411924 (1)	154239 (1)	566163 (1)

5.3.5 River Lochy

Watershed and Site Characteristics

River Lochy is a medium-sized river; it has a catchment area of 1252 km^2 and a discharge of 32 m^{3}s^{-1} (6-149 m^{3}s^{-1}) measured at the Camisky NRFA station (No. 91002) (Figure 5.17). Discharge data from Camisky is applicable to the two potential counter sites visited by IFR staff.

Figure 5.17. Potential counter sites visited by IFR on River Lochy.

Species and Run Timing

River Lochy supports salmon and trout, which have overlapping size distributions and run timing (spring to fall). Notably, some fish migrate during the winter and early spring. Spring migrations of salmon in River Lochy are uncommon. Historically, the spawning salmon abundances were between 2000 and 10 000 fish, but sea trout abundances are unknown. Sea trout are generally smaller than grilse, but co-migrate from May to September.

IFR Site Visit

IFR staff visited two potential sites on River Lochy with River Lochy staff – the gorge (Site 1) and the canal pool (Site 2). Site 1 is a deep narrow bedrock section of the river that would likely cause fish to exhibit milling behaviour, potentially causing double counting and thus affecting the accuracy of abundance estimates. IFR did not run the model because a counter previously placed at this site was deemed to perform poorly.

Site 2 is a low gradient glide that was highly suitable for a counter setup due to channel morphology, anticipated fish migration behaviour, and access. Channel morphology was deepest on river right and shallow on river left - this triangular-shaped channel is ideal for operating hydroacoustic counters and a diversion fence (Figure 5.18). With this triangular morphology, increases in river discharge result in comparatively smaller increases in stage height than in a confined channel. Furthermore, the channel would be wadeable at higher discharges making a diversion fence a possible approach. A second main advantage of this site was access. IFR was able to drive directly to the site and access it along a property owner’s road, reducing the time and challenges associated with carrying gear into the site. Of course this is especially true if there is no mains power and batteries are required. The location is also on private property, which would provide adequate security. Finally, Lochaber Fisheries Trust staff indicated that fish continually migrate through this section of the river and holding would be minimal. Notably, the main challenge with this site is the lack of mains power. Mains power, however, could be established at this site as it is located on a property and power is nearby. Access to this site makes batteries a viable option in the absence of mains power.

Figure 5.18. River Lochy canal pool, a potential counter site for River Lochy. Photo courtesy of InStream Fisheries Research.

Model Output and Counter Evaluation for River Lochy – Canal Pool

The decision and cost model retained 52 technologically and logistically feasible counter scenarios out of a possible 184 for the canal pool site on River Lochy (Table 5.14). The channel_type variable removed all counter scenarios where channel_type = “fish pass”. Although there is no mains power at the site, mains power is possible and would be the preferred power_type so all counter scenarios with power_type = “battery” were removed. Max_depth was greater than 100 cm threshold, removing options for flat pad sensors.

Limited Capital Budgets

The five least expensive options include only video and hydroacoustic counters, varying in the types of structures (scenarios with or without fences). Video counter scenarios offer the least expensive capital costs starting at £45 270, followed by scenarios ranked 2 through 5 using multibeam hydroacoustic counters ranging from £62 337 to £85 436 (Table 5.14). Capital cost increased steadily through to the 31st ranked scenario (cost of £195 595), but increased to £572 993 for the 32nd ranked scenario. This major increase in cost was due to the inclusion of a permanent “concrete sill” for the fence instead of a removable “chain ballast” structure_pad.

Limited Operational Budgets

The five least expensive options over a 10-year operational period include optical beam and hydroacoustic counters. Counter scenarios ranked 1 through 4 use optical beam counters and have a 4.7-fold lower operational cost than the 5th ranked counter scenario that uses a multibeam hydroacoustic counter (Table 5.14). We do not recommend, however, using the optical beam counters because of the large risk associated with operating such a large fence that would be required for an optical beam counter (e.g., Vaki Riverwatcher). All counter scenarios that use hydroacoustic counters have similar operational costs ranging from £660 150 to £681 150 when Echoview counting software is used, but 10-year operational costs increased to £1 834 150 when Echoview is not used.

The 10-year total costs show similar results to the 10-year operational costs, with the counter scenarios ranked 1 and 2 using optical beam counters and scenarios ranked 3 through 5 using multibeam hydroacoustic counters (Table 5.14). There was a marked difference in total cost between counter scenarios using these two counter types, whereby optical beam counters (ranked 1 and 2 with total 10-year costs of £236 607 and £263 607, respectively) were 2.8-fold less expensive than scenarios using hydroacoustic counters (ranked 3, 4, and 5 with total 10-year costs of £741 377, £748 476, and £749 074, respectively). Considering the costs and IFR’s professional experience, we recommend using a single hydroacoustic counter with a fence structure and Echoview software for the operation of Site 2 – the canal pool on River Lochy.

Table 5.11. Decision and cost model output for the canal pool site on the River Lochy. Options are ranked by 10-year total cost, from least to most expensive. Costs are provided in GBP, and cost rankings are provided in parentheses. Res. represents resolution.

Option	Technology	Company	Settings	Counter	No. counters	Sensor	Structure	Structure pad	Counting software	Capital cost	10-year operational cost	10-year total cost
108	optical beam	Vaki	NA	Riverwatcher	1	NA	floating fence	chain ballast	automated	88993 (8)	**147614 (1)**	**236607 (1)**
116	optical beam	Vaki	NA	Riverwatcher	2	NA	floating fence	chain ballast	automated	115993 (22)	**147614 (2)**	**263607 (2)**
32	hydroacoustic	Teledyne BlueView	low	BlueView	1	NA	floating fence	chain ballast	Echoview	89727 (11)	662150 (6)	**741377 (3)**
40	hydroacoustic	Teledyne BlueView	high	BlueView	1	NA	floating fence	chain ballast	Echoview	96826 (14)	662150 (7)	**748476 (4)**
45	hydroacoustic	Teledyne BlueView	low	BlueView	2	NA	none	none	Echoview	100424 (15)	**660150 (5)**	**749074 (5)**
48	hydroacoustic	Teledyne BlueView	low	BlueView	2	NA	floating fence	chain ballast	Echoview	102424 (19)	662150 (8)	753074 (6)
46	hydroacoustic	Teledyne BlueView	low	BlueView	2	NA	picket fence	none	Echoview	100424 (16)	671150 (19)	760074 (7)
13	hydroacoustic	BioSonics	low	D-TX	1	NA	none	none	Echoview	102037 (17)	670150 (18)	761237 (8)
107	optical beam	Vaki	NA	Riverwatcher	1	NA	floating fence	concrete sill	automated	616716 (35)	**147614 (3)**	764330 (9)
16	hydroacoustic	BioSonics	low	D-TX	1	NA	floating fence	chain ballast	Echoview	104037 (20)	672150 (20)	765237 (10)
4	video	various	NA	various	1	NA	floating fence	chain ballast	none	**45270 (1)**	721864 (27)	766234 (11)
56	hydroacoustic	Teledyne BlueView	high	BlueView	2	NA	floating fence	chain ballast	Echoview	119072 (23)	662150 (9)	769722 (12)
14	hydroacoustic	BioSonics	low	D-TX	1	NA	picket fence	none	Echoview	102037 (18)	681150 (26)	772237 (13)
115	optical beam	Vaki	NA	Riverwatcher	2	NA	floating fence	concrete sill	automated	643716 (43)	**147614 (4)**	791330 (14)
124	hydroacoustic	Sound Metrics	low	DIDSON 300	1	NA	floating fence	chain ballast	Echoview	144688 (26)	667150 (14)	801338 (15)
132	hydroacoustic	Sound Metrics	high	DIDSON 300	1	NA	floating fence	chain ballast	Echoview	149049 (27)	667150 (15)	805699 (16)

140	hydroacoustic	Sound Metrics	low	DIDSON 300	2	NA	floating fence	chain ballast	Echoview	186873 (30)	672150 (21)	847523 (17)
148	hydroacoustic	Sound Metrics	high	DIDSON 300	2	NA	floating fence	chain ballast	Echoview	195595 (31)	672150 (22)	856245 (18)
31	hydroacoustic	Teledyne BlueView	low	BlueView	1	NA	floating fence	concrete sill	Echoview	617450 (36)	662150 (10)	1269100 (19)
39	hydroacoustic	Teledyne BlueView	high	BlueView	1	NA	floating fence	concrete sill	Echoview	624549 (39)	662150 (11)	1276199 (20)
47	hydroacoustic	Teledyne BlueView	low	BlueView	2	NA	floating fence	concrete sill	Echoview	630147 (40)	662150 (12)	1280797 (21)
15	hydroacoustic	BioSonics	low	D-TX	1	NA	floating fence	concrete sill	Echoview	631760 (41)	672150 (23)	1292960 (22)
3	video	various	NA	various	1	NA	floating fence	concrete sill	none	572993 (32)	721864 (28)	1293957 (23)
55	hydroacoustic	Teledyne BlueView	high	BlueView	2	NA	floating fence	concrete sill	Echoview	646795 (44)	662150 (13)	1297445 (24)
123	hydroacoustic	Sound Metrics	low	DIDSON 300	1	NA	floating fence	concrete sill	Echoview	672411 (47)	667150 (16)	1329061 (25)
131	hydroacoustic	Sound Metrics	high	DIDSON 300	1	NA	floating fence	concrete sill	Echoview	676772 (48)	667150 (17)	1333422 (26)
139	hydroacoustic	Sound Metrics	low	DIDSON 300	2	NA	floating fence	concrete sill	Echoview	714596 (51)	672150 (24)	1375246 (27)
147	hydroacoustic	Sound Metrics	high	DIDSON 300	2	NA	floating fence	concrete sill	Echoview	723318 (52)	672150 (25)	1383968 (28)
69	hydroacoustic	Teledyne BlueView	high	BlueView	1	NA	none	none	none	**62337 (2)**	1834150 (29)	1885987 (29)
64	hydroacoustic	Teledyne BlueView	low	BlueView	1	NA	floating fence	chain ballast	none	**77247 (4)**	1836150 (31)	1902897 (30)
70	hydroacoustic	Teledyne BlueView	high	BlueView	1	NA	picket fence	none	none	**73557 (3)**	1845150 (44)	1908207 (31)
77	hydroacoustic	Teledyne BlueView	low	BlueView	2	NA	none	none	none	87944 (6)	1834150 (30)	1910594 (32)
72	hydroacoustic	Teledyne BlueView	high	BlueView	1	NA	floating fence	chain ballast	none	**85346 (5)**	1836150 (32)	1910996 (33)
80	hydroacoustic	Teledyne BlueView	low	BlueView	2	NA	floating fence	chain ballast	none	89944 (12)	1836150 (33)	1914594 (34)
78	hydroacoustic	Teledyne BlueView	low	BlueView	2	NA	picket fence	none	none	87944 (7)	1845150 (45)	1921594 (35)
21	hydroacoustic	BioSonics	low	D-TX	1	NA	none	none	none	89557 (9)	1844150 (43)	1922757 (36)

24	hydroacoustic	BioSonics	low	D-TX	1	NA	floating fence	chain ballast	none	91557 (13)	1846150 (46)	1926757 (37)
88	hydroacoustic	Teledyne BlueView	high	BlueView	2	NA	floating fence	chain ballast	none	106592 (21)	1836150 (34)	1931242 (38)
22	hydroacoustic	BioSonics	low	D-TX	1	NA	picket fence	none	none	89557 (10)	1855150 (52)	1933757 (39)
156	hydroacoustic	Sound Metrics	low	DIDSON 300	1	NA	floating fence	chain ballast	none	132208 (24)	1841150 (39)	1962858 (40)
164	hydroacoustic	Sound Metrics	high	DIDSON 300	1	NA	floating fence	chain ballast	none	136569 (25)	1841150 (40)	1967219 (41)
172	hydroacoustic	Sound Metrics	low	DIDSON 300	2	NA	floating fence	chain ballast	none	174393 (28)	1846150 (47)	2009043 (42)
180	hydroacoustic	Sound Metrics	high	DIDSON 300	2	NA	floating fence	chain ballast	none	183115 (29)	1846150 (48)	2017765 (43)
63	hydroacoustic	Teledyne BlueView	low	BlueView	1	NA	floating fence	concrete sill	none	604970 (33)	1836150 (35)	2430620 (44)
71	hydroacoustic	Teledyne BlueView	high	BlueView	1	NA	floating fence	concrete sill	none	613069 (34)	1836150 (36)	2438719 (45)
79	hydroacoustic	Teledyne BlueView	low	BlueView	2	NA	floating fence	concrete sill	none	617667 (37)	1836150 (37)	2442317 (46)
23	hydroacoustic	BioSonics	low	D-TX	1	NA	floating fence	concrete sill	none	619280 (38)	1846150 (49)	2454480 (47)
87	hydroacoustic	Teledyne BlueView	high	BlueView	2	NA	floating fence	concrete sill	none	634315 (42)	1836150 (38)	2458965 (48)
155	hydroacoustic	Sound Metrics	low	DIDSON 300	1	NA	floating fence	concrete sill	none	659931 (45)	1841150 (41)	2490581 (49)
163	hydroacoustic	Sound Metrics	high	DIDSON 300	1	NA	floating fence	concrete sill	none	664292 (46)	1841150 (42)	2494942 (50)
171	hydroacoustic	Sound Metrics	low	DIDSON 300	2	NA	floating fence	concrete sill	none	702116 (49)	1846150 (50)	2536766 (51)
179	hydroacoustic	Sound Metrics	high	DIDSON 300	2	NA	floating fence	concrete sill	none	710838 (50)	1846150 (51)	2545488 (52)

5.3.6 River Dee

Watershed and Site Characteristics

River Dee at the Woodend NRFA station (No. 12001) has a catchment area of 1370 km^2 and a discharge of 27 m^{3}s^{-1} (8-74 m^{3}s^{-1}) (Figure 5.19). Discharge data from the Woodend gauge station is applicable to the potential counter site visited by IFR staff.

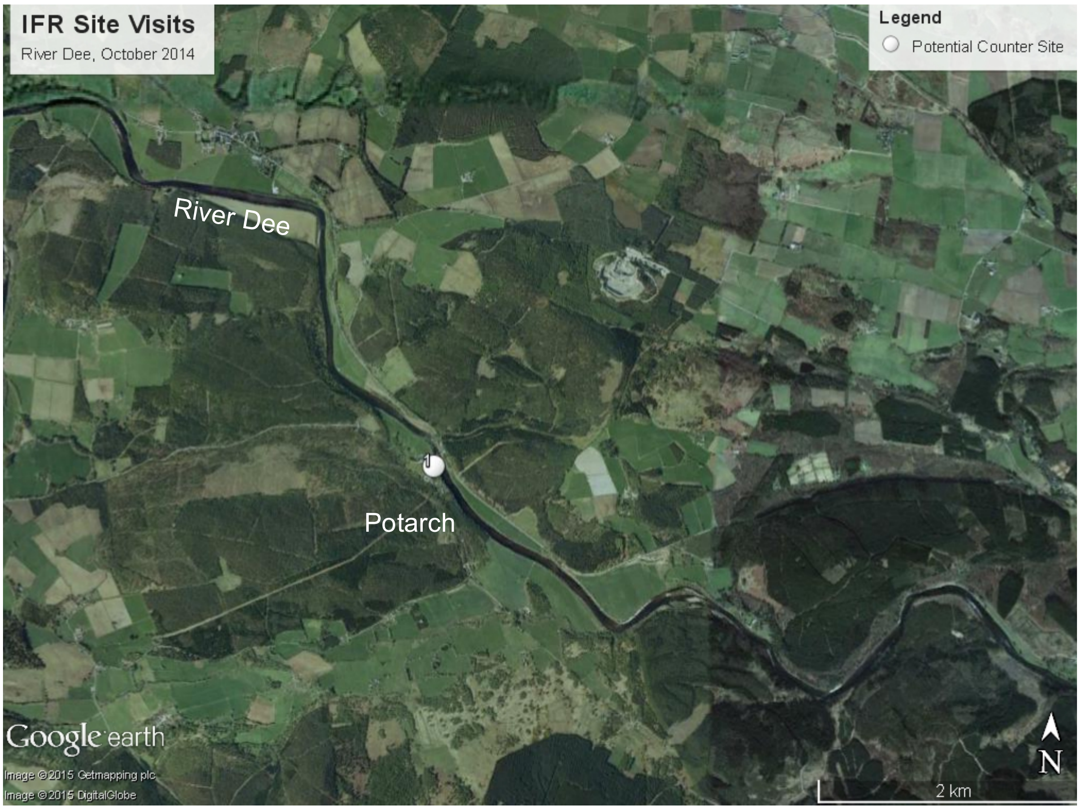


Figure 5.19. Potential counter site visited by IFR on River Dee.

Species and Run Timing

River Dee supports a significant proportion of salmon in Scotland, where 3570 fish were caught by rod and reel in 2014 (River Dee Trust 2014). River Dee also supports large populations of trout (sea trout rod catch of approximately 1 500 fish in 2014), which have overlapping size distributions and run timing (spring to fall) with salmon. Spring runs of salmon are of specific interest. The River Dee is designated as a SAC for salmon runs.

IFR Site Visit

IFR staff visited one potential site on River Dee with Dee District Salmon Fishery Board staff – downstream of the Potarch Bridge. Though this site has potential as a counter site, its large channel width makes it difficult for technologies other than hydroacoustic counters (Figure 5.20). The site is low gradient and can be deep in some areas. Large debris flows are possible during high discharge events that would make operating a diversion fence risky. The triangular shape of the channel makes it suitable for hydroacoustic counters. One disadvantage of the site is the exposure to the public and the associated security risk to equipment. Public can easily access the site; this should be a major consideration when making decisions about a site. Notably, the site also lacks access to mains power, but given its proximity to existing power lines, mains power could be easily installed.

Figure 5.20. River Dee at Portarch Bridge, a potential counter site for River Dee. Photo courtesy of InStream Fisheries Research.

Model Output and Counter Evaluation for River Dee

The decision and cost model retained 44 technologically and logistically feasible scenarios out of a possible 184 for the Potarch Bridge site on River Dee (Table 5.15). The channel_type variable removed all counter scenarios where the channel_type = “fish pass”. Although, there is no mains power at the site, mains power is possible and would be the preferred power_type so all counter scenarios with power_type = “battery” were removed. Other variables that removed other counter options were max_depth > 100 cm and wadeable = “no”, which removed flat pad counters and picket fences, respectively. Finally, maximum_ww = 50 removed the counter scenarios that involved resistivity counters, as the max width per sensor or channel is limited to 8 m.

Limited Capital Budgets

The five least expensive options include video and hydroacoustic counters, varying in the types of structures and sensor units. Video counter scenarios offer the least expensive capital costs starting at £51 500 (Table 5.15). Although this option is deemed suitable by the model, we do not recommend using video in this location, as the technology is susceptible to environmental changes and the logistics and risks of installing a fence that spans the width of the site (50 m). Counter scenarios ranked 2 through 4 include both single multibeam and single splitbeam hydroacoustic counters, and ranged from £83 477 to £91 576 in capital costs. The capital costs of other hydroacoustic options increase substantially due to the use of permanent structure pads (e.g., concrete sill) for securing fences instead of using a removable structure pad (e.g., chain ballast). Costs increased from a maximum of £201 825 when using a chain ballast or no structure pad to a minimum of £846 890 when using a concrete sill structure pad.

Limited Operational Budgets

The five least expensive options over a 10-year operational period include optical beam and hydroacoustic counters. The top four ranked counter scenarios used optical beam counters, while the 5th ranked option used a multibeam hydroacoustic counter (Table 5.15). Optical beam counters automate fish counting and have built-in video validation capabilities, which leads to a low operational cost of £141 364 over 10 years. The 10-year operational cost of the 5th ranked counter scenario that used a hydroacoustic counter and included Echoview counting software increased to £653 483. The amount of time required for data post-processing and the cost of third party software attributed to the high cost of operating a hydroacoustic counter over a 10-year period. All counter scenarios that used hydroacoustic counters have similar operational costs, ranging from £653 483 to £663 483 when Echoview counting software is used. 10-year operational costs increase to £1 836 150 when Echoview is not used.

The 10-year total costs show similar results to the 10-year operational costs, with counter scenarios ranked 1 and 2 using optical beam counters and scenarios ranked 3 through 5 using multibeam hydroacoustic counters. There was a marked difference in total cost between counter scenarios using these two counter types, whereby optical beam counters (ranked 1 and 2 with total 10-year costs of £236 587 and £263 587, respectively) were 2.7-fold less expensive than scenarios using hydroacoustic counters (ranked 3, 4, and 5 with total 10-year costs of £746 039, £751 087 and £752 570, respectively) (Table 5.15). Considering the costs and IFR's professional experience, we recommend using a single hydroacoustic counter with a fence structure and Echoview software for the operation of Site 1 – Potarch Bridge on the River Dee.

Table 5.12. Decision and cost model output for the Potarch Bridge site on the River Dee. Options are ranked by 10-year total cost, from least to most expensive. Costs are provided in GBP, and cost rankings are provided in parentheses. Res. represents resolution.

Option no.	Technology	Company	Res.	Counter	No. counters	Sensor	Structure	Structure pad	Counting software	Capital cost	10-year operational cost	10-year total cost
108	optical beam	Vaki	NA	Riverwatcher	1	NA	floating fence	chain ballast	automated	95223 (6)	**141364 (1)**	**236587 (1)**
116	optical beam	Vaki	NA	Riverwatcher	2	NA	floating fence	chain ballast	automated	122223 (14)	**141364 (2)**	**263587 (2)**
32	hydroacoustic	Teledyne BlueView	low	BlueView	1	NA	floating fence	chain ballast	Echoview	95957 (7)	**653483 (5)**	**738940 (3)**
40	hydroacoustic	Teledyne BlueView	high	BlueView	1	NA	floating fence	chain ballast	Echoview	103056 (10)	653483 (6)	**746039 (4)**
48	hydroacoustic	Teledyne BlueView	low	BlueView	2	NA	floating fence	chain ballast	Echoview	109104 (12)	653483 (7)	**751087 (5)**
13	hydroacoustic	BioSonics	low	D-TX	1	NA	none	none	Echoview	102037 (9)	661483 (17)	752570 (6)
16	hydroacoustic	BioSonics	low	D-TX	1	NA	floating fence	chain ballast	Echoview	104037 (11)	663483 (18)	756570 (7)
56	hydroacoustic	Teledyne BlueView	high	BlueView	2	NA	floating fence	chain ballast	Echoview	125302 (15)	653483 (8)	767285 (8)
4	video	various	NA	various	1	NA	floating fence	chain ballast	none	**51500 (1)**	721864 (24)	772464 (9)
124	hydroacoustic	Sound Metrics	low	DIDSON 300	1	NA	floating fence	chain ballast	Echoview	150918 (18)	658483 (13)	798901 (10)
132	hydroacoustic	Sound Metrics	high	DIDSON 300	1	NA	floating fence	chain ballast	Echoview	155279 (19)	658483 (14)	803262 (11)
140	hydroacoustic	Sound Metrics	low	DIDSON 300	2	NA	floating fence	chain ballast	Echoview	193103 (22)	663483 (19)	845086 (12)
148	hydroacoustic	Sound Metrics	high	DIDSON 300	2	NA	floating fence	chain ballast	Echoview	201825 (23)	663483 (20)	853808 (13)
107	optical beam	Vaki	NA	Riverwatcher	1	NA	floating fence	concrete sill	automated	890613 (28)	**141364 (3)**	1031977 (14)
115	optical beam	Vaki	NA	Riverwatcher	2	NA	floating fence	concrete sill	automated	917613 (35)	**141364 (4)**	1058977 (15)
31	hydroacoustic	Teledyne BlueView	low	BlueView	1	NA	floating fence	concrete sill	Echoview	891347 (29)	653483 (9)	1534330 (16)
39	hydroacoustic	Teledyne	high	BlueView	1	NA	floating	concrete	Echoview	898446 (31)	653483 (10)	1541429

		BlueView					fence	sill				(17)
47	hydroacoustic	Teledyne BlueView	low	BlueView	2	NA	floating fence	concrete sill	Echoview	904494 (33)	653483 (11)	1546477 (18)
15	hydroacoustic	BioSonics	low	D-TX	1	NA	floating fence	concrete sill	Echoview	899427 (32)	663483 (21)	1551960 (19)
55	hydroacoustic	Teledyne BlueView	high	BlueView	2	NA	floating fence	concrete sill	Echoview	920692 (36)	653483 (12)	1562675 (20)
3	video	various	NA	various	1	NA	floating fence	concrete sill	none	846890 (24)	721864 (25)	1567854 (21)
123	hydroacoustic	Sound Metrics	low	DIDSON 300	1	NA	floating fence	concrete sill	Echoview	946308 (39)	658483 (15)	1594291 (22)
131	hydroacoustic	Sound Metrics	high	DIDSON 300	1	NA	floating fence	concrete sill	Echoview	950669 (40)	658483 (16)	1598652 (23)
139	hydroacoustic	Sound Metrics	low	DIDSON 300	2	NA	floating fence	concrete sill	Echoview	988493 (43)	663483 (22)	1640476 (24)
147	hydroacoustic	Sound Metrics	high	DIDSON 300	2	NA	floating fence	concrete sill	Echoview	997215 (44)	663483 (23)	1649198 (25)
64	hydroacoustic	Teledyne BlueView	low	BlueView	1	NA	floating fence	chain ballast	none	**83477 (2)**	1836150 (26)	1909127 (26)
72	hydroacoustic	Teledyne BlueView	high	BlueView	1	NA	floating fence	chain ballast	none	**91576 (5)**	1836150 (27)	1917226 (27)
80	hydroacoustic	Teledyne BlueView	low	BlueView	2	NA	floating fence	chain ballast	none	96624 (8)	1836150 (28)	1921274 (28)
21	hydroacoustic	BioSonics	low	D-TX	1	NA	none	none	none	**89557 (3)**	1844150 (38)	1922757 (29)
24	hydroacoustic	BioSonics	low	D-TX	1	NA	floating fence	chain ballast	none	**91557 (4)**	1846150 (39)	1926757 (30)
88	hydroacoustic	Teledyne BlueView	high	BlueView	2	NA	floating fence	chain ballast	none	112822 (13)	1836150 (29)	1937472 (31)
156	hydroacoustic	Sound Metrics	low	DIDSON 300	1	NA	floating fence	chain ballast	none	138438 (16)	1841150 (34)	1969088 (32)
164	hydroacoustic	Sound Metrics	high	DIDSON 300	1	NA	floating fence	chain ballast	none	142799 (17)	1841150 (35)	1973449 (33)
172	hydroacoustic	Sound Metrics	low	DIDSON 300	2	NA	floating fence	chain ballast	none	180623 (20)	1846150 (40)	2015273 (34)
180	hydroacoustic	Sound Metrics	high	DIDSON 300	2	NA	floating fence	chain ballast	none	189345 (21)	1846150 (41)	2023995 (35)
63	hydroacoustic	Teledyne BlueView	low	BlueView	1	NA	floating fence	concrete sill	none	878867 (25)	1836150 (30)	2704517 (36)

71	hydroacoustic	Teledyne BlueView	high	BlueView	1	NA	floating fence	concrete sill	none	886966 (27)	1836150 (31)	2712616 (37)
79	hydroacoustic	Teledyne BlueView	low	BlueView	2	NA	floating fence	concrete sill	none	892014 (30)	1836150 (32)	2716664 (38)
23	hydroacoustic	BioSonics	low	D-TX	1	NA	floating fence	concrete sill	none	886947 (26)	1846150 (42)	2722147 (39)
87	hydroacoustic	Teledyne BlueView	high	BlueView	2	NA	floating fence	concrete sill	none	908212 (34)	1836150 (33)	2732862 (40)
155	hydroacoustic	Sound Metrics	low	DIDSON 300	1	NA	floating fence	concrete sill	none	933828 (37)	1841150 (36)	2764478 (41)
163	hydroacoustic	Sound Metrics	high	DIDSON 300	1	NA	floating fence	concrete sill	none	938189 (38)	1841150 (37)	2768839 (42)
171	hydroacoustic	Sound Metrics	low	DIDSON 300	2	NA	floating fence	concrete sill	none	976013 (41)	1846150 (43)	2810663 (43)
179	hydroacoustic	Sound Metrics	high	DIDSON 300	2	NA	floating fence	concrete sill	none	984735 (42)	1846150 (44)	2819385 (44)

5.3.7 River Polla

Watershed and Site Characteristics

River Polla is a small river in northern Scotland (Figure 5.21). Currently there are no NRFA gauging stations on River Polla.

Figure 5.21. Potential counter site visited by IFR on River Polla.

Species and Run Timing

River Polla supports both salmon and trout (majority of the fish being sea trout), which do not have overlapping size distributions but do have overlapping run timing (summer to fall). Most of the salmon are grilse but some multi-sea-winter fish are present. Typical grilse salmon and sea trout rod catches for the River Polla are around 70 and 100+ individuals, respectively.

IFR Site Visit

IFR staff visited one potential site on River Polla upstream of the stone bridge near the ocean confluence (Figure 5.21). For this site visit, Donna-Claire Hunter, the project coordinator for MSS, hosted IFR on the River Polla and little information was available on run timing and species composition. A site just above a rock weir has the most potential as a counter site since fish would likely not hold above the rock weir (Figure 5.22). The narrow channel width and shallow depths make it ideal for placing a resistivity counter with no need for a diversion fence. Overall, the section of river IFR visited is located near the ocean confluence and the lower extent of spawning has a low gradient, typically has low turbidity, and has mainly gravel and cobble as substrate. One disadvantage of the site is the exposure to the public and the associated security risk to equipment. Public can easily access the site, however, this is a remote location with infrequent traffic and would be less of an issue than in more urban areas with the same exposure. Note that this should be considered when making decisions about a site. River Polla site also lacks access to mains power, but given its proximity to existing power lines, mains power could be easily installed.

Figure 5.22. River Polla, upstream of the stone bridge near the ocean confluence. Photo courtesy of InStream Fisheries Research.

Model Output and Counter Evaluation for the River Polla

The decision and cost model retained nine technologically and logistically feasible counter scenarios out of a possible 184 for Site 1 on River Polla (Table 5.16). The channel_type variable removed all counter scenarios where channel_type = “fish pass”. Although there is no mains power at the site, mains power is possible and would be the preferred power_type. All counter scenarios with power_type = “battery” were removed. The main variable used to remove the majority of the counter options was min_depth (> 90 cm min_depth required for hydroacoustic counters); this removed all counter options that used hydroacoustic technology.

Limited Capital Budgets

The five least expensive options included video, resistivity and optical beam counters, varying in the types of structures (with and without fences). Video counter scenarios offer the least expensive capital costs starting at £33 010, followed by resistivity counters with flat pad sensors at £33 823 (Table 5.16).

Although the optical beam counter is ranked fourth in capital cost, its capital cost is 2.3- and 2-fold greater than video and resistivity counters, respectively (Table 5.16). The reason for this large difference in capital cost is due to the relatively large cost of the Vaki Riverwatcher. From a capital cost perspective, the model results indicate that video and resistivity counters would be the most cost-effective options.

Limited Operational Budgets

The five least expensive options over a 10-year operational period include resistivity and optical beam counters. The large cost of operating video counters, attributable to the cost of reviewing video footage to count fish, lead to the worst cost rankings over a 10-year operational period and are typically 4.6-fold higher than the operational costs associated with the resistivity counters and optical beam, which ranged from £60 883 to £65 898 over 10-years (Table 5.16).

The total cost over 10-years (including capital and 10-year operational costs) ranged from £96 841 to £169 631 for the top four ranked scenarios, with scenarios ranked 5 through 9 having a range in total cost of £301 868 to £489 933 (Table 5.16). The reason for the large increase in cost between scenarios 4 and 5 is related to whether or not a structure is used and if that structure is removable (less expensive) or permanent (more expensive). Scenarios ranked 8 and 9 both use video technology and the high cost over 10 years is mainly attributable to the high cost of reviewing video to count fish. We recommend any of the options included in this set of counter scenarios for Site 1 on River Polla, with the main consideration being the cost of building a permanent structure.

Table 5.13. Decision and cost model output for the stone bridge site on the River Polla. Options are ranked by 10-year total cost, from least to most expensive. Costs are provided in GBP, and cost rankings are provided in parentheses. Res. represents resolution.

Option no.	Technology	Company	Res.	Counter	No. counters	Sensor	Structure	Structure pad	Counting software	Capital cost	10-year operational cost	10-year total cost
95	resistivity	Aquantic	NA	Logie 2100C	1	flat pad	none	none	automated	**33823 (2)**	**63018 (2)**	**96841 (1)**
97	resistivity	Aquantic	NA	Logie 2100C	1	flat pad	picket fence	none	automated	**37903 (3)**	73315 (7)	**111218 (2)**
108	optical beam	Vaki	NA	Riverwatcher	1	NA	floating fence	chain ballast	automated	**76733 (4)**	**65898 (3)**	**142631 (3)**
116	optical beam	Vaki	NA	Riverwatcher	2	NA	floating fence	chain ballast	automated	**103733 (5)**	**65898 (4)**	**169631 (4)**
107	optical beam	Vaki	NA	Riverwatcher	1	NA	floating fence	concrete sill	automated	235970 (7)	**65898 (5)**	**301868 (5)**
93	resistivity	Aquantic	NA	Logie 2100C	1	NA	Crump weir	none	automated	248582 (8)	**60883 (1)**	309464 (6)
115	optical beam	Vaki	NA	Riverwatcher	2	NA	floating fence	concrete sill	automated	262970 (9)	65898 (6)	328868 (7)
4	video	various	NA	various	1	NA	floating fence	chain ballast	none	**33010 (1)**	298586 (8)	330696 (8)
3	video	various	NA	various	1	NA	floating fence	concrete sill	none	192247 (6)	298586 (9)	489933 (9)

5.4 Limitations of the Decision and Cost Model

We recognize a number of limitations of the decision and cost model that are outlined below.

Changing costs – The decision and cost model is assumed to produce accurate assessments of feasible technology and costs. Structural and material costs presented in this report are current as of September 2015, however upgrades in technologies and changes in costs of materials are inevitable. Therefore, a major limitation of the decision and cost model is that it is subject to updating and changes in costs should be considered at the time of counter site construction.

Integrating technologies – There is great value in combining technologies to generate creative applications of technology to fisheries stock assessment. A major limitation of the decision and cost model is that it only considers conventional fish counter technologies and is unable to account for the value of combining technologies.

Biases – The decision and cost model seems to work best for small- to medium-sized rivers (i.e., bankfull widths < 40 m). This bias toward smaller rivers is because of the inherent difficulty with installing and operating fish counters on large rivers. Most of the successes with fish counters have been on smaller rivers. Assessments of larger rivers requires different types of Technologies to be combined or unique counter setups that are not typically applied to most smaller rivers (see Section 6.0 – Opportunities for Combining Technologies for examples). While the generality of the decision and cost model makes it useful across a large number of rivers in Scotland, it reduces its effectiveness when applied to larger rivers that require more specific applications.

Risk assessment – The decision and cost model does not account for risk associated with manufactures, or the operations of different counter setups. It provides a general reference to the risks but does not evaluate counter scenarios based on risk as it does costs. The model user should assess risk.

6.0 Opportunities for Combining Technologies

Integrating Technologies to Improve Automated Counter Estimates

Existing counter technologies (resistivity, optical beam and hydroacoustics) can face challenges in relation to stock assessment and catchment management, especially in rivers with multiple tributaries that may contain distinct populations. Integrating other technologies with electronic counters may aid in the enumeration of fish populations.

One limitation associated with current counter technologies concerns the identification of target species. Of course it can be difficult to generate accurate species-specific abundances from counters when species have overlapping size distributions and migration periods. In Section 3.2.2, Species Identification Models, we developed a framework for estimating species-specific population sizes using video identification and fish lengths. In the absence of video footage, researchers can use electronic telemetry tags (passive integrated transponders [PIT], acoustic, radio) to understand the relative proportion of multiple species and their migration timing over a counter.

In many rivers, high turbidity, local environmental characteristics (e.g., river width, bank shape), and specific differences in catchability or low fish densities may preclude the use of a single methodology (Martignac et al. 2014). In British Columbia, where the Fraser River is a vital pathway for many Pacific salmon species and populations, DIDSON hydroacoustic gear, drift gillnet test fishing and Genetic Stock Identification (GSI) are used to generate in-season, population-specific estimates of the number of adult salmon returning to the Fraser River. This information is used in-season to guide fisheries openings and post-season to generate population-specific estimates of recruitment.

In many situations, the placement of a counter in a river may be determined by factors other than that which the study design identifies as optimal. A counter too far downstream in a watershed may not capture the spatial behaviour of the species or population of interest. Conversely, a site further upstream can fail to assess tributary and mainstem fish below. Pairing telemetry and counter technologies can aid in determining the distribution of fish in large watersheds with multiple tributaries. For example, counters are located in small side-channels of the Cheakamus River (British Columbia, Canada) to provide accurate estimates of abundance. PIT arrays are paired with the counters to determine the relative proportion of fish that pass over the counter (Fell et al. 2013). Fixed radio telemetry stations throughout the mainstem of the Cheakamus River confirm the distribution of fish in other reaches of the watershed. Data are used to determine reach-specific abundances and are combined to estimate abundance at a watershed scale.

Integrating Technologies to Provide Additional Biological Information

Linking counter technologies can provide researchers with the ability to overcome some of the individual limitations of each technology. In the Murray-Darling Basin in Australia, investigators combined the use of DIDSON, Vaki Riverwatcher and fish traps to assess the behaviour of fish migrating through a fish pass (Baumgartner et al. 2010). Researchers found that each unit provided complementary data on fish abundance and behaviour.

Currently, IFR collaborates with a research group at the University of British Columbia (UBC) to study sockeye salmon fish passage at a diversion dam in southwestern British Columbia, Canada. Researchers in this watershed integrate telemetry and counter technologies to understand the factors that govern in-river survival of sockeye salmon (Casselman et al. 2014). Pairing telemetry stations with counters at strategic locations allows for cross-validation of technologies to determine if survival trends scale up from tagged individual animals to the population level. In addition, data on the migration timing and success of tagged fish can be linked to estimates of abundance through a counter to generate daily estimates of population level survival. Using this integrative approach, IFR and UBC have made ecologically relevant and accurate recommendations to dam managers on how to reduce the impacts of operations on salmon.

Biological and biochemical sampling can be combined with counter technologies to provide information on migration ecology and developmental processes. Collection of biological samples (e.g., scales, otoliths) from study subjects can provide fundamental information on the biology and ecology (e.g., one-sea-winter vs. multi-sea-winter) of the species being enumerated. Molecular analyses, chemical elements and isotopes or parasite identification are all natural marks that can provide insights into life history characteristics. In the River Moy, Ireland, the use of DIDSON and GSI allowed stock assessment of discrete sub-populations within a large river system (Brennan 2013).

Combining technologies with counters will advance fisheries research. Use of this integrative approach can lead to cost-effective solutions to challenging monitoring conditions and provide additional information relevant to the management of salmon populations (e.g., age and population structure, population dynamics). Moving forward, such approaches need to be developed, tested and applied to a wide range of sites and management objectives.

References

Baumgartner, L., Bettanin, M., McPherson, J., Jones, M., Zampatti, B., and Beyer, K. 2010. Assessment of an infrared fish counter (Vaki Riverwatcher) to quantify fish migrations in the Murray-Darling Basin. Industry and Investment NSW, Report No. 116 ISSN 1837-2112.

Brennan, L.O. 2013. A Stock Assessment of Atlantic salmon in Large Riverine Catchments (Doctoral dissertation) National University of Ireland, Galway: ProQuest/UMI, 2013.

Casselman, M.T., Burnett, N.J., Bett, N.N., Middleton, C.T., Martins, E.G., Braun, D.C., McCubbing, D., and Hinch, S.G. 2014. BRGMON-14 Effectiveness of Cayoosh flow dilution, dam operation, and fishway passage on delay and survival of upstream migration of salmon in the Seton-Anderson watershed. Annual Report – 2013. Report prepared for St'át'imc Government Services and BC Hydro. The University of British Columbia, Vancouver, BC. 66 p. + 2 Apps.

Fell, C., McCubbing, D., Wilson, L.J., and Melville, C.C. 2013. Cheakamus River Chum Salmon Escapement and Fry Production Monitoring 2001-2013. Cheakamus River Monitoring Program #1A & 1B. Technical report for BC Hydro – Coastal Generation. 42 p. + App.

Eatherley, D.M.R., Thorley, J.L., Stephen, A.B., Simpson, I., MacLean, J.C. and Youngson, A.F. 2005. Trends in Atlantic salmon: the role of automatic fish counter data in their recording. Scottish Natural Heritage Commissioned Report No. 100 (ROAME No. F01NB02).

Lucas, M.C., and Baras, E. 2000. Methods for studying spatial behaviour of freshwater fishes in the natural environment. Fish and Fisheries 1:283–316.

Martignac, F., Daroux, A., Bagliniere, J. L., Ombredane, D., and Guillard, J. 2014. The use of acoustic cameras in shallow waters: New hydroacoustic tools for monitoring migratory fish population. A review of DIDSON technology. Fish and Fisheries. DOI:10.1111/faf.12071

7.0 Spatial Considerations for a Counter Network

Background

Marine Scotland Science is planning on increasing the number of fish counters in Scottish rivers to improve the ongoing assessments of Atlantic salmon (*Salmo salar*) abundance. In addition to site- and technology-specific requirements, and cost, it is important to consider the spatial distribution of a counter network when deciding on where to deploy additional counters. Specifically, the amount of spatial coverage should be considered. Spatial coverage, in the current context, can be defined as the percent of Scottish Atlantic salmon populations for which a counter-based estimate of abundance is available. Although at least one counter on every river is required for 100% coverage, the fact that salmonid populations covary (Cattaneo et al. 2003, Pyper et al. 2005, Kilduff et al. 2014) means that coverage of one river provides partial coverage of all correlated rivers. Mathematically, the coverage of the x th river as provided by the m countered rivers (c_x) could be defined as:

$$c_x = \max_{y=1,2,\ldots,m} \rho_{x,y}^{2} * 100$$

where,

$$\rho_{x,y} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

and $\rho_{x,y}$ is the Pearson correlation coefficient between the xth and yth rivers. Total Scottish coverage (C, hereafter ‘coverage index’) is the mean of the s riverine coverages weighted by the size of each population (N).

$$C = \frac{\sum_{j=1}^{s} c_j \,.\, N_j}{\sum_{j=1}^{s} N_j}$$

The coverage index relies on knowing correlations between streams. This could be problematic as counts are unavailable for most rivers. In the absence of such data, the correlations between rivers would have to be estimated from the rod catch data (Youngson 2002, Thorley et al. 2005). Similarly, the size of each population could be determined from the rod catches corrected for the inferred exploitation rate (Thorley et al. 2007).

Due to its flexibility, the coverage concept is a useful tool for thinking about counter deployment. When considering the addition of a single counter to an existing network, the coverage index can be used to compare competing sites. Alternatively, the concept can be used to compare alternative network arrangements. If the alternatives vary in price, then the criterion of choice can be the increase in coverage per unit expenditure. The weighting of rivers can also be adjusted to take into account additional considerations such as whether particular populations are of greater scientific or conservation concern. The concept also provides a framework for incorporating other sources of information such as traps and redd counts (Youngson et al. 2007) which can be scaled according to their accuracy relative to counters.

Challenges to the use of the coverage concept include the dependence on rod catches and multi-population rivers. Rod catches can vary regionally due to net catches, discharge, angler effort and other factors that are not directly related to abundance. This variation will tend to artificially inflate the correlation within rivers in the same region and deflate the correlation among rivers in different regions. A partial solution is to use the long-term trends to quantify the correlations (Youngson 2002). Larger Scottish rivers support multiple populations. The resultant spatio-temporal variation in abundance complicates the coverage concept but does not invalidate it. A workable solution is to redefine the concept so that small rivers and larger tributaries are the base units and to discount counters on the mainstems of large rivers with populations that cannot be separated by a combination of run-timing and fish size.

References

Cattaneo, F., Hugueny, B., and Lamouroux, N. 2003. Synchrony in brown trout, *Salmo trutta*, population dynamics: a ’Moran effect’ on early-life stages. Oikos 100:43–54.

Kilduff, D.P., Botsford, L.W., and Teo, S.L.H. 2014. Spatial and temporal covariability in early ocean survival of Chinook salmon (*Oncorhynchus tshawytscha*) along the west coast of North America. ICES Journal of Marine Science 71:1671–82.

Pyper, B.J., Mueter, F.J., and Peterman, R.M. 2005. Across-species comparisons of spatial scales of environmental effects on survival rates of northeast Pacific salmon. Transactions of the American Fisheries Society 134:86–104.

Thorley, J.L., Youngson, A.F., and Laughton, R. 2007. Seasonal variation in rod recapture rates indicates differential exploitation of Atlantic salmon, *Salmo salar*, stock components. Fisheries Management and Ecology 14: 191–98.

Thorley, J.L., Eatherley, D., Stephen, A., Simpson, I., Maclean, J., and Youngson, A. 2005. Congruence between automatic fish counter data and rod catches of Atlantic salmon (*Salmo salar*) in Scottish Rivers. ICES Journal of Marine Science 62:809–17.

Youngson, A. 2002. Rod catch trends for early-running MSW salmon in Scottish Rivers (1952–1997): divergence among stock components. ICES Journal of Marine Science 59:836–49.

Youngson, A., MacLean, J.C., Bacon, P.J., Godfrey, J.D., Smith, G.W., and Thorley, J.L. 2007. Salmon Assessment in Scotland: Bringing information resources into line with recent research on methods. Scottish Fisheries Research Report No. 68. The Scottish Executive Environment Scottish Fisheries Research Report; Rural Affairs Department.

8.0 Future Research and Recommendations

8.1 Future Research

IFR noted several worthwhile areas of future research while completing this report, and emphasize the importance of considering these areas when implementing a counter network in Scotland. Access to mains power at counter sites throughout Scotland will provide an ease of operation, however mains power is prone to power fluctuations that can lead to power loss and subsequent data loss. Consequently, there is a need to investigate potential renewable power sources (e.g., wind, solar, hydropower generators) to power counters in remote areas to eliminate the dependence for mains power. Careful consideration is needed to select an optimal renewable power source for each potential counter site given variation in site characteristics (e.g., variable sun exposure due to a range in latitudes and local weather).

Further investigation into Mark 12's hardware availability and software functionality is needed. Mark 12 technology and reference material is currently not commercially available and information on the counter is extremely limited. Furthermore, its use has been limited to fish passes and small sensor units and has not been tested in free-flowing river channels. IFR only assessed Mark 12 technology in fish passes, but these counters likely have applications in other channel types.

SalmonSoft's FishTick software can potentially provide significant cost savings for video analysis. Aside from a review completed by the Environment Agency of Wales, limited information on its time savings and effectiveness exists as a video counting software. FishTick could provide significant reductions in video analysis, making video a cost-effective form of fish counting technology; however this has not been adequately assessed.

Further investigation into the accuracy of length data generated by multibeam hydroacoustic counters (operating at low resolution) is needed. Considering that these technologies have no innate fish species identification abilities, fish lengths are generally used to determine the species of individuals when analyzing hydroacoustic data. Length accuracies of high resolution hydroacoustic data have been extensively researched; however there has been no analysis of the accuracy of fish lengths collected at low resolution. Low resolution hydroacoustic fish length data will need to be validated with known fish lengths to confirm the accuracy of the counter.

Raw data that make up Aquantic's graphical trace plots need to be acquired in order to manipulate the Logie 2100C's counting algorithm. This will allow alternative algorithms to be written by the counter user, which could increase counter accuracies across a broader range of conditions and population characteristics.

Existing counter technologies can face challenges in relation to stock assessment and catchment management, particularly in rivers with several tributaries that may contain distinct populations. Integrating other remote sensing technologies (e.g., telemetry) with fish counters may aid in the enumeration of fish populations. Use of this integrative approach can lead to cost-effective solutions to challenging monitoring conditions and provide additional information relevant to the management of salmon populations.

Further development of the spatial coverage index for evaluating counter networks is needed. Various metrics could be used to determine the relative value of different counter network configurations. A spatial coverage index would provide valuable knowledge on the amount of information a counter network provides. This could be used to evaluate the trade-off between information (spatial coverage) and cost.

Finally, we emphasize the need to develop expertise throughout Scotland through training and knowledge exchanges with experienced personnel to build capacity within MSS and local fisheries biologist. Knowledge exchanges could be facilitated through visiting a range of existing counter sites, workshops and training programs for specific technologies or equipment.

8.2 Recommendations

Our findings indicate the necessity for the validation of counter data. Validation should be completed for all counter technologies, including those that are not typically considered (e.g., hydroacoustic counters). When validation data is used to generate abundance estimates, the number of fish validated is directly related to the accuracy of abundance estimates. We recommend a minimum of 500 fish be validated for most counter setups, although counter and site conditions will influence the minimum number required.

Notably, the decision and cost model herein provides real options for counter scenarios, but does not take into account the importance of site visits. We recommend a minimum of one year of monitoring at potential counter sites to collect the information needed to make an informed decision on the deployment of a suitable counter setup. Moreover, site-specific evaluations are critical for ensuring the proper application of counter technology.

Appendices

Appendix 1. Counter Literature Review

Counter Type	Reference	Summary
Didson	Baumgartner, L.J., Reynoldson, N., Cameron, L., and Stanger, J. 2006. Assessment of a Dual-frequency Identification Sonar (DIDSON) for application in fish migration studies. NSW Department of Primary Industries -Fisheries Final Report Series No. 84 ISSN 1449-9967	Movements of salmon were recorded using a passive integrated transponder (PIT) tag and detector system as they migrated through Tongland fish pass. Salmon were captured in 2007 and 2008 in a box trap about 900m below the entrance to the fish pass. A total of 11 of 29 fish tagged were recorded to have found the pass. Overall rate of passage decreased as time of year advanced. Most fish traversed to the upper chambers of the pass within a day. There was variation in time taken to traverse the sections of the pass, primarily due to delay at the exit sections. Some of the increased delay in upper sections may have been due to higher likelihood of impending nightfall by the time fish had traversed the pass. However, several of the few fish detected leaving the pass were delayed over one or more days. The cause of low detection in the exits is unclear.
Didson	Belcher, E.O. 2004. Case study: Alaska Department of Fish and Game uses DIDSON to count salmon swimming up-river to spawn. Available at http://www.soundmetrics.com/NEWS/REPORTS/AlaskaFishCaseStudy_WA.pdf.	Fish communities of the Murray-Darling Basin are highly migratory, exhibiting movements in both upstream and downstream directions. Until recently, fish migration studies within the Murray-Darling Basin focused primarily on species of recreational or commercial importance. However, recent studies have also demonstrated that larval native fish also undertake substantial passive downstream movements and that many small-bodied species are also migratory. The ecology of migrations vary greatly between species but are usually in response to increases in water temperature or river flow. Fish movements are also highly seasonal, sometimes peaking during summer and autumn and, in some cases, individuals have traversed over 2,300km during flood conditions. Although migrations over such large scales are infrequent, many fish species are frequently observed to either negotiate fishways or accumulate downstream of obstructions. Across the Murray-Darling Basin thousands of weirs obstruct the passage of fish and contribute to significant declines in many fish species. As part of a

		plan to rehabilitate native fish populations, the Murray-Darling Basin Authority (MDBA) is restoring fish passage along the Murray River from the sea upstream to the Hume Dam – a distance of 2,225 km. To monitor and assess the outcomes of the construction program, a team of freshwater scientists from the states of New South Wales, Victoria and South Australia were established. This tri-state research team is conducting a comprehensive research program that is monitoring fish as they approach, pass through, and leave the fishways. Four techniques are providing data on the effectiveness of the newly installed fishways: electrofishing accumulations; passive integrated transponder tagging to detect long distance movements, direct sampling of the fishways and developing long-term electronic monitoring tools. Many fish within the Murray-Darling Basin are long-lived (> 10 years). This means that the benefits of a fishway construction program may not be immediate, and increases in fish numbers may take time. It is impossible to continuously trap fishways to gather information on migratory behaviour. The long-term deployment of an electronic monitoring unit to continuously monitor fish migrations is therefore an attractive alternative to manual trapping. If a system can be found which determines count and length information accurately, it could be used to determine long-term trends in fish passage and document increases in fish migration rates over time. This study aimed to perform a field study on the effectiveness of an infrared fish counter, the Vaki Riverwatcher in anticipation of wider application throughout the Murray-Darling Basin. The limitations and advantages of the system were fully explored in both controlled and field environments
Didson	Boswell, K.M., Wilson, M.P., and Cowan Jr., J.H. 2008. A Semi automated Approach to Estimating Fish Size, Abundance, and Behavior from Dual-Frequency Identification Sonar (DIDSON) Data, North American Journal of Fisheries Management 28 (3):799-807, DOI: 10.1577/M07-116.1	This study aimed to ascertain the influence of turbidity and migration rate on the count accuracy and size determination of an automatic infrared fish counter. The effect of turbidity on enumerating silver perch (Bidyanus bidyanus) migration rates was insignificant when compared to the inability of the infrared counter to deal with large numbers of migrating fish. The infrared counter underestimated counts by 56–84% at moderate migration rates (12 fish h)1) and by 62–82% at the highest migration rate (120 fish h)1). When multiple fish were simultaneously passed through the counter, the software detected them as a single fish and overestimated fish length. Fish passed through the unit ranged from 340 to 520 mm but the infrared counter estimated the range to be 140–780 mm, with the lengths of a high proportion of individuals being

		underestimated. Most issues of inaccuracy appeared to be software-related and could be overcome with further software development. Further assessment of the applicability of the unit to enumerate fish migration, at high migration rates, should then be considered.
Didson	Burwen, D.L., Fleischman, S.J., Miller, J.D. 2007. Evaluation of Dual-Frequency Imaging Sonar for Detecting and Estimating the size of migrating salmon. Alaskan Department of Fish and Game, Fishery Data Series No. 07-44: 1-34. Anchorage.	Freshwater fish need to move within and among different habitats. Objects that obstruct migrations, such as dams and weirs, have led to worldwide declines in fish populations. Although the adoption of various management strategies (such as weir removal and fishway construction), has improved fish populations in many areas the success of any rehabilitation project relies heavily on a fundamental understanding of the biological requirements of fish. Such biological information is needed to ensure that any effects of human disturbance can be adequately ameliorated. The ability to observe fish in their natural environment is often difficult to achieve, especially in turbid or low visibility conditions. Although many recent advances in technology have been developed, traditional methods generally require catching the fish in some way to obtain biological information. Whilst in some cases this is the only practical method to obtain data, it is largely unknown whether handling fish can alter their 'natural' behaviour. Recently developed sonar systems are currently being assessed in North America and their non-invasive application to fish migration studies is very promising. One such device, the Dual-Frequency Identification Sonar (DIDSON), uses sound-distorting lenses to create high quality video images (Figure 1). When operating in high frequency mode, these features can define the outline, shape and even fins of target fish. In addition, DIDSON software can count and measure fish automatically. With such features, this technology can potentially allow the observation of fish behaviour such as spawning, feeding and migration. To date, no assessment of this technology for fisheries-based applications has ever been undertaken in Australia. Subsequently, this study was undertaken to provide the first assessment of a DIDSON unit in Australian systems. The results indicated that the DIDSON is a powerful tool for observing freshwater fish populations. When used in conjunction with conventional trapping equipment, the DIDSON consistently provided additional data on fish behaviour that could not be otherwise determined. For example, at fishways on the Murray River, the DIDSON demonstrated that many more fish were approaching and entering the fishways than were trapped as they passed through. In many cases, these fish were actively avoiding traps or

		displayed a behavioural impediment to entering the fishway. In addition, several fish actively migrated downstream through the fishway when no traps were in place. The DIDSON also provided useful observations of non-migratory activity and non-finfish fauna. In particular, predatory birds and fish were observed to use fishways to actively hunt prey. Such observations are not possible through conventional sampling, especially in turbid conditions. A ground-truthing trial was also performed to determine the accuracy of the automatic counting and measuring interfaces of the operating software. In general, total fish numbers were frequently underestimated and estimated fish lengths were quite variable. Further development of the operating software could alleviate these problems. Despite some limitations with its automated features, when operated manually, the DIDSON was a powerful tool that provided a viable alternative to traditional fish sampling techniques. Possible research applications of the technology to Australian systems include habitat mapping, fish-habitat associations, migration studies, bottom mapping, underwater survey and determination of sampling gear efficiency. The results of this study show that further use of a DIDSON unit would add substantial value to data collected from a number of research projects in Australia
Didson	Burwen, D.L., Nealson, P.A., Fleischman, S.J., Mulligan, T.J., and Home, J.K., 2007. The complexity of narrowband echo envelopes as a function of fish side-aspect angle. ICES Journal of Marine Science 64.5: 1066-1074	Advantages and disadvanges of DIDSON sonar counter in the Wood, Anchor, and Kenai rivers of Alaska
Didson	Burwen, D.L., Fleischman, S.J., and Miller, J.D., 2010. Accuracy and Precision of Salmon Length Estimates Taken from DIDSON Sonar Images. Transactions of the American Fisheries Society 139(5): 1306-1314.	We present a semiautomated analytical approach incorporating both image and acoustic processing techniques to apply to dual-frequency identification sonar (DIDSON) data. Our objectives were (1) to develop a standardized analysis pathway in order to reduce the effort associated with counting, measuring, and tracking fish targets; and (2) to empirically obtain estimates of basic target information (e.g., size, abundance, speed, and direction of travel). Analyses were conducted on DIDSON data collected at three different locations (the Kenai River, Alaska; Mobile River, Alabama; and Port Fourchon, Louisiana) with different equipment and deployment configurations. We developed an efficient postprocessing approach that can be applied to a variety of

		data sets, independent of user and deployment method. For two of the three data sets analyzed, the estimates of fish abundance derived from DIDSON analyses were not significantly different from the manual counts of DIDSON files. The analyses produced estimates of mean fish length, direction and speed of travel, and target surface area for all targets within each data set. A consistent analysis platform increases the acceptance and reliability of the DIDSON as a tool for fisheries surveys and further demonstrates the usefulness of DIDSON technology in fisheries applications
Didson	Cronkite, G.M.W., Enzenhofer, H.J., Ridley, T., Holmes, J., Lilja, J., and Benner, K. 2006. Use of High-Frequency Imaging Sonar to Estimate Adult Sockeye Salmon Escapement in the Horsefly River, British Columbia, iv+47 pp.	Large river systems can be challenging in relation to stock assessment and catchment management, especially those large rivers with numerous or important tributaries that may contain sub-populations or stocks. Initial testing of existing counter technology (resistivity, infrared and split-beam hydroacoustics) in such a system - the River Moy, Co. Mayo - highlighted the difficulties in their use and operation. In this study, an alternative hydroacoustic system, DIDSON (Dual-frequency Identification Sonar), was deployed and assessed for the first time in Ireland. The DIDSON's near video quality imagery allowed for observations of fish migrations and it was easy to install and operate. Methodologies for the operation and data processing using DIDSON in Irish rivers for counting Atlantic salmon have been established, including software development of DIDSON SMC Software (SoundMetrics) (e.g. CSOT Analysis), allowing for the acquisition of real time data and quality fish length measurements. As an alternative to adult counts, mark-recapture estimates were successfully carried out on Atlantic salmon smolts on the River Deel (a tributary of the River Moy) using a screw trap. Both classic and Bayesian models were successfully applied. These stock assessment data were also used to determine the main environmental influences on Atlantic salmon migration in the River Deel. While air and water temperature were shown to be significant to adult migration, no direct correlations were determined with smolt migration. The combined use of DIDSON and Genetic Stock Identification was developed for salmon stock assessment. The genetically determined proportion of River Deel fish were used, along with the DIDSON count, to provide the first estimate of a large river system, the River Moy, using this unique methodology. This advance in stock assessment methodology allowed for a stock assessment of all discrete populations within a large river system.
Didson	Cronkite, G.M.W., Enzenhofer,	Experiments were conducted with a multibeam dual-frequency identification sonar

	H.J., and Holmes, J.A. 2008. Evaluation of the BlueView ProViewer 900 Imaging Sonar as a tool for counting adult sockeye salmon in the Adams River, British Columbia. Canadian technical report of fisheries and aquatic sciences 2798: iv + 21 p.	(DIDSON) to evaluate the accuracy and precision of estimating lengths from images of tethered fish insonified at side aspect in an Alaskan river. Live tethered Chinook salmon Oncorhynchus tshawytscha and sockeye salmon O.nerka were suspended in front of a long-range DIDSON (1.2 MHz, 48 beams) equipped with an ultra-highresolution lens. Lengths measured manually from DIDSON images were highly correlated with the actual lengths (R2 ¼ 0.90, RMSE ¼ 5.76 cm). No range dependency in the accuracy of the range estimates was documented. We conclude that relatively accurate and precise estimates of fish length are now possible with certain DIDSON system configurations at up to 21 m.
Didson	Enzenhofer, H.J. and Cronkite, G. 2005. A simple adjustable pole mount for deploying DIDSON and split-beam transducers. Canadian technical report of fisheries and aquatic sciences 2570: iv + 14 p.	Experiments were conducted using a DIDSON acoustic system to evaluate the potential for estimate fish size from images of tethered and free swimming fish in two alaskan rivers. DIDSON is a recently developed imaging sonar that incorporates a sophisticated lensing system to improve image quality. In the firhst experiment, DIDSON images were collected from six Chinook salmon and four sockeye salmon tethered in the center of the DIDSON's multibeam array. in the second experiment, 130 pacific salmon and Dolly Varden were allowed to swim freely through the DIDSON multibeam array ater being released from a weir live box. length estimates from DIDSON images of tethered fish were subject to a positive bias that incereased with range of the fish from the transducer (approximately 1.3cm/m of range). Mreasurements from the free swimming fish did not demonstrate the same size bias with range. possible cases for the differing results are discussed, as well as the performance of the DIDSON with respect to detecting fish, determining direction of travel, and tarcking fish at high densities.
Didson	Galbreath, P.F., and Barber, P.E. 2005. Validation of a Long-Range Dual Frequency Identification Sonar (DIDSON-LR) for Fish Passage Enumeration in the Methow River. Final Report - PSC Southern Fund 2004/2005 Project 24 pages.	High-frequency, narrowband acoustic signals may contain more information on fish size and orientation than previously thought. Our observations of dual frequency identification sonar (DIDSON) images of fish orientation paired with split-beam echo envelopes helped clarify why metrics such as echo duration have performed better than target strength measurements when predicting salmon lengths at side aspect. Fish orientation has a pronounced effect on the duration and shape of split-beam echo envelopes from large (80–130 cm) salmon insonified at side aspect. At near-normal aspect angles, echo envelopes are unimodal, symmetrical, and resemble echo envelopes from calibration spheres. With increasing oblique-aspect angle, echo shapes become less symmetrical as the number of peaks increases, and echo duration and

		amplitude become more variable. Using angle and range coordinates, peaks in an echo envelope can be traced to their origin on a DIDSON image. At oblique-aspect angles, discrete peaks develop that are reflected from regions close to the head and tail. In addition, the distance between peaks increases with increasing aspect angle and is larger than can be explained by swimbladder length.
Didson	Gray, D., Bachman, R., Kowalske, T., Forbes, S., Meredith, B., and Coonradt, E. 2014. 2014 Southeast Alaska drift gillnet Fishery Management Plan. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J14 - 03, Douglas.	We evaluated the BlueView ProViewer 900 imaging acoustic system as a tool for counting migrating adult sockeye salmon (Oncorhynchus nerka) in clear-water riverine spawning environments in British Columbia, Canada. Hourly fish passage rates during our testing on the Adams River did not exceed approximately 252 fish/hour because spawning returns were much lower than the predicted returns available when we chose this stock for our testing. We applied standard techniques to perform tests on the accuracy and precision of the resulting ProViewer counts compared with concurrent visual counts. The results showed that the salmon count data produced using the Blueview ProViewer 900 were systematically biased relative to visual counts, except if we assumed that all the variability in these data was associated with the visual counts. Variability between observers counting the net upstream passage from the ProViewer data files was high at 25.7%, and with repeated independent counts of the ProViewer files expecting to achieve the same count 80.7% of the time. These results were believed to be due to the level of image resolution and idiosyncrasies of the ProViewer software. Improvements to the software could increase the usefulness of the ProViewer for counting migrating salmon in rivers.
Didson	Gurney, W.S.C., Brennan, L.O., Bacon, P.J., Whelan, K.F., O'Grady, M., Dillane, E., and McGinnity, P. 2014. Objectively Assigning Species and Ages to Salmonid Length Data from Dual-Frequency Identification Sonar. Transactions of the American Fisheries Society 143(3): 573-585.	We estimated adult sockeye salmon (Oncorhynchus nerka) escapement in the Horsefly River between August 06 and October 09, 2005, using a dual-frequency identification sonar (DIDSON) imaging system. This project was the first attempt to integrate the DIDSON system operationally into sockeye salmon assessment programmes in British Columbia. Our primary objectives were 1. To assess the ability of a high-frequency imaging sonar system deployed in a fixed position immediately upstream of a fish deflection weir to produce escapement estimates of migrating adult salmon returning to the Horsefly River.2. Determine an effective method for data handling and processing to produce updated estimates of fish passage in a timely manner. 3. Determine if increases in passage rate impact the ability to produce estimates of fish passage within the ensonified region.4. Implement use of in-river accessory equipment to optimise our

		ability to detect and enumerate fish passage. 5. Test the effectiveness of solar panels and high amperage batteries to power the acoustic system for extended periods.6. Train field staff to setup and operate a fixed-location hydroacoustic facility so they can manage future deployments of the DIDSON. -- Sockeye salmon returning to the Horsefly River were directed through an 11 m wide opening in a weir installed across the river to allow DIDSON enumeration at high-frequency using manual counting techniques. Maximum sockeye salmon passage observed was approximately 8000 fish per hour during the season. We estimated total sockeye salmon escapement into the Horsefly River from 06 Aug to 09 Oct. Based on analysis of visual counts and DIDSON based counts, we found that the DIDSON data were not biased by undetected fish and we conclude that the DIDSON counts of escapement on the Horsefly River are as accurate as counts of migrating fish through an enumeration fence. We compared the distribution of the on-screen DIDSON length measurements ($N = 2874$) with length measurements from the tagging site of the mark and recapture project located 100 m downstream of the DIDSON site ($N = 6260$), and found that both measurements were normally distributed with a single mode and that the mean DIDSON length was significantly larger than the mean length of tagged fish ($P < 0.05$). Based on these findings, we conclude that the DIDSON and mark-recapture programme provided estimates of escapement for the same population of sockeye salmon, i.e., neither method was biased relative to the other by selective sampling. We expected that the mean length of fish measured with the DIDSON system would be larger than the mark-recapture programme due to biases in length measurements associated with beam spreading and the downrange resolution of the system as deployed. Empirical corrections for these biases, which are range- and window-length dependent, respectively, can be derived on-site in future applications of the DIDSON technology. We found that overall the DIDSON counts were statistically indistinguishable from comparative visual counts made from the weir, yielding an error of 0% from this source. We made measurements of precision by comparing the manually counted data sets between observers and found the error from this source was ± 6%. The 95% confidence limits (CIs) from temporal sub-sampling ranged from 4 to 10% depending on the number of minutes of data used from each hour. Combining the errors from these three known sources gave a total confidence limit of ± 14% to give a total population estimate of 645

		310 ± 90 599. The use of a DIDSON system will allow accurate and cost effective enumeration of sockeye salmon on the Horsefly River for fisheries management purposes.
Didson	Hateley, J. and Gregory, J. 2006. Evaluation of a multi-beam imaging sonar system (DIDSON) as Fisheries Monitoring Tool: Exploiting the Acoustic Advantage. Technical Report.	Closed-circuit television was used to provide a visual record of the events associated with the counts recorded by a resistivity fish counter. The fish seen were classified as ' large ' fish 250 cm length and ' small ' fish of < 50 cm. Some of the ' large ' fish escaped detection by the counter, some ' small ' fish were counted and some counts were registered when nothing was seen. The sensitivity of the counter varied inversely with water conductivity which varied inversely with discharge. Evidence was obtained suggesting that fish ascending a weir tend to swim closer to the bottom than do those descending. It was found that fish tended to move upstream just after sunset and downstream just before sunrise except when the water was turbid and when the fish were very close to spawning. The numbers of fish movements recorded increased during those periods when discharge was decreasing after a spate but when spawning activity was at its peak, increased activity occurred in the complete absence of any change in discharge. Instances of the same fish re-crossing the counting zone several times were recorded and the simultaneous passage of more than one fish through the counting zone was observed.
Didson	Holmes, J.A., Cronkite, G.M.W., and Enzenhofer, H.J. 2005. Feasibility of deploying a dual frequency identification sonar (DIDSON) system to estimate salmon spawning ground escapement in major tributary systems of the Fraser River, British Columbia. Canadian technical report of fisheries and aquatic sciences 2592: xii + 51 p.	We have designed an adjustable pole mount that attaches to a boat or other stationary platform. The mount allows the precise aim of an acoustic transducer. The mount allows manual control of the deployment depth, bearing, roll angle and tilt angle of an attached split-beam transducer or DIDSON dual imaging sonar transducer. It can be attached to boat gunnels up to 27 cm thick, or to a stationary platform such as a modified stepladder for riverine applications. We describe the construction, assembly and deployment of the stainless steel and powder-coated aluminium pole mount. We also describe the add-on attachments that allow: 1) the extension of the mount by 1 m; 2) the addition of a second transducer and; 3) the 90° rotation of a DIDSON transducer for bottom profiling.
Didson	Holmes, J.A., Cronkite, G.M.W., Enzenhofer, H.J., and Mulligan, T.J. 2006. Accuracy and precision	A long range model of a Dual Frequency Identification Sonar (DIDSON-LR) was operated in parallel with visual observations to validate reliability of the instrument to enumerate fish passage at distances up to 40 m. Two testing designs were used. The

	of fish-count data from a "dual-frequency identification sonar" (DIDSON) imaging system. ICES Journal of Marine Science 63(3): 543-555.	first involved manually passing a tethered salmon to and from across the field of a DIDSON-LR installed in a pond at the Washougal Salmon Hatchery (Washington Department of Fish and Wildlife, Washougal). The second involved making visual counts of naturally migrating salmon in the Methow River (Okanogan County, Washington). In both tests, data recorded for the visual observations was compared to that noted on concurrently recorded DIDSON-LR files. The visual and DIDSON data for the hatchery pond trials were 100% concordant. Of 55 visual observations of migrating salmon in the Methow River, 48 concordant observations were noted on the DIDSON-LR recordings. In seven instances, no observation was made on the DIDSON-LR recording. These discrepancies are more likely explained by improper installation of the DIDSON or observer error rather than technical inadequacy of the instrument. When operated at low frequency (0.7 MHz), the DIDSON-LR provided images of fish at distances to 42 m (the limit of our tests). For fish passing at the farther end of this range, the recordings were easier to read when a 20m window length was used in combination with a 20m Start Length, as opposed to a 40m Window Length and a 1 m Start Length. When operated at its higher frequency (1.2 MHz) the DIDSON-LR provided images of improved resolution, although the maximum distance at which it could be operated was 33 m - a 20 m Window Length and a Start Length up to 13 m. In either case (LF or HF), however, the level of resolution of the images was only sufficient to provide a qualitative measure of size and pattern of movement. The level of resolution did not to permit distinguishing between species of similarly sized fish, e.g., between Chinook salmon Oncorhynchus tshawytscha and steelhead Oncorhynchus mykiss, which were both migrating in the Methow River during our trials and had overlapping size ranges (total range 60 to 100 cm). Additional DIDSON-LR files recorded over extended periods without visual observation confirmed that salmon/steelhead passage at the Methow River site occurred primarily during the hours from 9 pm to 2 am. Use of a DIDSON-LR in a planned series of recordings should provide data of sufficient reliability to calculate an accurate estimate of net escapement of salmon/steelhead to an open system such as the Methow River. Photos and video clips illustrating operation of the DIDSON-LR and the effects of the different settings on resolution of the resulting images are provided at: http://www.critfc.org/didson-lr.
Didson	Langkau, M.C., Balk, H., Schmidt,	This management plan provides an overview of the expected salmon run sizes,

	M.B., and Borcherding, J. 2012. Can acoustic shadows identify fish species? A novel application of imaging sonar data. Fisheries Management and Ecology, 19(4): 313-322.	regulations, management issues, and harvest strategies for the Southeast Alaska drift gillnet fisheries in 2014. Drift gillnet fisheries are planned at Tree Point and Portland Canal (District 1), Price of Wales and Stikine (Districts 6 and 8), Taku River / Snettisham (District 11), Lyn Canal (District 15), and In the following terminal hatchery areas: Neets Bay (District 1), Nakat Inlet (District 1), Anita Bay (District 7), Speel Arm (District 11), Deep Inlet (District 13), and Boat Harbor (District 15)
Didson	Lilja, J., Ridley, T., Cronkite, G.M.W., Enzenhofer, H.J., Holmes, J.A. 2008. Optimizing sampling effort within a systematic design for estimating abundant escapement of sockeye salmon (*Oncorhynchus nerka*) in their natal river. Fisheries Research (Amsterdam) 90.1-3: 118-127	Fishery managers need robust ways of objectively estimating the quantitative composition of fish stocks, by species and age-class, from representative samples of populations. Dual-frequency identification sonar data were used to first visually identify fish to a broad taxon (Salmonidae). Subsequently, kernel-density estimations, based on calibrated size-at-age data for the possible component species, were used to assign sonar observations both to species (Atlantic Salmon Salmo salar or Brown Trout Salmo trutta) and age-classes within species. The calculations are illustrated for alternative sets of calibration data. To obtain close and relevant fits, the approach fundamentally relies on having accurate and fully representative subcomponent distributions. Firmer inferences can be made if the component data sets correspond closely to the target information in both time and space. Given carefully chosen suites of component data, robust population composition estimates with narrow confidence intervals were obtained. General principles are stated, which indicate when such methods might work well or poorly.
Didson	Lilja, J., Romakkaniemi, A., Stridsman, S. and Karlsson, L. 2010. "Monitoring of the 2009 salmon spawning run in River Tornionjoki/Torneälven using Dual-frequency IDentification SONar (DIDSON). A Finnish-Swedish collaborative research report. March 2010. 43p.	In March 2005, the Environment Agency began a full evaluation of a standard DIDSON unit and it's associated data-processing software, applied to a range of fisheries applications across England and Wales. These applications included: 1. Monitoring salmon smolt in small shallow streams- River Frome. 2. Counting fish at high passage rates - River Tywi sea trout and River Wye twaite shad. 3. Counting fish at low passage rates with high debris loads - Silver eels, River Dee smolt. 4. Behavioural studies: Using DIDSON as a surrogate for video - River Tyne Fish Deflection System; River Tyne fish counter; Benacre, Soham and Bourne Eau fish deflector systems. 5. Mobile applications One: As an aid to interpretation of split-beam data. 6. Mobile applications Two: Resolution of small targets in shoals. 7. Fish stock assessment – Biomass estimates of Rochdale Canal. DIDSON was found to be very simple to use. Its live output is in the form of images that

		can be easy to interpret and its 96 acoustic beams (in high frequency mode) combine to give it a wide overall beam angle without the disadvantages a split-beam system would incur in shallow water. It is very deployment friendly. The data gathered can be played back as if it were video which allows fish targets to be examined and behaviour studied by anyone with basic computer skills. However, there were applications where it was more difficult for an observer to identify fish targets.The software to automate this process is relatively easy to implement. Its effectiveness comparing output to fish identified from a full image playback mode was found to vary considerably between applications and for many the associated lower target detection rate may not warrant the time saved by automation. This will have resource implications for potential medium to long term monitoring applications.
Didson	Maxwell, S.L. and Gove, N.E. 2004. The feasibility of estimating migrating salmon passage rates in turbid rivers using a Dual Frequency Identification Sonar (DIDSON) 2002. Regional Information Report 1 No. 2A04-05, Alaska Department of Fish and Game Division of Commercial Fisheries, Anchorage, AK.	The dual-frequency identification sonar (DIDSON) system was identified during strategic planning as a new acoustic technology with the potential to deliver a cost-effective means of producing salmon escapement estimates with similar or better levels of precision and accuracy as mark-recapture programs (MRP). The objectives of our 2004 field work were to determine where the DIDSON acoustic imaging system could be used to estimate sockeye salmon (Oncorhynchus nerka) and Chinook salmon (O. tshawytscha) escapement in the Fraser River watershed and to determine the additional equipment needed (e.g., weirs, mounting system and platform) for effective operation of a DIDSON imaging system. We developed a preliminary list of 22 sites on 10 rivers for investigation through consultation with stock assessment staff in Kamloops and knowledge of the requirements of fisheries managers and general criteria for hydroacoustic sites. Based on a combination of in-stream testing and site visits, we conclude that the DIDSON system could be used effectively to estimate escapement of sockeye salmon in Scotch Creek, Chilko, Horsefly, Mitchell and Seymour Rivers, and probably the Lower Adams River as well. Additional equipment needed to effectively enumerate populations in these systems is minimal but includes a transducer mounting pole and bracket, a modified step-ladder from which the transducer is deployed and that can be used as a viewing platform for species composition estimates, a secure shed for topside equipment (computer and battery bank), solar panels to provide power, and 5-10 m of weir, depending on the site. Although additional work is needed on some systems to choose the most appropriate site for deployment (Mitchell River) or to

		confirm that fish do not exhibit unusual behaviours (e.g., milling, holding) that would degrade the performance of the DIDSON system (Mitchell River, Scotch Creek, Seymour River), we do not believe that the additional time commitment required to address these issues is large. The Lower Shuswap, Lower Stuart, and Tachie Rivers were not suitable for deployment of the DIDSON system in our judgement. We suspect that acoustic counting of migrating fish in the Lower Stuart River, particularly Chinook salmon, could be accomplished with shore-based side-looking split-beam systems, but at least one season of testing would be required to confirm this hypothesis. Neither the Lower Shuswap nor the Tachie were amenable to acoustic counting because of the high probability of unusual fish behaviour and poor site characteristics, respectively. The list of deployment sites and operational requirements (e.g., accessory equipment and sampling strategy) documented in this report can be cross-referenced to existing management priorities in order to determine deployment opportunities that best exploit the capabilities of the DIDSON technology within existing programs.
Didson	Maxwell, S.L., Faulkner, A.V., Fair, L. and Zhang, X. 2011. A comparison of estimates from 2 hydroacoustic systems used to assess sockeye salmon escapement in 5 Alaska Rivers. Alaska Department of Fish and Game, Fishery Manuscript Series No. 11-02, Anchorage.	The reliability of sockeye-salmon (Oncorhynchus nerka) count data collected by a dual-frequency, identification sonar (DIDSON) system is evaluated on the basis of comparisons with visual counts of unconstrained migrating salmon and visual counts of salmon constrained to passing through an enumeration fence. Regressions fitted to the DIDSON count data and the visual count data from the enumeration fence were statistically indistinguishable from a line with slope¼ 1.0 passing through the origin, which we interpret as agreement in both counts. In contrast, the regressions fitted to the DIDSON count data and the unconstrained visual count data had slopes that were significantly <1.0 (p< 0.001) and are consistent with an interpretation of systematic bias in these data. When counts of both unconstrained and constrained fish from the DIDSON system were _50 fish event_1, repeated counts of the DIDSON files were observed to produce the same counts 98e99% of the time, respectively, and based on the coefficient of variation, counts of individual passage events varied <3% on average. Therefore, the DIDSON count data exhibit high precision among different observers. As an enumeration fence provides a complete census of all fish passing through it, we conclude that fish-count data produced by the DIDSON imaging system are as accurate as visual counts of fish passing through an enumeration fence when counts range up to 932 fish event_1, the maximum count recorded during our study, regardless of the

		observer conducting the count. These conclusions should be applicable to typical riverine applications of the DIDSON system in which the bottom and surface boundaries are suitable for acoustic imaging, the migrating fish are adult salmon, and the transducer is carefully aimed so that the beams ensonify the area through which the salmon are migrating.
Didson	Mercer, B. and Associates Ltd. 2012. 2011 Teslin River DIDSON Sonar Feasibility Study. 31 pages	This study addresses a fish species discrimination method based on normalised elliptic Fourier descriptors applied to acoustic shadows derived by Dual-frequency Identification Sonar (DIDSON). Acoustic shadows of templates (20, 30, 40 and 50 cm) and live fish of four species [bream, Abramis brama (L.); barbel, Barbus barbus (L.); chub, Leuciscus cephalus (L.); and trout, Salmo trutta (L.)] were projected on a plate in an experimental set-up and tested on suitability for species discrimination. Twenty-centimetre templates were correctly classified in 97.5% of the cases, indicating a size threshold. The larger templates reached values of 100% correct classification based on cross-validated discriminant function analysis. It was also possible to classify moving fish based on screenshots of their acoustic shadows with a certainty of 83.9%. Extended field tests are required to evaluate the method for use in practical monitoring applications in multispecies river environments
Didson	Metheny, M.D. 2012. Use of dual frequency identification sonar to estimate salmonid escapement to Redwood creek, Humboldt county California. A Thesis Presented to The Faculty of Humboldt State University In Partial Fulfillment of the Requirements for the Degree Master of Science in Natural Resources: Fisheries Biology, 90 pages.	Atlantic salmon spawning run into the River Tornionjoki/Torneälven was monitored by Dualfrequency Identification Sonar (DIDSON) in 2009. In the beginning of the spawning run, one DIDSON unit was deployed at the river mouth (Tornio site), and two DIDSON units were deployed about 100 km upstream from the sea (Kattilakoski site). The plan was to collect run timing index data from the Tornio site by monitoring only a part of the river transect, and to enumerate all upstream migrants at the Kattilakoski site by monitoring the whole river transect. Monitoring at the Tornio site was started in late May and but it was interrupted after one month, when the unit was moved to the Kattilakoski site due to a system breakdown at that site. The results from the Torno site from the early part of spawning migration indicate that the site selection was not successful, as a too small fraction of the total upstream passage was detected in order to provide a reliable run timing index. At the Kattilakoski site monitoring supposedly covered the whole migration period, i.e. from the end of May until the late August. Acoustic data were collected for 78% and 65% of the available sample time on the Swedish and the Finnish shore, respectively. The near-bottom area at the 15-20 meter wide deepest mid-

		cannel was in constant shadow. In spite of the monitoring problems due to the mid-channel shadow area and the equipment breakdowns due to voltage peaks during thunderstorms, the Kattilakoski site was found to be fairly suitable for permanent monitoring of the salmon spawning run. Counts at Kattilakoski were expanded across the unsampled periods, but it was assumed that no salmon passed the monitoring site through the mid-channel shadow area. Records and catch samples from angling, and fish ladder data from the nearby River Kalixälven were used to infer the species composition and the separation between grilse (1SW) and multi-sea-winter (MSW) salmon in the counts. It was concluded that length measurements from the DIDSON data underestimated the true length of the observed fish. After a preliminary correction of length measurements and species identification it was concluded that 31 780 salmon and 2130 fish of other species (mainly sea trout) passed the site. Salmon counts were further divided between grilse (5420 ind.) and MSW salmon (26 360 ind.). The median date of salmon migration (grilse and MSW salmon combined) was on 1 July. The preliminary calculations taking into account salmon that ascended the river but did not pass the Kattilakoski site (either being caught or spawned below the site) indicated that totally about 33 000 – 35 000 salmon ascended the river in 2009. Future monitoring with auxiliary investigations may bring new information based on which the 2009 data have to be reassessed. The auxiliary investigations should include estimation of precision (detection rate may vary between persons post-processing the data) of counts, improving and verification of length measurements, data collection from the mid-channel shadow area, and special studies to quantify the amount of salmon that do not pass the counting site. A more permanent mounting system of the DIDSON units and fish deflection weirs could be planned and built up. Electronic equipment must also be better protected against breakdowns due to thunderstorms. Finally, obtaining direct information concerning the timing and dynamics of river entry of fish would require more test runs with one or several DIDSON units at various sites near the river mouth (Tornio).
Didson	Moursund, R.A., Carlson, T.J. and Peters, R.D. 2003. A fisheries application of a dual-frequency identification sonar acoustic	The upstream migration of adult sockeye salmon (Oncorhynchus nerka) in the Horsefly River was monitored by a DIDSON imaging sonar during the dominant stock-cycle year 2005 using a systematic 20-min h−1 sampling scheme. We used a subset of these data collected between 16 and 29 September to investigate whether this sampling protocol

	camera. ICES Journal of Marine Science 60: 678-683.	was justified based on temporal variation in the salmon migration data. During post-processing, the 20-min sequence was split into two 10-min periods and the number of migrating salmon was counted separately. Cross- and autocorrelation analysis showed that estimates from the first and second 10-min samples were similar (r = 0.65) and variation between them (i.e. within the hour) was random, supporting the conclusion that systematic-hourly sampling is a defensible sampling design for acoustic enumeration when temporal variation in fish migration is unknown a priori. Using a simple benefit–cost model (statistical reliability of point estimates of salmon escapement–sampling effort), we recommend a minimum sampling effort of 10-min h^{-1} and a maximum effort of 20-min h^{-1} for projects using a systematic sampling scheme in which the goal is to estimate total upstream salmon escapement. An alternative sampling approach targets high-passage events such as diurnal peaks or periods when total daily upstream escapement exceeds 25 000 fish d^{-1}, for increased sampling effort while reducing sampling effort during low-passage periods. This design will improve the statistical reliability of the resulting point estimates of upstream escapement relative to that achievable with a systematic effort with no overall change in total sampling effort over the course of the migration period.
Didson	Mueller, A.M., Burwen, D.L., Boswell, K.M. and Mulligan, T. 2010. Tail-Beat Patterns in Dual-Frequency Identification Sonar Echograms and their Potential Use for Species Identification and Bioenergetics Studies. Transactions of the American Fisheries Society 139.3: 900-910.	We tested the feasibility of using a dual frequency identification sonar (DIDSON) to count migrating adult salmon in turbid Alaskan rivers as a potential replacement for Bendix echo counting sonars. Our evaluation was divided into five main components: 1) a comparison of sockeye salmon (Oncorhynchus nerka) counts from DIDSON, Bendix sonar, and split beam sonar against visual tower and video counts; 2) a range test in a turbid river to test the DIDSON's detection limits; 3) a comparison of two sonars (DIDSON and split beam) at the Miles Lake sonar site; 4) a comparison of two sonars (DIDSON and Bendix) at the Kenai River; and 5) a test of the performance of the DIDSON on rocky river bottoms and artificial substrates. The sonar, video, and tower methods produced similar sockeye salmon counts in the clear Wood River, although the split beam sonar was only tested at relatively low fish passage rates. We detected an artificial target 17-18 m from the transducer in the turbid Copper River. More total fish were counted from DIDSON images compared to counts obtained from split beam sonar echograms with the largest difference occurring in the first 5 m at the Miles Lake sonar site on the Copper River. The discrepancy was greater if downstream-moving fish

		were subtracted from upstream-moving fish. In the turbid Kenai River, a DIDSON (high frequency) and Bendix sonar comparison of fish counts produced mixed results with one dataset producing regression slopes close to one while a second dataset was more dissimilar. From DIDSON images, we observed a variety of fish behaviors that could impact counts made by more traditional sonars. We successfully deployed DIDSON and observed fish over rocky river bottoms and artificial substrates. Advantages of the DIDSON include easy-to-detect images of fish; a wider viewing angle, better coverage of the water column, simpler aiming and operation, accurate upstream-downstream target resolution, background subtraction feature, less multipathing, and reasonable measures of fish length out to 12 m. Disadvantages include limited range capabilities, high electronic data loads, and manual target counting. In addition, the majority of the DIDSON's electronics are deployed in the river making the unit vulnerable to damage from debris. Better data storage methods and automated fish counting software are being investigated. The DIDSON exceeded our expectations for counting salmon in turbid rivers and is our choice for a Bendix sonar replacement.
Didson	Osborne, B.M. and Melegari, J.F. 2008. Site Selection and Feasibility of Enumerating Dolly Varden using Dual Frequency Identification Sonar in the Hulahula River, Arctic National Wildlife Refuge, Alaska, 2006. Fisheries Information Services, Annual Report FIS 04-103, U.S. Fish and Wildlife Service.	We tested the feasibility of using a dual frequency identification sonar (DIDSON) to count migrating adult salmon in turbid Alaskan rivers as a potential replacement for Bendix echo counting sonars. Our evaluation was divided into five main components: 1) a comparison of sockeye salmon (Oncorhynchus nerka) counts from DIDSON, Bendix sonar, and split beam sonar against visual tower and video counts; 2) a range test in a turbid river to test the DIDSON's detection limits; 3) a comparison of two sonars (DIDSON and split beam) at the Miles Lake sonar site; 4) a comparison of two sonars (DIDSON and Bendix) at the Kenai River; and 5) a test of the performance of the DIDSON on rocky river bottoms and artificial substrates. The sonar, video, and tower methods produced similar sockeye salmon counts in the clear Wood River, although the split beam sonar was only tested at relatively low fish passage rates. We detected an artificial target 17-18 m from the transducer in the turbid Copper River. More total fish were counted from DIDSON images compared to counts obtained from split beam sonar echograms with the largest difference occurring in the first 5 m at the Miles Lake sonar site on the Copper River. The discrepancy was greater if downstream-moving fish were subtracted from upstream-moving fish. In the turbid Kenai River, a DIDSON (high frequency) and Bendix sonar comparison of fish counts produced mixed results with

		one dataset producing regression slopes close to one while a second dataset was more dissimilar. From DIDSON images, we observed a variety of fish behaviors that could impact counts made by more traditional sonars. We successfully deployed DIDSON and observed fish over rocky river bottoms and artificial substrates. Advantages of the DIDSON include easy-to-detect images of fish; a wider viewing angle, better coverage of the water column, simpler aiming and operation, accurate upstream-downstream target resolution, background subtraction feature, less multipathing, and reasonable measures of fish length out to 12 m. Disadvantages include limited range capabilities, high electronic data loads, and manual target counting. In addition, the majority of the DIDSON's electronics are deployed in the river making the unit vulnerable to damage from debris. Better data storage methods and automated fish counting software are being investigated. The DIDSON exceeded our expectations for counting salmon in turbid rivers and is our choice for a Bendix sonar replacement.
Didson	Petreman, I.C., Jones, N.E. and Milne, S.W. 2014. Observer bias and subsampling efficiencies for estimating the number of migrating fish in rivers using Dual-frequency IDentification SONar (DIDSON) Fisheries Research 155: 160-167.	A Logie 2100C resistivity fish counter was installed in the Keogh River in the summer of 1997. Data were collected on fish numbers, sizes, and time of migration and compared to alternative methods of enumeration (area-under-the-curve and mark-recapture estimates). Counter escapement estimates of 8246 coho adults, 8505 pink salmon and 92 steelhead adults were calculated based on observed counter efficiency, through video validation techniques. Area-under-the-curve (AUC) estimates for pink salmon were high (15,631 adults) in part due to some escapement into the river occurring before counter operation began. Coho AUC estimates varied and very dependant on the values used for residence time in the stream count areas. AUC estimates ranged from 5411 to 13,060 adults, with no confidence limits available due to low tag re-sightings. Mark-recapture data for steelhead predicted a similar value for escapement to counter data, with an estimate of 98 fish.
Didson	Pipal K., Jessop, M., Boughton, D. and Adams, P. 2010. Using dual-frequency identification sonar (DIDSON) to estimate adult steelhead escapement in the San Lorenzo River, California. California Fish and Game 96 (1):	Multiple beam high resolution sonars were used to enumerate the 2012 Chinook salmon (Onchorynchus tshawytscha) escapement to the Teslin River system. This was the first year of a full sonar project at this site following a feasibility study in 2011. The sonar was operated on the mainstem Teslin River at the site identified during the 2011 feasibility study; approximately 12 km upstream of the confluence of the Teslin and Yukon Rivers at Hootalinqua. The camp and sonar station set-up was initiated on July 3. Sonar operation began on July 17 and operated continuously through to September

	90-95.	3. A total of 3,396 targets identified as Chinook salmon was counted during the period of operation. An additional 58 Chinook were estimated to have passed during the 20.5 hours the sonars were inoperative over the course of the project. The total escapement was estimated to be 3,454. The first Chinook salmon was observed on July 27, ten days later than anticipated. A peak daily count of 186 fish occurred on August 21, at which time 76% of the run had passed the sonar station; 90% of the run had passed the station on August 25. A carcass pitch was conducted over approximately 120 km of the mainstem Teslin River, yielding 147 sampled Chinook. Of these, 95 (66%) were female and 52 (34%) were male. The mean fork length of females and males sampled was 853 mm and 773 mm, respectively. The DFO scale lab determined ages from 118 Chinook sampled. Age-5 (68%) was the dominant age class, followed by age-4 fish (28%) and age-3 fish (4%). A total of 106 tissue samples was collected for GSI analysis.
Didson	Tiffan K.E., Rondorf D.W. and Skalicky J.J. 2004. Imaging fall Chinook salmon redds in the Columbia River with dual frequency identification sonar. North American Journal of Fisheries Management 24: 1421–1426.	I used dual frequency identification SONAR (DIDSON) to estimate escapement of adult coho salmon, Chinook salmon, steelhead and coastal cutthroat trout entering Redwood Creek to spawn. Effective estimates of salmonid escapement include a quantifiable error associated with the number of fish. The errors associated with DIDSON estimates were described and computed to assess whether or not the technology is appropriate for monitoring salmonid escapement in Redwood Creek. DIDSON counts of unidentified fish were assigned a species using models developed from spawning survey observations in the Redwood Creek watershed. The DIDSON deployment on Redwood Creek worked well during flows below 3000 cubic feet per second. Multiple regression of environmental variables showed no clear relationships with daily fish passage rates. Between 17 November 2009 and 18 March 2010, I estimated that 2,435 Chinook salmon, 375 coho salmon, 775 steelhead and 400 coastal cutthroat trout entered Redwood Creek to spawn. Calculation of sampling variance and a census of 88 hours suggested that a sample of 10 minutes to represent the hour resulted in a 9-13% confidence interval around the point estimate.
Didson	Tiffan, K., Haskell, C. and Kock, T. 2010. Quantifying the behavioral response of spawning chum salmon to elevated discharges from Bonneville Dam, Columbia	Kenai river Chinook salmon passage was estimated in 2010 using split beam sonar and experimental DIDSON counter/ the splitbeam sonar operated continuously from 16 may to 4 august, when operations were curtailed due to milling salmon that prevented accurate counting. the DIDSON was successfully deployed on both banks of the river and operated successfully on 48 days between 11 june and 10 august. based on split

	River, USA. River Research Applications 26: 87-101.	beam sonar target strength and range thresholds, total upstream passage of chinook salmon was estimated to be 13248 (SE 235) fish during the early run (16 may - 30 june) and 18401 (SE 698) fish for the late run (1 july - 10 august) Detailed comparison of split beam and DIDSON data indicated taht the assumption underpinning split beam traget strength based estimates are not valid. it is recommended taht target based strength based split beam sonar estimate be discontinued in favor of DIDSON based estimate 2011.
Didson	Upper Fraser Fisheries Conservation Alliance and Department of Fisheries and Oceans (2010) System-wide DIDSON Estimation of Sockeye Salmon Escapement in the Quesnel River System. Project # 07350-35/FSWP 09 D SIFM 93. 65 pages.	The uses of an acoustic camera in fish-passage research at hydropower facilities are being explored by the U.S. Army Corps of Engineers. The ‘‘Dual-Frequency Identification Sonar’’ (DIDSON) is a high-definition imaging sonar that obtains near-video quality images for the identification of objects underwater. Developed originally for the U.S. Navy by the University of Washington’s Applied Physics Laboratory, it bridges the gap between existing fisheries-assessment sonar and optical systems. The images within 12m of this acoustic camera are sufficiently clear such that fish can be observed undulating as they swim and their orientation ascertained in otherwise zero-visibility water. In the 1.8 MHz high-frequency mode, this system comprises 96 beams over a 29_ field-of-view. The high resolution and fast frame rate provide target visualization in real time. The DIDSON can be used where conventional underwater cameras would be limited by low light levels and high turbidity.
Didson	Xie, Y., Gray, A.P., Martens, F.J., Boffey, J.L. and Cave, J.D. 2005. Use of Dual-Frequency Identification Sonar to Verify Salmon Flux and to Examine Fish Behaviour in the Fraser River. Pacific Salmon Comm. Tech. Rep. No. 16: 58 p.	We observed patterns in echograms of data collected with a dual-frequency identification sonar (DIDSON) that were related to the tail beats of fish. These patterns reflect the size, shape, and swimming motion of the fish and also depend on the fish’s angle relative to the axis of the beam. When the tail is large enough to reflect sound of sufficient intensity and the body is angled such that the tail beat produces periodic changes in the range extent covered by the fish image, then the tail beat becomes clearly visible on echograms that plot the intensity maximum of all beams. The analysis of DIDSON echograms of a mix of upstreammigrating Chinook salmon Oncorhynchus tshawytscha and sockeye salmon O. nerka resulted in the separation of two groups: (1) fish of sockeye salmon size that swam with a tail-beat frequency (TBF) between 2.0 and 3.5 beats/s and (2) fish of Chinook salmon size with a TBF between 1.0 and 2.0 beats/s. There was no correlation between TBF and fish size within each group, which suggests that the observed difference in TBF between the two groups was species-

		specific rather than an indirect effect of the groups' difference in size. The technique of extracting TBF from DIDSON echograms may also be useful for bioenergetics studies. Compared with electromyogram telemetry, it offers the advantages of being nonintrusive and faster to set up and analyze and therefore is suitable for analyzing larger sample sizes. The disadvantages are that the technique's potential is limited to relatively large fish, it can cover only relatively small areas, it cannot be used to follow individual fish over long distances, and some environments are too noisy to produce DIDSON images of sufficient quality.
Didson	Xie, Y., Michielsens, C.G.J., Gray, A.P., Martens, F.J. and Boffey, J.L. 2008. Observations of avoidance reactions of migrating salmon to a mobile survey vessel in a riverine environment. Canadian journal of fisheries and aquatic sciences/Journal canadien des sciences halieutiques et aquatiques 65 (10): 2178-2190.	A study using a fixed-location, Dual Frequency Identification Sonar (DIDSON) was initiated in 2004 to assess the population status of Dolly Varden Salvelinus malma in the Hulahula River, Alaska. An abundance estimate from the DIDSON data was generated to describe the variability in run size and timing of Dolly Varden. During 2006 data collection began August 1 and continued through September 20. A total of 1,157 hours of data was collected, providing an estimate of 7,471 Dolly Varden migrating upriver. Species identification was accomplished with hook and line sampling, beach seining, and an underwater camera. A total of 127 fish was captured, identified as Dolly Varden, sexed, and measured. Based on observed swimming pattern, estimated size, and lack of other species observed or captured, all fish enumerated were assumed to be Dolly Varden. Visual observations using an underwater video camera positioned in the ensonified zone detected 125 fish and of these, 68 were identified as Dolly Varden. The remaining 57 fish were too small to identify. No fish were observed during two aerial surveys conducted using helicopter (September 17 and 20) flown from the DIDSON site to the river mouth. Positional data indicated that most fish were detected by the DIDSON with few fish observed near the outer range limits of acoustic detection. Most fish traveled on the river bottom. The peak daily count of 535 fish occurred on September 1. The hourly passage rates of upriver fish showed a slight diel pattern (highest during nighttime hours). The estimate of Dolly Varden migration upriver is conservative because it only included fish that passed while DIDSON was in operation.
Resistivity	Dunkley, D. and Shearer, W. 1982. An assessment of the performance of a resistivity fish counter. J. Fish Biol. (1982) 20, 717-737	Monitoring trends in abundance of Endangered Species Act (ESA) listed adult steelhead (Oncorhynchus mykiss) is essential to assessing their viability. However, in central and southern California (the southern extent of their range), monitoring is difficult due to the low abundance and patchy distribution of adults. The only successful method

		has been counting stations at barriers (e.g., dams, weirs, etc.) that involve a certain amount of ESA “take” in handling listed fish. As a new alternative that avoids “take,” we have successfully used dual-frequency identification sonar (DIDSON) for monitoring adult steelhead abundance (Pipal et al. In press). The operational aspects of using DIDSON to monitor small fish populations in a more urbanized setting are different than for its more common use to enumerate large runs of salmon in more remote regions. We have deployed DIDSON in three different locations in central California to monitor steelhead and have gained significant insight into the necessary operational considerations. These are described here in detail and include the following:1) site selection, 2) DIDSON unit configuration, 3) deployment and system security, 4) data management (recording, processing and storage), 5) species identification, 6) and data analyses, which include a Decision Support Tool used to standardize fish counts. We also identify areas needing further research, particularly species identification, and offer suggestions for possible solutions.
Resistivity	McCubbing, D., Ward, B. and Burroughs, L. 1999. Salmonid escapement enumeration on the Keogh River: a demonstration of a resistivity counter in British Columbia. Fisheries Technical Circular No 104	In order to assess the accuracy and reliability of automated fish counters for counting adult Atlantic salmon, *Salmo salar* L., a "Logie' resistivity counter was installed in late June 1989 in the control dam above the fishway in Northeast River, Placentia, Newfoundland, Canada. The counter was in operation for 26 days (1-26 July). The accuracy of daily counts recorded by the counter was verified by visual counts of Atlantic salmon released from a trap located downstream of the counter and immediately above the fishway. All the fish released from the trap had to pass over the counter. A total of 517 salmon (mainly grilse) was released from the trap and the net number of upstream migrants recorded by the counter was also 517. This is the first test and use of an open-channel counter in eastern Canada. The results suggest that some counting fences and fishways may be easily adapted for installation of automated counters and that counters offer a cost-effective means of counting adult Atlantic salmon.
Resistivity	Reddin, D., O'Connell, M. and Dunkley, D. 1992. Assessment of an automated fish counter in a Canadian river. Aquaculture and Fisheries Management 1992, 23,	An application of a new automated fish counting device – the Riverwatcher System (RW) – was used to monitor upstream fish movements in a pool-and-weir fish pass in the River Ze ˆ zere, Portugal, for 141 days from June 2002 to May 2003. Fish populations were also collected downstream using multimesh gillnets (5 different mesh sizes ranging from 30 mm to 85 mm knot to knot; ratio between mesh sizes of about

	113-121	1.30) and electrofishing for comparison with fish records produced by the RW. More than 3000 individual Iberian nase Chondrostoma polylepis ascended the fish pass and moved through the RW during the study period. However, only 18% of the records produced by the RW contained silhouettes similar to fish; no individual smaller than 15 cm TL was recorded by the counter. Most seasonal movements (73.9%) occurred in spring and were associated with reproduction. Displacements seemed to occur independently of time of day. Water temperature (range: 12–22_C) was the only significant environmental variable (P < 0.01) influencing upstream movements of this species. Further development of hardware and software will be necessary to improve performance of the counter, particularly in Mediterranean rivers, where more turbid waters and a greater proportion of small-size species are present.
Resistivity	Smith, I., Johnstone, A., and Dunkley, D. 1996. Evaluation of a portable electrode array for a resistivity fish counter. Fisheries Management and Ecology, 1996, 3, 129-141	Vaki, Ltd., of Iceland has designed a system for counting the in-river migration of salmonids via infrared sensors. The Vaki fish counter is used in Iceland, the United Kingdom, and Europe but is much less used in North America partly because of the system's unknown ability to count large populations accurately. In tests in the Big Qualicum River of Vancouver Island, British Columbia, we found the accuracy of the counter to be inversely correlated with migration rate of chum salmon *Oncorhynchus keta*. The fish counter was very accurate (.95%) for migration rates less than 500 fish/h but accuracy declined to 76% at a rates exceeding 1,500 fish/h. The principal cause for the decline in accuracy was the inability of the infrared sensors to count the passage of more than one fish simultaneously.
Vaki	Armstrong, J.D., Armstrong, R.M., Graham, J.L., Middlemas, S.J., Ribbens, J.C.H., Rycroft, P. and Stewart, D.C. 2012. Movements of Returning Atlantic Salmon Through Tongland Fish Pass. Marine Scotland Science Report 05/12	We tested the efficacy of a dual-frequency identification sonar (DIDSON) for imaging and enumeration of fall Chinook salmon *Oncorhynchus tshawytscha* redds in a spawning area below Bonneville Dam on the Columbia River. The DIDSON uses sound to form near-video-quality images and has the advantages of imaging in zero-visibility water and possessing a greater detection range and field of view than underwater video cameras. We suspected that the large size and distinct morphology of a fall Chinook salmon redd would facilitate acoustic imaging if the DIDSON was towed near the river bottom so as to cast an acoustic shadow from the tailspill over the redd pocket. We tested this idea by observing 22 different redds with an underwater video camera, spatially referencing their locations, and then navigating to them while imaging them with the DIDSON. All 22 redds were successfully imaged with the DIDSON. We

		subsequently conducted redd searches along transects to compare the number of redds imaged by the DIDSON with the number observed using an underwater video camera. We counted 117 redds with the DIDSON and 81 redds with the underwater video camera. Only one of the redds observed with the underwater video camera was not also documented by the DIDSON. In spite of the DIDSON's high cost, it may serve as a useful tool for enumerating fall Chinook salmon redds in conditions that are not conducive to underwater videography.
Vaki	Baumgartner, L., Bettanin, M., McPherson, J., Jones, M., Zampattin B. and Beyer, K. 2012. Influence of turbidity and passage rate on the efficiency of an infrared counter to enumerate and measure riverine fish. J. Appl. Ichthyol. 28 (2012), 531-536	Chum salmon Oncorhynchus keta that spawn in main-stem habitats below Bonneville Dam on the Columbia River, USA, are periodically subjected to elevated discharges that may alter spawning behaviour. We investigated behavioural responses of spawning chum salmon to increased water velocities associated with experimental increases in tailwater elevation using acoustic telemetry and a dual-frequency identification sonar. Chum salmon primarily remained near their redds at base tailwater elevations (3.5m above mean sea level), but displayed different movement and behavioural responses as elevations were increased to either 4.1 or 4.7m for 8-h periods. When velocities remained suitable (<0.8m s_1) during elevated-tailwater tests, female chum salmon remained near their redds but exhibited reduced digging activity as water velocities increased. However, when velocities exceeded 0.8ms_1, the females that remained on their redds exhibited increased swimming activity and digging virtually ceased. Female and male chum salmon that left their redds when velocities became unsuitable moved mean distances ranging from 32 to 58m to occupy suitable velocities, but returned to their redds after tailwaters returned to base levels. Spawning events (i.e. egg deposition) were observed for five of nine pairs of chum salmon following tests indicating any disruptions to normal behaviour caused by elevated tailwaters were likely temporary. We believe a chum salmon's decision to either remain on, or leave, its redd during periods of unsuitably high water velocities reflects time invested in the redd and the associated energetic costs it is willing to incur. Published in 2009 by John Wiley & Sons, Ltd.
Vaki	Santos, J.M., Pinheiro, P.J., Ferreira, M.T. and Bochechas, J. 2008. Monitoring fish passes using infrared beaming: a case study in	System-wide DIDSON estimation of sockeye salmon escapement in the Quesnel river system. Project Objectives as outlined in the proposal, and used to guide the completion of the project were as follows: 1) DIDSON site selection: Identification and utilization of the best possible DIDSON field site for producing a total Quesnel Lake

	an Iberian river. Journal of Applied Ichthyology 24: 26-30.	system sockeye salmon escapement estimate in 2009. 2) Installation and operation of 2 DIDSON systems (one on each river bank, directly opposite) for the entire sockeye salmon migration period, including on-site visual counts. 3) Generation of a total 2009 Quesnel Lake system (Quesnel Lake sockeye Conservation Unit) sockeye salmon escapement estimate, and comparison to the upstream estimates of spawning escapement. 4) Establishment of a capacity-sharing relationship between the UFFCA, NSTC and DFO for providing experience to First Nations fisheries technicians on all aspects of a DIDSON project - from concept to completion phases.
Vaki	Shardlow, T.F. and Hyatt, K.D. 2004. Assessment of the Counting Accuracy of the Vaki Infrared Counter on Chum Salmon. North American Journal of Fisheries Management, 24(1): 249-252	Beginning in 2004 the Pacific Salmon Commission implemented a split-beam sonar system to provide real-time estimates of salmon abundance returning to the Fraser River at Mission B.C., replacing less robust single-beam technology which had been in operation since 1977. Dualfrequency identification sonar (DIDSON) provides more detailed information on underwater objects and provides an opportunity to verify some important assumptions in the split-beam methodology. Analysis of DIDSON information confirmed that the left-bank split-beam system produces valid estimations for upstream fish-flux in the "commonly insonified zones" for the two comparable technologies. Analysis of a limited amount of DIDSON information indicated that the "nearest-neighbour" extrapolation method used in the split-beam fish flux model produces reasonable estimates of fish flux at high passage rates in the blind zone. DIDSON studies indicated that the direction of travel and swimming speed of fish migrating in the middle of the channel were not significantly different from similar statistics routinely collected from the leftbank split-beam system. Unknown "fish-like" targets previously observed near the right bank and other indiscernible targets were clearly identified as debris. Also, in the area of the right bank, salmon were clearly identified as migrating towards the shore, but still oriented upstream. DIDSON studies confirmed that fish react to the transecting vessel by changing their normal upstream swimming direction. This avoidance behaviour was found to be more sensitive to the vertical separation between fish and the vessel than the horizontal separation. Trials were also conducted using the DIDSON technology at an upstream site near Boston Bar B.C. and the technology was found to be applicable for the riverine conditions in that area.
Comparison of Vaki	Baumgartner, L., Bettanin, M., McPerson, J., Jones, M., Zampatti,	Detailed avoidance reactions of adult migrating salmon to a mobile survey vessel were successfully observed with side-looking dual frequency indentification sonar (DIDSON)

and DIDSON	B. and Beyer, K. 2010. Assessment of an infrared fish counter (Vaki River watcher) to quantify fish migrations in the Murray-Darling Basin. Industry & Investment NSW – Fisheries Final Report Series No. 116. ISSN 1837-2112.	in the lower Frasner River (BC, Canada). Both adult sockeye (Oncorhynchus nerka) and pink salmon (Oncorhynchus gorbuscha) returning to the river were found to avoide the approaching vessel by initiating lateral movements away from the vessel, making the fish unlinkely to be insonified by the downward looking transducer towed by the vessel. The vessel was found to have an estimated mean interference range of 4m from its propeller. Analyses of the data concluded that once the vessel and fish were separated by more than 7 m, the vessel no longer affected the normal migration behaviour of the fish.
Comparison of Didson Vaki Resistivity	Brennan, L.O. 2013. A Stock Assessment of Atlantic salmon in Large Riverine Catchments. Vol. I and II. A thesis submitted to The National University of Ireland in fulfilment of the requirements for the Degree of Doctor of Philosophy. Head of Department: Prof. Martin Feely. Supervisors: Prof. Ken Whelan and Tiernan Henry. Earth & Ocean Sciences, School of Natural Sciences, National University of Ireland, Galway. 368 (Vol I) + 116 (Vol II) Pages. Available at <http://aran.library.nuigalway.ie/xmlui/handle/10379/3517>	Fixed-location, side-looking, multibeam, sonar techniques offer a practical approach to estimate thenumbers of migrating fish in rivers that are too large or occluded for traditional sampling methods,such as weir trapping, visual observation techniques, and netting. While this technology has been usedto enumerate salmonid escapement in coastal river systems of western North America, little use andevaluation has occurred in inland waters such as the Great Lakes, where rivers and runs of fish areconsiderably smaller than those along the Pacific coast. We use a “Dual-frequency IDentification SONar”(“DIDSON”) imaging sonar system to investigate the error and variability among nine people performingfish counts. There was no significant difference found among observers’ estimates of fish abundanceper DIDSON file; however, the total count of all fish differed from the benchmark value by as muchas 26%. Post-processing simple fish counts from DIDSON raw data is labour-intensive and costly. Three subsampling methods of fish passage estimations were developed and evaluated for their accuracy and precision for daily and seasonal time frames. The random and systematic subsampling methods had similar seasonal and daily accuracy and precision with few exceptions. Automation-assisted counting was much more accurate and efficient for seasonal estimates. A ratio of approximately 2:1 was found for the automated to manual fish counts and this varied little among years. The DIDSON multibeam sonar unit is useful in estimating potamodromous fish migrations for large tributaries of the Great Lakes. DIDSONimage processing costs can be minimized through suitable subsampling approaches. The automation-assisted method is the most cost-effective means of estimating moderate levels of fish passage overlonger study periods. Multiple individuals can be used interchangeably for the manual post-processing of DIDSON data.

Comparison of Didson and Splitbeam	Miller, J.D., D.L. Burwen, and S.J. Fleischman. 2013. Estimates of Chinook salmon passage in the Kenai River using split-beam and dual-frequency identification sonars, 2010. Alaska Department of Fish and Game, Fishery Data Series No. 13-58, Anchorage.	This study aimed to develop and test an electrode array for a resistivity fish counter that could be easily installed in a small river without a weir. An electrode array consisting of three steel cables laid in parallel across the stream channel and connected to a microprocessor-based counter was tested in an Atlantic salmon, Salmo salar L., spawning tributary. The accuracy of the counter was assessed by observing fish movements with closed-circuit television. Most salmon moving upstream were registered correctly (90% overall). Detection of downstream movement was less reliable (60% overall), as a consequence of downstream swimming behaviour. The accuracy of the downstream count was improved by tensioning the cable electrodes, but remained lower than that of the upstream count. Since salmon swam repeatedly up- and downstream, this discrepancy resulted in an overestimate of the net upstream count. The accuracy of the downstream count needs to be improved before a bed-mounted electrode array could be used for routine salmon counting.

Appendix 2. Questionnaire Results

Summary of results from counter questionnaire from various counter users.

General information

Watershed	Counter	Type	Structure	Cost (GBP)	Main Activity Required	Main Operations Cost	person-day	Annual operating costs (GBP)
Unknown	Vaki	Optical	Crump Weir					
Unknown	Logie	Resistivity	Crump Weir					
Unknown	Logie	Resistivity	Crump Weir					
River Dee, Scotland	Vaki	Optical	Fishway	£25,000 (2008)	Maintenance	salary	20	£3000-£10 000
Kirkcudbrightshire Dee, Scotland	Vaki	Optical	Fishway	£20,000 (2007)	Maintenance	salary	27	£3000-£10 000
Galloway, Scotland	Vaki	Optical	Fishway		Maintenance	salary		£3000-£10 000
Deveron, Scotland	Logie	Resistivity	Crump & fish Weir		Infrastructure	salary	25	£0-£3000
Deveron, Norway	DVR	Video	None		Analysis	salary	60	£20000-£50000
River Shin, Scotland	not Logie	Resistivity	Fishway					
North Esk, Scotland	Logie	Resistivity	Crump Weir	£250 000 (1980)-Logie <£10000 (1990)-Westwater	Maintenance	Equipment	50/site	>£50000
Tweed, Scotland	Vaki	Optical	Fishway	£25 000 (2010)	Data collection and processing	salary	7	£0-£3000
Spey, Scotland	Split-beam	Acoustic Sonar	None	£80,000 for five year (1996-2001)	Data collection and processing	salary	>200	£0-£3000
Kamloops, Canada	Didson / Aris	Acoustic Sonar	Deflection Weir		Data collection and processing			>£50000

1. What type of technology do you use? (Q3 – 13 answered)

Technology	Number	Overall Percentage
Optical Beam (Vaki)	5	38%
Sonar (Didson, Aris, Splitbeam)	2	15%
Resistivity (Logie, Mark)	5	38%
Real-time Video	1	8%

2. Infrastructure used to deploy and operate counter in river? (Q4 – 13 answered)

Structure	Number	Overall Percentage
Fishway	5 --- (4 for optical, 1 for resistivity)	38%
Purpose-built weir (Crump weir)	5 --- (1 for optical, 4 for resistivity)	38%
Deflection fence	1 --- (1 for acoustic sonar)	8%
Fish weir	1 --- (1 for resistivity)	8%
None	1 --- (1 for split beam)	8%

It should be noted that deflection fences are only used in North America.

3. What quantitative methods do you use to evaluate data quality? (Q16 – 6 answered, 7 skipped)

Vaki

- Check with biological staff
- don't know
- Video analysis to check counter accuracy (number)

Video

- Data from video systems running in "time lapse" modus in itself a control. In video surveillance with sufficient frame rate, no object can pass cameras without being detected.

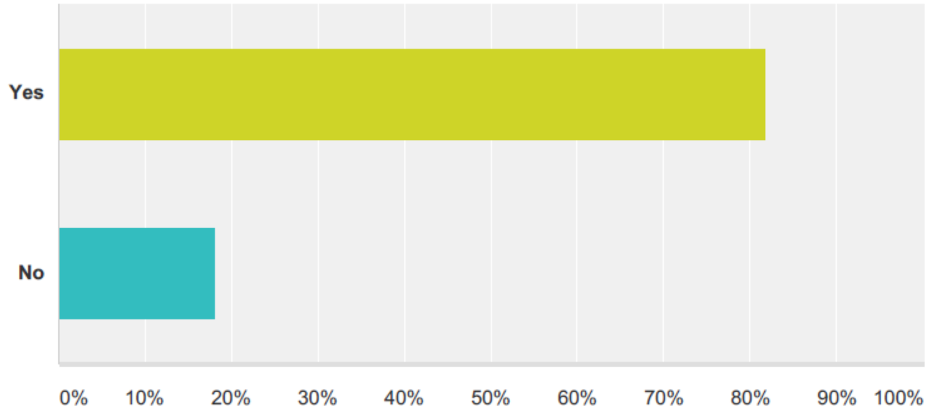
Acoustic Sonar

- Video cameras placed under acoustic beam to film fish for periods

Resistivity

- Use a fish counter signal processing key

4. Are your data analyzed in season (e.g. estimates of fish passage over the counter are produced and updated during fish migrations)? (Q20 – 11 answered 2 skipped)



Answer Choices	Number	Overall Percentage
Yes	9 --- (3 for Resistivity, 2 for Acoustic, 3 for Optical)	81.8%
No	2 --- (1 for Resistivity, 1 for Optical)	18.2%

5. Which additional method(s) would improve your data processing? Pick all that apply. (Q21 – 7 answered 6 skipped)

<u>Vaki</u>

- Automating quality control
- Visualization of data
- Summary of tables of data
- Error elimination
- Automating species assignment (applying known %s of each spp to unidentified fish)
- Don't know
- Having a Scotland wide network of users to provide support when needed

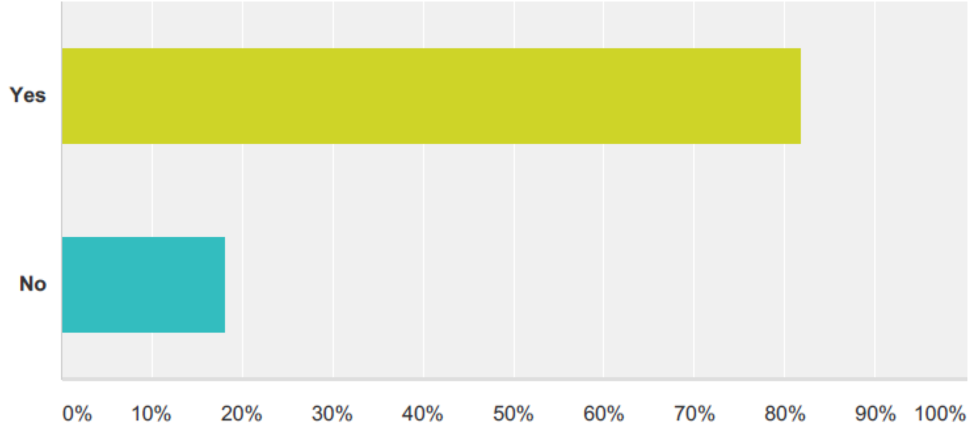
<u>Acoustic Sonar</u>

- Automating quality control
- Visualization of data
- Summary of tables of data
- Error elimination
- Eliminating sporadic Ethernet disconnections

<u>Resistivity</u>

- Automating quality control
- Visualization of data
- Summary of tables of data
- It is difficult to say as there are a lot of trade-offs. We would want to at least maintain current level of data processing and so if any of the above methods would result in less time being spent to achieve the same results then this would be welcome

6. **Do you validate fish passage detection rates? This refers to validating the counters up and down count accuracy. For example, this could include comparing observations of fish moving over the counter with counter output. If 10 fish were observed passing up over the counter but the counter only detected 9 the counter would only be 90% accurate. (Q22 – 12 answered 1 skipped)**



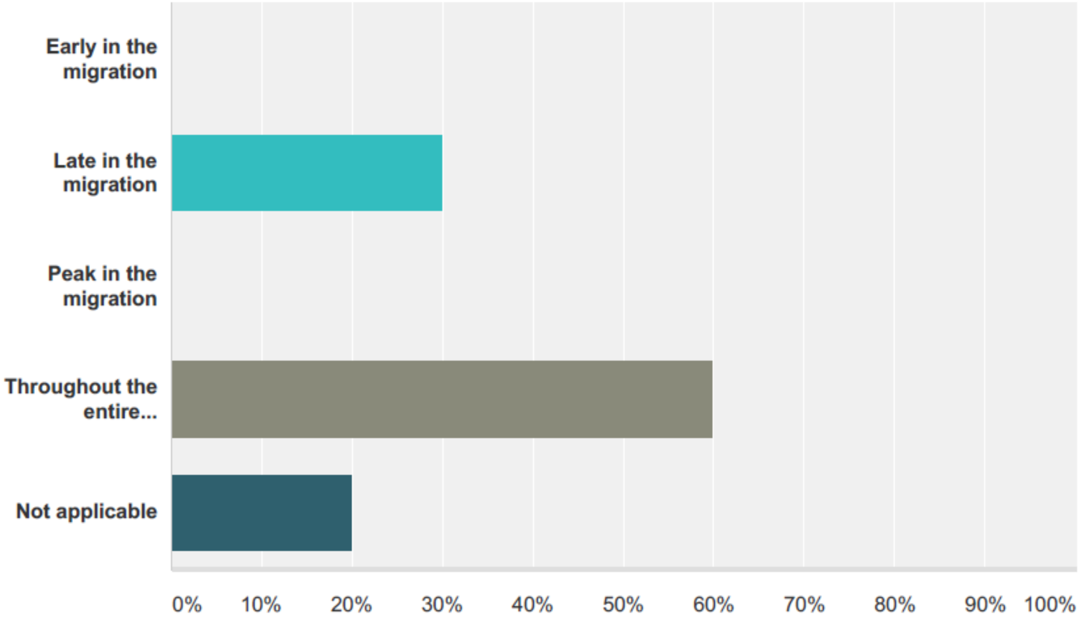
Answer Choices	Number	Overall Percentage
Yes	10 --- (3 for Resistivity, 2 for Acoustic, 4 for Optical, 1 for video)	80.0%
No	2 --- (2 for Optical)	20.0%

7. **If "no" was answered to previous question "Do you validate fish passage detection rates?", why not? (Q23 – 2 answered 11 skipped)**

Optical

- not enough time but will do sometime soon. Confident that counter is reliable
- staffing issues too date and validation planned for 2015

8. **During which part of the fish migration do you validate fish passage detection rates? Pick all that apply. (Q26 – 10 answered 3 skipped)**



Answer Choices	Number	Overall Percentage
Early in migration	0	0.0%
Late in migration	3 --- (2 for Resistivity, 1 for Optical)	30.0%
Peak of migration	0	0.0%
Entire migration	6 --- (1 for Resistivity, 2 for Acoustic, 2 for Optical, 1 for video)	60.0%
Not applicable	2 --- (1 for Resistivity, 1 for Optical)	20.0%

9. How do you validate your fish passage detection rates? (Q27 – 8 answered 5 skipped)

Acoustic
- Compare individual video observations to counter produced fish passage records
- Compare individual visual observations to sonar produced fish passage records

Resistivity
- Not applicable
- Compare individual visual observations to counter produced fish passage records
- Compare individual video observations to counter produced fish passage records
- Compare signals with signal validation key which was constructed using in-river calibration

Video
- Video surveillance can be evaluated continuously through the season, based on observation of water turbidity

Optical
- applicable
- Compare individual visual observations to counter produced fish passage records
- Compare individual video observations to counter produced fish passage records

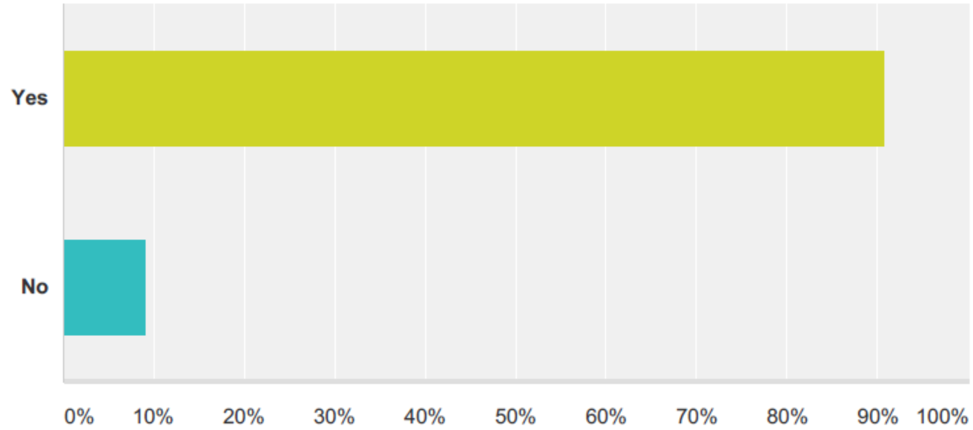
10. How do you use your validation information? Pick all that apply. (Q28 – 8 answered 5 skipped)

Answer Choices	Number	Overall Percentage
To calculate absolute abundance	3 --- (1 for Resistivity, 1 for Optical, 1 for video)	37.5%
For making sure the counter accuracy is consistent from year to year	5 --- (3 for Resistivity, 2 for Optical)	62.5%
Not applicable	1 --- (1 for acoustic)	12.5%

Acoustic

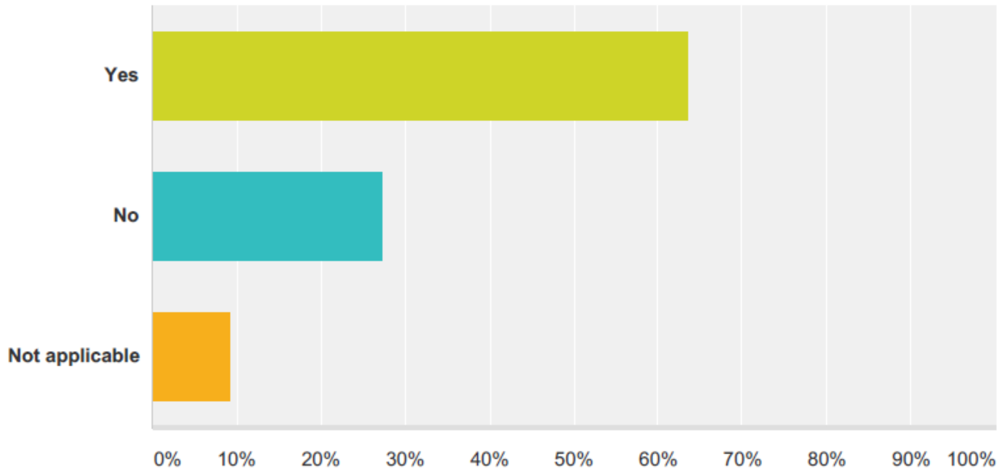
- To ensure no fish are going past the sonars (DIDSON and ARIS) undetected

11. Are there more than one species passing over the counter at the same time of year? (Q29 – 11 answered 2 skipped)



Answer Choices	Number	Overall Percentage
Yes	10 --- (3 for Resistivity, 2 for Acoustic, 4 for Optical, 1 for video)	90.9%
No	1 --- (1 for resistivity)	9.1%

12. Do you validate species identification? (Q30 – 11 answered 2 skipped)



Answer Choices	Number	Overall Percentage
Yes	7 --- (2 for Resistivity, 2 for Acoustic, 2 for Optical, 1 for video)	63.6%
No	3 --- (2 for Resistivity, 1 for Optical)	27.3%
Not applicable	1 (1 for optical)	9.1%

13. If yes to the question "do you validate species identification?" How do you determine different species? (Q31 – 6 answered 7 skipped)

Answer Choices	Number	Overall Percentage
Using video	1 --- (1 for video)	16.7%
Using size discrimination	2 --- (1 for Resistivity, 1 for Acoustic)	33.3%
Both	3 --- (1 for Resistivity, 1 for Acoustic, 1 for Optical)	50.0%

Acoustic

- Fish behaviour (e.g. tail beat frequency; traveling in groups), and spatial separation of species (e.g. Chinook normally migrate down the middle while Sockeye are more off to the side riverbanks.)

Resistivity

- We are fortunate in that species can be discriminated by size and the counter is set up to only count the target species
- Run timing

14. How often do you validate species identification? (Q32 – 8 answered 5 skipped)

Answer Choices	Number	Overall Percentage
Every year	4 --- (1 for Resistivity, 1 for Acoustic, 1 for Optical, 1 for video)	50.0%
1 out of 2 years	1 --- (1 for Resistivity)	12.5%
1 out of 3 years	0	0.0%
1 out of 5 years	0	0.0%
Only when there are large # of non-targeted species	1 --- (1 for Resistivity)	12.5%
Only when river conditions permit	1 --- (1 for Acoustic)	12.5%
Never	1 --- (1 for Optical)	12.5%

Acoustic

- Difficult to validate species identification in more turbid locations which can make live counting very difficult.

Resistivity

- Qualitative assessment of in-river fishery catch of other species (e.g. sea trout)

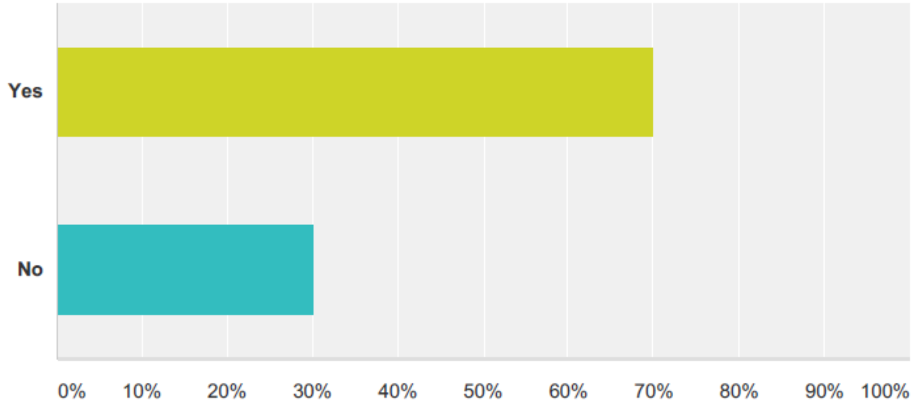
15. What type of abundance estimates do you produce with the counter data? (Q35 – 9 answered 4 skipped)

Answer Choices	**Number**	**Overall Percentage**
Minimum estimate – this estimate is produced using just the raw counter data with no validation	3 --- (1 for Resistivity, 2 for Optical)	33.3%
Absolute estimate – this estimate would incorporate the counter accuracy values (fish passage detection rates) from each year to account for fish missed or erroneous counts produced by the counter	5 --- (3 for Resistivity, 1 for Acoustic, 1 for Optical)	55.6%
Index – this would be applying a correction factor (similar to a counter accuracy estimate) to the raw data. The difference between and index and absolute count estimate is the index applies the same correction factor each year whereas the absolute abundance estimate corrects the raw data with accuracy estimate for each year.	1 --- (for Resistivity, 1 for Acoustic)	11.1%

Video

- Wide systems give direct counts and are not estimates. That does not mean there are errors, but they are evaluated.

16. If there are more than one species, do you produce species-specific estimates of fish passage abundance? (Q36 – 10 answered 3 skipped)



Answer Choices	**Number**	**Overall Percentage**
Yes	7 --- (2 for Resistivity, 4 for Optical, 1 for video)	70.0%
No	3 --- (2 for Resistivity, 1 for Acoustic)	30.0%

17. Do you account for uncertainty in your estimates of fish passage abundance by including uncertainty in counter accuracy or species identification? (Q38 – 8 answered 5 skipped)

Answer Choices	**Number**	**Overall Percentage**
Uncertainty is not accounted for	6 --- (2 for Resistivity, 2 for Acoustic, 2 for Optical)	75.0%
Bootstrapping	1 --- (1 for Resistivity)	12.5%
Simulations (e.g. Monte Carlo)	1 --- (1 for Resistivity)	12.5%

Video

- Uncertainty is evaluated from different parameters: water flow, turbidity, etc.

Optical

- Uncertainties are classed as sea trout or later brown trout rather than salmon due to previous experience and video analysis.

18. Which would help improve your analyses and generation of fish passage abundance estimates? Pick all that apply. (Q41 – 7 answered 6 skipped)

Answer Choices	**Number**	**Overall Percentage**
Accounting for uncertainty	4 --- (1 for Resistivity, 1 for Acoustic, 2 for Optical)	57.1%
Automation of estimating fish passage abundance	5 --- (2 for Resistivity, 2 for Acoustic, 1 for Optical)	71.4%
Species-specific fish passage abundance estimates	5 --- (2 for Resistivity, 1 for Acoustic, 2 for Optical)	71.4%
More accurate fish passage abundance estimates	6 --- (2 for Resistivity, 2 for Acoustic, 2 for Optical)	85.7%
More precise fish passage abundance estimate	3 --- (1 for Resistivity, 1 for Acoustic, 1 for Optical)	42.9%

19. Do you know approximately total installation cost in GBP and what year they were incurred? (Q45 – 5 answered 8 skipped)

Optical

- £25,000 (2010)
- £20,000 (2007)
- £25,000 (2008)

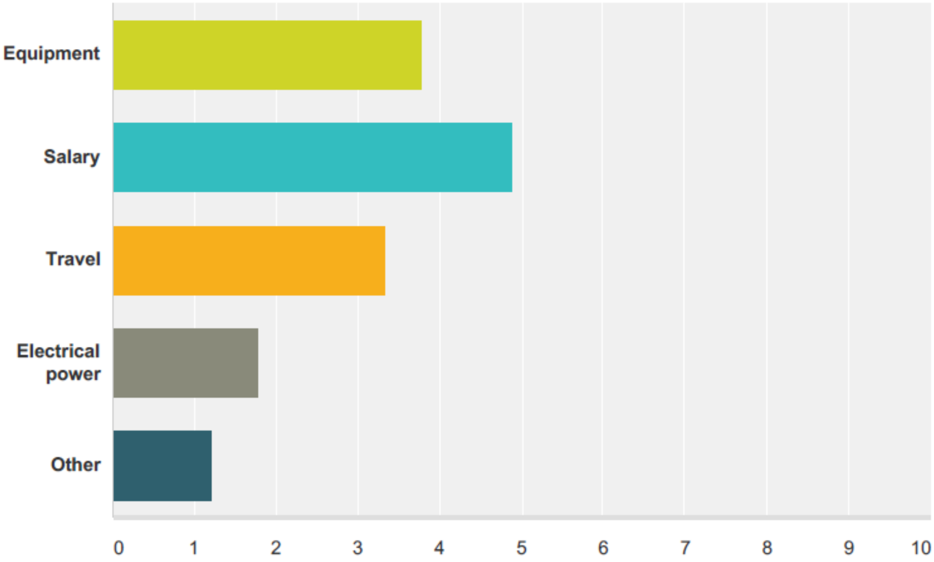
Resistivity

- £250,000 (1980) -- Logie, <£10,000 (1990) -- Westwater

Acoustic

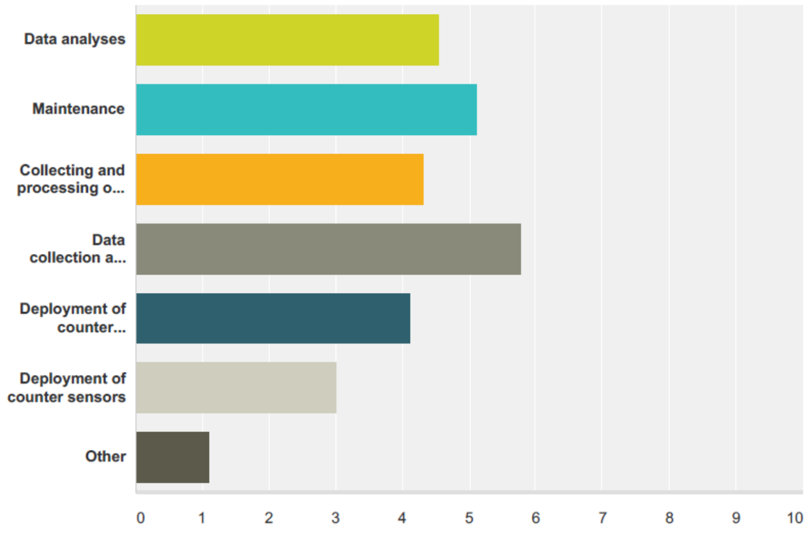
- £80,000 for five year (1996 to 2001)

20. Please rank the types of counters operation costs, where the most costly operating cost is ranked 1st and the least costly operating cost is ranked 5th. (Q47 – 9 answered 4 skipped)



	1	2	3	4	5	Total	Score
Equipment	**11.11%** 1	**55.56%** 5	**33.33%** 3	**0.00%** 0	**0.00%** 0	9	3.
Salary	**88.89%** 8	**11.11%** 1	**0.00%** 0	**0.00%** 0	**0.00%** 0	9	4.
Travel	**0.00%** 0	**33.33%** 3	**66.67%** 6	**0.00%** 0	**0.00%** 0	9	3.
Electrical power	**0.00%** 0	**0.00%** 0	**0.00%** 0	**77.78%** 7	**22.22%** 2	9	1.
Other	**0.00%** 0	**0.00%** 0	**0.00%** 0	**22.22%** 2	**77.78%** 7	9	1.

21. **Please rank the main annual counter operator activities in order of cost, where the most costly operating activity is ranked 1st and the least costly operating activity is ranked 7th. (Q48 – 9 answered 4 skipped)**



	1	2	3	4	5	6	7	Total	Score
Data analyses	11.11% 1	22.22% 2	22.22% 2	22.22% 2	0.00% 0	22.22% 2	0.00% 0	9	4.56
Maintenance	44.44% 4	0.00% 0	11.11% 1	22.22% 2	11.11% 1	11.11% 1	0.00% 0	9	5.11
Collecting and processing of validation data	0.00% 0	11.11% 1	33.33% 3	33.33% 3	22.22% 2	0.00% 0	0.00% 0	9	4.33
Data collection and processing	33.33% 3	33.33% 3	22.22% 2	0.00% 0	11.11% 1	0.00% 0	0.00% 0	9	5.78
Deployment of counter infrastructure (e.g. fence to funnel fish into the counting area of the river)	11.11% 1	33.33% 3	0.00% 0	0.00% 0	22.22% 2	33.33% 3	0.00% 0	9	4.11
Deployment of counter sensors	0.00% 0	0.00% 0	11.11% 1	22.22% 2	33.33% 3	22.22% 2	11.11% 1	9	3.00
Other	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	11.11% 1	88.89% 8	9	1.11

22. How many person-days are used each year to operate the counter? (Q49 – 8 answered 5 skipped)

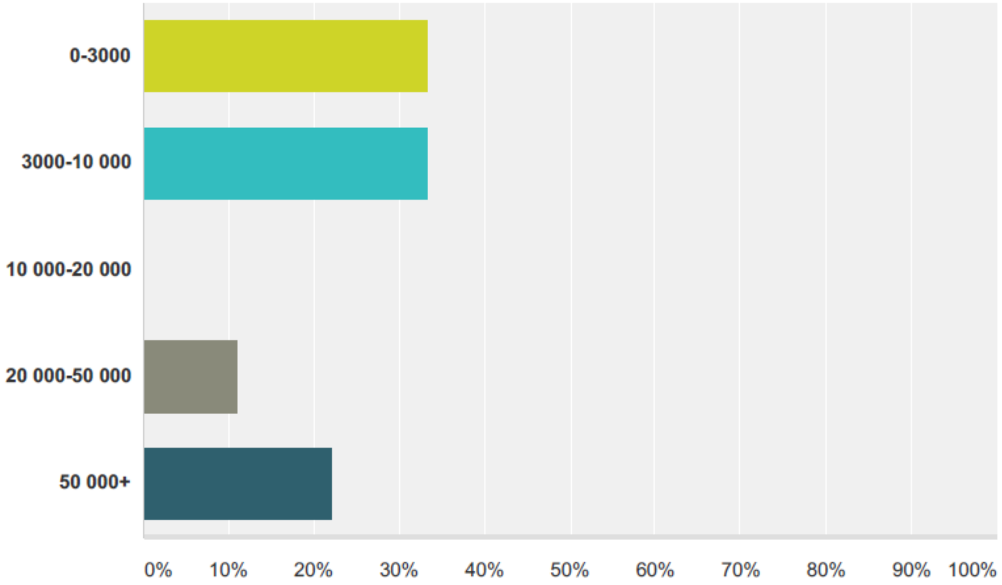
Acoustic
- Approx. 60 person days for one sonar project/year
- 200+ days

Optical
- 7 days V
- 25 days V
- 27 days V
- 20 days V

Resistivity
- 25 days
- 50 days per site

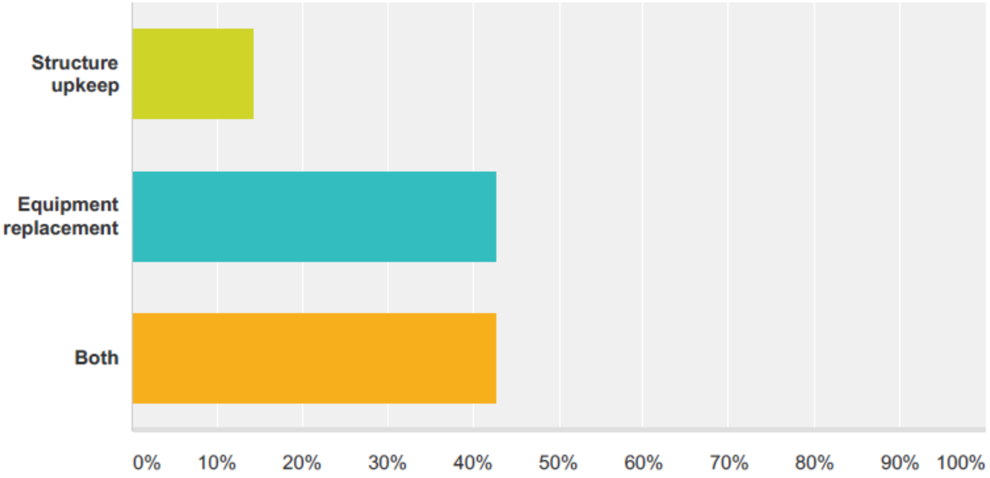
Video
- 60 days

23. What are the approximate annual operating cost of the counter? Values are in GBP. (Q50 – 9 answered 4 skipped)



Answer Choices	Number	Overall Percentage
0-3000	3 --- (1 for Resistivity, 1 for Acoustic, 1 for Optical)	33.3%
3000-10000	3 --- (3 for Optical)	33.3%
10000-20000	0	0.0%
20000-50000	1 --- (1 for Video)	11.1%
50000+	2 – (1 for resistivity, 1 for acoustic)	22.2%

24. What non-annual cost are associated with counter operations? (Q51 – 7 answered 6 skipped)



Answer Choices	Number	Overall Percentage
Structure upkeep	1 --- (1 for Optical)	14.3%
Equipment replacement	3 --- (1 for Acoustic, 1 for Optical, 1 for video)	42.9%
Both	3 --- (1 for Resistivity, 2 for Optical)	42.9%

Appendix 3. Permit Costs

Introduction

Northwest Hydraulic Consultants Ltd. (NHC) was requested to investigate the expected permitting environment and costs associated with the construction of new weir structures associated with the Scottish Salmon Counter Network (the Project). These costs are required as background and additional information related to the construction and implementation cost estimates. There may be other costs to consider of providing additional data needed in support of permit applications, including for example in the case of structures to be put into a fish pass evidence that this would not result in the fish pass no longer providing any minimum flow laid down in the Controlled Activities Regulations licence.

Environment

NHC examined available online information and references related to the permitting environment in Scotland, and the likely roles and agencies that would be involved in the construction of a weir structure for a fish counter installation. We also contacted associates in the UK and discussed the type of project and expected permitting requirements. Our assumptions were:

- The permitting would be similar regardless of the project proponent.
- The permitted structure was a simple weir that did not impound or abstract water.
- There was an ancillary structure associated with the weir that occupied less than 10 m^2 (e.g. data collection platform, equipment, etc.).
- The structure was located on private lands and access is controlled or restricted.

Permitting

1. SEPA Permitting

You must be authorized by Scottish Environment Protection Agency (SEPA) if you carry out any controlled water activity (CAR). A *controlled activity* is any activity which directly or indirectly has, or is likely to have, a significant adverse impact on the water environment. This includes:

- any activity liable to cause pollution of the water environment, such as the discharge of a pollutant into water
- abstraction of water
- construction, alteration or operation of impounding works in surface water or wetlands
- carrying out building or engineering in or near to inland water or wetlands
- artificial recharge or augmentation of groundwater.

Based on our current understanding, the construction of a fish counter weir across a river in Scotland is an engineering works and a potential impoundment, and subject to general binding rules (GBR), registration and licensing.

The document - The Water Environment (Controlled Activities) (Scotland) Regulations 2011 (as amended) - A Practical Guide – provides specific guidance to the permitting environment for engineering structures. This is important with respect to the determination of either *simple* or *complex* licensing. Based on Table 5 (pg. 31) of the guide, most new fish counting weirs spanning the entire river would require complex licensing. The application process to obtain a permit can be competed online (http://apps.sepa.org.uk/WfdReg/pages/welcome.aspx).
Based on the current charging scheme for controlled activities, (http://www.sepa.org.uk/regulations/authorisations-and-permits/charging-schemes/charging-schemes-and-summary-charging-booklets/#CurrentChargingScheme), the fees would include the online application (£82 per activity) and complex licencing fees (£3013). The works would be subject to a subsistence charge (pg. 18). The expected maximum value of this charge should not exceed £3233 per annum.
The total potential fees are:

Application: £82
Complex Licence: £3013
Subsistence Charge: £3233 per annum.

However, according to Clause 6, SEPA may waive the both application and subsistence charge (the licence charge may still apply) for activities deemed to be and "Environmental Service". Annex III of the *Water Environment Charging Scheme Guidance* (2015) document outlines the groups of activities that would be considered for an exemption.

We conclude that the proposed fish counting weirs and structures under the Project likely fall under Clause 4 – "Maintenance of native fish populations", and would be exempt from all application, licencing and subsistence charges.

2. Local Government Permitting

The next potential permitting issue may be a local government building permit or local government Planning Permission.

Local Authorities must abide by Scottish National Heritage (SNH) policies and must issue a building permit for the construction of any structure. As an example, to obtain a building permit ("planning permission") from the City of Edinburgh council, and application can be filled online (https://eplanning.scotland.gov.uk/WAM/).
Fees for planning vary from £202 for small changes, £401 for "changes of use" and new houses and go up to a maximum of £20 055 for larger developments. There is an online fee calculator. Based on the structure being a non-residential building with a footprint of 75 m² or less, the fees will be £401.
It is not known whether the weir structure or ancillary work would be subject to this level of local government approvals, and this may be best dealt with on a case-by-case basis.

3. Application Costs

Depending on the determination of applicable permitting environments and status of SEPA exemption, NHC estimates that 2-5 days of time would be required per installation for development of the application packages, presentation to the regulator and amendments or questions. At a daily rate of £400 per day, the application charges may range from £800 to £2000 per project.

Closure

We trust this memorandum documents the necessary information for the Scottish Fish Counting Structures - Permitting Environment and Costs. For further information or detail, please contact any of the undersigned

Northwest Hydraulic Consultants LTD.
Barry Chilibeck, MASc, PEng APEGBC #17430
Principal

NOTIFICATION
This document has been prepared by Northwest Hydraulic Consultants Ltd. in accordance with generally accepted engineering and geoscience practices and is intended for the exclusive use and benefit of the client for whom it was prepared and for the particular purpose for which it was prepared. No other warranty, expressed or implied, is made.

Northwest Hydraulic Consultants Ltd. and its officers, directors, employees, and agents assume no responsibility for the reliance upon this document or any of its contents by any party other than the client for whom the document was prepared. The contents of this document are not to be relied upon or used, in whole or in part, by or for the benefit of others without specific written authorization from Northwest Hydraulic Consultants Ltd. and our client.

References for Appendix 3

SEPA (2015) The Water Environment (Controlled Activities) (Scotland) Regulations 2011 (as amended) – A Practical Guide.
URL: http://www.sepa.org.uk/media/34761/car_a_practical_guide.pdf (accessed on 7 January 2016)

SEPA (2015) Water Environment (Controlled Activities) Fees and Charges (Scotland) Scheme 2015.
URL: https://www.sepa.org.uk/media/143534/water_environment_charging_scheme_2015.pdf (accessed 7 January 2016)

SEPA (2015) Water Environment Charging Scheme Guidance – Water Environment (Controlled Activities) Fees and Charges (Scotland) Scheme 2015.
URL: http://www.sepa.org.uk/media/143521/water_environment_charging_scheme_guidance_2015.pdf (accessed 7 January 2016)

The Scottish Government
Riaghaltas na h-Alba

Any enquiries regarding this publication should be sent to us at
The Scottish Government
St Andrew's House
Edinburgh
EH1 3DG

ISBN: 978-1-78544-964-2 (web only)

Published by The Scottish Government, February 2016

Produced for The Scottish Government by APS Group Scotland, 21 Tennant Street, Edinburgh EH6 5NA
PPDAS63552 (02/16)