Evaluation of Aerial Surveys for Assessing Sardine Abundance in British Columbia, 2008-2011

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EVALUATION OF AERIAL SURVEYS FOR ASSESSING SARDINE ABUNDANCE IN BRITISH COLUMBIA, 2008-2011

by

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ABSTRACT

Flostrand, L., and Schweigert, J. 2014. Evaluation of aerial surveys for assessing sardine abundance in British Columbia, 2008-2011. Can. Manuscr. Rep. Fish. Aquatic. Sci. 3041: v + 92 p.

A variety of aerial survey methods were tested to detect and characterize summer Pacific Sardine (*Sardinops sagax*) biomass in British Columbia (BC) waters in 2008-2011. The interest to explore the feasibility of the different methods was linked to development of a United States (U.S.) aerial survey Sardine biomass index that was incorporated into the California Current Sardine population assessment in 2009. Between years, the methods deployed in BC varied by type of plane and aviation service, image recording method, survey design and spatial coverage. This report provides an overview of the methods and outcomes from the BC surveys and evaluates their effectiveness for acquiring data needed to develop indices of Sardine biomass. From evaluation of the methods tested in BC in relation to the methods deployed in the U.S., the authors conclude that the use of *Compact Airborne Spectrographic Imager* (CASI) technology to acquire and analyze imagery data appears to be superior to other methods if the data are collected from altitudes greater or equal to 4000 feet by a twin engine plane. However, the authors do not support aerial surveys as the most feasible option for developing an index of Sardine biomass in BC because of variable weather conditions that can obstruct survey efforts throughout the extensive coast, limited seasonal availability of applicable aviation services, and relatively high costs and uncertainty in the results associated with of image analyses.

RÉSUMÉ

Flostrand, L. et Schweigert, J. 2014. Évaluation des relevés aériens utilisés pour évaluer l'abondance de la sardine en Colombie-Britannique de 2008 à 2011. Rapp. manus. can. sci. halieut. aquat. 3041 : v + 92 p.

Diverses méthodes de relevé aérien ont été testées pour détecter et caractériser la biomasse estivale de la sardine du Pacifique (*Sardinops sagax*) dans les eaux de la Colombie-Britannique (C.-B.) entre 2008 et 2011. L'intérêt d'explorer la faisabilité de différentes méthodes découle de la création par les États-Unis (É.-U.) d'un indice de la biomasse de sardines préparé au moyen de relevés aériens. Cet indice a été incorporé dans l'évaluation de la population de sardines du courant de Californie en 2009. D'une année à l'autre, les méthodes déployées en C.-B. ont varié sur plusieurs points, dont les types d'avions et de services d'aviation utilisés, les méthodes de capture d'image, la conception des relevés et la couverture spatiale. Le présent rapport fournit un aperçu des méthodes et des résultats des relevés de la C.-B. et évalue leur efficacité vis-à-vis de l'obtention des données nécessaires pour créer les indices de la biomasse des sardines. En évaluant les méthodes testées en C-.B. comparativement aux méthodes déployées aux É.-U., les auteurs concluent que l'utilisation de la technologie d'*imageur spectrographique compact aéroporté* (CASI) pour acquérir et analyser les données d'imagerie semble être supérieure aux autres méthodes, si les données sont recueillies à des altitudes supérieures ou égales à 4000 pi par un avion bimoteur. Toutefois, les auteurs ne sont pas d'avis que les relevés aériens sont l'option la plus réalisable pour la mise au point d'un indice de la biomasse des sardines en C.-B.; les conditions météorologiques variables peuvent nuire aux efforts de relevé partout sur la très longue côte, la disponibilité saisonnière des services d'aviation convenables est limitée, et l'analyse des images représente un coût relativement élevé et des résultats incertains.

INTRODUCTION

Pacific Sardine (*Sardinops sagax*) from the Northeast Pacific (California Current) population has a distribution that can range between Baja California to Southeast Alaska (Schweigert 1988, Ware 2001). In winter and spring months, most of the Pacific Sardine population resides in waters off the California coast but prior to, and during summer months, large aggregations of Pacific Sardine migrate to forage in more northern and nutrient rich waters. The population collapsed in the late 1940s and was recovering slowly through the early 1990s when sardine first reappeared off southern Vancouver Island (Hargreaves et al 1994, McFarlane et al 2005). Subsequently, efforts to develop and improve scientific monitoring of this population in the United States of America (U.S.), Canada and Mexico evolved through collection of rangewide stock assessment data and annual meetings of the *Trinational Sardine Forum*. The U.S. has conducted annual stock assessments of the coastwide population incorporating fisheries data from all three nations and research data collected from U.S. and British Columbia (BC) waters to set harvest limits domestically. Results from these assessments have formed the basis of harvest advice in Canada. The *Trinational Sardine Forum* has enabled information related to sardine fisheries, fisheries management and research to be shared among participants in the three countries to improve understanding of population dynamics and resource management (e.g. Flostrand et al 2011).

Information on the seasonal distribution, size composition and strength of recruiting year classes is important to characterize and predict trends in sardine population biomass and migration. Prior to 2009, biological data used to inform the Sardine population stock assessments were primarily from commercial fishing catches and research vessel surveys (Hill et al 2008). Following the large recruitments from the 2003 and 2005 sardine year classes, representatives of the U.S and Canadian sardine fishing industries expressed concern about the apparent discrepancy between biomass estimates produced by stock assessments and observations made on the fishing grounds. Observations from fishing activities included those from acoustic soundings and spotter plane overflights.

A consortium was formed by the U.S. West Coast sardine industry to develop a credible index of Sardine abundance through U.S. Pacific coast aerial survey methods and a pilot study was conducted off Oregon in 2008 (Wespestad et al 2008). The methods were reviewed by U.S. Stock Assessment Review (STAR) panels in May and September of 2009, following which the U.S. Pacific Fisheries Management Council (PFMC) endorsed the development and inclusion of an aerial survey biomass index into the stock assessment model. Full-scale U.S. aerial surveys were subsequently performed jointly by the *Northwest Sardine Survey LLC* and *California Wetfish Producers Association* in 2009 and 2010 and then by the *Northwest Sardine Survey LLC* alone in the coastal waters off Washington and Oregon in 2011-2013. Results from the 2009-2012 U.S. surveys were incorporated into stock assessment models that were used to set U.S. and Canadian fishery harvest allowances for the 2010-2013 fishing years (Jagielo et al 2009-2012; Hill et al 2009-2012; DFO 2012a; DFO 2012b).

During developmental and implementation stages of the U.S. aerial surveys, communication between U.S. and Canadian fishing industry, fishery managers and science representatives occurred to consider the feasibility of conducting summer Sardine aerial surveys over potential Sardine habitat in BC waters. The objectives being to map the distribution of Sardine and to identify and census school numbers and sizes to estimate regional biomass Financial support was provided by the *Canadian Pacific Sardine Association* and the *First Nations Sardine Association* and through the DFO *Larocque* relief program funding from 2008-2011. Compared to the U.S., spotter planes and pilots have not been an integral part of the BC sardine fishery and the summer availability of aviation services in BC equipped to conduct marine aerial photography through extensive systematic surveys was limited. The possibility of employing the same services as those used in the U.S. was considered but issues with cross border contracting and scheduling difficulties prevented that from being a practical option. However, several services that specialize in aerial surveys in BC were identified, each having different combinations of plane type, photographic technology and technical expertise.

Different aerial photography services and methods were deployed each of the years that trials were conducted in BC, partly due to the limited availability of the services during the required time frame. A goal of each BC sardine aerial survey was to spot and photograph verifiable Sardine schools in locations where they were confirmed, or believed to occur, by recent commercial or research fishing observations. This was seen as a key initial validation step linked to the environmental conditions at the time of each survey. In 2008, trials to test the feasibility of combining sardine and cetacean aerial surveys were conducted. In 2009-2011 survey methods were dedicated to systematically photographing surface waters of potential BC sardine habitat to test methods for recording, detecting and quantifying Sardine schools.

This report provides the background and describes the methods, results and conclusions pertaining to aerial surveys undertaken to observe Sardine schools in BC waters in 2008-2011. Information from contractor reports for the 2010 and 2011 BC surveys are included in appendices. Table 1 summarizes some specifications of the BC and U.S. survey methods to assist in comparisons.

Table 1. Summary specifications relating to sardine aerial survey methods applied in BC (2008-2011) and in the U.S. (2009-2013 combined). WCVI=west coast of Vancouver Island; CC= Central Coast of BC; QC= Queen Charlotte (for Sound or Strait); JS= Johnstone Strait; SOG= Strait of Georgia.

Survey	**BC 2008**	**BC 2009**	**BC 2010**	**2011 BC**	**U.S. 2009-2013**
Survey date(s)	October 8 & 9	July 24 & 27	September 21	July 26 & 27	July & August (August & September in 2012)
Service provider	*West Coast Wild Adventures*	*Range & Bearing Corporation*	*Selkirk Remote Sensing Ltd*	*ASL Environmental Sciences Inc.*	*Northwest Sardine Survey LLC;* Jagielo et al (2009-2014)
Regional coverage	WCVI: offshore & nearshore	WCVI: offshore & nearshore	CC, QCI Sound, QC Strait, JS: offshore & nearshore	WCVI, CC, QCI Sound, QC Strait, JS, SOG: nearshore only (<5km)	Oregon, Washington (& California 2009 & 2010), offshore and nearshore
Survey design/ flight patterns	Various: offshore triangular zigzag paths, paths parallel to shore; paths above inlets; circular paths over a fishing boat and where Sardines were believed to be present.	Overlapping transects in north-south orientation	Various: linear transects in east to west orientation and in connecting diagonal paths as well as paths above inlets.	Most flight paths approximately 1 km parallel to shore or above inlets.	Parallel discrete transects each 35 nmi in east-west orientation (ending ~3 nmi from shore), each spaced 7.5 or 15 nmi apart
Transect replication	Same locations surveyed more than once on the same day and on different days at varying altitudes and environmental conditions.	Replicate flight paths and mosaics created to record images from same area with time delay of 10-30 minutes to identify non stationary objects (fish school movement)	No replication of transects but spatial overlap between consecutive images was compared to detect artifacts and identify objects and possible fish schools.	No replication of flight paths. In addition to CASI data collection, digital still photos were taken for use in object verification and reference purposes.	Some replication of sets of transects staggered by 5 nmi occurred. Spacing between transects within a replicate varied between years and areas. High density spacing (7.5nmi) in addition to standard spacing (15nmi) was also used. Portions of some transects were flown multiple times at varying altitudes to get closer views for photography.
Aircraft	Single engine Cessna 180 (with floats)	Twin engine Piper Navajo	Twin engine Piper Chieftain	Single engine DeHavilland Beaver (with floats)	Single engine (i.e. Piper PA18 Super Cub & Cessna 180) and twin engine (i.e. Cessna 336 Skymaster)
Plane speed over ground	100 knots (~185 km/hour)	100 knots	100 knots	100 knots	100 knots

Table 1 continued.

Survey	BC 2008	BC 2009	BC 2010	2011 BC	U.S. 2009-2013
Altitude	1,000 - 7,800 feet	16,000 feet - Air clearance required for restricted airspace.	5,000 feet - Air clearance required for restricted airspace.	Most 1000 -2500 feet.	4000 feet
Main method of image acquisition	Nikon D200 digital camera, Lens: AF-SVR-Nikor, 70-200mm, 1:2.8 G	Canon 5D Mark II digital camera, 21 megapixel 35 mm full frame; 5616x3744 pixel, 16 mm focal length, polarization filter;	Wild RC30; Nominal focal length of 153 mm; Lens Wild Universal Aviogon/ 4-S; Film= Agfa Agiphot x 100 PE1, 100 colour negatives (9'x9'in size); 420 nm antivignetting 2x filter; Exposure 4/640- 4/500.	Compact Airborne Spectrographic Imager (CASI) configured to acquire imagery in 6 spectral channels	Canon EOS 1D Mark III and Canon EOS 5D Mark II (digital cameras). At least 21 mega pixels 24 mm lens
Applied motion compensation	No	Yes	Yes	Yes	Yes
Image records GPS and time stamped	No	Yes	Yes	Yes	Yes
Position of camera	Oblique views from left bubble window from which digital ad hoc photos taken.	Camera belly mounted through vertical port hole	Camera belly mounted through vertical port hole	Cameras belly mounted through vertical port hole	Camera belly mounted through vertical port hole
Area overlap between photographs	None	60% or more	60%	CASI continuous image stream (overlap not required). Digital photographs had 10% area overlap.	60% or more
Enhancement for image analysis	Adjusted contrast and brightness using *Microsoft Office Picture Manager*	Optimized black & white 16 bit 1 Channel Image 40 MB size (more manageable) mosaics, better sub surface classification.	*PCI Geomatica* (& focus image tool) used to screen images, optimize feature detection and prepare overlays for change detection analyses.	CASI image data calibrated into radiance units. Three sets of band products were derived from 6 band CASI multi spectral data.	*Adobe Photoshop* software *(i.e. Lightroom 2.0* software used to make the sardine schools visible. *CS3-Extended* for measuring school size and shape.
Coordinated with sardine fishing	Yes- commercial seiner	Yes- research trawler	No	Yes- research trawler	Yes- commercial seiners (2009-2012)

OVERVIEWS BY SURVEY YEAR

2008: Side window observations from a single engine Cessna 180 float plane

Goals:

- To detect Sardine schools from a float plane with verification from commercial fishing activities and to assess detectability of confirmed school sign at varying altitudes and environmental conditions. These trials were not intended to produce a set of photographic observations that could be analyzed to quantify schools;
- To assess whether cetaceans could be detected, identified to species, and counted in conjunction with Sardine school observations in order to conduct combined surveys.

Methods and observations

Flight trials were planned for and implemented on October 8 and 9th 2008, with the aviation services of *West Coast Wild Adventures* (based out of Ucluelet, BC) and two DFO Science staff as spotters. The plane utilized was a Cessna 180 (single engine float plane, Figure 1), which was synchronized to a Garmin flight logger (GPS, altitude, speed over ground and heading). The nominal plane speed was 100 knots throughout the survey.

Over the two days, a combination of different flight patterns were used to search for Sardine schools in areas where Sardine occurrence had been confirmed an in exploratory areas of potential habitat. Flight patterns included: triangular zigzags extending offshore; linear paths parallel to shore; linear paths over inlets, and circular paths at constant and varying altitudes over fishing boats, whales, marine birds and tideline (Figure 1). The range in survey altitude also varied during the flight paths from 1,000- 7,800 feet (305-2,380m) so that spotters could evaluate the effect on viewing conditions (field of view, contrast, sun glare, ability to resolve detail).

On October 8th, the survey started over Barkley Sound and by 11:10 the plane circled at varying altitudes (2000-4500 feet) over waters of Amphitrite Bank where a commercial purse seine fishing boat had caught sardines earlier that morning. No putative sardine schools were visually detected. The plane then flew at 2500 feet from Pachena Point following southwest and northeast paths and ending in Tofino for refueling and lunch. No putative Sardine schools were visually detected but gulls, humpback whales and krill patches were observed and photographed as possible sign related to the occurrence of Sardine. After refuelling, additional southward and northeast triangular paths extending offshore were surveyed north of Tofino, as well as paths over several inlets (Sidney Inlet and Pretty Girl Cove), all from an altitude of approximately 2000 feet. No sign of Sardine was detected until approximately 17:00 when the plane returned to circle over waters near Amphitrite Bank where a seine vessel was capturing Sardine. All three spotters observed and distinguished large darkened patterns in the water which were determined to be Sardine (patches were 2-3 km long with variable widths) but the dark patches were not fully visible from some angles of the plane. The plane circled the area multiple times and varied altitude within 2000-3500 feet.

On October 8th, environmental conditions for conducting an aerial survey were excellent to good and there was no cloud cover. Winds were generally 5-15 knots, and in some areas of northwest zigzags (after 1500 hours) some whitecaps appeared from winds estimated to be up 20 knots.

On October 9th, survey efforts started over Barkley Sound and by 09:30 the plane first circled at varying altitudes (2000-4500 feet) over waters off Amphitrite Point at 2500 feet. No putative sardine schools were detected. The plane then flew away from Pachena Point and followed westward and northeast paths at 2000-2500 feet. To avoid cloud patches, the headings were altered and the plane descended to 1500-2000 feet. In areas of high cloud, shadows obscured light penetration and created large and variably defined shadows on the water. Spotters noted that cloud shadows would obstruct the ability to detect or differentiate putative sardine sign. Inlets around Flores Island were surveyed at ~4000 feet and ~2000 feet. In some parts of the inlets, the topography of land caused shadows on the water which compromised viewing conditions. The plane returned to waters near Amphitrite Point by 12:10 and circled three more times each between ~2500 feet and 4500 feet. No sardine fishing activity was underway and no Sardine were detected

On October 9th, conditions were good to poor with large patches of fog and cloud in areas offshore, especially in areas off Pachena Point. Cloud or mist diffracted and reduced sunlight and although this generally resulted in less sun glare it also caused less light penetration into the water to detect sub-surface objects. There was a relatively calm sea state for most of the flight time (i.e. swell 2-3m), with winds from 5-20 knots and white caps appearing in coastal waters by 10:30.

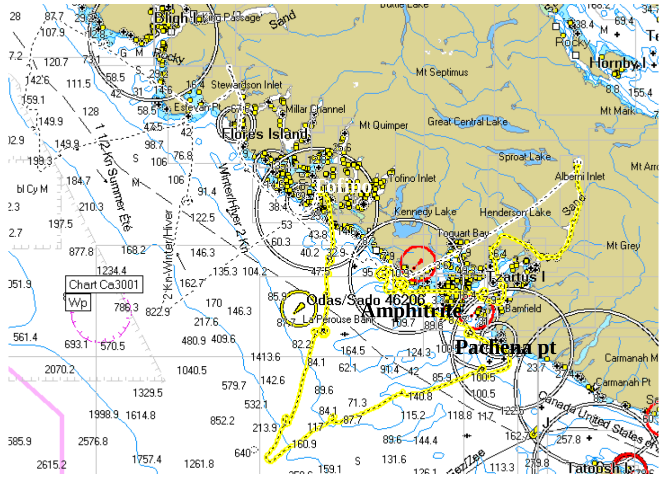
Over the two survey days, a Nikon D200 digital camera was used to photograph putative sign of Sardine schools and other subjects of interest (whales, tidelines, kelp beds, fishing boat, interference from cloud shadow etc.). A total of 25 photographs were taken at vertical and oblique angles out the passenger window (depending on pitch of plane). No clear sign of Sardine was detectable in any of the photographs from unaltered image files and from images enhanced by contrasting and modifying colour using *Microsoft Office Picture Manager*.

Conclusions Spotter detection and photography of Sardine schools during these trials was difficult, even where a large school of Sardine was known to exist. It was determined that combining Sardine and cetacean surveys may not be feasible because at good viewing conditions (low wind, no cloud) cetaceans cannot be reliably identified and counted at altitudes $\geq$ 2000 feet and flying at 1000-1500 feet greatly restricts the field of view for detecting Sardine schools.

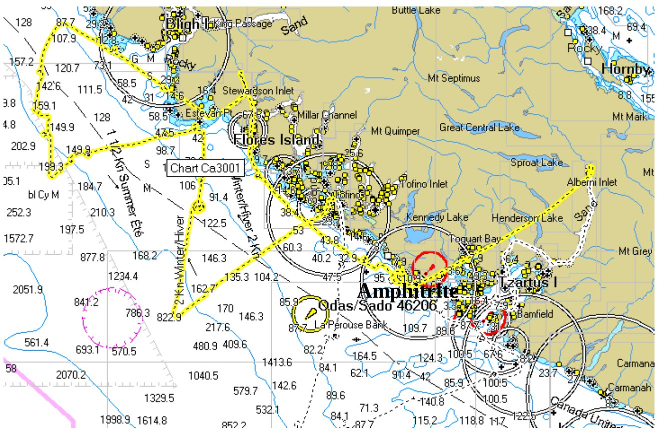
Pros: It was an efficient and relatively inexpensive method of viewing putative Sardine sign and confirming the presence of Sardine related to fishing activities.

Cons: It was not effective at collecting sequential photographs for post survey analyses to detect, verify or quantify putative Sardine schools.

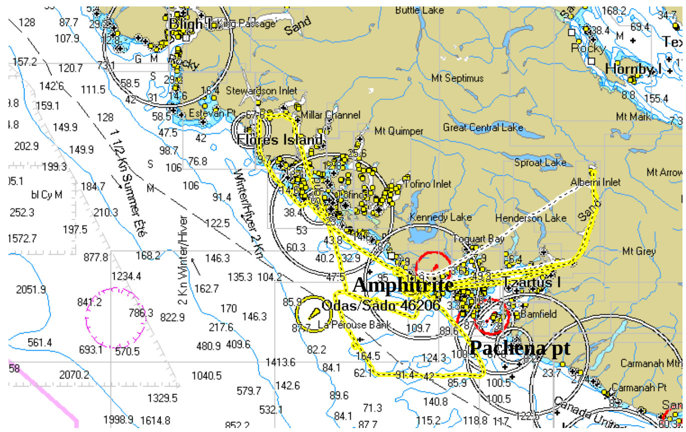
A) Cessna 180 (owned and operated by *West Coast Wild Adventures*).



B) October 8 morning flight paths (before refueling and lunch in Tofino).



C) October 8 – Afternoon flight paths (after refueling and lunch in Tofino).



D) October 9 – Flight paths

Figure 1. The 2008 aerial survey float plane and mapped flight paths (yellow tracks) off the west coast of Vancouver Island (latitudes ranging between 48^o 37'N and 49^o 43'N).

2009: Digital vertical photography from twin engine Piper Navajo

Goals

- To systematically photograph marine waters off the west coast of Vancouver Island to record and detect putative Sardine schools in association with research vessel observations.
- To analyse sets of image files and OrthoPhoto mosaics to characterize and quantify the distribution of observations representing putative Sardine schools.

Methods and observations

Aerial photography services and survey design options were planned with associates of *Range and Bearing Corporation* (based out of Victoria, BC) who implemented the installation of remote sensing and data logging systems on their Piper Navajo twin engine plane (Figure 2). The plane had a porthole window on the bottom of the fuselage from which photographs were taken. Regional coverage and survey dates were planned to overlap with a DFO research vessel trawl survey off the west coast of Vancouver Island so that Sardine observations from trawl sampling could be related to observations from the aerial survey. The trawl survey dates were July 22-August 5 (Appendix A, Flostrand et al 2011,). The nominal plane speed was 100 knots throughout the survey.

Aerial survey dates were July 24 and 27 and photography occurred over linear flight paths that followed due north and south courses. A total of 24 transects were photographed in areas lacking cloud cover and which overlapped with areas where Sardines had been observed by the research trawl vessel. Transect lengths varied from 26-38 km and the total linear distance photographed was approximately 700 km. The widths of effectively photographed ground distances ranged from 4-8 km depending on transect conditions (Figure 2, Appendix B). Approximately 15% of the total area photographed included land features. The spatial overlap between consecutive photographs along a transect was at least 60% and the spatial overlap between widths of adjacent transects was up to 60%. Adjacent overlapping of photographed areas was conducted so that observations would not be missed due to sun glare and other interference compromising image quality. This also enabled the replication of photograhed areas varying in time by 10 to 30 minutes. This replication was used in analyses to detect and differentiate putative Sardine schools from kelp beds by comparing the consistency of observations over time. Analyses which compared images representing the same area and photographed at different times the same day were referred to as “change detection”.

On July 24, two sets of four transects were photographed in areas south of Brooks Peninsula, with one path being completely replicated to provide a complete set of additional views of the same area with time differentials ranging from of 60-90 minutes. Winds were generally at least 15 knots and increased to over 20 knots. Photographs from July 24th show whitecaps from wind distorted surface waters (Figure 3).

On July 27, 16 more transects were completely photographed in areas south of Nootka Sound and off Estevan Point and no transect paths were completely replicated. In addition, one transect was cancelled due to cloud interference. Winds were relatively calm that day (5-10 knots), with very little evidence of whitecaps.

All photography was done using forward motion compensation with a 21 MegaPixel Canon 5D Mark II 35 mm full frame digital camera with a focal length of 16 mm, pixel resolution was 5616 x 3744 and a polarization filter was used. The range in vertical angles captured in photographs from the altitude of 16,000 feet was 90-96.7^o (along track) and 90-73.7^o (across track). The camera imagery was size calibrated by geometric ad boresight calibration methods (from known distances between subjects). Raw colour images were at 48 bit 120 megabytes files. Image files were geotagged into 16 byte single band tiff files and geopositioned into OrthoPhotos. OrthoPhotos of transects were made into line mosaics (GSD of 2.0 m/pixel). To optimize the detection of putative Sardine schools, colour image files were converted to 16 bit black and white 40 megabyte image files and sets of OrthoPhotos were compiled into mosaics for each transect (Figures 3 to 5).

More than 20 separate observations representing putative sardine schools were detected from these survey efforts, all relating to July 24th transects. Furthermore, change detection observations confirmed that shapes and sizes of putative schools changed considerably over short time lapses (Figure 5). Methods to automate change detection observations were considered but were not successfully applied due to photographic interference mainly from weather (such as chop on water, cloud shadows and variable sun glare). Therefore, all putative schools were manually determined and vectors outlining their shapes were traced. The total area of all independent putative sardine schools was estimated to be approximately 4 hectares but analyses did not include quantification of biomass through assumptions of a school surface area to biomass conversion relationship.

Conclusions

Survey methods and photographic imagery of black and white optimized OrthtoPhoto data sets in association with change detection replicates and research vessel observations were able to detect, confirm and characterize sardine schools.

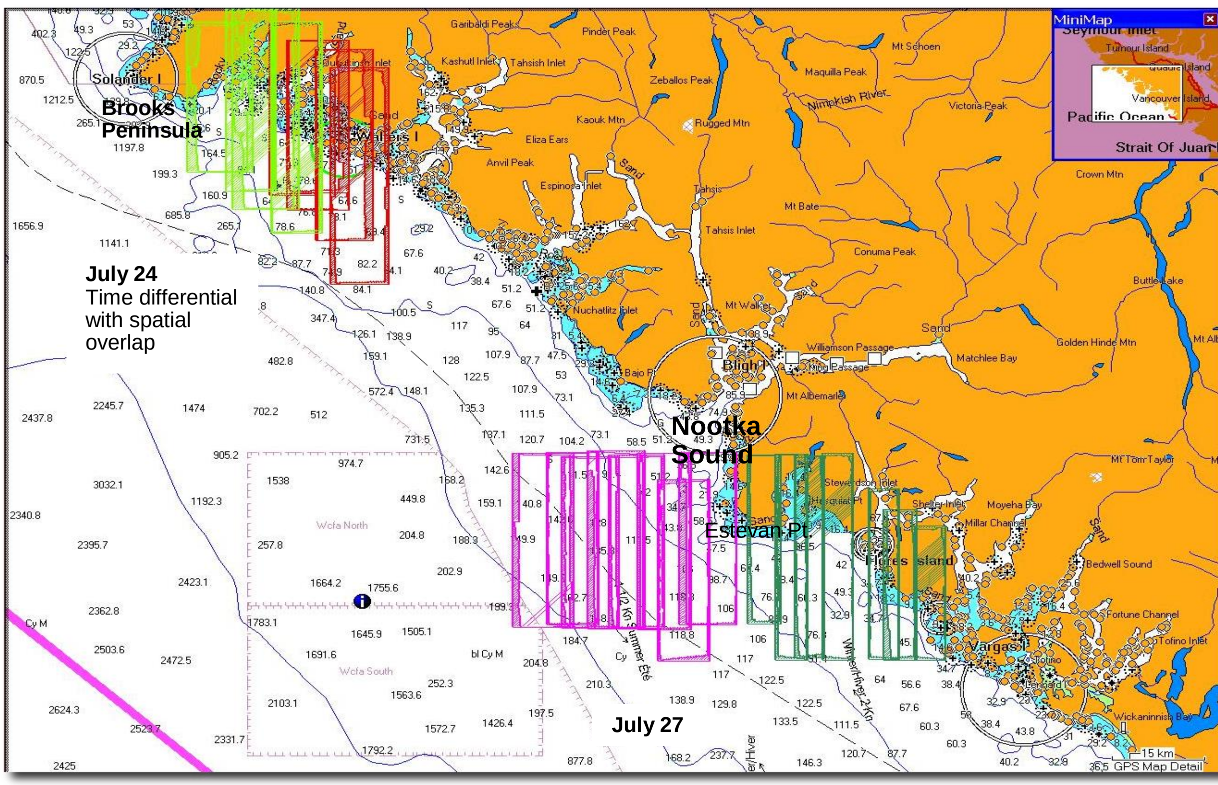
Pros of trials:

1) Able to coordinate flights to areas where research trawl surveys had observed sardines to improve confidence that putative schools were sardine.
2) Able to fly at relatively high altitudes both offshore and nearshore which enabled transects to have wide area coverage for photographing high resolution images.

Cons of trials:

1) Scheduling delays occurred waiting for air clearance into restricted airspace and for days with good survey conditions.
2) Insufficient resources were available for detailed analysis and quantification of images showing putative sardine schools to estimate biomass.

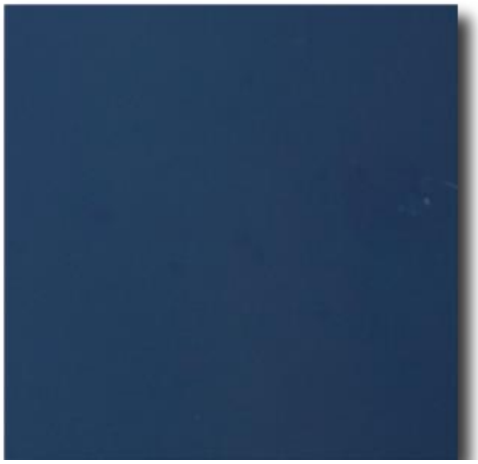
A) Piper Navajo twin engine
(owned and operated by *Range and Bearing Corporation*)



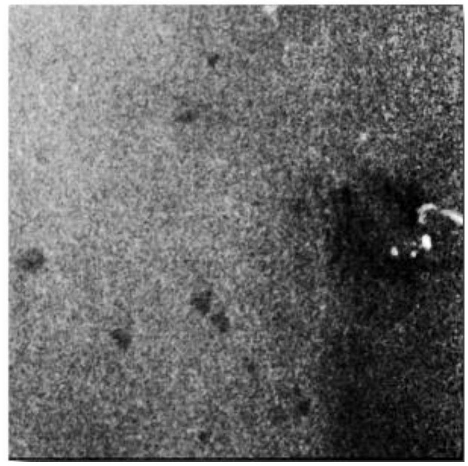
B) 2009 transect coverage

Figure 2. The 2009 aerial survey plane and transect clusters off the west coast of Vancouver Island (1= red, 2=light green, 3= pink, 4=dark green), latitudes range between 49^{o} 8.5'N and 50^{o} 8.3'N.

Figure 3. Example of a complete transect mosaic prepared from July 24 observations (right panel), showing effects of wind (white caps) and solar glare. Close up view of surface water showing effects of wind (left panel).

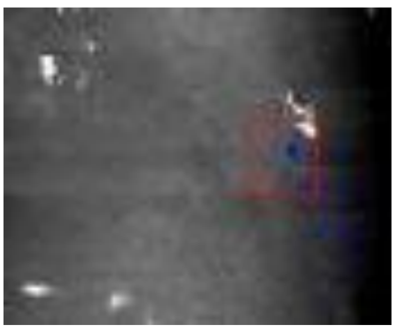


A) from a 48 bit, 120 MB file



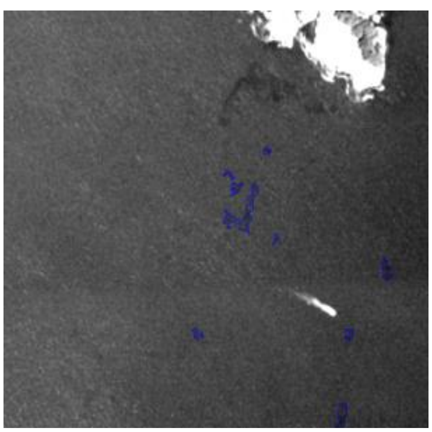
B) from a 16 bit, 40 MB file

Figure 4. An example of image otimization from a 2009 aerial survey photograph showing the raw colour image on the left (panel A) and the black and white contrasted image on the right (panel B).

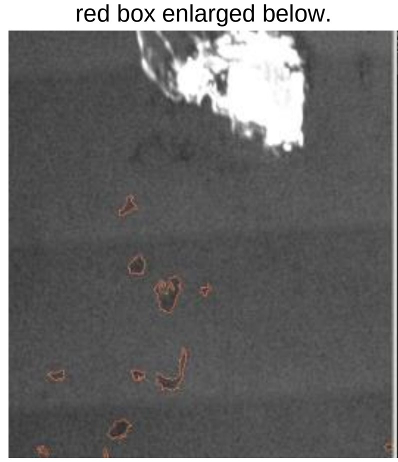


A) Part of Transect 3 mosaic, red box enlarged below.

B) Part of Transect 2 mosaic, red box enlarged below.



C) Enlarged section of Transect 3. Blue patterns outline putative sardine schools. White mark is moving speed boat.



D) Enlarged section of Transect 2. Orange patterns outline putative sardine schools.

Figure 5. Example images collected from the 2009 survey off the west coast of Vancouver Island used in “change detection”analyses. Putative sardine schools identified by variations in object shapes and positions between replicated areas with time differentials of 10-90 minutes.

2010: Vertical photography from twin engine Piper Chieftan using 9 inch film

Goals

- To systematically photograph marine waters off the Central Coast and the northeast coast of Vancouver Island, including the Queen Charlotte and Johnstone straits, to detect putative Sardine schools using aerial linear transects.
- To assess image acquisition and develop processing methods using high resolution print negatives (based on scanning images from negatives) for the purpose of analysing images to characterize and quantify putative Sardine schools.

Methods and observations

Aviation and aerial photography services and survey design options were planned with *Selkirk Remote Sensing Ltd* (based out of Pitt Meadows, BC). Their services included a Piper Chieftan plane (twin engine without floats, Figure 6), with a data logger (gps, altitude, speed over ground, heading) that was synchronized to computer and camera systems. The nominal plane speed was 100 knots throughout the survey.

Although the desired survey period was early to mid August, the survey was delayed until September 21 due to a combination of poor survey conditions (persistent heavy fog over large portions of the coast in early and mid August) and scheduling conflicts with the aviation service having prior commitments. On September 21, flight patterns and aerial photography occurred along east to west (and west to east) linear transects; diagonal linear transects between east and west transects, and paths parallel to shore or over inlets (Figure 6). Twenty-four predetermined transect lines were recorded and an additional 10 sets of *ad hoc* photographs were taken to record sightings of possible sardine sign and other subjects of interest such as whales, tidelines and kelp beds (Appendix C). The order of the transects was based on efforts to to reduce the likelihood of interfernce from fog and and cloud. Aerial photography occurred between the local time of 12:15 and 16:30 and between the latitudes of 50^o, 41.0N' and 52^o,0.0N', with a refueling break in Bella Bella between 13:10 and 14:20. For all transects, a constant survey altitude of 5000 feet was maintained. One spotter was present to note potential Sardine schools and other observations and a technician was present to operate and adjust photography equipment as required. Environmental conditions during the survey were relatively good, with winds varying from 3-8 knots, and clear skies for most of the areas except for southern parts of the region.

All photography was done using forward motion compensation with a Wild RC 30 camera (Figure 6) with a 152.8 mm focal length; a Wild Universal Aviogon lens/4-S; 420 nm antivignetting filter; 4/640 – 4/500 exposure; using 9 inch x 9in Agfa x100 PE colour negative film (processed at *HAS Images Inc*., in Dayton, Ohio). The camera had been calibrated according to United States Geological Survey spatial calibration specifications. Photographs were systematically taken every 10 sec with a 60% overlap between coverage of consecutive images. A total of 516 photographs were taken representing a distance of 423 linear km (by approximately 2 km wide) of unreplicated coastal waters. Exposures from the 9x9 inch film were developed to colour negatives and scanned at 2116.834 dpi to 12 um digital images (19968x19968 pixels) and saved to JPEG TIF files.

All TIF digital image files were viewed and screened in unaltered format to cross reference with transect coverage, spotter notes, and images obscured by cloud or taken over land were identified. To aid in the detection and differention of putative Sardine schools, *ALS Environmental Services Ltd* was contracted to assess image acquisition and to develop processing methods using the 9 inch colour negatives for analysing images to characterize and quantify putative Sardine schools. They provided a report that describes the methods and outcomes of their efforts (Brown et al 2010) and relevant sections of that report are included in Appendix D. Brown et al (2010) found evidence of image contamination from photographic artefacts throughout the set of photographs that needed to be accounted for during subsequent analyses. A subsample of 120 images were selected based on their showing of features such as putative fish schools, fishing boats, possible cloud shadow, kelp beds near land, and interference from sun glare. These 120 images were then further analysed using the *Focus Image* tool of *PCI Geomatica* to enhance imagery. Of the 120 images examined, there were two possible sightings of Sardine schools varying in size and shape but identification confidence was low since no independent observations were made to verify whether Sardines were present in the areas of interest.

Conclusions

Recording to nine inch film and scanning images to digital files from negatives could be an effective method of acquiring high resoluation imagery for analyses; however, it may not be the most economical, efficient and reliable type of data collection compared to alternative methods.

Pros:

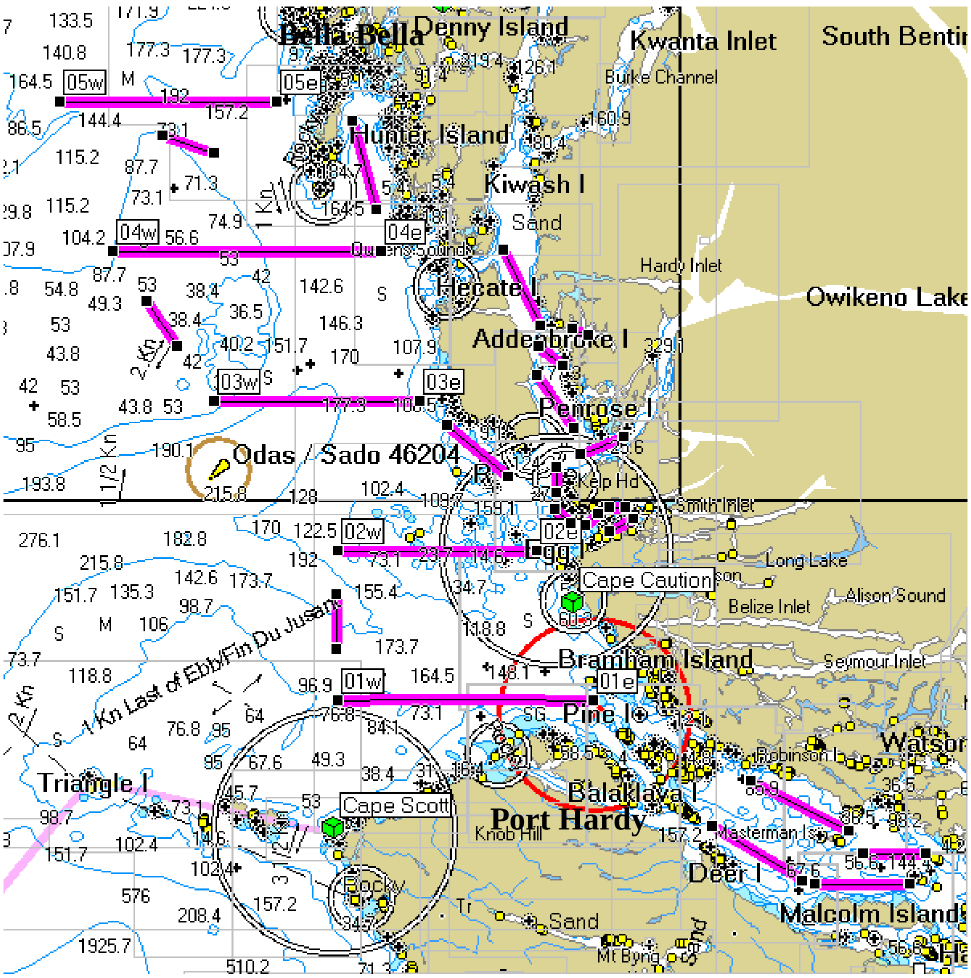
1) The plane was suitable for offshore and high altitude flights.
2) The camera was able to photograph at high resolution at relatively high altitudes (e.g. 5000 feet and more).

Cons:

1) The film negatives and scanned images had contamination from photographic artefacts (horizontal striping, vignetting from lens flare, etc).
2) Several delays in scheduling occurred due to persistent fog or wind as well as the unavailability of technical support (especially the plane). Trials would have been better if conducted one to two months earlier when most Sardine fishing activity was occuring in BC waters. The survey lacked methods to verify the presence of sardine in the areas surveyed, such as from research or commericial fishing observations.
3) The technical team of *Selkirk Remote Sensing* was not experienced with marine aerial surveys and had limited capacity to conduct quantifative analysis of the photos.

A) Piper Chieftan twin engine plane

B) Wild RC camera (using 9x9 inch colour negative film)



A) 2010 transect coverage

Figure 6. The 2010 aerial survey plane, camera and mapped flight paths off the northeast corner of Vancouver Island and Central Coast of British Columbia (latitudes ranging between 50° 41.0’N and 52°,0.0’N).

2011: Compact Airborne Spectrographic Imager (CASI) vertical photography from single engine DeHavilland Beaver float plane

Goals

- To systematically photograph marine waters off the west coast of Vancouver Island, the Central Coast, and the Queen Charlotte, Johnstone and Georgia straits, to detect putative sardine schools using near shore (< 5km) flight paths.
- To have Compact Airbrone Spectrographic Imager (CASI) images analysed to chartacterize and quantify putative Sardine schools for estimating biomass.

Methods and observations

Aerial photography services and survey design options were planned with *ASL Environmental Services Inc*. (based out of Victoria, BC) who coordinated the installation of remote sensing and data logging equipment and chartered the aviation services of *Saltspring Air Ltd*. (based out of Salt Spring Island, BC). A detailed report was written by ALS that describes and discusses methods and results from the survey and analysis of images (Borstad et al 2011) and relevant sections of that report are included as Appendix E.

A DeHavilland Beaver float plane was used which had a porthole on the bottom of the fuselage from which all imagery was recorded. The regional coverage and survey dates were planned to overlap with a DFO research vessel trawl survey off the west coast of Vancouver Island so that Sardine observations from trawl sampling could be related to observations from the aerial survey. The trawl survey dates were July 17-31 (Appendix A, DFO 2012b). Aerial survey dates were July 26 and 27 and aerial photograhy occurred over a combination of flight paths and courses which followed shorelines and inlets (Figure 7). For planning purposes, an altitude of 2500 feet or more was desired but accomodations had to be made to vary altitudes due to regional cloud cover. Due to safety restrictions, the float plane flight paths always remained relatively close to shore. The nominal plane speed was 100 knots throughout the survey.

Four flights (also called transects) were conducted as part of the survey efforts. Flight 1 occurred on July 26 (11:20-15:35) and 446.9 km of the west coast of Vancouver Island was photographed at a nominal altitude of 1500 feet, extending from Barkley Sound to Quatsino Sound. Flight 2 occurred on July 26 (16:25-18:40) and 267.2 km of the sourthern Central Coast was photographed at nominal altitudes of 1000- 1500 feet from Port Hardy to Kitasu Bay (mostly following an outer coastal route to Swindle Island) and from Hoskin Channel along Price Island to Shearwater. Flight 3 occurred on July 27 (10:14-12:49) and 299.0 km of the southern Central Coast was photographed at a nominal altitude of 1000 feet over inshore waters from Shearwater to Port Hardy, and coverage included parts of Spiller Channel, Dean Channel, Fishery Channel, Fitz Hugh Sound, Smith Sound and the Queen Charlotte Strait. Flight 4 occurred on July 27 (14:21-17:39) and 399.4 km was photographed at nominal altitudes of 3000-5000 feet over inshore waters from Port Hardy to Pat Bay (Saanich), and coverage included parts of the Queen Charlotte Strait, Johnstone Strait, Broughton Archipelago and the Georgia Strait.

Two methods of systematically collecting remote images were used. The primary method used CASI equipment configured to six spectral channels, which collected 105 image files, each with continuous vertical views of paths below the aircraft. CASI images were processed to optimize features at three band widths.The second method used a Nikon D90 digital camera which collected 3983 discrete image files of areas that overlapped approximately 10% between sequential frames, resulting from a photograph being taken every 10.8 seconds. Images from the Nikon D90 were intended and used for verification and reference purposes in association with CASI imagery. Nikon digital photos were enhanced through *Adobe Photoshop* as jpg files to increase contrast of objects in images. Additional *ad hoc* digital and video imagery (taken from oblique views of a passenger window) was also collected for comparison to CASI observations. For more information on the methods and results of these analyses, refer to information from Borstad et al (2011) in Appendix E.

Expertise aquired from previous developments using CASI aerial survey technology on capelin in Newfoundland and herring in BC and Alaska (Nakashima and Borstad, 1997, 1998, Funk and Borstad, 1998, Brown et al, 1998) was beneficial to the planning and analysis of the 2011 BC survey efforts. Raw CASI image data received radiometric callibration that converted digital values into radiance units. Three sets of band products were derived from six band CASI multi spectral data. The products are indices that measure 1) absorption by fish schools near 545 nm; 2) fluorescence by phytoplankton near 675 nm, and 3) chlorophyll in plants near 711 nm. From the interpretation of three band products from six band CASI multispectral data, 23 positive and 13 probable detections of different fish schools were noted and the surface area of putative schools were measured. A detection was considered positive if research vessel observations confirmed the presence of sardines in the waters, therefore all positive sightings were from the west coast of Vancouver Island. Probable sightings were made in areas lacking fishing verification, and included observations from the west coast of Vancouver Island (9), the Central Coast (2) and the Queen Charlotte Strait (2). Approximately 70% of the images representing putative fish schools had area estimates that were less than 500 m^2. Using a conversion factor of 0.02 tonnes sardine per meter squared of photographed fish school, derived from U.S. surveys (Jagielo et al 2011) biomass estimates of 225 tonnes and 190 tonnes correspond to 23 positive and 13 possible school sightings, respectively.

<u>Conclusions</u>

Benefiting from the expertise at *ASL Environmental Sciences Inc*, CASI data collection and analytical methods detected putative sardine schools in imagery covering near-shore areas of the BC coast at relatively low costs.

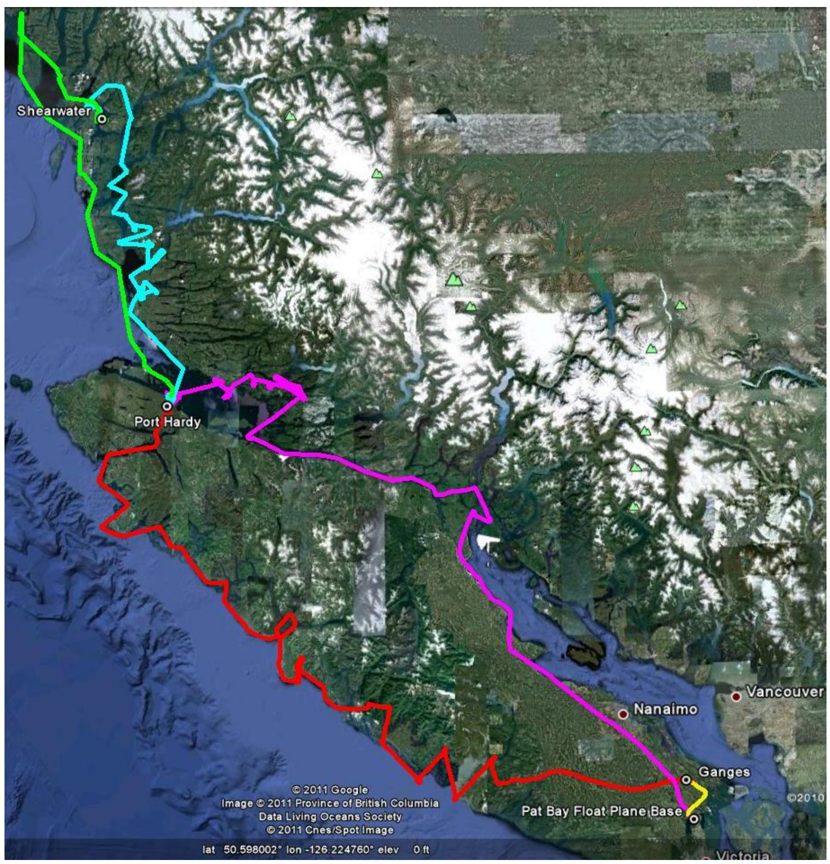
Pros:

1) CASI technology offers continuous images that can be effectively and efficiently analysed to detect and quantify putative sardine schools.
2) *ASL* associates have expertise with pelagic fish surveys and were able to advise on methods to optimize sampling design and data analysis.
3) Other methods of image recording and calibration were used to complement and verify CASI observations.

Cons:

1) The use of a single engine aircraft (with floats) had operational restrictions to remain near shore which excluded large regions of potentially important BC sardine habitat.
2) Lower than planned and desired flight altitudes were realized which reduced field of view (coverage) of image data;
3) The focus quality of the digital photographs was compromised (obtained to complement CASI images) because the camera had been set for higher altitudes, not those realized because of the need to fly below cloud cover (i.e. from 2500 to 1500 feet). *Ad hoc* methods to adjust and optimize digital camera settings would have been beneficial.

A) DeHavilland Beaver float plane (owned and operated by *Saltspring Air Ltd*).



B) 2011 transect coverage

Figure 7. The 2011 aerial survey plane and mapped flight paths (red, green, blue and pink routes) off Vancouver Island and extending north into the Central Coast of British Columbia (latitudes ranging between 48° 50.0' and 52° 40.0').

DISCUSSION

The U.S. stock assessment model used to estimate the abundance of the California Current Pacific Sardine population is strongly influenced by the biomass indices that are included as input data (Hill et al. 2012). Biomass estimates derived from a U.S. led (*National Oceanic and Atmospheric Administration*) acoustic-trawl survey that has extended from the U.S. and Mexican border off northern Baja California to the northwest coast of Vancouver Island, in most years since 2006, have been incorporated into the U.S. sardine assessment model as the primary index (Hill et al 2014). However, since their inclusion in the modelling process in 2009, the U.S. aerial survey estimates of Sardine biomass in U.S. waters have also had a significant influence on the estimates of population biomass and corresponding harvest allowances for the 2010 through 2013 fishing years (e.g. Hill et al 2009, 2010, 2011, 2012). Sardine abundance estimates from the DFO research trawl survey off the west coast of Vancouver Island have not been incorporated into the population assessment model, in part because survey methods are not standardized to how and when surveys have been conducted in the U.S. Similarly, it is unclear how or whether Canadian aerial survey estimates of Sardine abundance could be included into the population assessment model.

After completion of the U.S. summer aerial surveys, data analysis followed a three step process to estimate biomass. The first step involved Stage 1 sampling to obtain measurements of individual school surface areas on aerial photographed transects. The second step involved Stage 2 sampling to obtain aerial photographed fish school surface area measurements that relate to individual school biomass estimates derived from purse seining and acoustic soundings (referred to as point sets), and the third step encoporated a statistical framework for estimating total regional biomass from transect sampling (Jagielo et al 2014). Stage 1 sampling methods employed a belt transect design which included systematic random sampling based on 64.8 km (35 nmi) length transects aligned in parallel in an east to west orientation perpendicular to the coastline, spaced apart latitudinally either 27.8 km (15 nmi) or 13.9km (7.5 nmi), such as depicted in Figure 8. The desired survey altitude was 4000 feet, which provided photographs representing width coverage of the earth's surface of approximately 1800m. Photographs were taken at time frequencies which enabled an area overlap of at least 60% between consecutive frames. To improve statistical coverage of biomass estimates, replication of complete sets of transects was planned for each survey year but replication was generally compromised due to logistical difficulties and cost restrictions (Jagielo et al 2009, 2010, 2011, 2012, 2014).

The distribution of surface area measurements of putative Sardine schools resulting from the 2011 BC trials is consistent with observations made from U.S. aerial surveys, whereby most measurements were less than 1200m^2 and peak frequencies were less than 500m^2 (Figure 9). Unlike the U.S. surveys, BC methods and coverage varied between years and did not include any Stage 2 sampling. BC observations lend themselves mostly to proof of concept applications rather than to informing on seasonal biomass.

Despite the adoption of aerial survey methods by the U.S., questions about their effectiveness remain. A review of the methodology conducted in the U.S. in 2009 identified several sources of uncertainty and bias that can affect Sardine biomass estimates from aerial surveys, including how reduced survey coverage and poor viewing conditions can negatively bias estimates. Loss or reduction in survey coverage arises from having to fly at lower altitudes than planned to avoid cloud cover and from not flying an area at all due to extreme weather interference such as from fog or storms. Effects from variability in water quality conditions (clarity, colour, chop), tidal currents, sea bottom, shoreline topography and fish behaviour (especially vertical distribution) can introduce unknown levels of error but generally towards a negative bias. Therefore, if all other sources of error could be ignored, it would be expected that biomass estimates from aerial surveys would result in minimum estimates of abundance (PFMC 2009, Jagielo et al 2014). The 2013 U.S. aerial survey coverage was greatly reduced due to weather resulting in poor viewing conditions. Consequently, the resulting biomass estimate was dubiously low and omitted from the 2014 stock assessment model because even as a minimum estimate it had little utility (Jagielo et al 2014; Hill et al 2014).

The review of the U.S. sardine aerial survey method also outlined several concerns and recommendations related to the possible bias of overestimating biomass due to the misidentification of sardine schools (PFMC 2009). The recommendations included: correlating aerial observations with research vessel or commercial fishing information in nearby areas; cataloging ground truthed images of schools of different species from different altitudes for use in photographic analyses; replicating survey coverage at lower altitudes to obtain more detailed observations, and characterizing multiple sardine biomass and school surface area relationships (Stage 2 sampling) for the variety of school sizes and shapes as well as from both offshore and near shore schools.

Without some additional sampling to confirm species identification and distribution and to develop school surface area to biomass conversion estimates, any potential biomass observed by aerial surveys would have low confidence. The relatively high confidence of assigning Sardine to the fish schools detected in the 2008, 2009 and 2011 BC aerial survey trials was based on correlations with fishing observations. Coordinating fishing vessel observations with aerial survey coverage may be expensive and logistically difficult, especially for assigning biomass estimates to school sizes. This has been the experience with the U.S. survey efforts, where Stage 2 sampling has been curtailed most years and realized sample sizes are smaller than desired, especially in 2013 (Jagielo et al 2014). Furthermore, due to the high degree of variabiliy in the school surface area and biomass relationships, there is a high degree of uncertainty associated with regression estimates (Figure 9c).

The costs of image analyses need to be accounted for in the planning and delivery of aerial survey programs because image analyses may be very costly depending on the level of effort required. During the analytical stages of reviewing image data from the U.S. and BC aerial surveys, no automated algorithms were used to detect and quantify putative Sardine schools due to the high level of error that could introduce. Although image enhancement methods were important in these analyses, interpretation of image data related to school detection and quantification was done manually. The quality of the results from image analyses is subject to the expertise of the analysts and variability among analysts may affect the error structure of the results (e.g. Jagielo et al 2011, 2012). The U.S. photographic datasets were analysed using both colour and black and white software enhancement (i.e. *Adobe Photoshop* related software, Jagielo et al 2009-2014). Image analysts from the 2009 and 2011 BC trials concluded that fish schools were difficult to differentiate in colour images (true or infrared band composites) and enhancement of black and white images produced the best quality observations (D.Campbell *pers comm;* Borstad et al 2011). For the 2009 BC trials, subsurface kelp and rock viewed in black and white or colour images appeared similar to fish schools. Thus change detection analysis was useful to try to differentiate fish schools from other observations, but change detection requires replication of the surveyed areas within a short time interval, which adds extra costs to survey coverage and photo-analyses and may be considered inefficient. Whereas for the 2011 BC trials that employed CASI technology, data collection, processing and analytical methods applied by Borstad et al (2011) were reliable at differentiating fish schools from kelp, algae blooms and rocks from single flight path observations, therefore were thought to be quite efficient. This is because their methods were based on prior knowledge associated with radiance imagery and multispectral data algorithms.

The conclusion from comparing the effectiveness of the different aerial survey methods for the purpose of characterizing Sardine biomass in BC waters, is that the best approach would be to use CASI technology with a twin engine plane that can fly at altitudes greater or equal to 4000 feet. A twin engine plane would be more expensive than a single engine floatplane but would facilitate offshore survey coverage, so that transect designs similar to that applied in the U.S. could be applied. Under clear skies, the CASI technology could be configured to optimize survey coverage at 2.6 x 2.6m pixels from a height of 6,860 feet, which would provide excellent and detailed coverage (Borstad et al 2011). Some type of Stage 2 would be needed to complement CASI observations for the purposes of species identification and to relate Sardine school area observations to biomass estimates. We also recommend that efforts be made to standardize the survey design as much as possible so that it is comparable between years and comparable to the U.S. survey design.

We conclude that it may not be feasible to rely on aerial surveys to characterize sardine biomass in BC waters over large regions of the coast when there is time sensitivity in obtaining observations. Logistical difficulties realized when planning and implementing BC aerial surveys were comparable to those incurred in the U.S. surveys. Hinderances from weather, (low cloud, fog and heavy winds) caused delays in survey scheduling as well as considerable loss of survey coverage. The extensive, remote and complex coast of BC that offers potential seasonal Sardine habitat also imposes safety concerns for marine aerial surveys, including limited refueling opportunities. Another logistical detail common to all BC aerial surveys was the necessity to be aware of Canadian Department of National Defense and Transport Canada air restrictions and requirements for obtaining pre-authorization to fly in restricted airspaces (Figure 10). Airspace restrictions can vary depending on survey areas, dates and altitudes because clearance is subject to factors such as planned military activities.

We do not recommend that aerial surveys be used to replace vessel surveys to observe Sardine biomass in BC. Although under the right environmental conditions an aerial survey can efficiently cover larger areas than a vessel survey, aerial surveys are more likely to be interrupted by logistical difficulties due to weather (which increases costs and reduces coverage). Furthermore, aviation services in BC that are available to respond to imposed scheduling changes may be limited. Aerial surveys also require some coordination with fishing activities to identify the species and validate putative sardine schools and biomass relationships and are less effective at detecting the presence of sardine at sub-surface depths than fishing vessels.

Hill et al. (2014) suggest how aerial surveys could be used to evaluate uncertainty associated with vessel surveys. For example, aerial surveys could be used to evaluate the potential ‘blind’ areas within the upper 10 m of the water column of acoustic-trawl survey’s and/or aerial surveys could be directed to regions of the coast missed by vessel surveys. Potential applications are relevant to improving survey coverage in BC waters since there has been considerable uncertainty in the extent of the northward migration of the Sardine population and corresponding seasonal biomass (DFO 2012b), especially in seasons when migrations extend outside the regions routinely surveyed by vessels and when there is considerable in-season variability in distribution.

Additionally, the future application of satellite imagery data to characterize the quality of potential Sardine habitat based on the spatial distributions of chlorophyll and sea surface temperatures and their congruence with observed seasonal Sardine distributions could be used to assist in planning and defining priority regions for surveys, potentially reducing overall costs of either vessel or aerial surveys (Zwolinkski et al 2011).

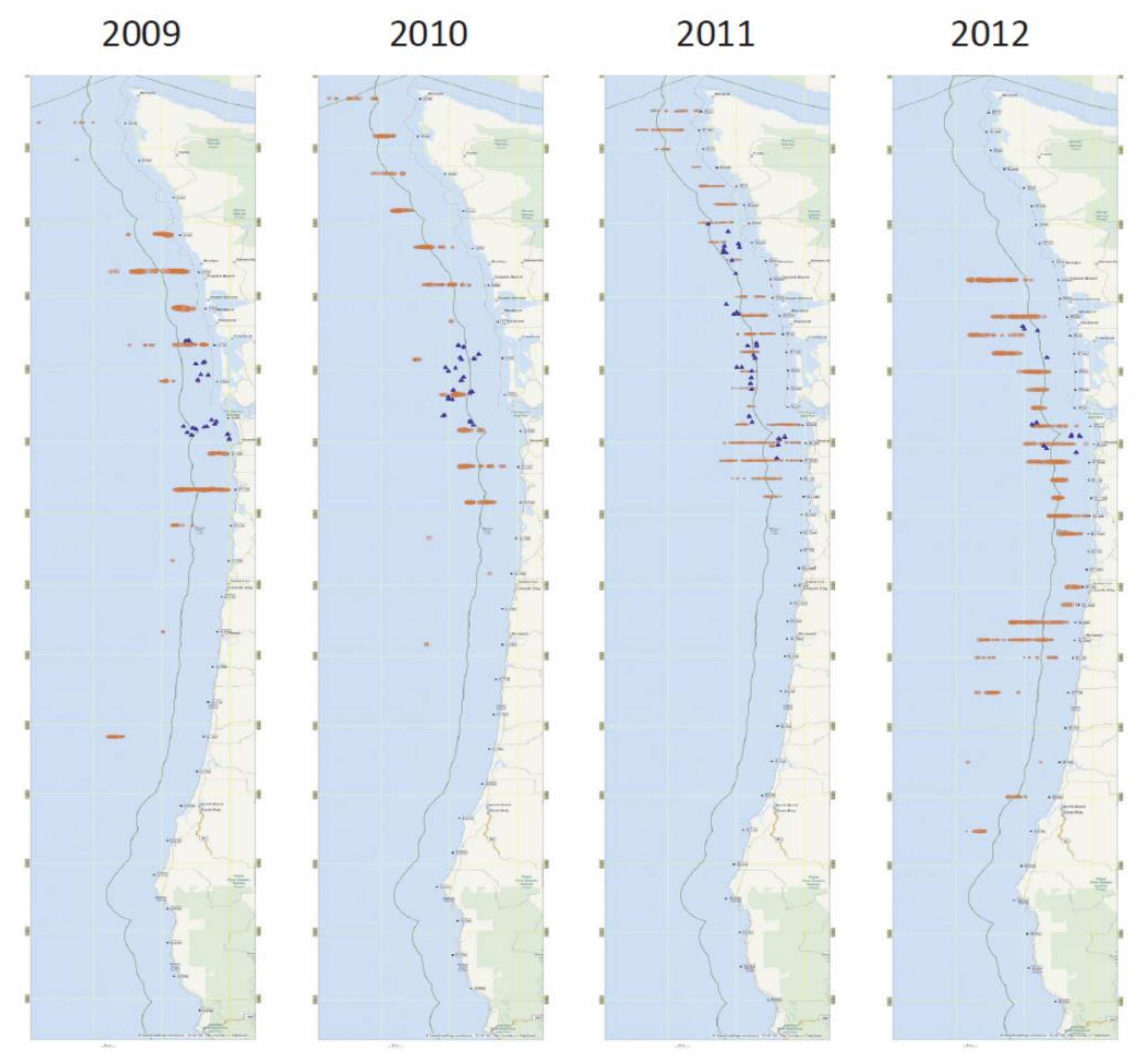


Figure 8. Observed 2009 to 2012 U.S. aerial survey sardine school distributions from Stage 1 transect photographs (red circles) and from sardine-directed Stage 2 sampling point sets (blue marks), figure from Jagielo et al 2012.

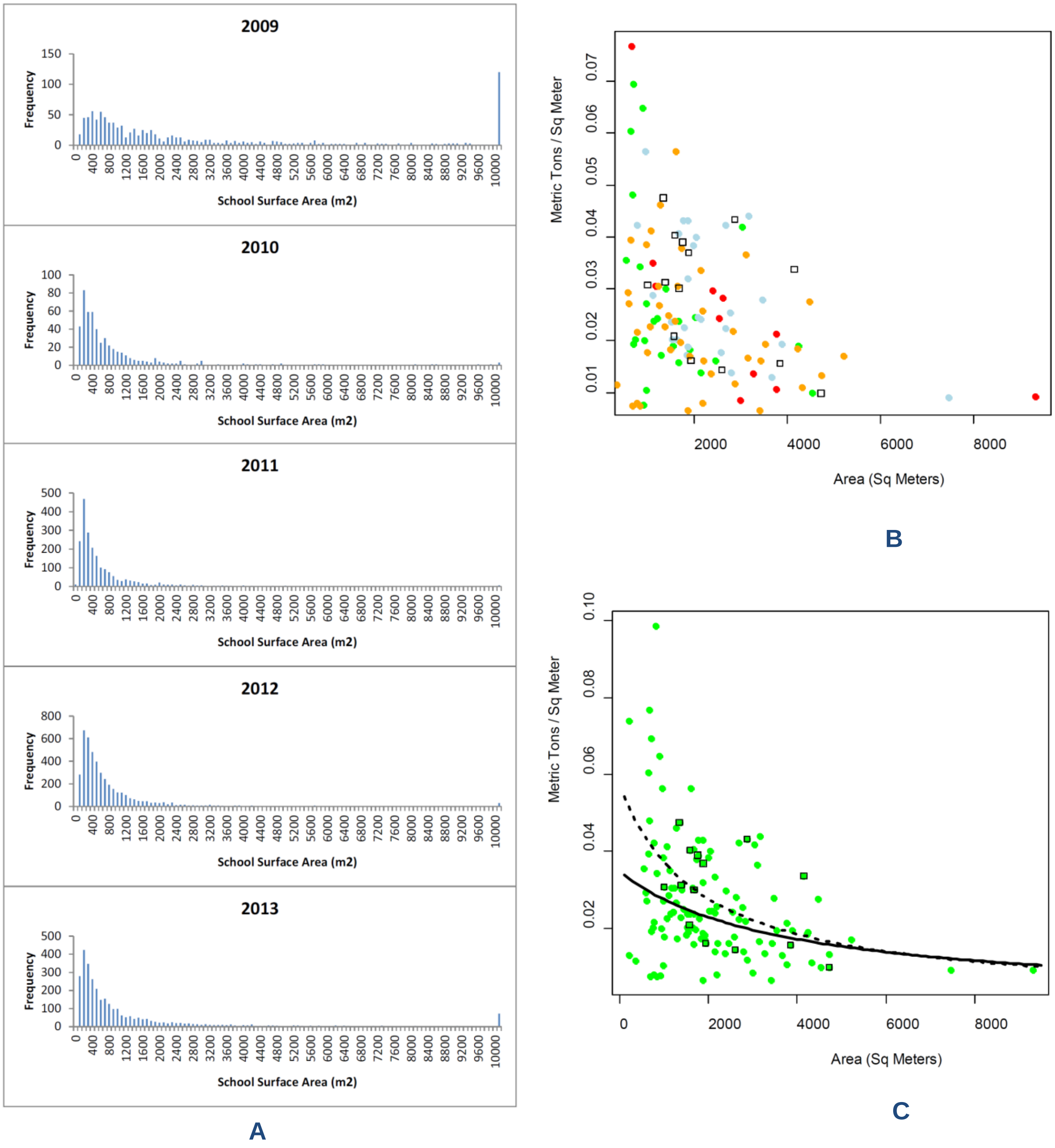


Figure 9. Estimated sardine school surface area observations from U.S. aerial surveys. A) Results from Stage 1 2009 to 2013 transect sampling reported in Jagielo et al (2012); B) Results from Stage 2 point set sampling to develop surface area and biomass relationships, where red= 2008, green=2009, blue=2010, orange=2011, black open squares= 2012, and no 2013 Stage 2 sampling; and C) Fit of a Michaelis-Menten model curve to the pooled 2008-2012 point set data (black line) and to the 2012 point set data alone (dashed line). Figures B and C reported in Jagielo et al (2014).

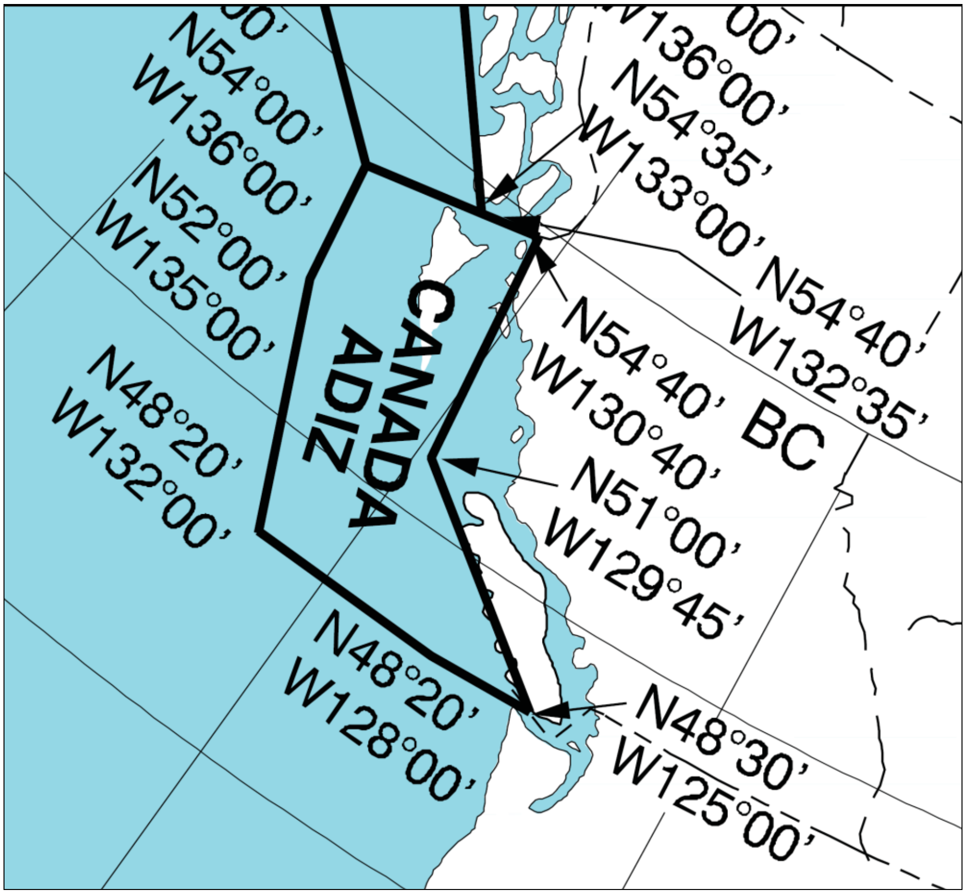


Figure 10. Boundaries of the Canadian Air Defense Identification Zone (ADIZ) off the British Columbia coast (Natural Resources Canada 2007). For additional information, refer to Transport Canada Airspace Requirements (http://tc.gc.ca/eng/civilaviation/publications/tp14371-rac-2-0-2599.htm#rac-2-2)

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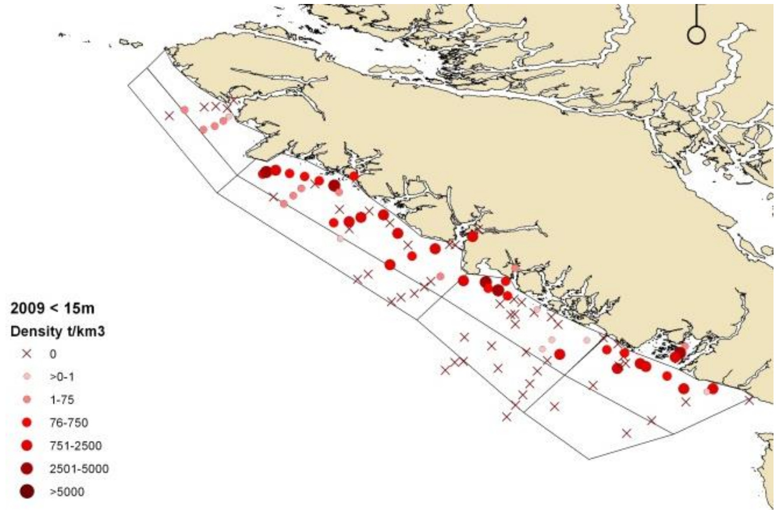
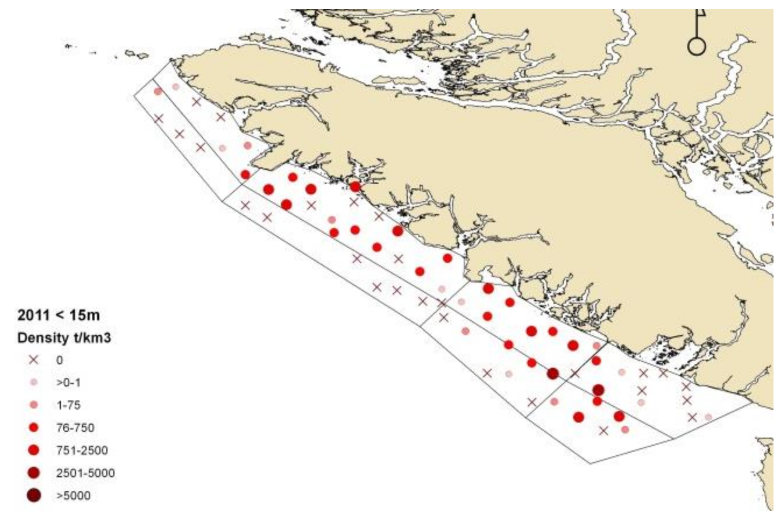
APPENDIX A: Spatial distributions of Pacific Sardine from 2009 and 2011 DFO west coast of Vancouver Island trawl surveys



2009 survey dates: July 22- August 5



2011 survey dates: July 17-31

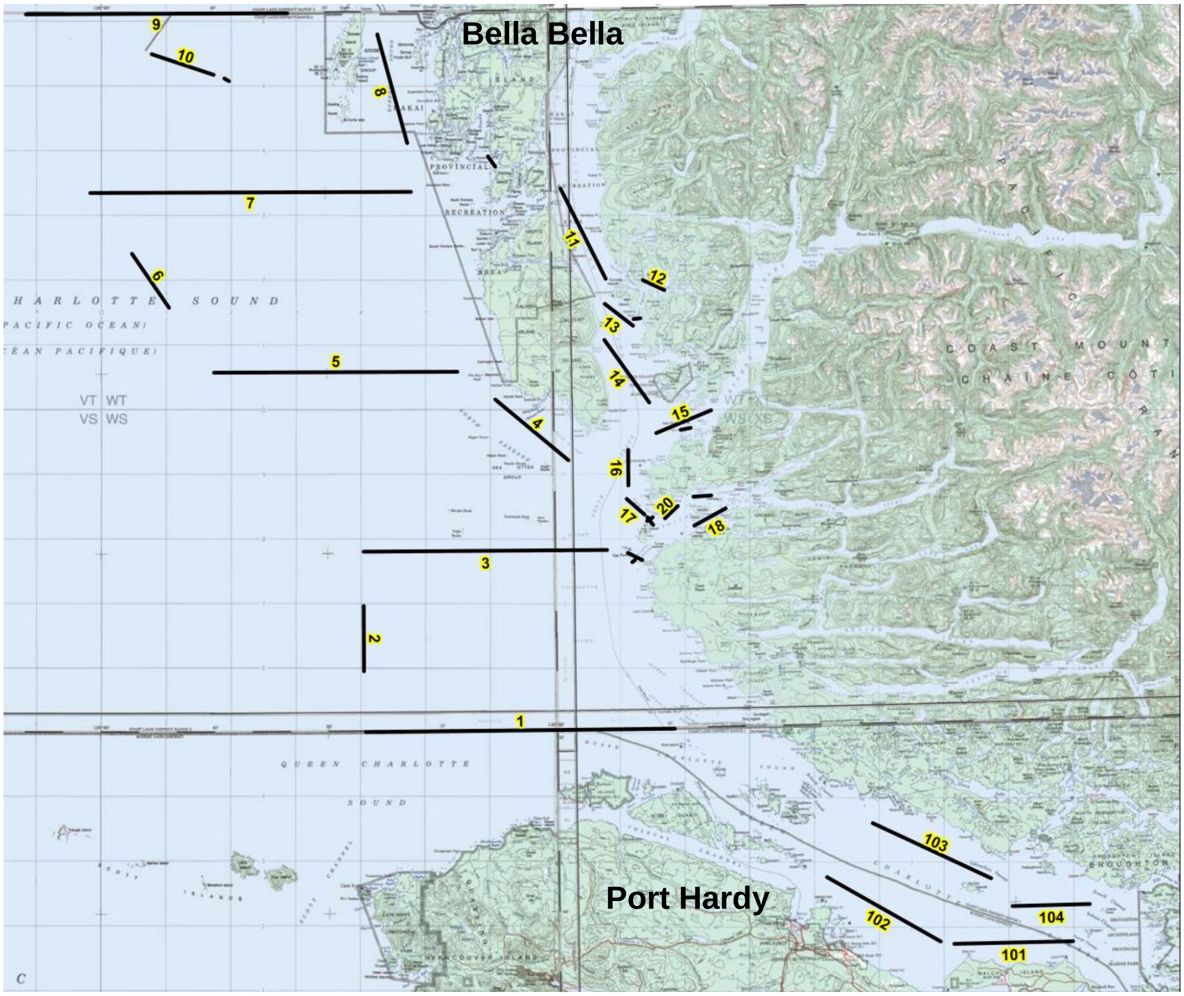
Sardine density groupings measured in tonnes caught per km^3 water trawled

APPENDIX B: 2009 Range and Bearing Coorporation, transect details

Transect details from the 2009 aerial survey off the west coast of Vancouver Island. Colour coding of transect clusters correlated with Figure 2. *Range and Bearing Coorporation* provided DFO staff with line mosaics from OrthoPhotos but reserved the right to withhold raw image files. Also, flights logs and time stamp data by frame were not made available to DFO.

Date	Cluster	Transect	Frames	Transect dimensions photographed	Area photographed (hectares)	Comment
July 24	**1**	1	77	8km x 38km	30,400	
July 24	**1**	2	65	8km x 34km	27,200	
July 24	**1**	3	53	8km x 30km	24,200	
July 24	**1**	4	58	8km x 31km	24,800	Replicate 1 change detection
July 24	**2**	5	53	7.5km x 26km	19,500	
July 24	**2**	6	64	7.5km x 32km	24,000	
July 24	**2**	7	73	7.5km x 36km	27,000	
July 24	**2**	8	73	7.5km x 38km	28,500	Replicate 2 change detection
July 27	**3**	1	62	8km x 31km	24,800	
July 27	**3**	2	58	8km x 31km	24,800	
July 27	**3**	3	63	8km x 31km	24,800	
July 27	**3**	4	59	8km x 32km	25,600	
July 27	**3**	5	62	8km x 32km	25,600	
July 27	**3**	6	59	8km x 32km	25,600	
July 27	**3**	7	62	8km x 32km	25,600	
July 27	**3**	8	57	8km x 32km	25,600	
July 27	**3**	9	63	8km x 32km	25,600	
July 27	**4**	10	64	5.0km x 30km	15,000	
July 27	**4**	11	59	4.7km x 37km	17,400	
July 27	**4**	12	63	4.2km x 32km	13,400	
July 27	**4**	13	60	4.5km x 37km	16,700	
July 27	***4***	*14*	*0*	*0km x 0 km*	*0*	*Aborted due to cloud*
July 27	**4**	15	48	4.5km x 30km	13,500	
July 27	**4**	16	43	4.0km x 26km	10,400	
July 27	**4**	17	31	4.5km x 26km	11,700	

APPENDIX C: 2010 Selkirk Remote Sensing Ltd, transect lines and film records



Map of transect lines filmed near parts of the BC coast

SELKIRK REMOTE SENSING LTD.
#160 - 18799 Airport Way
Pitt Meadows, BC
Canada, V3Y 2B4

Tel. (604) 460-8115
Fax (604) 460-8135
Web www.selkirk.com
E-mail selkirk@selkirk.com

Roll No.: SRS 8129/8130

Aerial Film Record

Client: Fisheries Canada

Project: Sardine Surveys

SRS Project No.: 10-3174

Client Project No.:

Camera: Wild RC 30 w/FMC
Lens: UAG-S s/n 13242

Focal Length: 152.819 mm

Filter: 420 nm AV 2X

Film: Agfa Aviphot X100 PE1 colour negative

Date	Line No. & Direction	Camera Frame Counter No's		Altitude ft, true, ASL	Exposure	Time (ZULU) Start/stop	Comments
21 Sep 2010	18 SW	5023	5029	5,000	4/630	1916	Complete
	20 NE	5030	5033	5,000	4/630	1919	Complete
	19 W	5034	5037	5,000	4/630	1924	Complete
	32009 NW	5038	5040	5,000	4/630	1925	Whales
	17 NW	5041	5045	5,000	4/630	1927	Complete
	32001 SE	5046	5050	5,000	4/630	1929	Whales
	16 N	5051	5057	5,000	4/630	1933	Some fog Complete
	15 NE	5058	5068	5,000	4/630	1936	Complete
	32002 SW	5069	5072	5,000	4/630	1938	Birds
	14 NW	5073	5086	5,000	4/630	1942	Complete
	13 NW	5087	5093	5,000	4/630	1947	Complete
	12 SE	5094	5098	5,000	4/630	1951	Complete
	3200 W	5098	5102	5,000	4/630	1952	Whales

SELKIRK REMOTE SENSING LTD.
#160 - 18799 Airport Way
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Tel. *(604) 460-8115*
Fax *(604) 460-8115*
Web *www.selkirk.com*
E-mail *selkirk@selkirk.com*

Roll No.: 8129/30 con't

Aerial Film Record

Client: Fisheries Canada

Project: Sardine Surveys Page 2

Date	Line No. & Direction	Camera Frame Counter No's **Annotated Numbers**				Altitude ft, true, ASL	Exposure	Time (ZULU) Stop	Comments
21 Sep 2010	8 N		5126	5145		5,000	4/630	2007	Complete
	32004 N		5146	5147		5,000	4/630	2008	Fisheries Boat
					0000				Blank Function Test Blank
	9 W		5148	5192		5,000	4/630	2130	Complete
	10 SE		5193	5204		5,000	4/630	2137	Complete
	32005 E		8205	5207		5,000	4/630	2138	Tidal Action
	7 W		5208	5262		5,000	4/630	2156	Complete
	6 SE		5263	5274		5,000	4/630	2203	Complete
	5 E		5275	5316		5,000	4/561	2213	Complete
	4 SE		5317	5333		5,000	4/561	2218	Complete
	32006 SW		5334	5337		5,000	4/561	2222	Whales
	32007 W		5338	5343		5,000	4/561	2224	Whales
	32008 W		5344	5347		5,000	4/561	2227	Whales
	3 W		5348	5389		5,000	4/561	2237	Complete
	2 S		5390	5401		5,000	4/561	2241	Complete

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E-mail selkirk@selkirk.com

Roll No.: 8129/30 con't

Aerial Film Record

Client: Fisheries Canada

Project: Sardine Surveys Page 3

Date	Line No. & Direction	Camera Frame Counter No's Annotated Numbers				Altitude ft, true, ASL	Exposure	Time (ZULU) Stop	Comments
21 Sep 2010	1 E		5402	5454		5,000	4/561	2254	Complete
	103 SE		5455	5477		5,000	4/500	2304	Complete
									SPLICE
	104 W		5482	5491		5,000	4/500	2312	Complete
	101 W		5492	5516		5,000	4/500	2321	Some cloud shadow Complete
	102 NW		5517	5539		5,000	4/500	2327	Complete

APPENDIX D: Detection of sardine in aerial photographs (from September 21, 2010 survey), by Brown et al (2010)

DETECTION OF SARDINES IN AERIAL PHOTOGRAPHS

Prepared for:

Jake Schweigert

Fisheries and Oceans Canada
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo. BC. V9T 6N7

By:

Leslie Brown, Jose B. Lim and Gary Borstad

ASL Environmental Sciences Inc.
#1 – 6703 Rajpur Place,
Victoria, B.C.
Canada V8M 1Z5

ASL File: PR-720
December 2010

**Some sections of the original Brown et al (2010) report were modified to facilitate inclusion as an appendix to this DFO manuscript. Specifically, page numbers were reformatted and some auxiliary information was omitted to minimize length.*

DETECTION OF SARDINES IN AERIAL PHOTOGRAPHS

Objective

To determine whether sardine schools can be detected in aerial photographs.

Data Processing

Image Data

The dataset consisted of 513 TIFF format images, scanned from colour film negatives at 2116.834 dpi (12 µm resolution) to yield final image dimensions of 19968 x 19968 pixels. Images consisted of 3 spectral bands (red, green, blue), with 8-bit colour depth per band. Images were originally captured using a Wild RC 30 with Forward Motion Compensation, fitted with a UAG-S lens (S/N 13242, focal length 152.819mm) and a 420 nm AV 2x (antivignetting) filter. Film was Agfa Aviphot x100 PE1. Data acquisition flights were conducted September 21, 2010, at an altitude of 5000 ft.

Image Artifacts

Four sample images were received for preliminary examination and testing (Figure 1). A number of artifacts were observed which could impede the successful detection of sardine schools, particularly using automated algorithms. These included:

- horizontal striping, probably related to scanning,
- vignetting (lens flare),
- dark/bright spots,
- sunglint,
- noise.

Striping, vignetting and sunglint are evident in the overviews in Figure 1. Figure 2 compares two otherwise relatively featureless images that share the same bright and dark artifacts. The dark artifacts are particularly noteworthy because they could be mistaken for sardine schools. Because placement of these bright and dark spots was consistent from image to image, regardless of scan direction (image orientation), we infer that the source was flaws/dirt on the camera lens or possibly the CMOS array. Figure 3 illustrates noise visible when the images were viewed at full resolution. Because the signal from fish schools can be subtle, noise reduction can improve the detection limits.

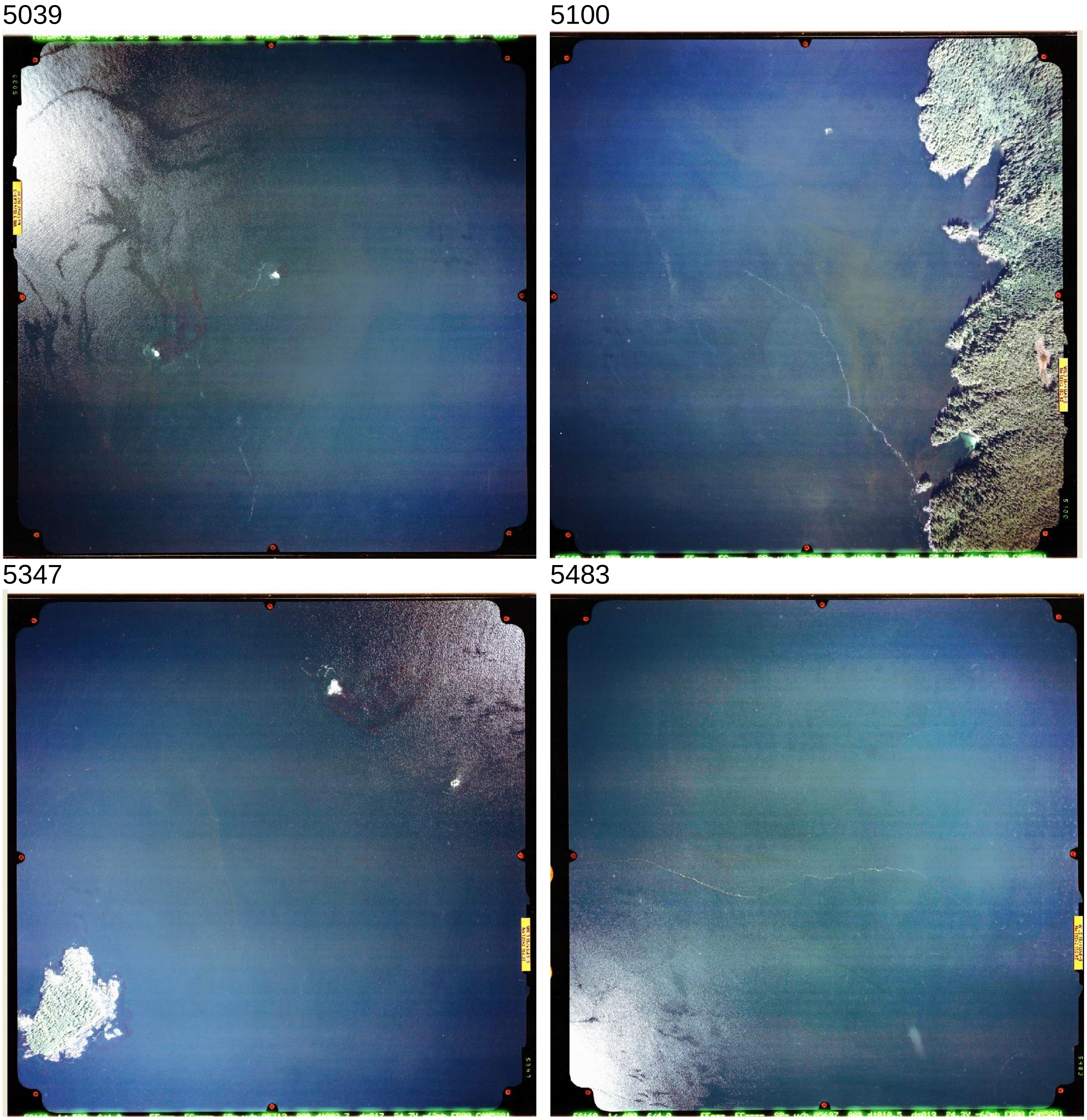

Figure 1. Sample images used for initial testing.

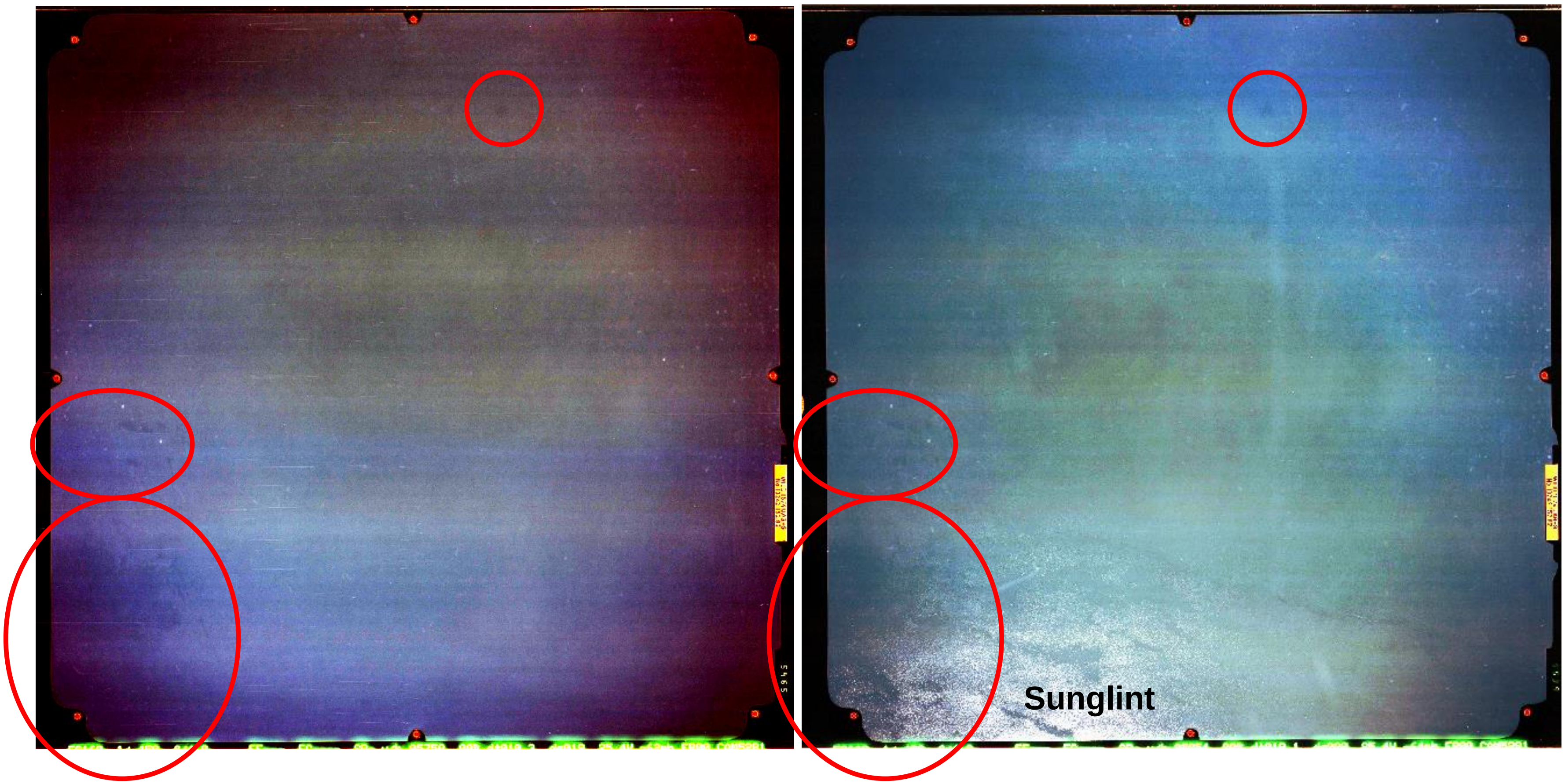

Figure 2. Images 5465 (left) and 5539 (right), enhanced to show consistent image artifacts. Circles highlight dark artifacts that could be mistaken for sardine schools. Image 5539 has been rotated 180° to match the orientations of the two images.

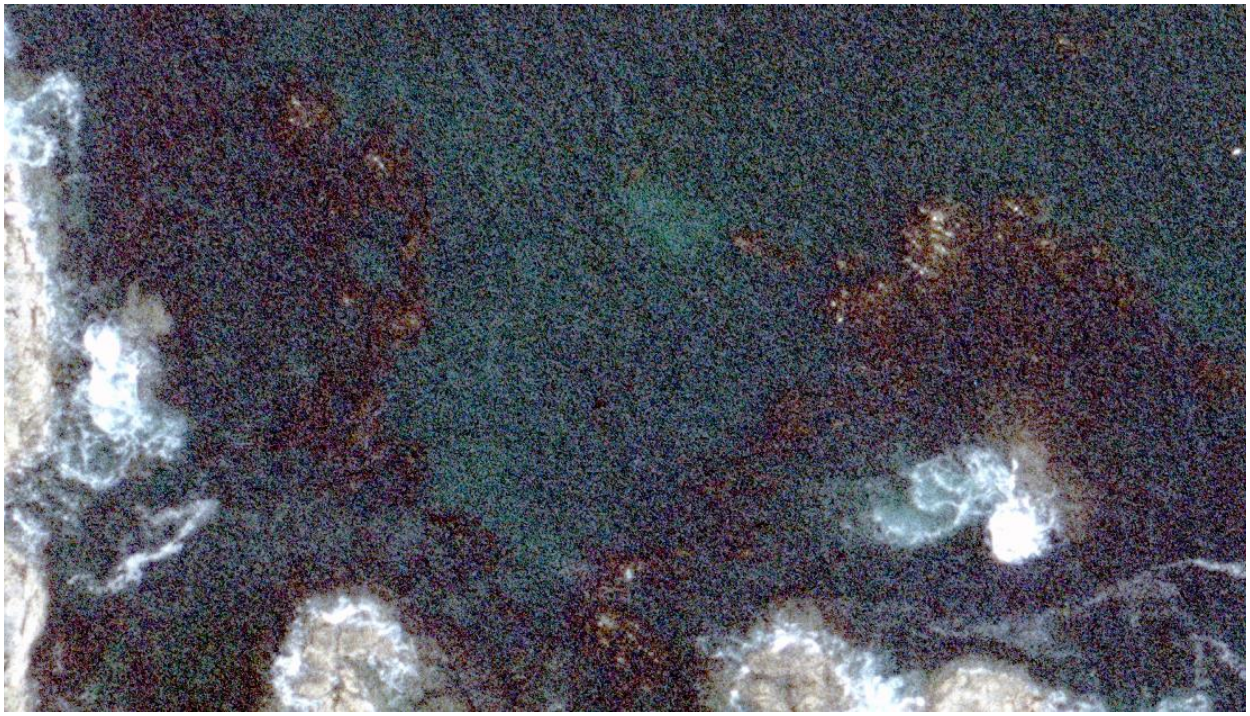
Figure 3. Section of image 5437 at full resolution, showing noise.

Experiments were conducted to attempt to reduce some of the artifacts. These included:

- noise reduction by low pass filtering or resampling,
- sunglint removal using band differences (Green minus Red),
- feature enhancement using band differences (Green minus average (Blue, Red)).

Sunglint removal and feature enhancement algorithms were based on previous experience working with imagery over water and with detection of fish schools. No attempt was made to correct striping or vignetting, as the algorithms are more complex, and beyond the scope of this quick analysis.

The conclusions from our testing were that none of the treatments were sufficiently successful to warrant the processing time required, and instead it was decided to manually screen as many images as possible. Striping, vignetting and noise artifacts were modulated as much as possible using interactive image enhancement, and areas containing sunglint or known bright or dark spots were ignored.

Image Screening

All image sreening was performed using the Focus image tool under PCI Geomatica. Focus permits interactive image enhancement to optimize feature detection, and also allows image overlays which can be useful for comparisons of artifacts.

Images from Wespestad *et al*. (2008)[1] of sardine schools off Washington and Oregon were used as examples of typical school appearance. Of the approximately 120 images examined, there were two possible sightings of sardine schools (Figure 5, Figure **7**7), however in both cases the identification confidence was low. The features in images 5124 and 5125 (Figure 5) were similar in appearance to those of Wespestad *et al*., but they also resembled what appeared to be beds of seaweed adjacent to nearby islands (Figure 6).

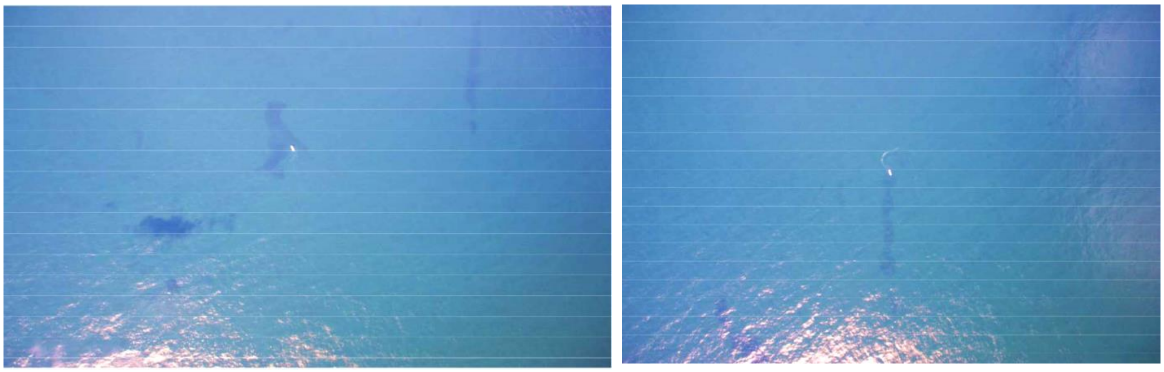

Figure 4. Sample aerial photographs of sardine schools from Wespestad *et al*. (2008).

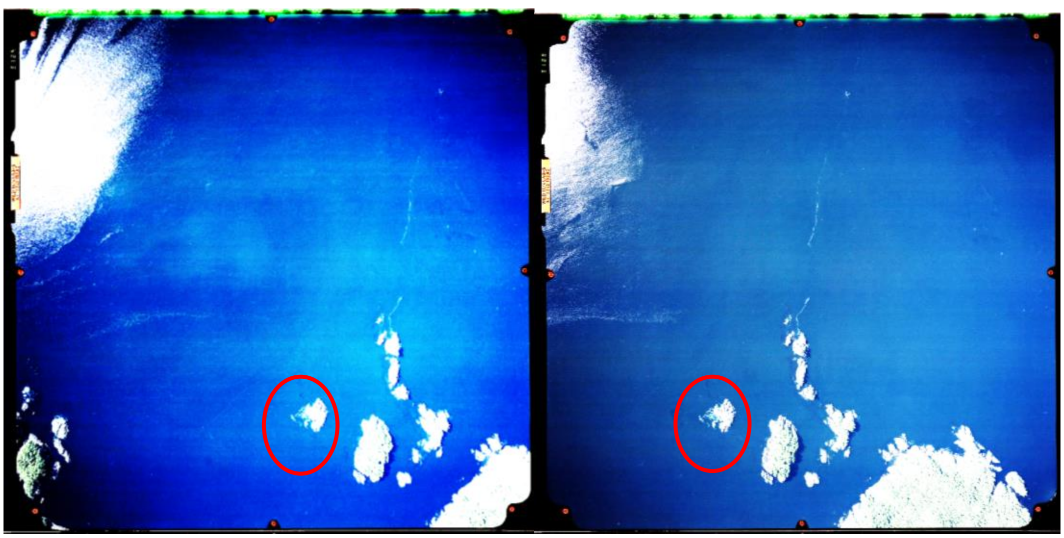

Figure 5. Possible sardine schools in images 5124 and 5125.

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[1] Wespestad, V.G., T. Jagielo and R. Howe, 2008. The feasibility of using an aerial survey to determine sardine abundance off the Washington-Oregon coast in conjunction with fishing vessel observation of surveyed schools and shoals. Report for Northwest Sardine Survey, Bellingham, WA

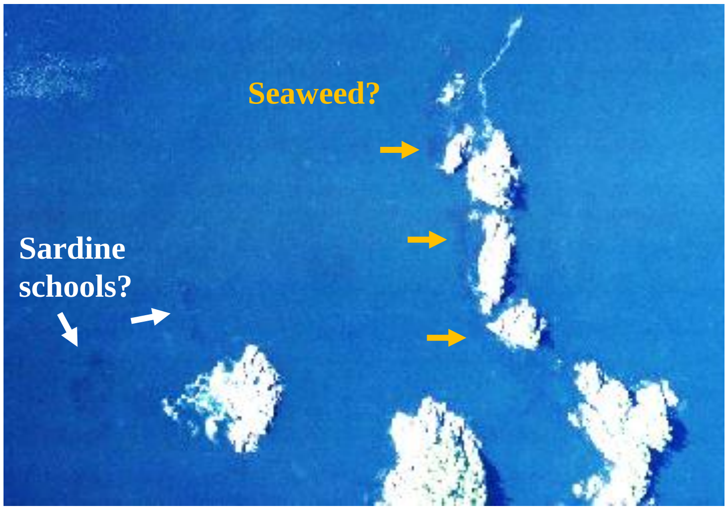

Figure 6. Close-up of possible sardine schools and nearby seaweed in image 5125.

The other possible sardine school in images 5440 and 5441 (Figure 7) resembled cloud shadow (see), but because no clouds were visible in these images or any of the others immediately preceding or following, we flagged them as possible sardine schools.

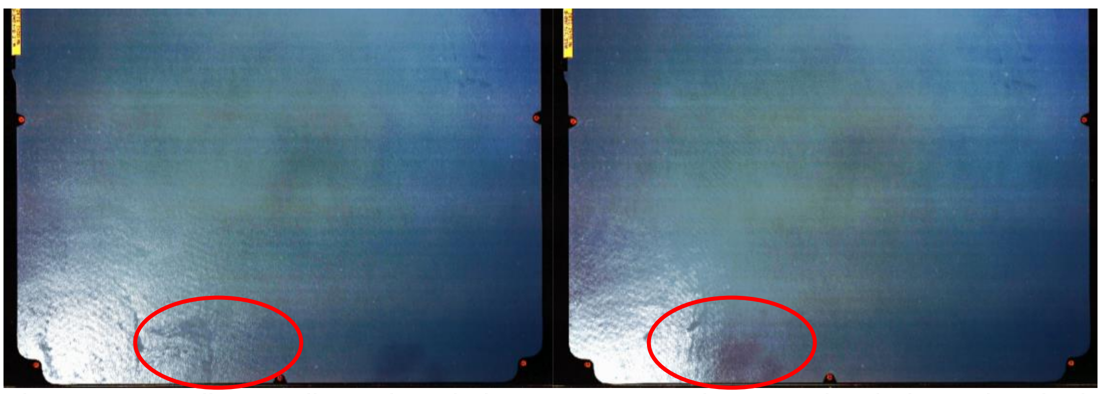

Figure 7. Possible sardine school in images 5440 and 5441. The dark patches in the upper right quadrant are artifacts also visible in Figure 2.

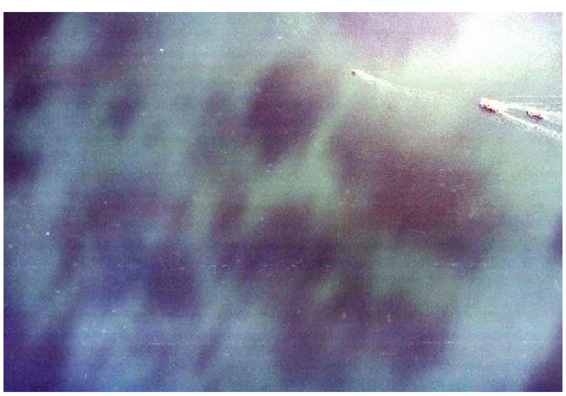

Figure 8. Cloud shadow in image 5534. Also visible in the upper right are three boats and their wakes.

Table 1. List of all images, whether they were screened (1), and whether specific features were present (boats, land, etc).

B=boat
L=land
S=sunglint-free
[Blank]=not examined
*=additional enhancement
(C)=looks like cloud shadow from jpg preview
F=interesting feature (bottom, tide line, sardines?)
E=test image
C=cloud/shadow

5023.TIF	1L	5108.TIF		5194.TIF		5279.TIF		5365.TIF		5450.TIF	
5024.TIF	1L	5109.TIF		5195.TIF		5280.TIF		5366.TIF		5451.TIF	
5025.TIF	1L	5110.TIF		5196.TIF		5281.TIF		5367.TIF		5452.TIF	
5026.TIF	1L	5111.TIF		5197.TIF		5282.TIF		5368.TIF		5453.TIF	
5027.TIF	1L	5112.TIF		5198.TIF		5283.TIF		5369.TIF		5454.TIF	
5028.TIF	1L	5113.TIF		5199.TIF		5284.TIF		5370.TIF		5455.TIF	
5029.TIF	1L	5114.TIF		5200.TIF		5285.TIF		5371.TIF		5456.TIF	
5030.TIF	1C	5115.TIF		5201.TIF		5286.TIF		5372.TIF		5457.TIF	1B
5031.TIF	Y	5116.TIF		5202.TIF		5287.TIF		5373.TIF		5458.TIF	1B
5032.TIF	Y	5117.TIF		5203.TIF		5288.TIF		5374.TIF		5459.TIF	1S
5033.TIF	1L	5118.TIF		5204.TIF		5289.TIF		5375.TIF		5460.TIF	1S
5034.TIF	1L	5119.TIF		5205.TIF		5290.TIF		5376.TIF		5461.TIF	1S
5035.TIF	1L	5120.TIF		5206.TIF		5291.TIF		5377.TIF		5462.TIF	1S
5036.TIF	1	5121.TIF	1L	5207.TIF		5292.TIF		5378.TIF		5463.TIF	1S
5037.TIF	1L	5122.TIF	1L	5208.TIF		5293.TIF		5379.TIF	1F	5464.TIF	1S
5038.TIF	1L	5123.TIF	1L	5209.TIF		5294.TIF		5380.TIF	1F	5465.TIF	1S
5039.TIF	E,1L	5124.TIF	1LF*	5210.TIF		5295.TIF		5381.TIF	1F	5466.TIF	1S
5040.TIF	1L	5125.TIF	1LF*	5211.TIF		5296.TIF		5382.TIF	1F	5467.TIF	1S
5041.TIF	1	5126.TIF	1	5212.TIF		5297.TIF		5383.TIF		5468.TIF	1S
5042.TIF	1L	5127.TIF		5213.TIF		5298.TIF		5384.TIF		5469.TIF	1S
5043.TIF	1LC	5128.TIF		5214.TIF		5299.TIF		5385.TIF		5470.TIF	1S
5044.TIF	1C	5129.TIF		5215.TIF		5300.TIF		5386.TIF	1F	5471.TIF	1S
5045.TIF	1C	5130.TIF		5216.TIF		5301.TIF		5387.TIF	1F	5472.TIF	
5046.TIF	1L	5131.TIF		5217.TIF		5302.TIF		5388.TIF	1F	5473.TIF	
5047.TIF	1L	5132.TIF		5218.TIF		5303.TIF		5389.TIF	1	5474.TIF	
5048.TIF	1L	5133.TIF		5219.TIF		5304.TIF		5390.TIF	1F	5475.TIF	
5049.TIF	1L	5134.TIF		5220.TIF		5305.TIF		5391.TIF	1F	5476.TIF	
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5051.TIF	1C	5136.TIF		5222.TIF		5307.TIF		5393.TIF	1F	5482.TIF	
5052.TIF	1C	5137.TIF		5223.TIF		5308.TIF		5394.TIF	1	5483.TIF	E
5053.TIF	1C	5138.TIF		5224.TIF		5309.TIF		5395.TIF		5484.TIF	
5054.TIF	1C	5139.TIF		5225.TIF		5310.TIF		5396.TIF		5485.TIF	
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5059.TIF	1	5144.TIF		5230.TIF		5315.TIF		5401.TIF		5490.TIF	
5060.TIF	1	5145.TIF		5231.TIF		5316.TIF		5402.TIF		5491.TIF	
5061.TIF	1	5146.TIF	1B	5232.TIF		5317.TIF		5403.TIF		5492.TIF	
5062.TIF	1	5147.TIF	1B	5233.TIF		5318.TIF		5404.TIF		5493.TIF	
5063.TIF	1	5148.TIF		5234.TIF		5319.TIF		5405.TIF		5494.TIF	(C)

5064.TIF	1L	5149.TIF		5235.TIF		5320.TIF		5406.TIF		5495.TIF	(C)
5065.TIF	1	5150.TIF		5236.TIF		5321.TIF		5407.TIF		5496.TIF	(C)
5066.TIF	1	5151.TIF		5237.TIF		5322.TIF		5408.TIF		5497.TIF	(C)
5067.TIF	1	5152.TIF		5238.TIF		5323.TIF		5409.TIF		5498.TIF	(C)
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5071.TIF	1L	5156.TIF		5242.TIF		5327.TIF		5413.TIF		5502.TIF	(C)
5072.TIF	1L	5157.TIF	1B	5243.TIF		5328.TIF		5414.TIF		5503.TIF	(C)
5073.TIF	1	5158.TIF	1B	5244.TIF		5329.TIF		5415.TIF		5504.TIF	(C)
5074.TIF		5159.TIF		5245.TIF		5330.TIF		5416.TIF		5505.TIF	(C)
5075.TIF		5160.TIF		5246.TIF		5331.TIF		5417.TIF		5506.TIF	(C)
5076.TIF		5161.TIF		5247.TIF		5332.TIF		5418.TIF		5507.TIF	(C)
5077.TIF		5162.TIF		5248.TIF		5333.TIF		5419.TIF		5508.TIF	(C)
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		5193.TIF				5364.TIF				5539.TIF	

Examples of enhanced photographs

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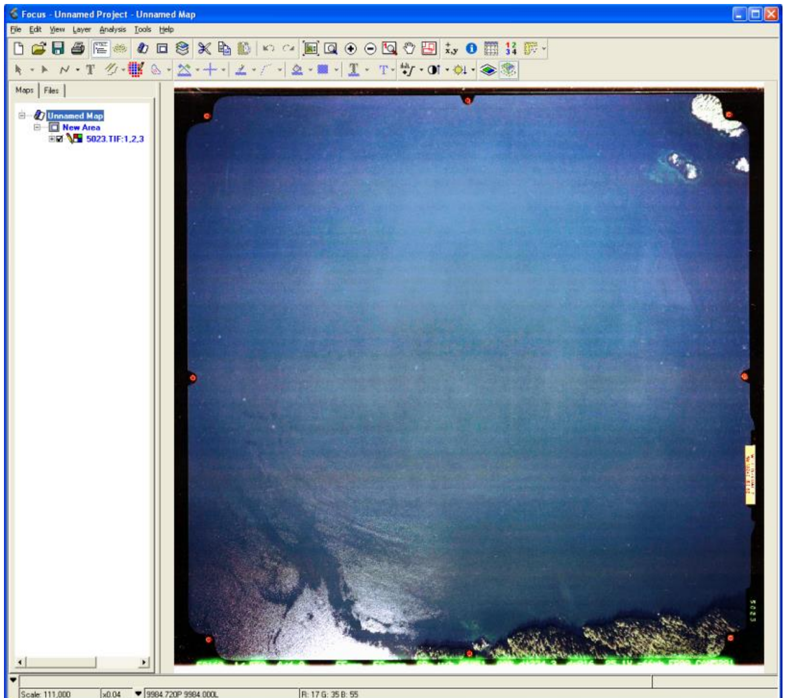

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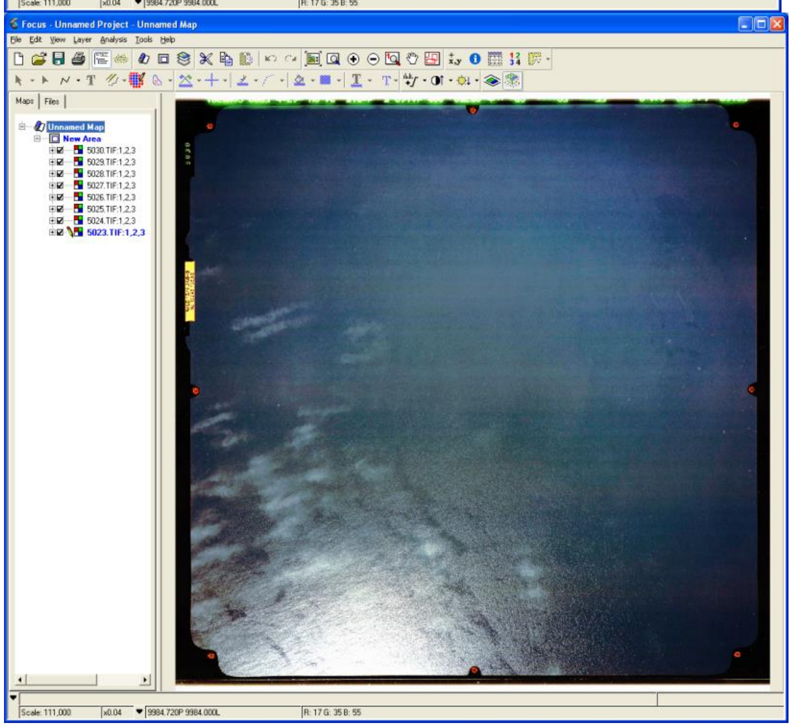
CLOUD



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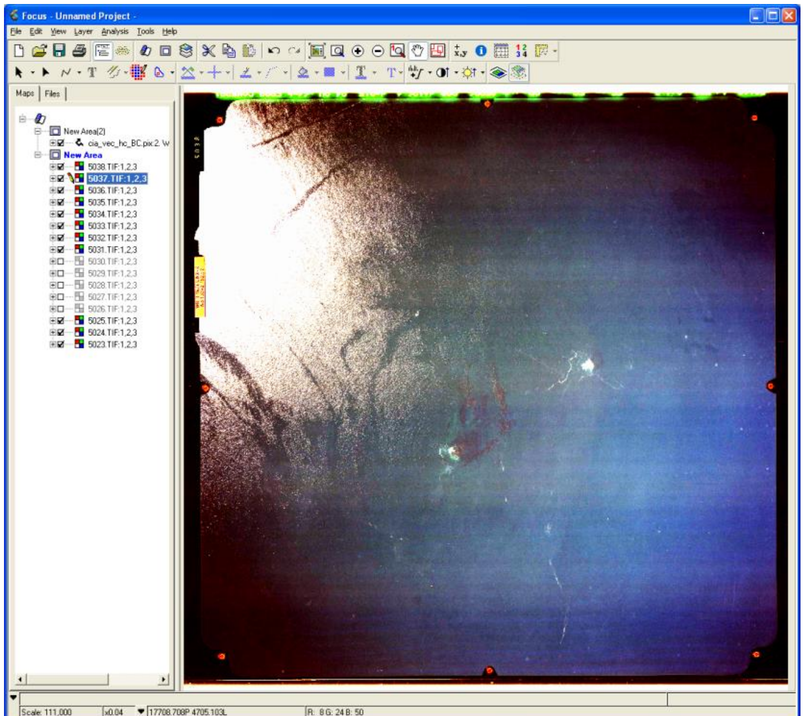
ISLAND &
SUNGLINT



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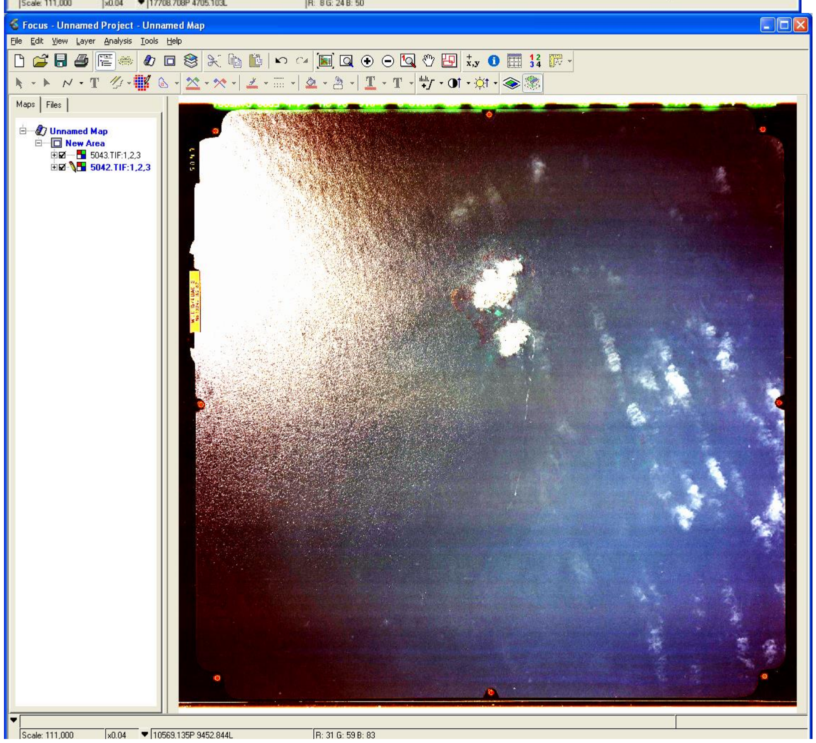
ISLAND,
CLOUD
SUNGLINT



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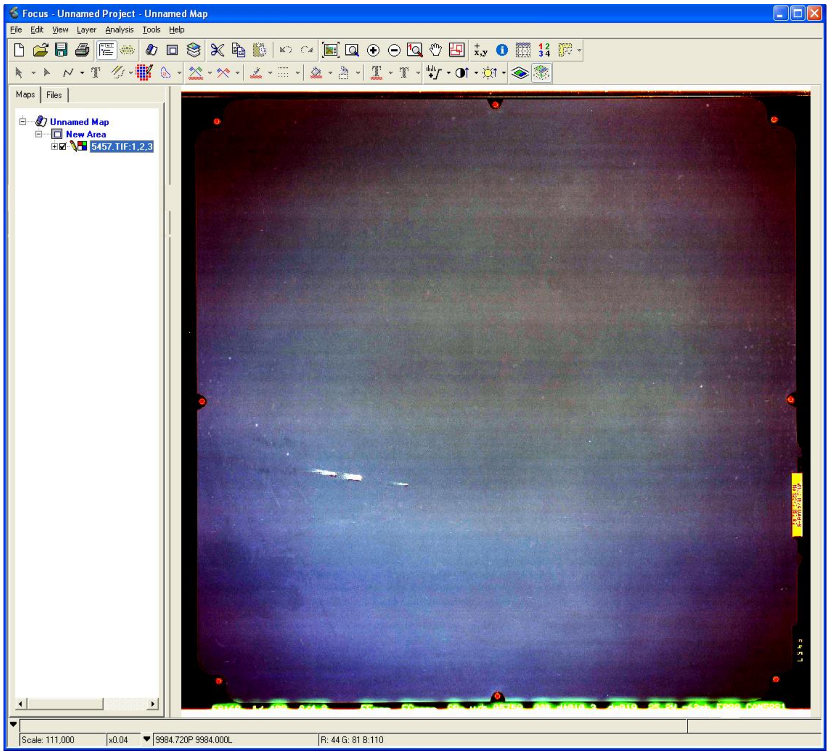

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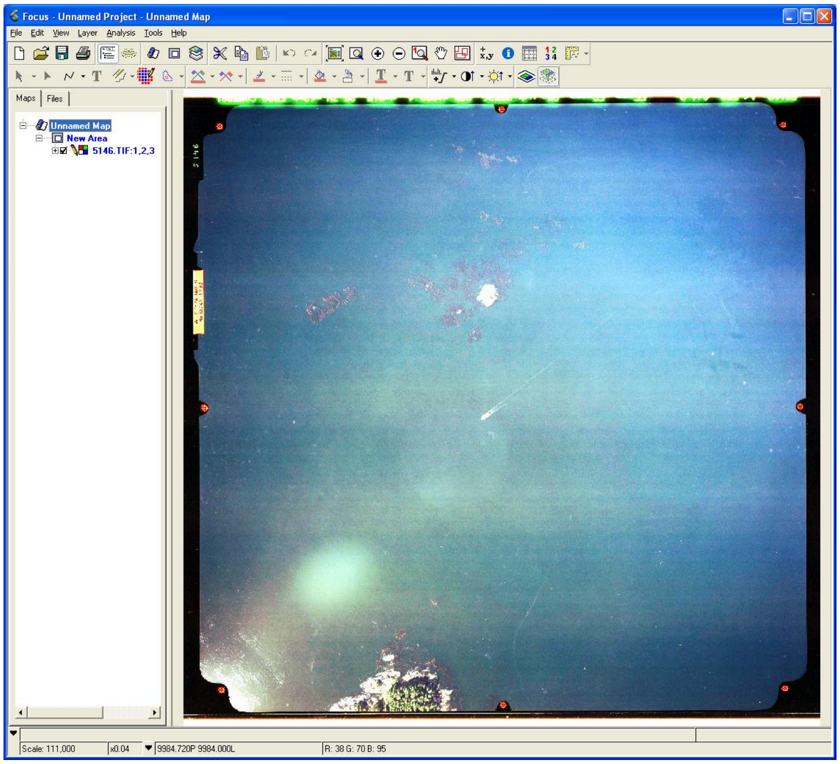
BOAT
SHORE
KELP
SUNGLINT



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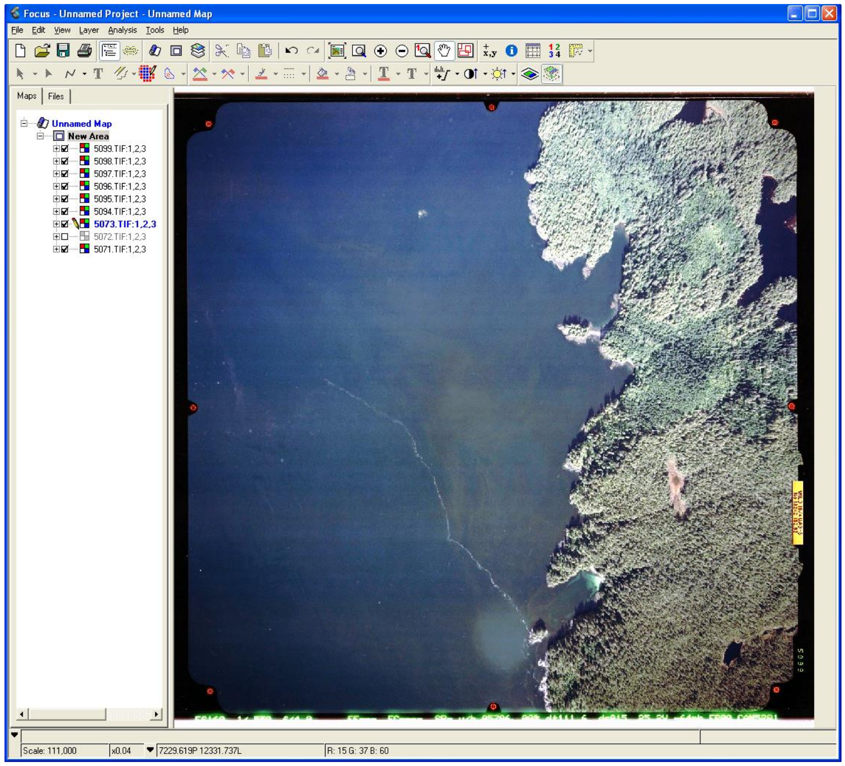
SUNGLINT
FREE
TIDELINE&
LAND



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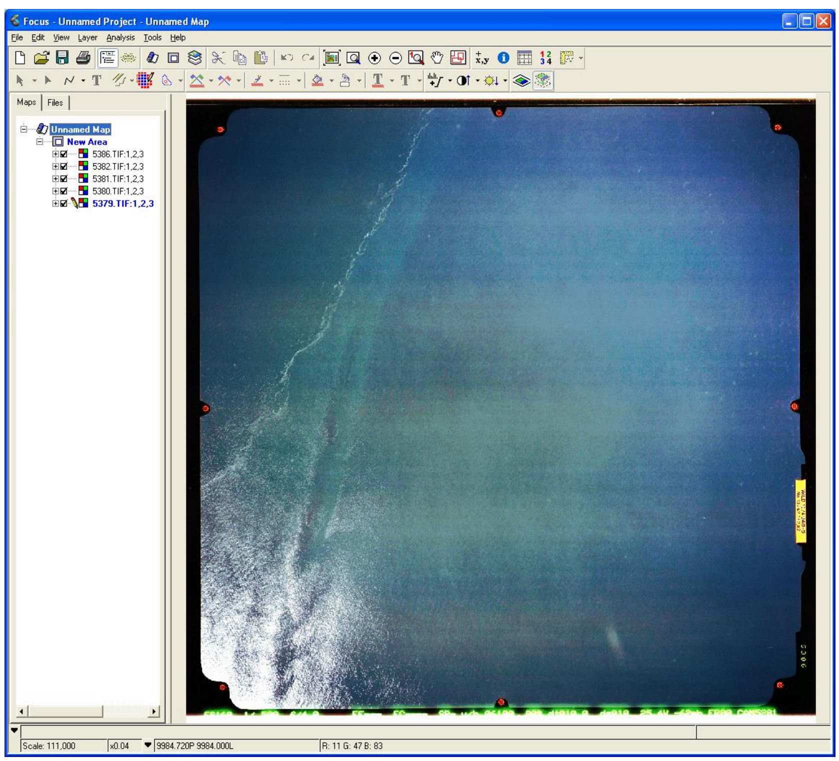

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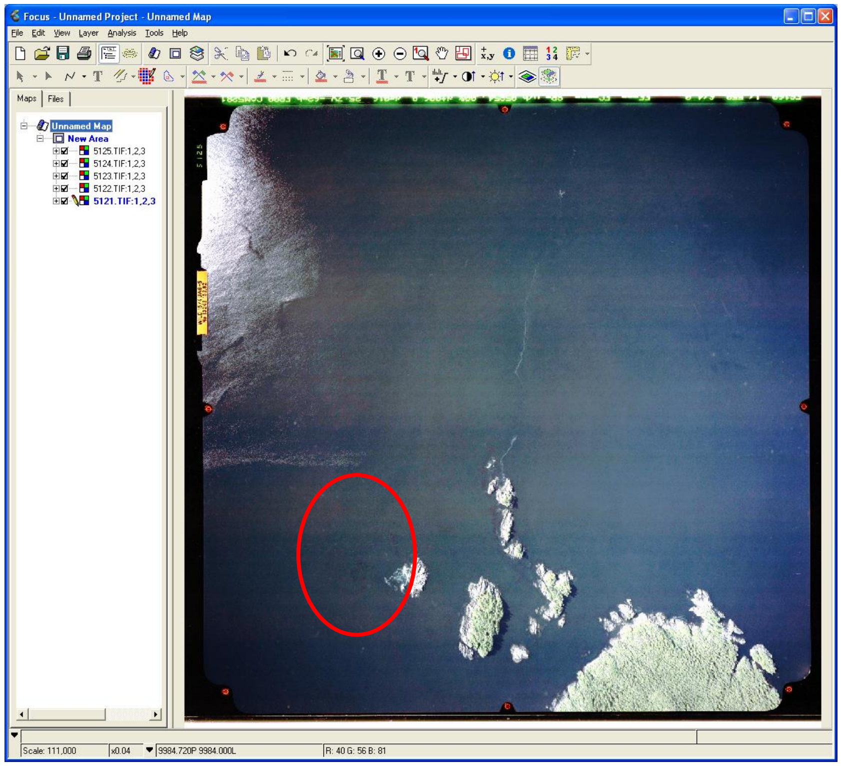
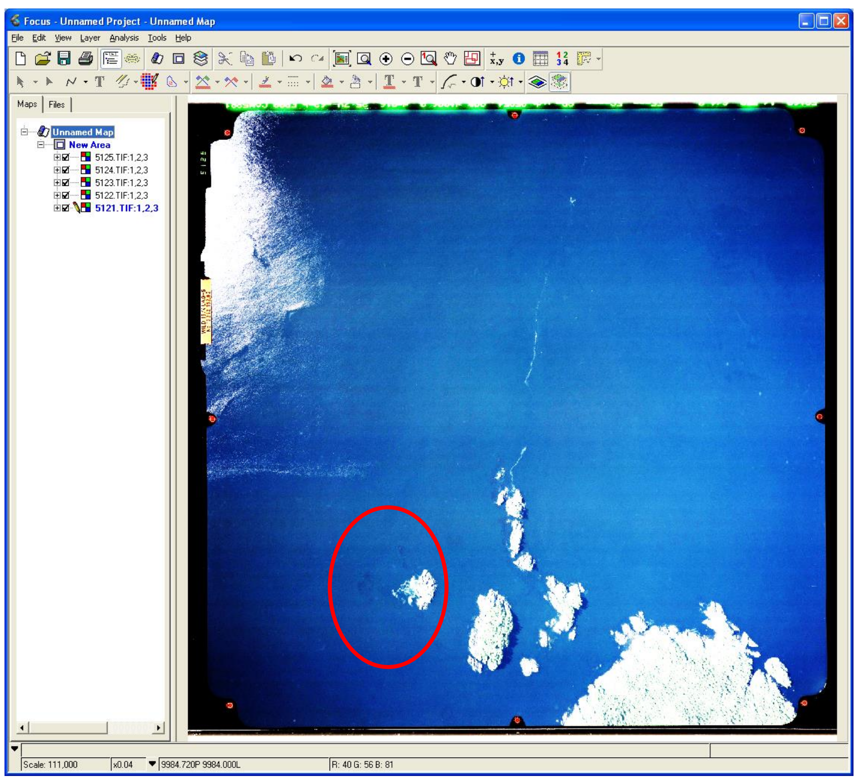
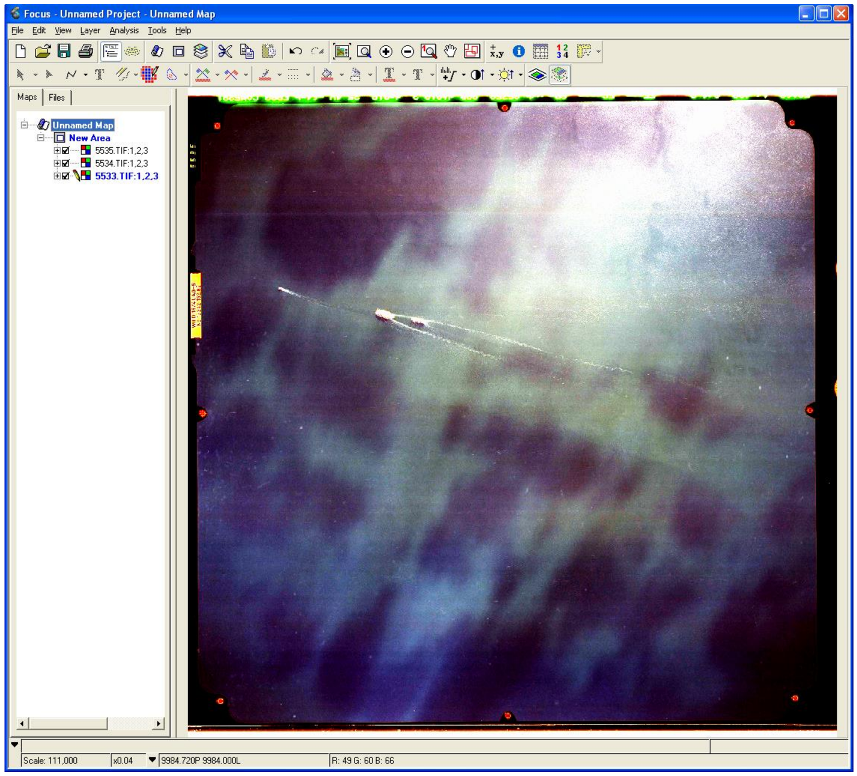


5125
SARDINES?

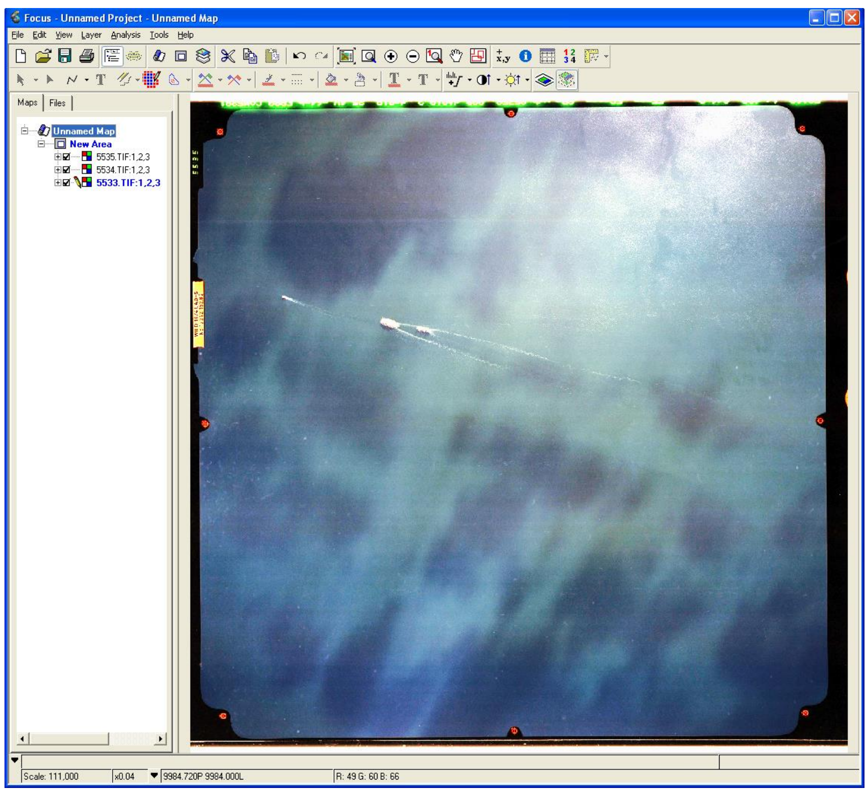
Root with
contrast
enhancement



5535
CLOUD
SHADOW &
BOATS



5535
CLOUD
SHADOW &
BOATS
With adaptive
enhancement



APPENDIX E: Airborne sardine survey of the south and central British Columbia coast, July 26-27, 2011, by Borstad et al (2011)

AIRBORNE SARDINE SURVEY OF THE SOUTH AND CENTRAL BRITISH COLUMBIA COAST, JULY 26-27, 2011

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ASL File: PR-745
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Final Version 1.00

**Some sections of the original Borstad et al (2011) report were modified to facilitate inclusion as an appendix to this DFO manuscript. Specifically, page numbers were reformatted and some auxiliary information was omitted to minimize length.*

EXECUTIVE SUMMARY

An experimental, exploratory aerial survey for Pacific Sardine (*Sardinops sagax*) was flown on July 26 and 27, 2011 off the southern and central coast of British Columbia. A single engine de Havilland Beaver aircraft on floats was flown with a Compact Airborne Spectrographic Imager (CASI) that had previously been used for operational surveys of capelin in Newfoundland and herring in Alaska.
In spite of very poor survey conditions, the CASI provided usable multi-spectral image data from which school areas could be extracted. The aerial survey found schools in waters off the west coast of Vancouver Island adjacent to those in which schools were found more or less simultaneously by the MV Ricker acoustic survey. A preliminary comparison with satellite SST and chlorophyll suggests that sardine habitat in this area is related to these parameters in the same way as seen by Zwolinski et al 2010 further south along the US coastline. The currents and water mass distribution around Cape Scott may determine whether or not sardines appear on the Central coast in any particular year.

ACKNOWLEDGEMENTS

Thanks to Harold Kirkpatrick, Lisa Cherneff and St. Clair McColl at Saltspring Air for great piloting, scheduling flexibility and all round support on this project. Thanks also to Wally Horniak at ASL, who provided important technical support to assure smooth CASI operations.

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INTRODUCTION

Study Objectives

This report documents an exploratory aerial survey for near surface sardine schools along the south and central coasts of British Columbia, conducted on July 26 and 27, 2011. The primary objective of the mission was to explore the West Coast of Vancouver Island and Central Coast up to Kitasu Inlet (Figure 1) using the ASL Compact Airborne Spectrographic Imager (CASI) multispectral camera.

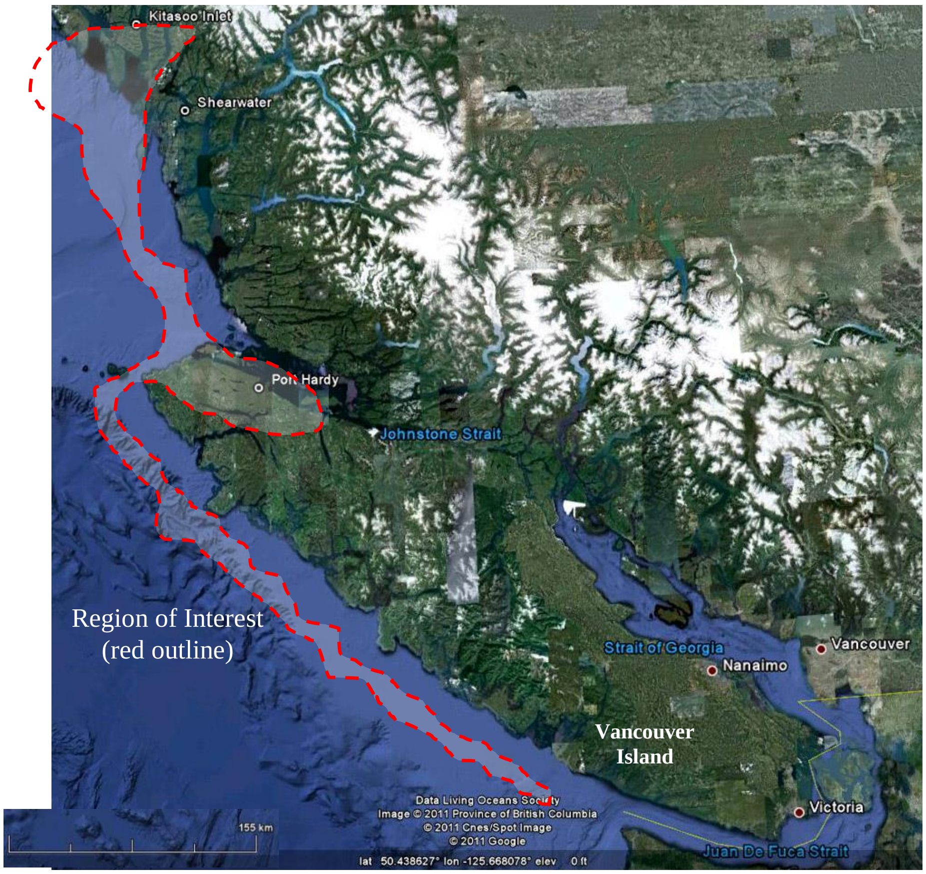


Figure 1. Generalized location map of sardines aerial survey shown in Google Earth.

Study Site and Target Areas

Four survey routes covering both the Eastern and Western Coasts of Vancouver Island and numerous coastal inlets of central British Columbia were flown. Flight path coverage and details are summarized in Appendix 9.1. The exact routing was decided *en route* and depended on factors such as current weather conditions, school sightings, water colour and other indicators of fish schools such as fishing boats, birds, etc.

EQUIPMENT AND METHODS

Compact Airborne Spectrographic Imager (CASI)

The Compact Airborne Spectrographic Imager (CASI) is a small, multispectral push-broom imager. It was built in 1990 by Itres Instruments Ltd. ™ of Calgary, Alberta, and modified in 1995 to improve the sensitivity in the blue range, and again in 2010 to replace the Exabyte tape drive with a solid state 8 GB Compact Flash Card.

Aircraft roll and pitch are measured by a Honeywell mechanical gyro and logged by a separate Auxiliary computer synchronised to CASI. Latitude and longitude are logged from a Magnavox 9212 GPS receiver, to provide data for subsequent geo-correction of the imagery. In addition, data from a broad band incident light sensor mounted on top of the aircraft are recorded to provide a record of variation of incident illumination. A handheld Garmin 76CSX GPS receiver was operated on the flight as a backup to the Magnavox. The Garmin unit was configured to acquire tracks every 1 second to match that of the CASI Unit.

The CASI Spectral Bands were configured to acquire imagery in 6 spectral channels as shown in Figure 2 and Table 1, taking advantage of knowledge of the spectral absorption of near surface fish schools (Borstad et al., 1992). We have used a similar band set for capelin in Newfoundland (Nakashima and Borstad, 1997, 1998), herring in British Columbia and Alaska (Funk and Borstad, 1998; Brown et al, 1998). Extra channels at 675 and 712 nm were defined to permit detection of chlorophyll fluorescence and the red signal from benthic and submerged macro-algae such as kelp.

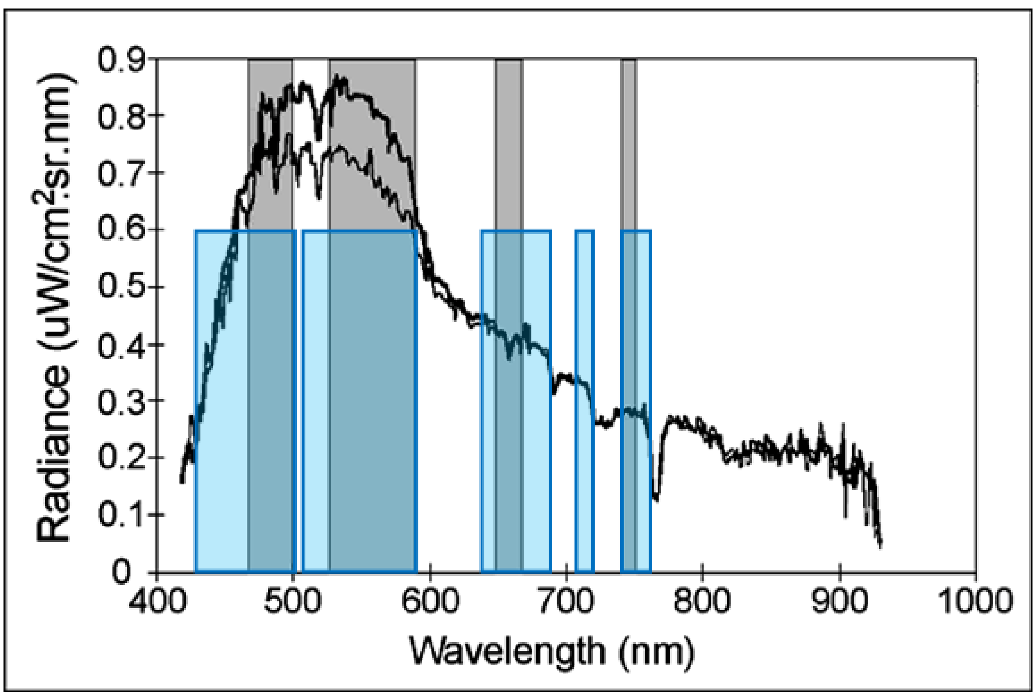


Figure 2. The upwelling spectral radiance from coastal water and a shallow capelin school, with spectral channels used by Nakashima and Borstad 1997 (in grey). Blue overlays indicate channels defined for these surveys.

Table 1. CASI Bandset (sardine.ccf) used during 2011 DFO Sardine Survey.

Band No	Wavelength Start (nm)	Wavelength End (nm)	Wavelength Centre (nm)	Comments
1	421.90	500.90	461.40	Blue Band
2	500.40	590.90	545.65	Green Fish Band
3	638.50	655.00	646.75	Red FLH Band
4	663.50	687.10	675.30	Red FLH Band
5	704.60	717.50	711.05	Near Infrared MCI Band
6	745.80	764.10	754.95	Near Infrared Baseline Band

CASI Installation

The CASI equipment was installed on July 25, 2011 prior to the flights (Figure 3). The plane, piloted by St. Clair McColl, landed at the Pat Bay Float Plane Base around 12:30 pm. Peter Willis and José Lim from ASL, with the help of St. Clair, installed all the necessary equipment on the plane. Final installation and power up tests were finalized by 4:00 pm.

Figure 3. Installation of the main CASI equipment in the back mounted sideways with LCD display/keyboard channelled to the right side of the middle seat (top). CASI camera, gyro system plus Nikon D90 high resolution camera in the back (bottom).

In a typical aerial survey using CASI, three people are usually involved – pilot, navigator, and CASI operator. In this particular survey, because fish school spotters were needed on both sides of the plane, a fourth person was required. Hence, the bulk of CASI equipment that usually sits beside the operator on the middle seat was installed behind the seat in the back of the plane. The LCD display and keyboard that typically sit on top of the CASI equipment were positioned on the seat beside the operator (Figure 3 top). The CASI camera head, gyro system, plus the additional Nikon D90 were mounted at the back of the plane over the removable bottom porthole (Figure 3 bottom).

Nikon D90 High Resolution Camera

A Nikon D90 camera with an 18-105 mm f/3.5-5.6 VR Nikon lens belonging to DFO was mounted beside the CASI optical head, viewing nadir with its horizontal axis parallel to the line of flight. At the planned survey altitude of 2500 ft, the focal length of the zoom lens must be set to about 26 mm (vertical FOV) to match the 33° field of view of CASI (more details are listed in Appendix 9.4).

With an average aircraft speed of 100 knots at this altitude, it was calculated that one photo must be acquired at least every 10.76 seconds to have 10% overlap on the horizontal plane. Acquiring a 12 Megapixel photograph every 10 seconds (i.e. taking both raw and jpg formats simultaneously), a 32 GB memory card provides enough storage for at least 4 hours or one transect line before the card needs to be replaced. With this setup, the resolution of the camera is estimated to be about 0.5 feet/pixel.

The camera shutter priority was set at 1/800 seconds, auto ISO setting was set to 1600 ISO, auto F-stop and auto white balance were turned on. The auto focus and VR mode were turned off because the camera will not engage at all if a perfect focus is not acquired.
Since the camera did not come with a time lapse option and had to be powered continuously, several off the-shelf hardware had to be quickly purchased. A wired (MC-36b) and wireless (TW-282) third party remote control timer and AC adapter (EH-5a) were purchased in order to remotely control and power up the camera. The CASI optical unit base mount was modified to accommodate the Nikon D90 camera and its peripherals.

The Nikon D90 was installed the day of the flight using the supplied quick released bolts prebuilt into the CASI camera base. The focal length of the lens was adjusted during the flight until a full view was obtained and the aircraft floats and port were not obstructing the view. The system was still set to take one picture every 10 seconds (i.e. 10% overlapped with original configuration). Although changing the focal lengths altered the percentage of overlap, we did not reprogram the camera. The camera was also manually focused at this point by setting it to infinity.

Three handheld digital cameras were used to take *ad hoc* oblique shots through each side of the plane. Gary Borstad who acted as navigator and starboard side fish spotter had a Sony DSC-TX5. José Lim was port side fish spotter had a Canon S90 and Kodak PlaySport Video ZX3. The Canon S90 took still pictures while the Kodak took both stills and High Definition Videos (1080p). Peter Willis was the CASI operator and also helped greatly in spotting numerous fish schools. All observations were noted on a log sheets. Borstad and Lim wore polarized sunglasses which helped reduce sky and cloud light reflected from the surface.

Data Acquisition

Four flights were flown on July 26 – 27, 2011. A DeHavilland Beaver on floats with serial number C-FZZJ chartered by ASL Borstad Remote Sensing and operated by Salt Spring Air from Salt Spring Island, BC was used. The July 26 morning flight was delayed because of mechanical problems, and got a late start at 11:20 AM with Harold Kirkpatrick as pilot, Gary Borstad as Navigator/Fish Spotter, José Lim Fish Spotter/Nikon D90 operator, and Peter Willis as CASI Operator. The pilot was earlier provided with the flight line coordinates, which were entered into the aircraft's own GPS system. On each flight line, the CASI operator monitored data acquisition using a real-time image display and also maintained a flight log. The navigator oversaw the onboard navigation using the Vista™ graphical navigation software, which received GPS signals from the same receiver as CASI. An overview of the 4 Transect Lines flown are shown in Table 2 and Figure 4. A narrative and more detailed illustrations of the transects and CASI acquisitions are shown in Appendix 9.1. The endurance of the DeHavilland Beaver with full tip tanks is about 5 hours. Each Transect Line required about 3 to 4 hours of flying time. The aircraft refueled at the Port Hardy Sea Plane Base and at the Shearwater Marine Centre.

Table 2. Overview of actual flight tracks and CASI data acquired. Detailed maps of each transect line are listed in Appendix 9.1.

Transect # Date	**Takeoff and landing location and time (PDT)**	**Flight Time**	**Distance Covered (km)**	**# CASI files acquired**	**Total Image Length (km)**	**Remarks**
Transit Jul 26	Pat Bay – Ganges	0:16:50	30	0	0	Aircraft repairs at Pat Bay, refuel at Ganges. Clear skies.
T1 Jul 26	Ganges 11:20 – Port Hardy 15:35	4:34:38	697	38	446.9	Cloudy on the West Coast of Vancouver Island. Aircraft at 1500 ft ASL. Several fish schools spotted.
T2 Jul 26	Port Hardy 16:25 – Shearwater 18:40	2:21:48	356	17	267.2	Overcast and low clouds, aircraft at 1000 ft ASL.
T3 Jul 27	Shearwater 10:14 – Port Hardy 12:49	3:20:03	431	28	299.0	Overcast and low clouds, aircraft at 1000 feet ASL.
T4 Jul 27	Port Hardy 14:21 – Pat Bay 17:39	3:21:25	622	32	399.4	Generally clear skies. Aircraft at 3000-5000 ft ASL.

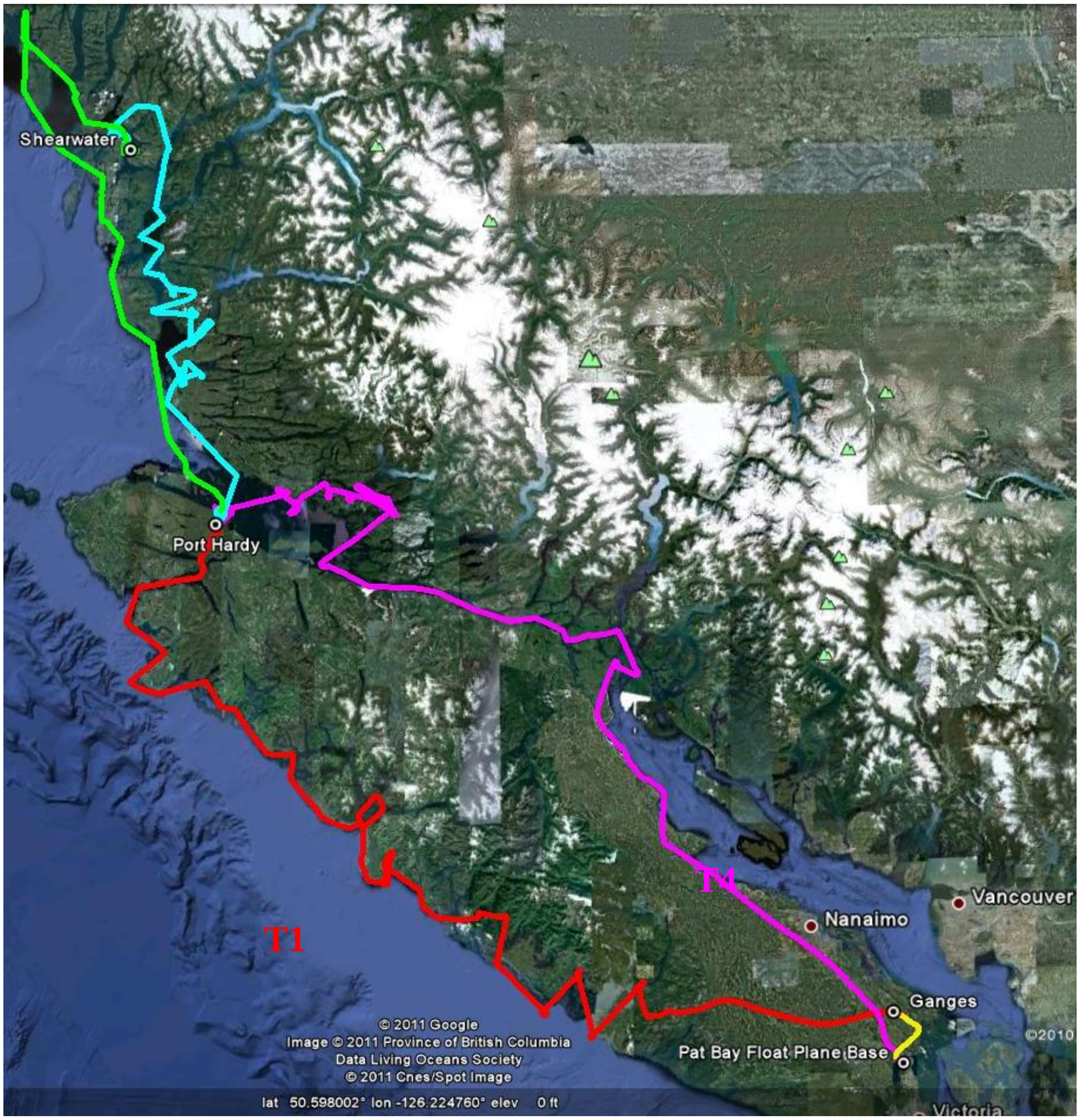


Figure 4. Overview of CASI sardine transects.

DATA AQUIRED

Flight Logs

Each of the ASL Borstad crew logged pertinent information such as weather, flight conditions (time, altitude, speed, etc.), visual observations (fish schools, water colour, birds, etc.), equipment readings (file number, integration time, etc.), and GPS settings (waypoints, tracks, etc.). Digital copies of the log file are included in the delivered hard drive. Important observations and comments were converted to waypoints. The waypoints were converted both to Garmin and Google Earth formats, which were used later as a source for ground truth data during data analysis. A final list and the paths where these files are located in the hard drive are given in Appendix 9.6.5.

GPS System

Three sets of GPS records were obtained, two from the internal GPS system from CASI and one from the hand held (Garmin) unit. The flight tracks were recorded in Garmin GPX format (for use in Map Source) and also converted to KML format for display in Google Earth (e.g. Figure 4).
Waypoints were collected on the handheld unit at the start of every CASI file and if important information was noted on the log sheets. The waypoints were also converted to KML format. A final list and the paths where these files are located in the hard drive are provided in Appendix 9.6.3.

CASI Data

A separate Compact Flash Card was used to store the image data for each of the 4 transects. Short test files were acquired immediately after initializing the card and again after the last CASI data file was acquired. The 4 Flash Cards from each of the Transect Lines were later downloaded in the office for processing as described in Section 4.

Excluding the test files, a total of 105 CASI files were acquired. The plane flew 2,106 km for the 4 Transects Lines of which 1,413 km were imaged (Table 2). All files were suitable for analysis, except one file acquired on the morning flight of July 27 (T3, File 18) which was corrupted. CASI *End Product* images are included on the delivered hard drive. These products include the mapped 6-band CASI Multispectral image and the derived 3-band SFM products. Intermediate images (raw, unmapped, etc.) and final images taken during transit over land are not included. It should be noted that special software such as PCI Geomatics or ENVI is needed to view the files. Both of these packages have free readers that can be downloaded from the company websites.

Because the start and end time of each CASI flight line were tagged in tandem to the GPS tracks, the total distance and location of each line can be located quickly. An example of how the path and location of each flight line and other collected waypoints can be viewed in Google Earth is shown in Figure 5.

The survey altitude varied according to local weather conditions. The CASI image swath is about 60% of the survey altitude. For a wider survey coverage, it would be necessary to fly at a higher altitude, but with the disadvantage of losing the ability to have visual confirmation of fish schools at this altitude. A wide angle lens is available for the ASL CASI, but the floats on this aircraft may interfere.

Nikon D90 Fixed Mount Camera

Table 3 summarizes the 3983 Nikon photos taken during the survey. Because of atmospheric haze and low contrast from the water, each photo was enhanced with an automatic equalize function, using the batch mode of Adobe Photoshop. Although we collected both Raw and JPG formats, we only processed the JPGs. The raw format photos are archived and included in the hard drive.

After all the photos were rotated and enhanced, we used GPicSync to automatically geo-code the pictures using GPS record. All photos were geocoded and a Google Earth KML file was created in which the exact location of each taken photo can be easily retrieved (Figure 6). Clicking on the thumbnail opens up the full resolution of the photo and file number.

We used a polarizing filter over the lens on the second day of the survey. The filter blocked most of the sun glint but the amount of glint depends on the azimuth of the flight track relative to the sun. Use of the filter reduces the light level and required a one f-stop reduction.

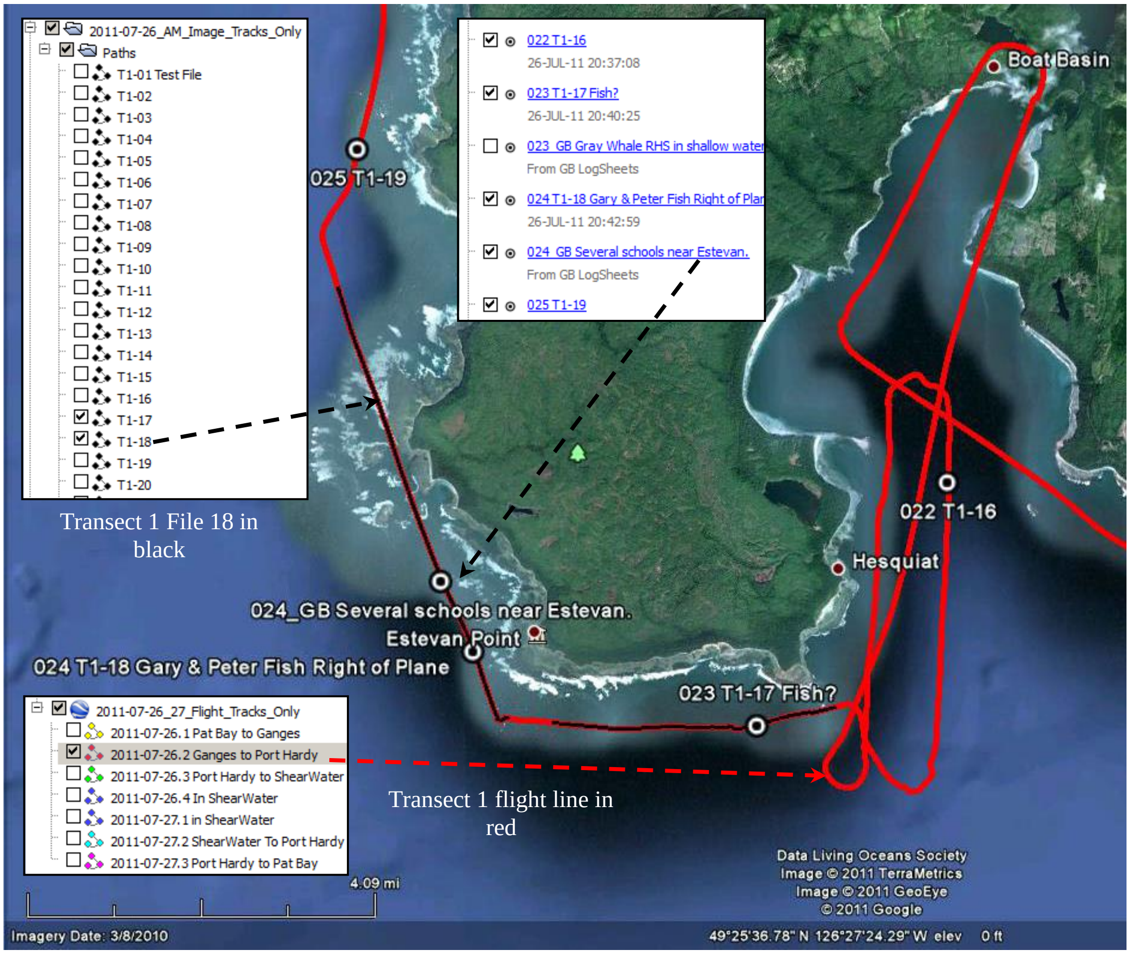


Figure 5. Example of collected CASI data and waypoints with tagged comments as shown in Google Earth™ (GE). Insets are layers with check marks that are enabled on the sidebar of GE.

Table 3. Acquired Nikon D90 photos from the CASI sardines survey.

Transect No.	Destination	Distance Covered (km)	Number of Photos (JPG)	Storage Used (GB) Raw & JPG
1	Ganges – Port Hardy	697	1,334	17.4
2	Port Hardy - Shearwater	356	706	9.12
3	Shearwater – Port Hardy	431	827	11.5
4	Port Hardy – Pat Bay	622	1,116	15.5

The photographs are slightly out of focus. Doubling the shutter speed to 1/1600 second did not make the photos sharper. At this shutter speed, both the lens opening and ISO settings were at their maximum. We were using a slow lens (f/3.5-5.6) but with the VR (Vibration Reduction) mode of the lens on during the flight. The VR mode may have created more problems than it resolved. Time constraints prevented adequate testing of the Nikon prior to the flights. More tests are needed to resolve the focus problem.

Because we changed the originally planned focal length due to porthole obstruction and also flew at a lower altitude because of poor weather, the photos did not match the swath width of CASI images and did not obtain the 10% overlap as planned. Where they are available, the photos help verify interpretation of the CASI products.

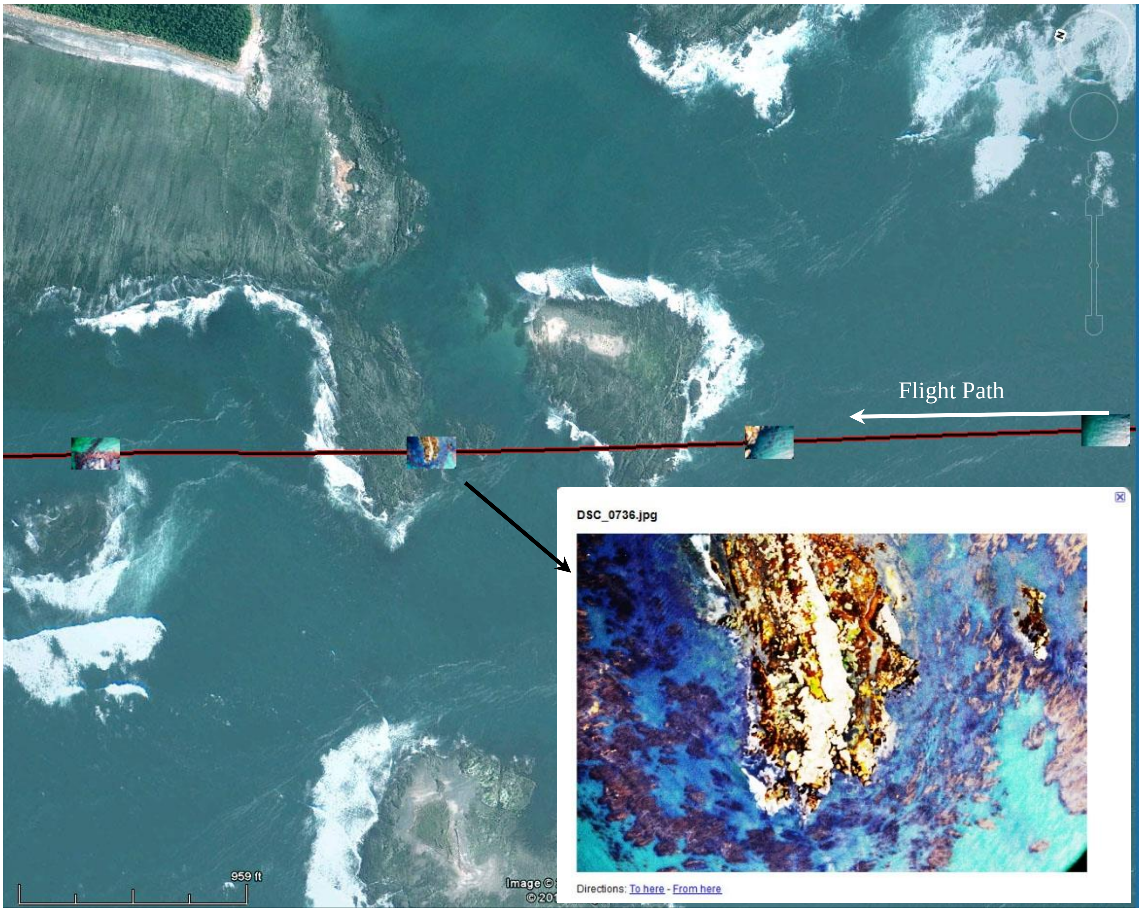


Figure 6. Example of geocoded photos shown in Google Earth along the flight track (red) and flight line (black). Inset photo has been batch rotated and enhanced.

Hand Held and Video Cameras

Oblique photos were taken *ad hoc* from both sides of the plane recording important information during the flight such as current weather conditions, actual ground conditions, and other interesting ground features (Table 4).

Table 4. Acquired oblique photos and videos from CASI sardines survey.

Transect No.	Destination	Distance Covered (km)	Number of Photos (JPG)	Number of Videos
1 2	Ganges – Port Hardy Port Hardy - Shearwater	697 356	558	26
3 4	Shearwater – Port Hardy Port Hardy – Pat Bay	492 622	492	45

Similar to the Nikon D90, the oblique photos were batch enhanced and geocoded into Google Earth format. Pictures that were taken on land or when the GPS was turned off are not tagged and are not included in the Google Earth database. The photos are however included in the delivered hard drive.

Since the Sony and Kodak camera's time were not synchronised with the GPS time, we use the ACDSee Photo Manager 12 program to shift the time stamps of each photo to the correct time. Examples on how the pictures would look like in Google Earth interface are shown in Figure 7.

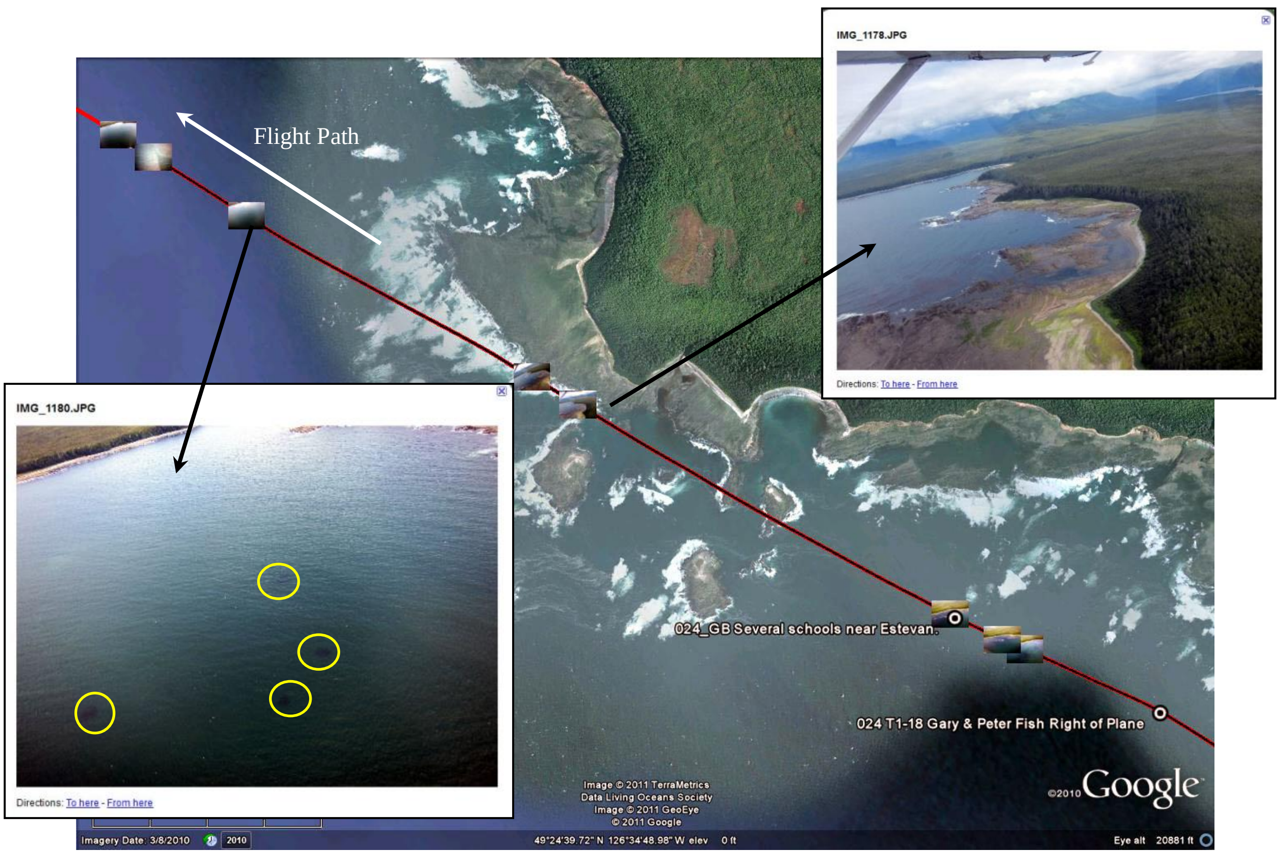


Figure 7. Example of two geocoded oblique photos showing fish schools (yellow circles) and coastline shape in Google Earth along the flight track (red) and flight line (black). Inset photos has been batch enhanced.

A video record was not part of the original plan, but a very small personal Kodak PlaySport Video ZX3 camera was used in an experimental mode. On the first day, the videos were taken from the windows and the quality of the high definition was found to be quite reasonable, given that the camera was not of high quality. On the second day, videos were taken at nadir from a small hole beside the Nikon D90. The nadir viewing videos were even better (Figure 8) and may be a viable alternative to the D90 for future surveys.

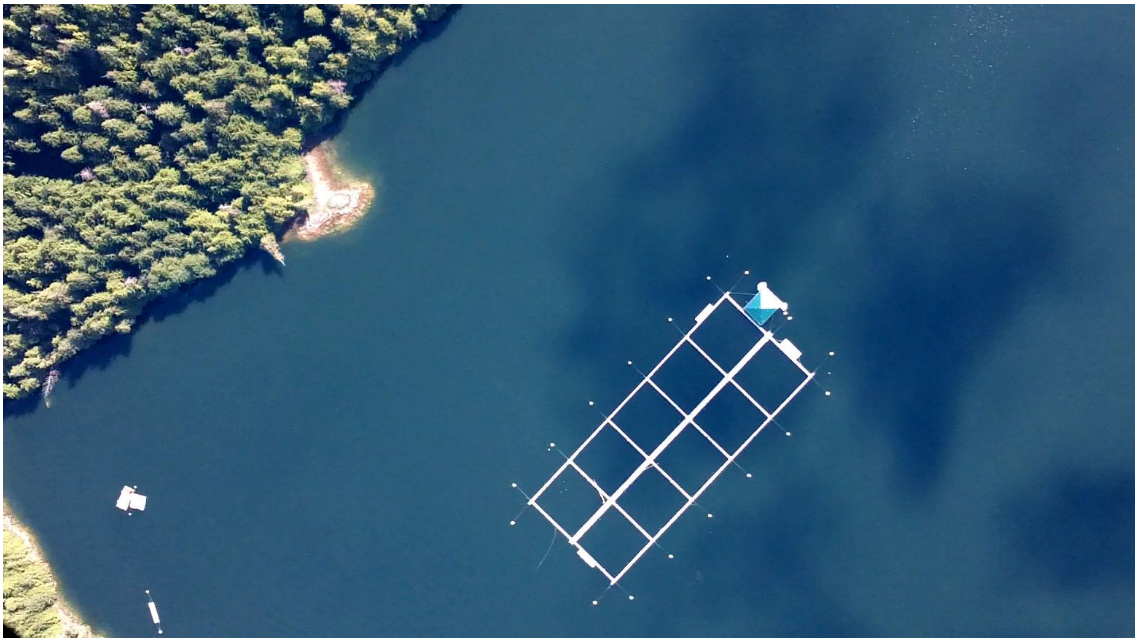


Figure 8. Screen grab of HD video (1080p) showing fish pens taken at 3,000 feet (File 100_0027.mov).

Data Archive

All the important data sets acquired are included on the 1 TB portable hard drive delivered, numbered chronologically as the data or information was collected. Important files or links are listed in the Appendix. Google Earth shortcuts are placed under one folder in the hard drive. Note - It is advisable not to rename or rearrange the different directories as some of the links and shortcuts, particularly for Google Earth will be broken if the directories are renamed or rearranged. Some of Google Earth files are very large and take time to load. Patience is required especially when opening the photo and image tags.

TRANSECT LINES FLOWN

Transect 1: Ganges – Port Hardy

After an 1120 PDT take off from Ganges harbour on Saltspring Island, the aircraft traversed north westerly to the west coast of Vancouver Island towards Barkley Sound (Figures 18-19), under overcast skies and with light winds. Several lines were flown in Barkley Sound, north along Long Beach and across Tofino and up Fortune Channel towards Clayoquot Sound. Low cloud and rain were present over most of the highlands of Vancouver Island, so the aircraft then returned to the outer coast along the northern side of Meares and Vargas Islands and continued northwards along the outer western coastlines of Vancouver Island usually at a distance of about 1 km from the shore.

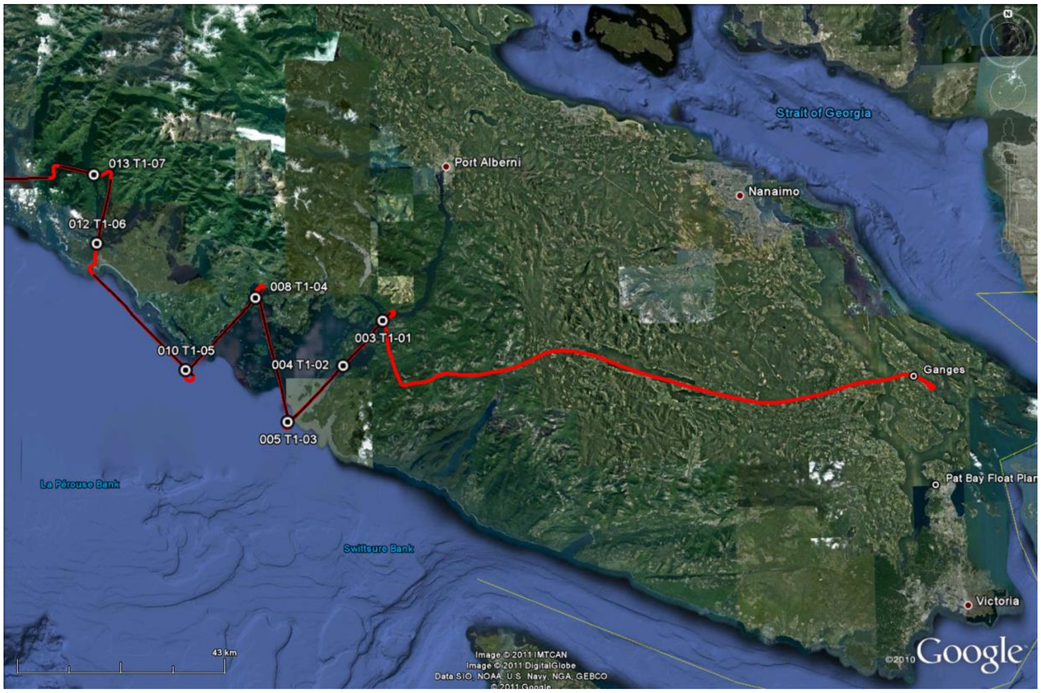


Figure 9. Transect 1: Files 01 to 07 (black lines are CASI images acquired)

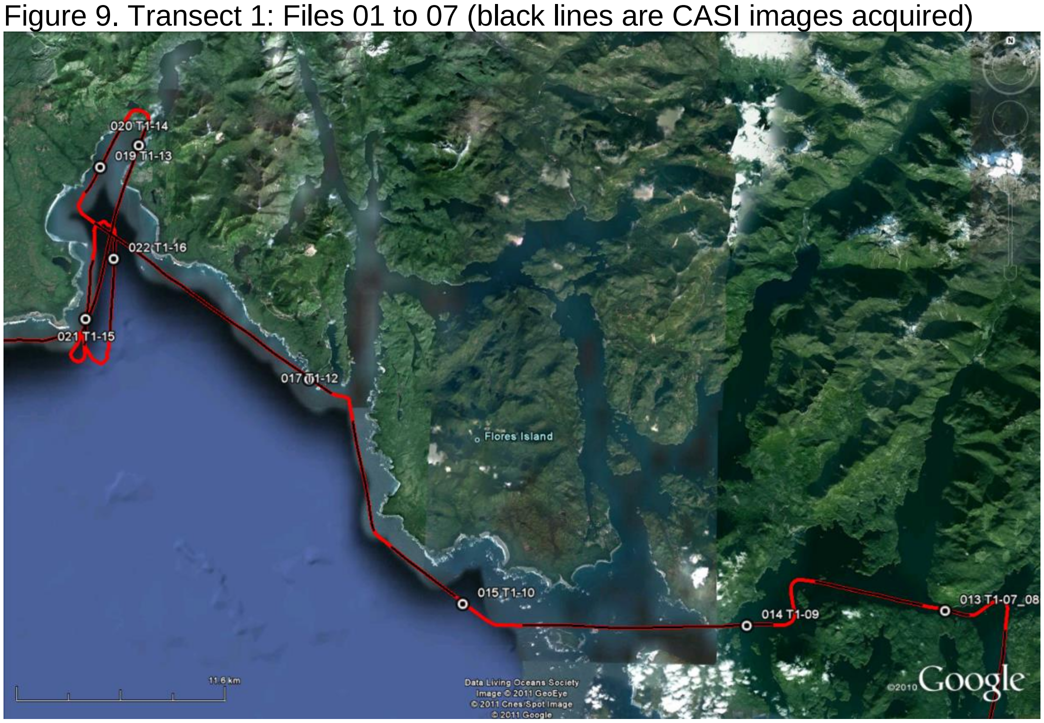


Figure 10. Transect 1: Files 08 to 16 (black lines are CASI images acquired)

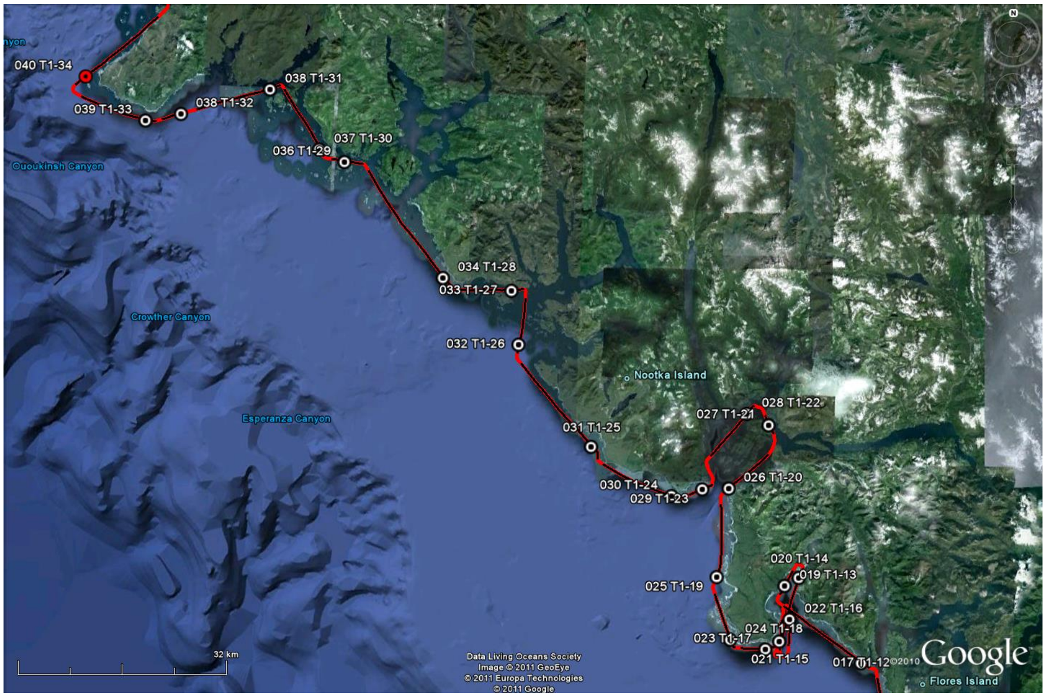


Figure 11. Transect 1: File 17-34 (black lines are CASI images acquired)

Fish schools were first spotted visually south of Estevan Point (Figures 19 and 20). After repeating one line in that area, the aircraft continued northward along the coast going inside Nootka Sound just off Bligh Island. Many more schools were observed between Estevan and Brooks peninsula, mostly in green waters. North of Brooks the aircraft transited Quatsino Sound through Coal Harbour and landed at Port Hardy at 1535 PDT (Figure 21). Due to clouds, all of the lines taken during this leg were acquired at 1500 ft altitude.

Transect 2: Port Hardy – Shearwater

After refuelling, the survey crew took off at 1625 PDT. Although the sun was quite low at this time, the sky was clear in Port Hardy. Two lines were acquired at 1500 ft altitude while crossing the channel separating Vancouver Island from the mainland, but lower cloud ceilings required that most subsequent lines were flown at 1000 ft (Figures 22 and 23). The aircraft travelled northward along the outer Central Coast up to Kitasu Bay on Swindle Island, returning via Hoskin Channel, along northern Price Island and landing at Shearwater at about 1840 PDT. The last 3 lines were acquired at 1500 ft. Although we flew at lower altitudes, we did not spot fish schools on this flight. Most of the waters encountered were dark green or blue black in colour. Taking advantage of the flexibility of the CASI instrument, the data acquisition parameters were altered during the flight to increase the recorded signal as light levels declined due to cloud and sun elevation.

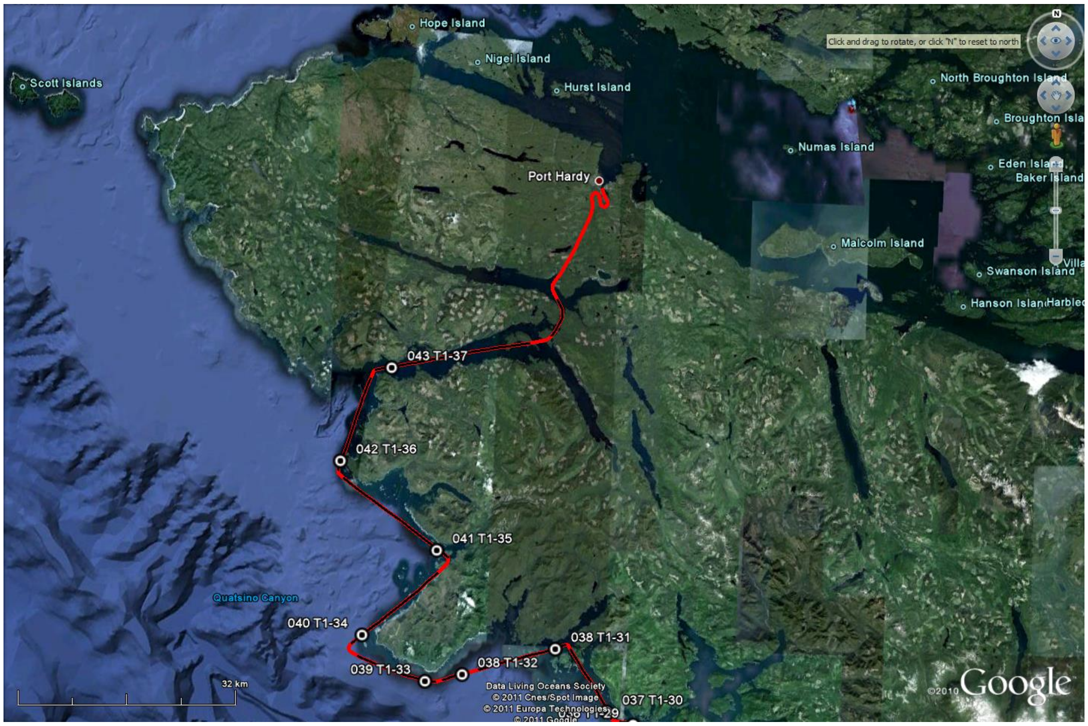


Figure 12. Transect 1: Files 31 to-43 (black lines are CASI images acquired)

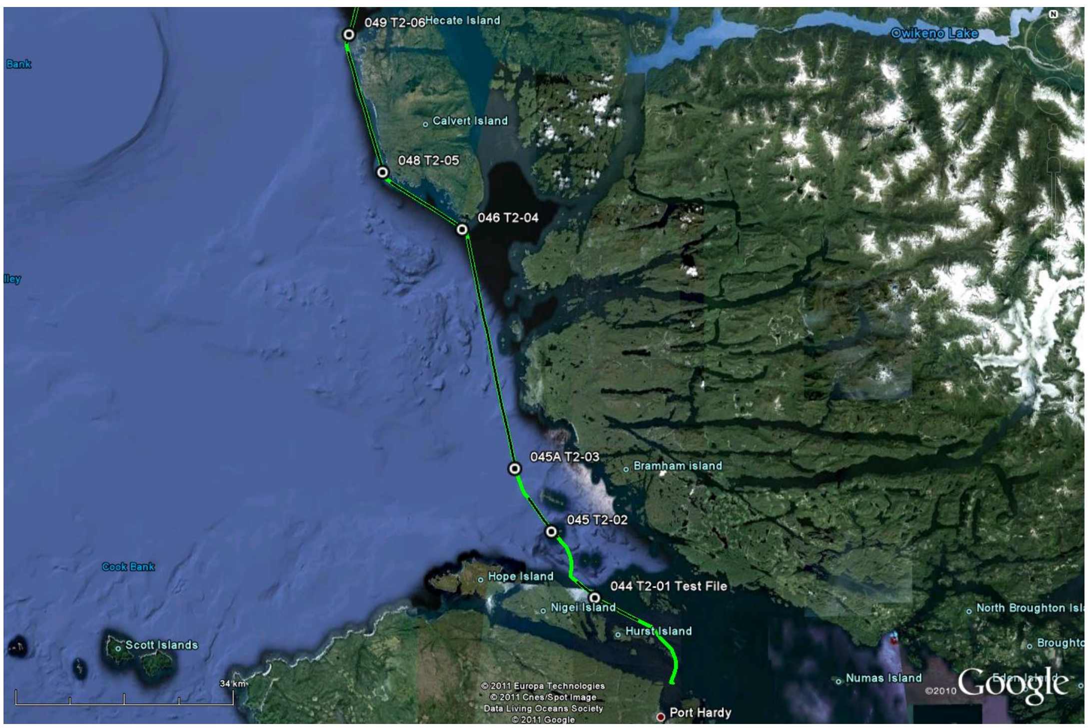


Figure 13. Transect 2: Files 01 to 05 (black lines are CASI images acquired)

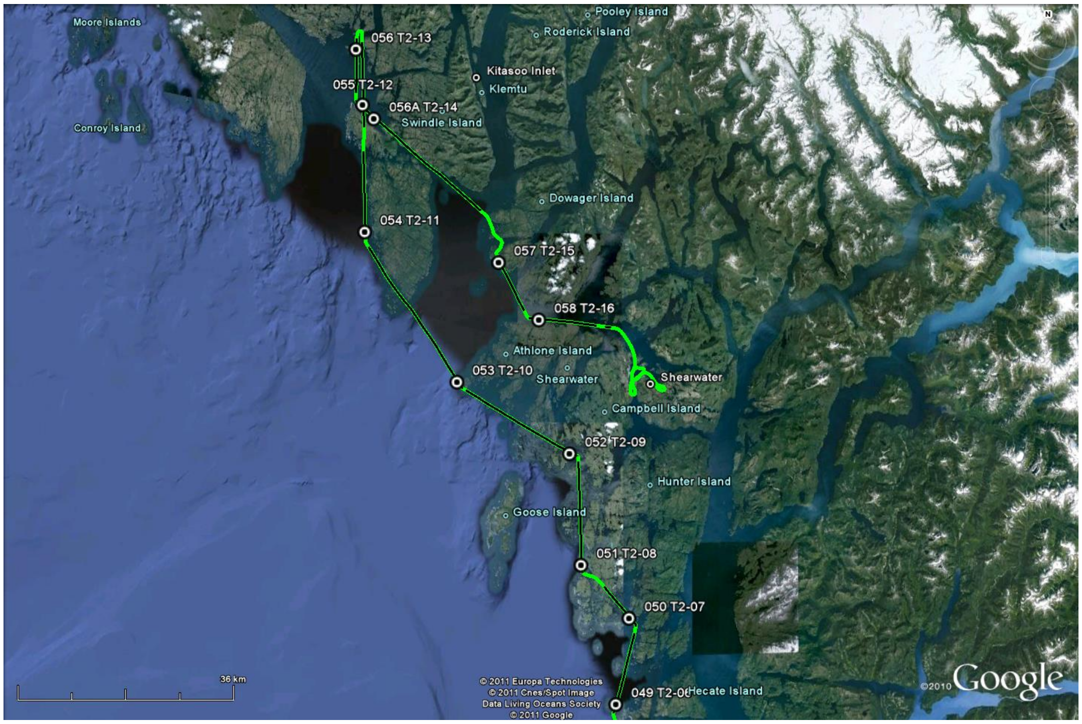


Figure 14. Transect 2: Files 06 to 16 (black lines are CASI images acquired)

Transect 3: Shearwater – Port Hardy

When the plane took off 1014 PDT, low clouds still covered most the area. Flying at 1000 ft., the aircraft traversed north-easterly rounding the inner channels of Spiller and Dean Channels and continuing south in Fisher Channel (Figure 24). Upon reaching Fitz Hugh Sound, a crisscross pattern of transects were made to cover both sides of the channel (Figure 25). The survey then flew southward acquiring several lines across Rivers Inlet (Figure 26). Several northeast southwest lines were acquired in Smith Sound, and two long lines were flown along the eastern coastlines of Queen Charlotte Strait. Final transects were done crossing the strait back to Port Hardy where the plane was landed at 1249 PDT for refuelling.

Most of transect 3 was acquired at 1000 ft. Waters north of Port Hardy appeared blue/black except for those near the mouth of Rivers Inlet. Only one 'probable' sighting of a fish school was made on this transect.

Figure 15. Transect 3: File 01-06 (black lines are CASI images acquired)

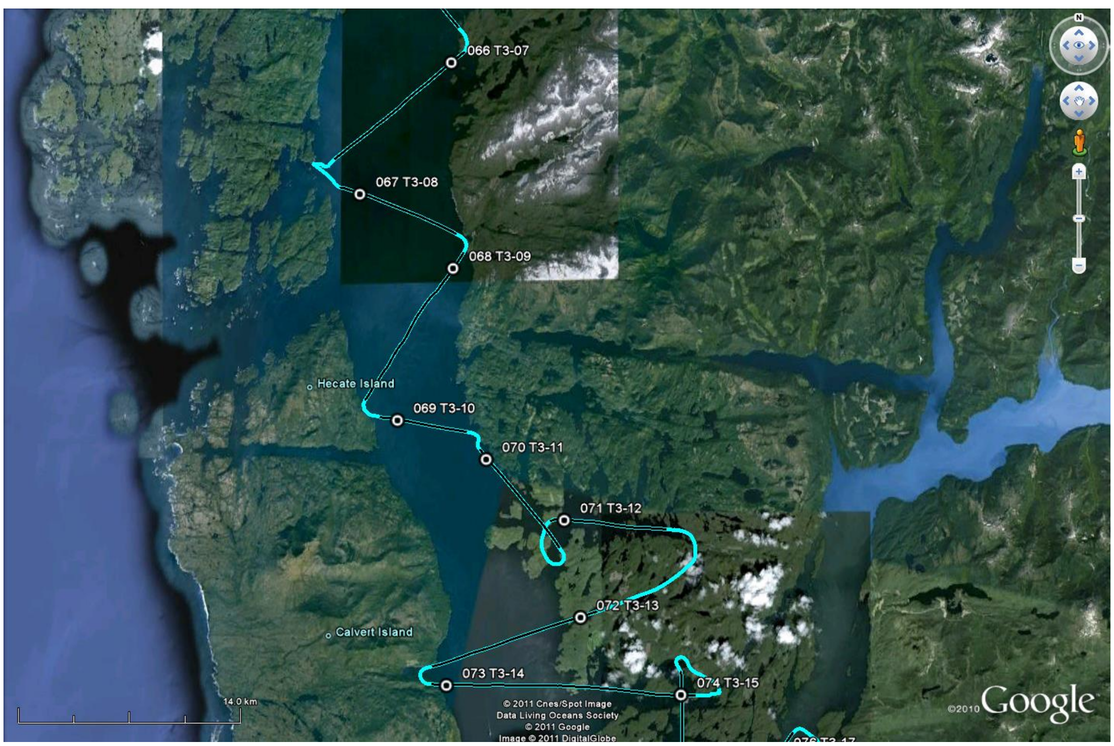


Figure 16. Transect 3: Files 07 to 15 (black lines are CASI images acquired)

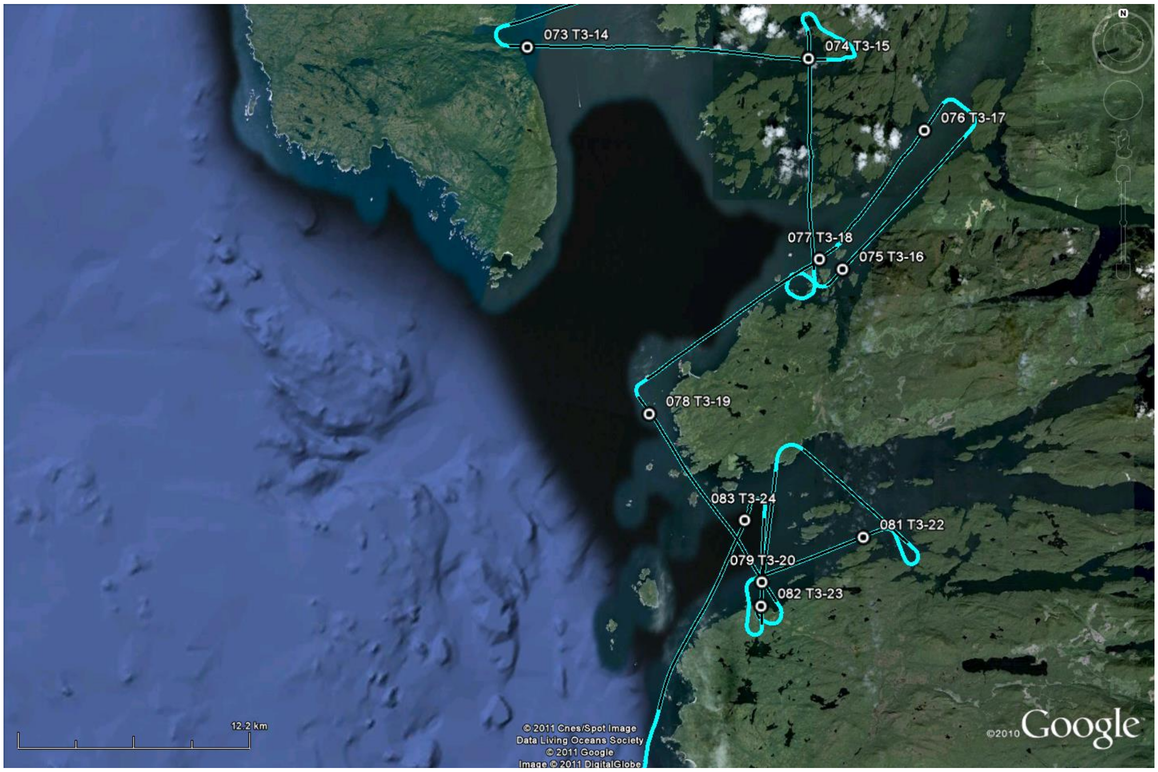


Figure 17. Transect 3: Files 14 to 24 (black lines are CASI images acquired)

Figure 18. Transect 3: Files 25 to 28 (black lines are CASI images acquired)

Transect 4: Port Hardy – Pat Bay

While refuelling at Port Hardy, the weather improved and most subsequent lines were acquired at 5000 ft altitude. The aircraft took off at 1421 PDT, flying eastward across Queen Charlotte Strait and into the Broughton Archipelago, then back into Johnstone Strait and south, deviating along the north and eastern coasts of Quadra, Maurella, Read, and Cortes Islands before continuing south along the western shore of the Strait of Georgia to Parksville and landing at Patricia Bay at 1739 PDT.

A major plankton bloom was occurring in the Broughton Archipelago and near Quadra Island and waters were green or brown. Waters in Johnstone Strait were blue/green and blue, as would be expected in this well mixed channel.

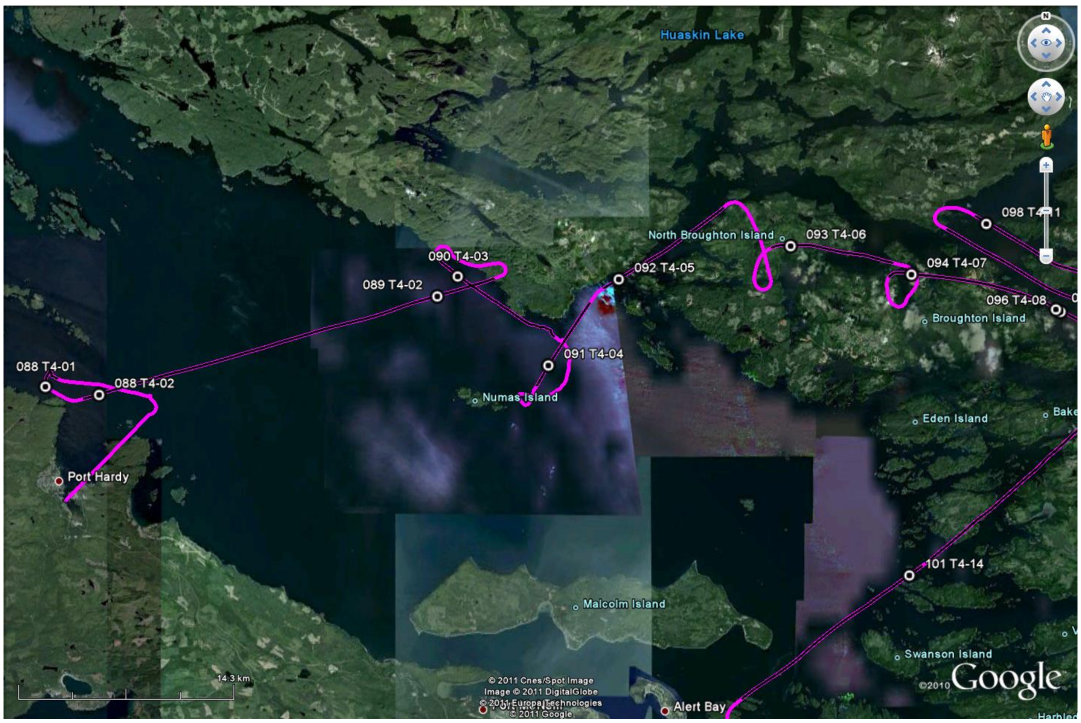


Figure 19. Transect 4: Files 01 to 14 (black lines are CASI images acquired)

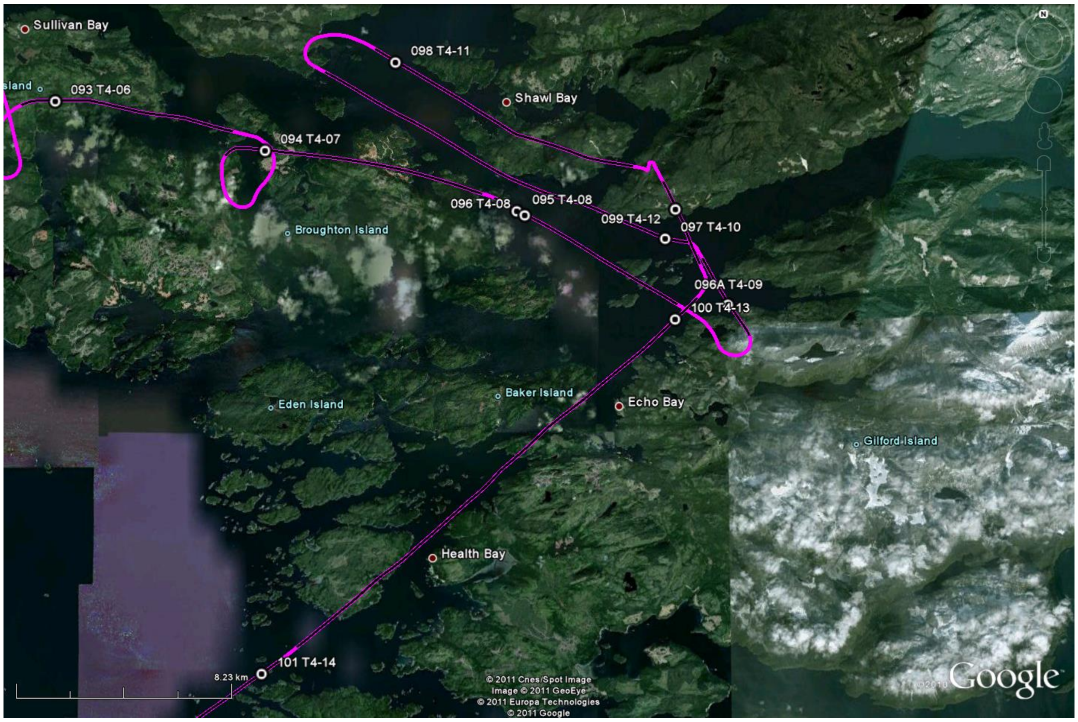


Figure 20. Transect 4: Files 06 to 14 (black lines are CASI images acquired)

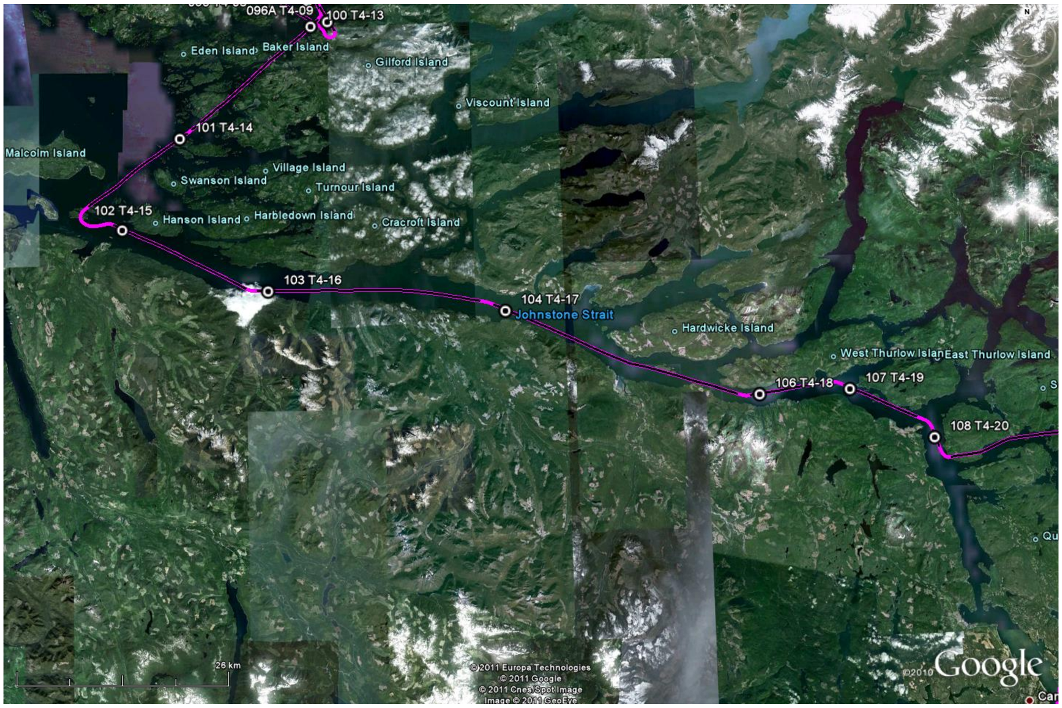


Figure 21. Transect 4: Files 13 to 20 (black lines are CASI images acquired)

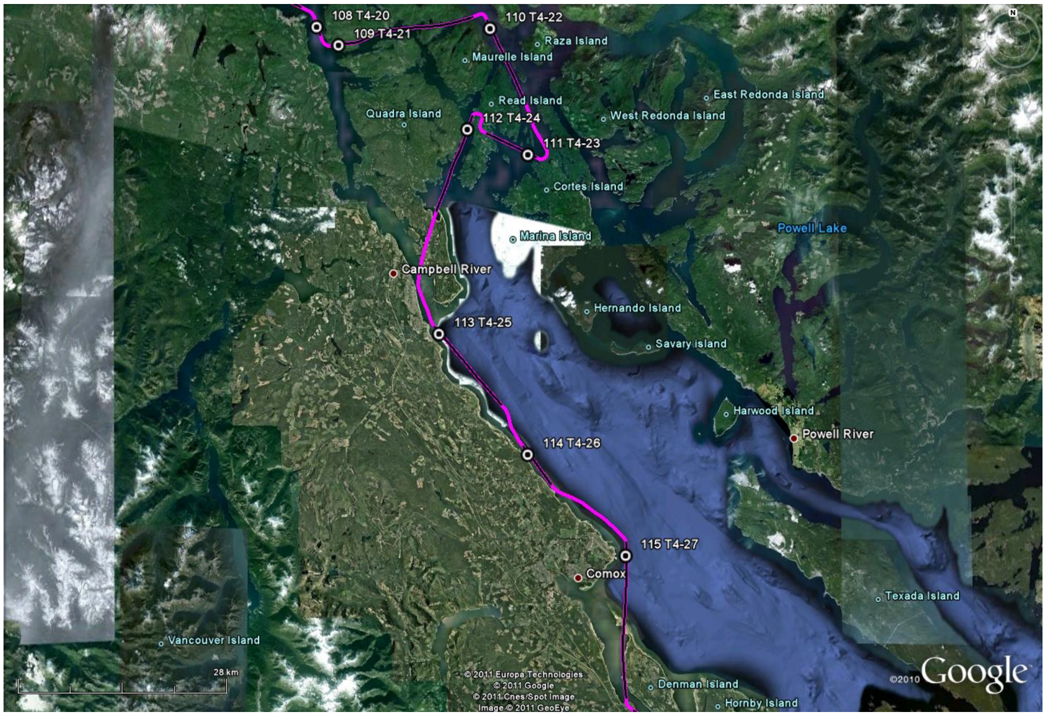


Figure 22. Transect 4: Files 20 to 27 (black lines are CASI images acquired)

Figure 23. Transect 4: Files 28 to 32 (black lines are CASI images acquired)

CASA DATA PROCESSING AND METHODOLOGY

The 2011 CASI survey data acquired was processed using ASL Borstad proprietary algorithms. A summary of the processing is shown in Figure 9.

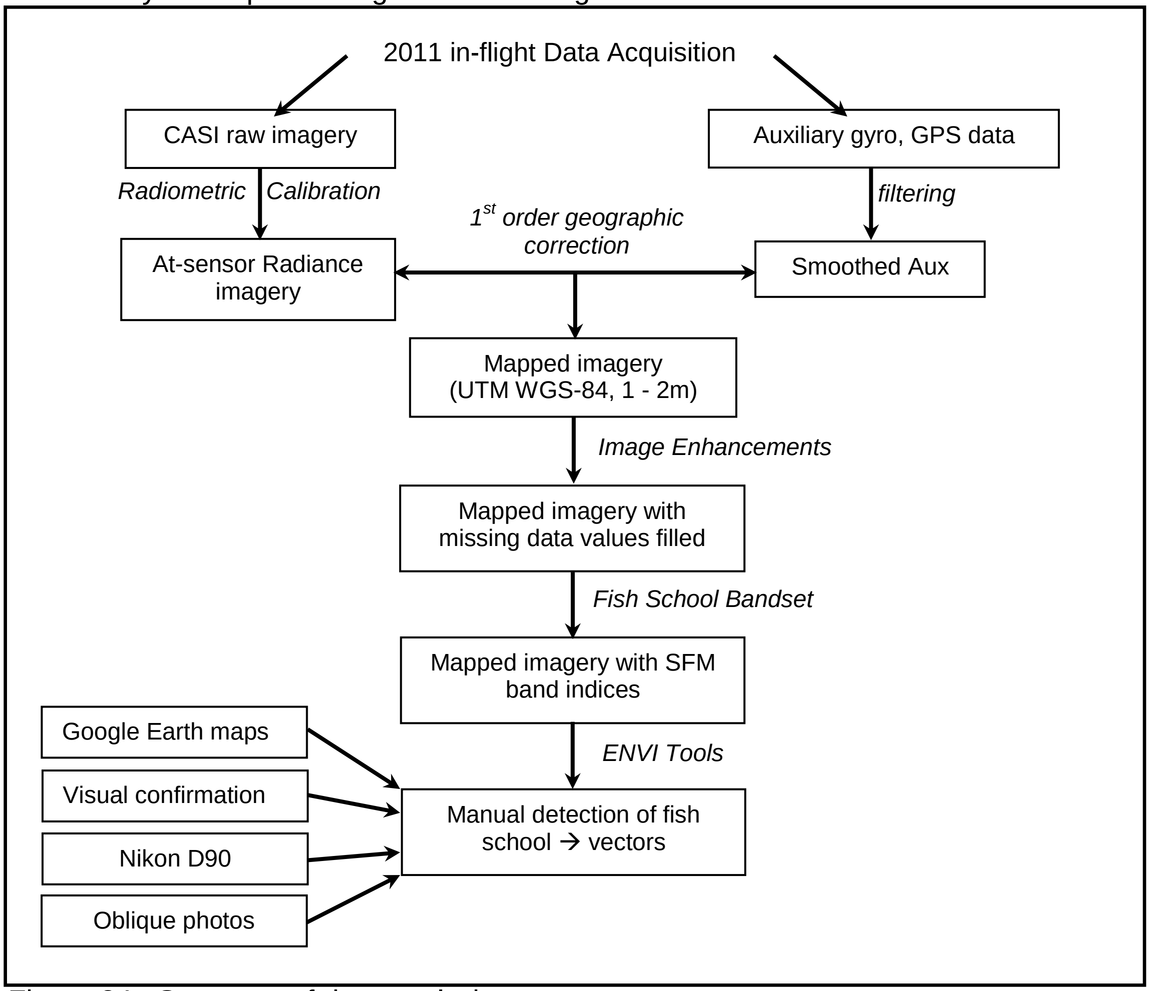


Figure 24. Summary of data analysis.

Radiometric Calibration (CDTD)

During radiometric calibration, the raw image data are read from tape and processed through an ASL Borstad program (*CDTD*) that converts the raw digital values into radiance units (nW/cm^2/sr/nm). The dark and electrical offset signals for each pixel of each scan line of the data are removed. The calculated values represent radiance at the sensor, including the effect of the atmosphere below the aircraft as well as the extra path radiance at the edge of the swath. The imagery can be viewed at this stage, but because no corrections have been applied for aircraft motion, it can be difficult to interpret. All of the 2011 data acquired for the Sardines Survey were processed to this level.

First Order Geographic Rectification (CMAP)

During acquisition, the roll and pitch of the aircraft are recorded by a two-axis mechanical gyro, and GPS position by a GPS receiver, for each scan line of image data. As part of the first order geo-correction process, ASL Borstad software (*CMAP*) uses this roll, pitch and GPS data for each scan line to remap the imagery and correct for aircraft motion, using nearest neighbour re-sampling. Aircraft yaw is not recorded by the gyro, but instead, a single adjustment is made for each flight line during processing. Data processed to this first-order stage are mapped north up to WGS84 coordinates, re-sampled to either 1.0 m pixel size or 2.0 m (i.e. depending on our flight altitude), and corrected for aircraft motion. In general, first order geo-corrections are accurate to within 10-25 metres over the ocean, but may be considerably distorted over sloping terrain or in turbulent flight conditions. All of the 2011 data were processed to this level. An example of the image catalogue is shown in Appendix 9.2.

For projects requiring precise mapping, a second stage rectification using ground control points is done after this first order mapping. For this project the images were not precisely navigated to a ground controlled reference image. Under clear skies and for acquisition of six spectral channels (as in this project) the ASL CASI would optimally be configured to acquire full coverage and square 2.6m x 2.6m pixels at 6,860 ft altitude and 100 knots ground speed. Because of low cloud, we flew at much lower altitudes and with instrument integration times much longer than normally used (in order to increase signal levels). We mapped the imagery at 1m ground sampling distance with the effect that the surveyed area was under-sampled in the along-track dimension. In order to map the image data at this resolution, we interpolate between adjacent scan lines, with 7 x 7 filtering in both dimensions.

Secondary Image Products

Three secondary products were calculated from the mapped CASI radiance imagery. All three products use an algorithm in which we calculate a radiance difference from a baseline calculated from two other bands. We normally use this type of algorithm to measure chlorophyll fluorescence (Fluorescence Line Height or FLH) as in the equation below:

$$FLH = \frac{b_2 - b_3}{(b_1 - b_3) * \left(\frac{\lambda_2 - \lambda_3}{\lambda_1 - \lambda_3}\right)}$$

where λ_1 and λ_3 are the baseline bands and λ_2 is the 'signal' band. Table 5 shows the product name, input bands along with the centre wavelengths for the corresponding CASI band. For convenience these are referred to as the Surface School Index (SSI), Fluorescence Line Height or FLH and Maximum Chlorophyll Index (MCI). The SSI measures the green spectral absorption by the fish schools against a baseline extrapolated from red and near-infrared wavelengths. FLH is an index of fluorescence from phytoplankton chlorophyll, and MCI measures an increase in near-IR reflectance from very high concentrations of phytoplankton, or from benthic, floating or terrestrial chlorophyll containing plants and algae.

Identification of Fish Schools

Fish schools were identified using the derived SSI Product as described in Section 4.3. This calculation is 'self normalizing' and requires less manipulation by the analyst to adjust enhancements to account for very large variations in illumination and water quality experienced on this survey.

Table 5. Derived 3 band products from the 6 band CASI multispectral data.

Product	Input CASI Bands $\lambda_1\,\lambda_2\,\lambda_3$	Centre Wavelength (λ) (nm)	Measures
Surface School Index (SSI)	4, 2, 6	675.3, 545.7, 754.9	Absorption by schools near 545nm
Fluorescence Line Height (FLH)	3, 4, 5	646.8, 675.3, 711.1	Fluorescence by phytoplankton near 675 nm
Maximum Chlorophyll Index (MCI)	4, 5, 6	675.3, 711.1, 754.9	'Red Edge' by chlorophyll containing plants at 711nm

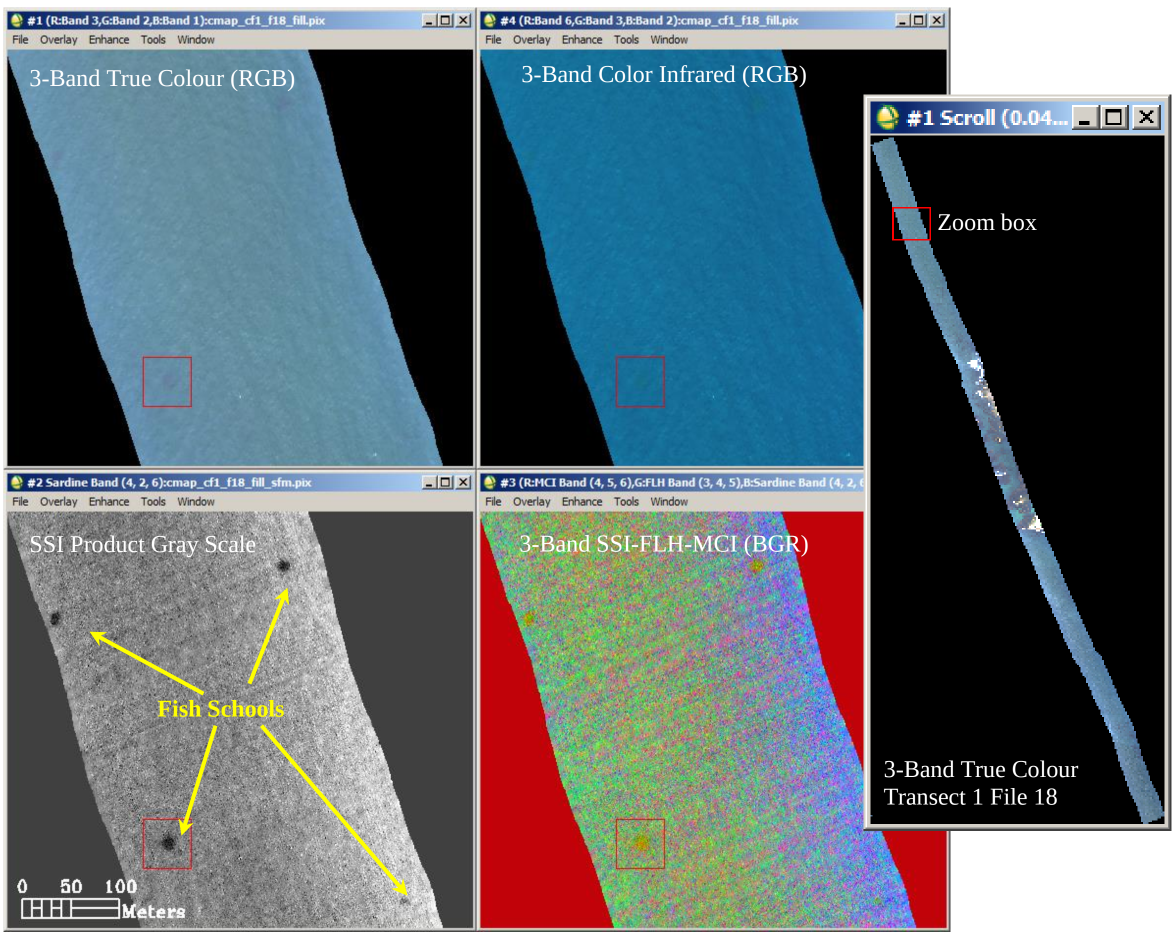


Figure 25. Delineation of fish schools primarily from using the derived SSI Product as compared to using standard band combinations such as true colour or colour infrared.

Viewing the product on a single channel, the features we recognize as schools are circular or elongated in shape and have a much darker tone compared to the background. Schools are difficult to differentiate in true colour or colour infrared band composites alone (Figure 10). Kelp viewed in the SSI Product can appear similar to fish schools, but is easily differentiated because it is bright in the MCI product, and red in the SC-FLH-MCI 3-Band composites (BGR - Blue-

Green-Red). Kelp or submerged rocks surrounded by kelp exhibit a strong MCI signal, and therefore have a reddish tinge whereas fish schools do not. Where available, we also used the Nikon D90 photos and high resolution photography from Google Earth (Figure 11) to locate stationary rocks.

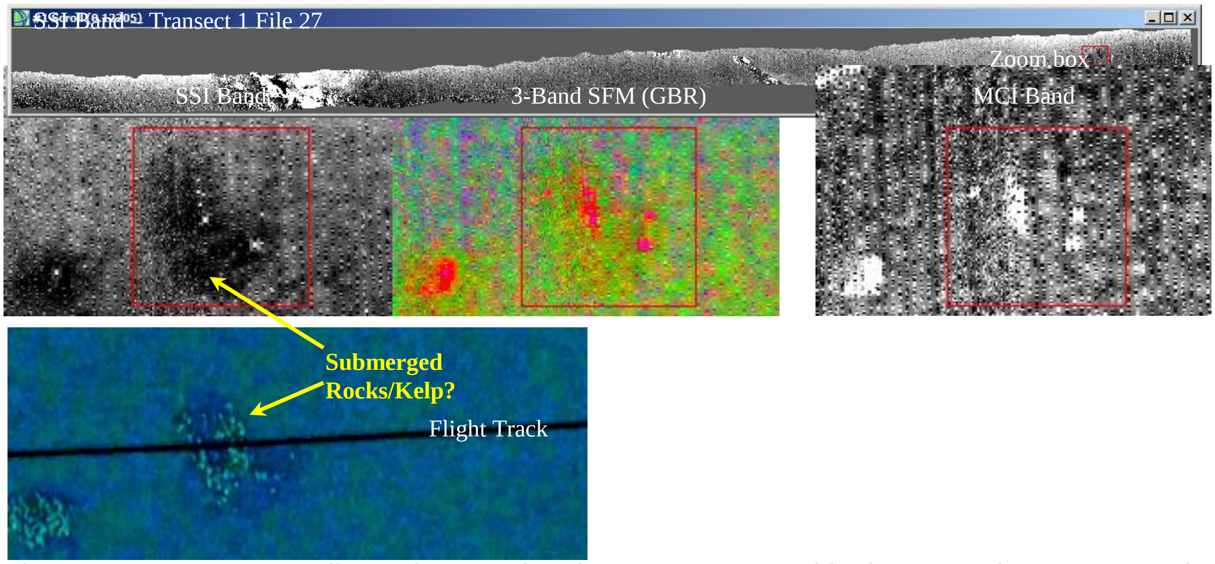


Figure 26. Kelp surrounding submerged rocks appear very red in the 3-Band SFM composites.

Area Determination

Fish schools were easily identified when the files were viewed at low resolution (central panel of Figure 12). After a fish school was identified, the area of the school was calculated using the built in *Growing ROIs* function in ENVI. A circular Region of Interest (ROI) was initially placed over the visually identified school, then the ROI was "grown" to neighboring pixels according to a specified number of standard deviations away from the mean of the ROI initially selected. The tool was applied on the SSI product (Figure 12), while varying thresholds until the operator was satisfied that the fish school was adequately covered, the ROI was saved and the area, shape, and location was recorded. Some schools imaged under very low illumination are underestimated because of noise in the calculation of SSI.

We have subjectively categorized the schools into two classes. The 'positive' class includes dark round or nearly round features in the SSI product which were also dark in the MCI product. Features which were dark in the SSI and bright in the MCI were interpreted as kelp. Most of the 'positive' class were located near where visual sightings of schools were also made.

The 'probable' sightings class includes features with similar morphology as the first but with less distinct shape, texture, and contrast in the SSI product. Some of these features were located on flight lines where no visual sightings were made - perhaps because of the differences in viewing (oblique visual observations versus nadir viewing for the CASI imaging). A few were found in darker blue black waters north of Port Hardy imaged under very low light conditions.

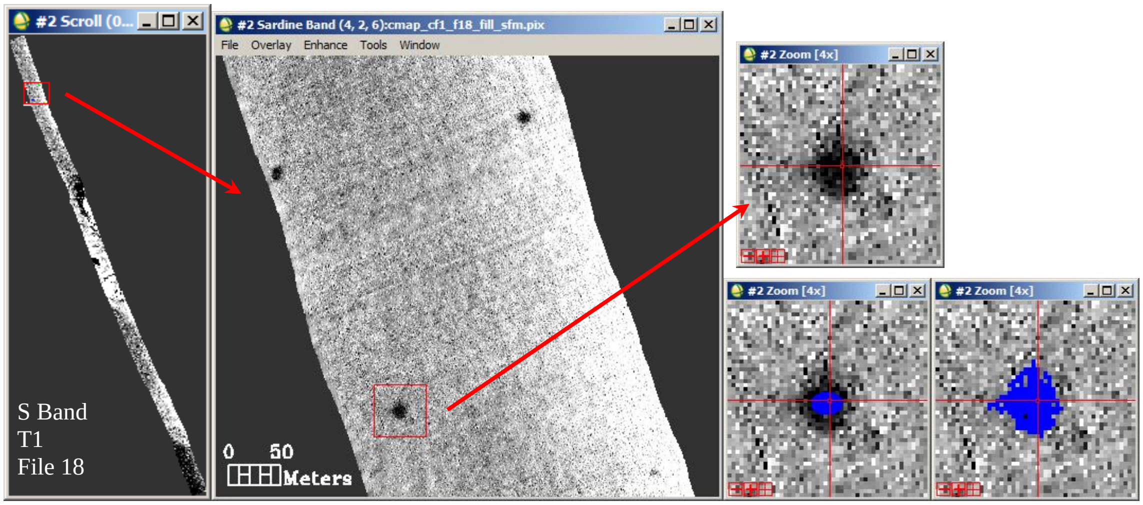


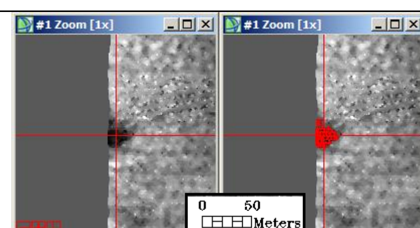
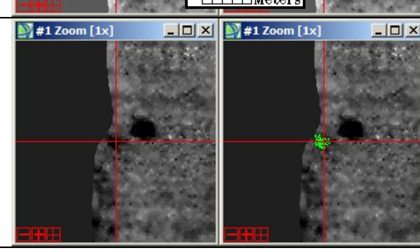
Figure 27. Growing ROI tool in ENVI showing the process involved in delineating the extent of the fish schools - in this case the ROI is delineated using 3 standard deviations and 4 neighbouring pixels.

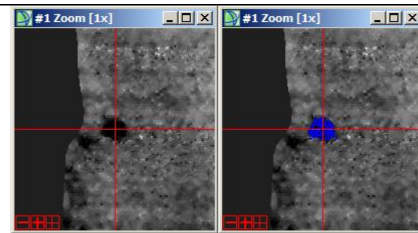
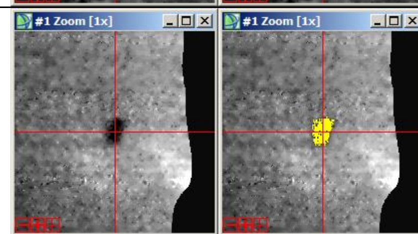
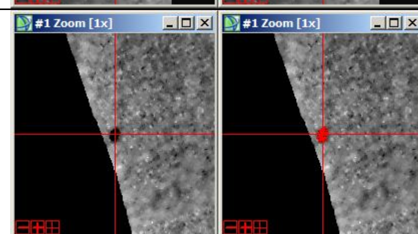
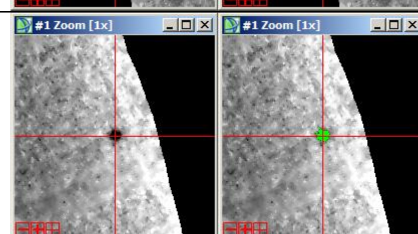
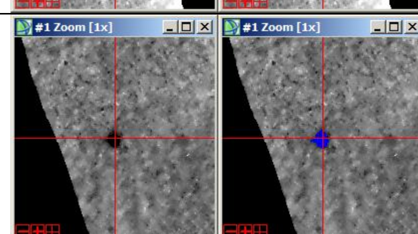
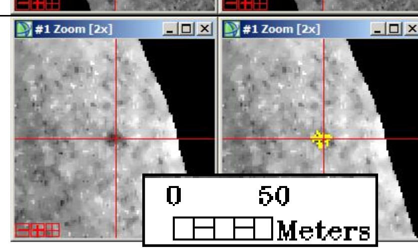
The location, shape and areal extent of each fish school were then converted to vectors. The vectors are in ESRI (ArcGIS) shape file (*.shp) format which is a popular open standard geospatial exchange data format recognized by most Geographic Information Systems (GIS) software. Locations of the digital copies of the vectors are listed in the Appendix 9.6.2.

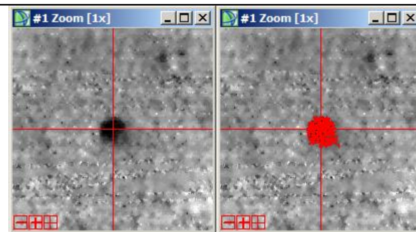
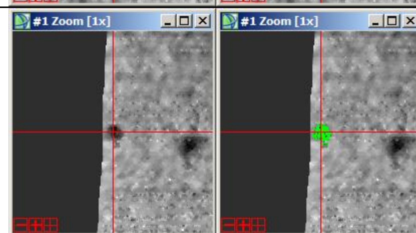
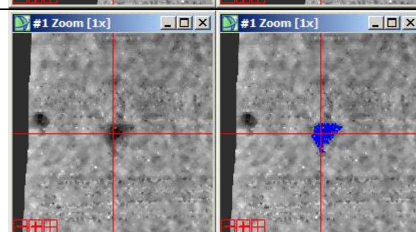
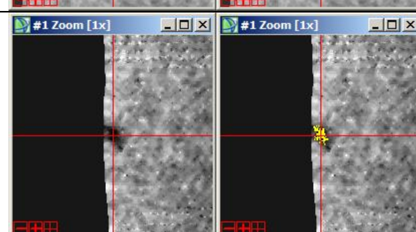
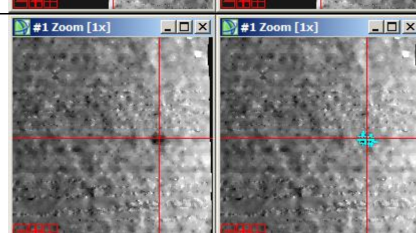
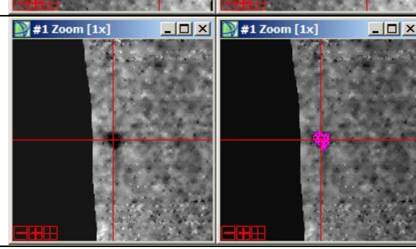
SCHOOL LOCATION AND AREAS

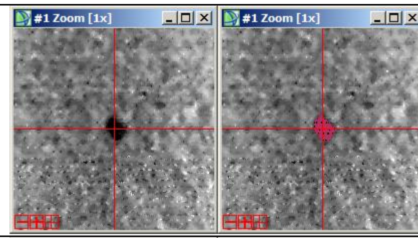
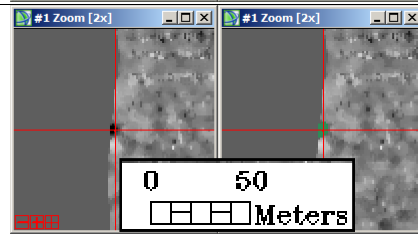
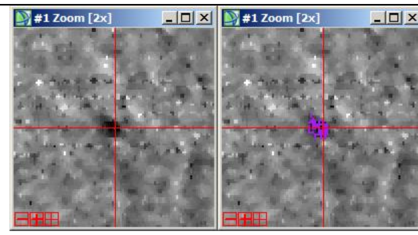
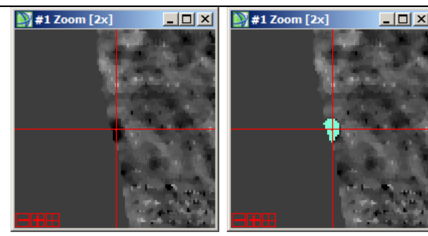
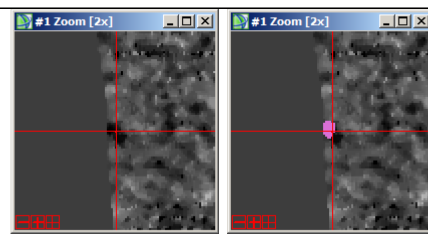
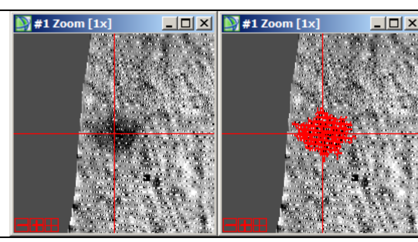
Positive Class

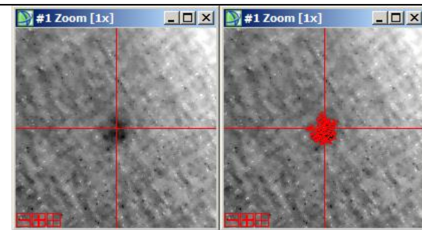
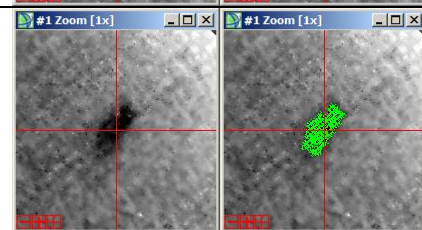
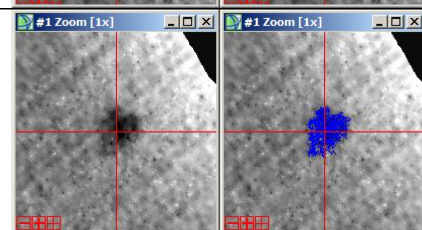
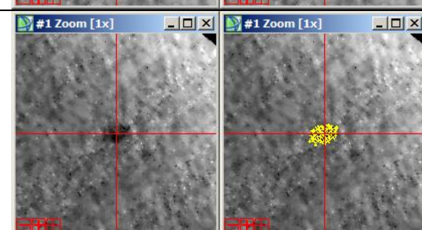
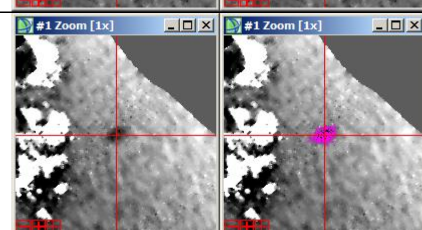
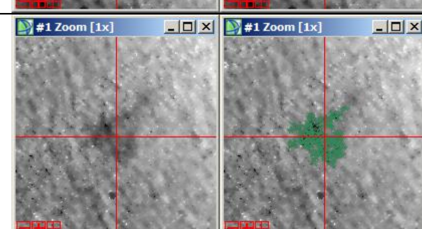
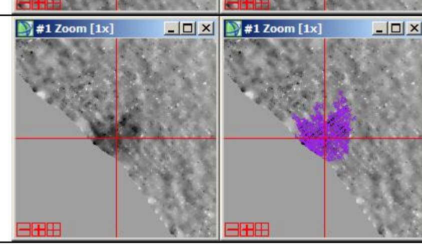
Table 6. List of areas identified as ‘positive’ class shown with 3x3 median filter. Nikon D90 images capturing the fish schools are included when available. Smaller targets are shown with 2x zoom. **Very small dark features with areas approximately 100 m^2 or less were not included in the area calculation for fish schools.*

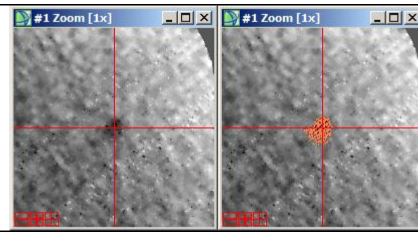
#	ROI Name	Latitude Longitude	Area (m^2) Nikon photo if available	ROI Shape and Extent
1	T1_F15.1	49.38312222 -126.45828889	354	
2	T1_F15.2	49.39179829 -126.45717828	110	

#	ROI Name	Latitude Longitude	Area (m^2) Nikon photo if available	ROI Shape and Extent
3	T1_F15.3	49.39189795 - 126.45680101	343	
4	T1_F15.4	49.39221988 -126.4542621	389	
5	T1_F18.1	49.43771389 - 126.59579167	119	
6	T1_F18.2	49.43813169 - 126.59255573	118	
7	T1_F18.3	49.43567586 - 126.59428996	180	
8	T1_F18.4	49.43507778 - 126.59103611	*43 Not included in area calculation Shown at 2X Zoom	

#	ROI Name	Latitude Longitude	Area (m^2) Nikon photo if available	ROI Shape and Extent
9	T1_F19.1	49.47110833 - 126.58857778	682	
10	T1_F19.2	49.48365926 - 126.58642916	223	
11	T1_F19.3	49.48351213 - 126.58541460	407	
12	T1_F19.4	49.47110833 - 126.58857778	119	
13	T1_F19.5	49.49558638 - 126.58247238	143	
14	T1_F19.6	49.49820293 - 126.58542352	178	

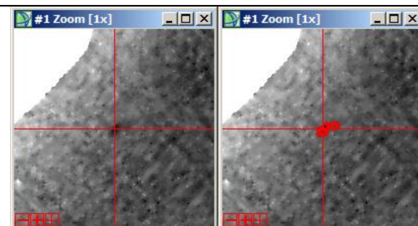
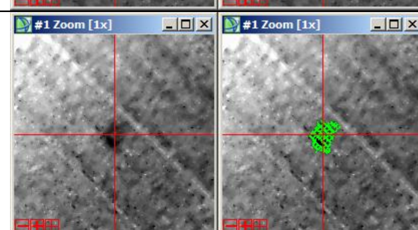
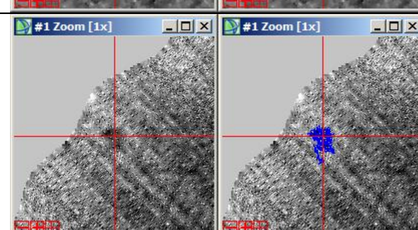
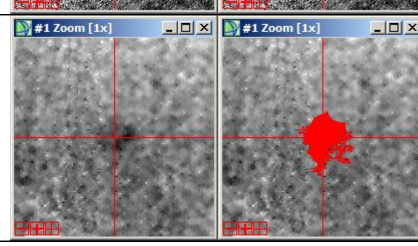
#	ROI Name	Latitude Longitude	Area (m^2) Nikon photo if available	ROI Shape and Extent
15	T1_F19.7	49.49791902 - 126.58389054	332 	
16	T1_F19.8	49.53935299 - 126.58552428	*33 Not included in area calculation Shown at 2X Zoom	
17	T1_F19.9	49.54862065 - 126.58517789	*65 Not included in area calculation Shown at 2X Zoom	
18	T1_F19.11	49.56281846 - 126.58786579	*61 Not included in area calculation Shown at 2X Zoom	
19	T1_F19.12	49.56464825 - 126.58803838	*44 Not included in area calculation Shown at 2X Zoom	
20	T1_F26.1	49.80574309 - 127.00918727	1423	

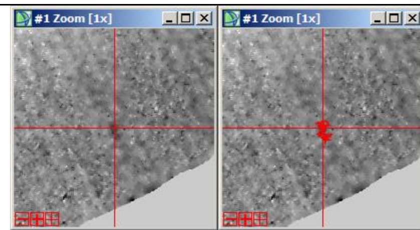
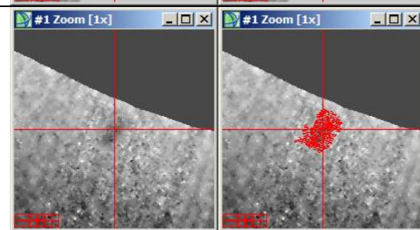
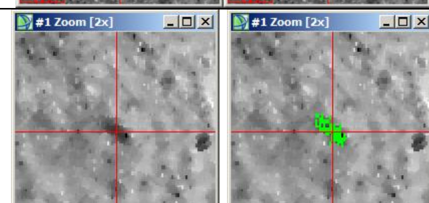
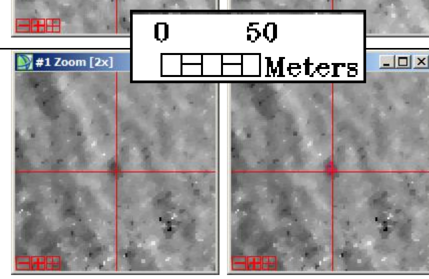
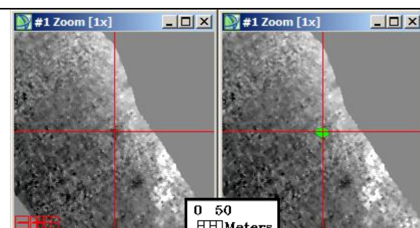
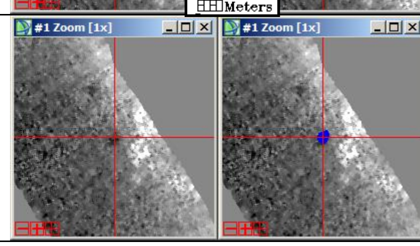
#	ROI Name	Latitude Longitude	Area (m^2) Nikon photo if available	ROI Shape and Extent
21	T1_F28.1	50.00052882 - 127.33612295	477 	
22	T1_F28.2	49.96036918 - 127.29598561	851	
23	T1_F28.3	49.95780908 - 127.29254860	1014	
24	T1_F28.4	49.95309780 - 127.28719463	330	
25	T1_F28.5	49.91384268 - 127.23786808	251	
26	T1_F28.7	49.88539050 - 127.20437908	1330	
27	T1_F28.8	49.87298425 - 127.19093524	1539	

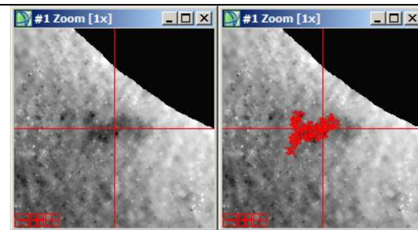
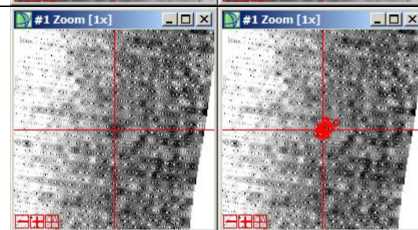
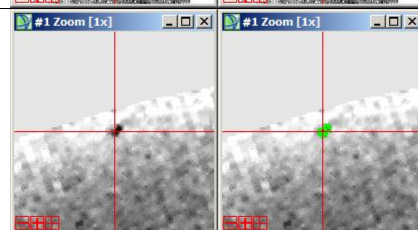
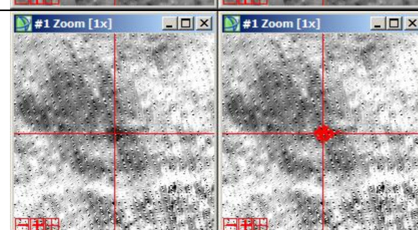
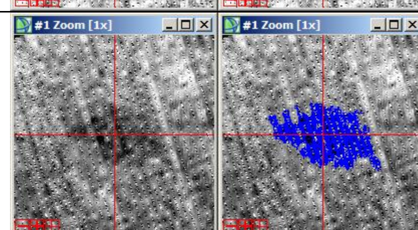
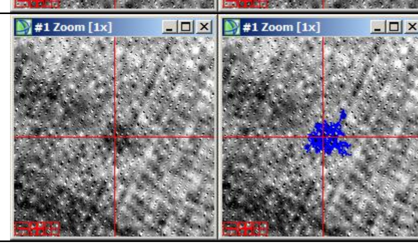
#	ROI Name	Latitude Longitude	Area (m^2) Nikon photo if available	ROI Shape and Extent
28	T1_F28.9	49.86372316 - 127.17568217	362	

Probable Class

Table 7**.** List of areas identified as 'probable' class shown with 3x3 median filter. Smaller targets are shown with 2x zoom. **Very small dark features with areas approximately 100 m^2 or less were not included in the area calculation for fish schools.*

	ROI Name	Latitude Longitude	Area (m^2)	ROI Shape and Extent
1	T1_F04.1	48.97365000 - 125.39596111	190	
2	T1_F04.2	48.96220278 - 125.41038611	452	
3	T1_F04.3	48.96220278 - 125.41038611	430	
4	T1_F09.1	49.22908520 - 126.07935179	1251	

	ROI Name	Latitude Longitude	Area (m^2)	ROI Shape and Extent
5	T1_F23.01	49.57351111 - 126.65725278	159	
6	T1_F24.01	49.58178074 - 126.72181402	693	
7	T1_F26.02	49.80575245 - 127.00711595	*104 Not included in area calculation Shown at 2X Zoom	
8	T1_F28.6	49.90894616 - 127.23410484	*23 Not included in area calculation Shown at 2X Zoom	
9	T1_F30.1	50.03866835 - 127.44791201	264 Imaged at 2m resolution	
10	T1_F30.2	50.03776069 - 127.44729887	356 Imaged at 2m resolution	

	ROI Name	Latitude Longitude	Area (m^2)	ROI Shape and Extent
11	T1_F35.01	50.32123836 - 127.98298473	786	
12	T3_F05.1	52.00311944 - 127.90899167	287	
13	T3_F13.1	51.54180833 - 127.87176667	119	
14	T4_F02.01	50.78523032 - 127.39045147	206	
15	T4_F02.03	50.81694302 - 127.21266981	3483	
16	T4_F15.03	50.51297500 - 126.62995278	833	

RESULTS AND DISCUSSION

Number and Size of Schools Observed

The 37 schools observed in the CASI images mostly exhibited a circular or oblong shape with diameters ranging from 5 to 60 meters in diameter (Appendix 9.3). Twenty three schools were seen in CASI imagery from the west coast of Vancouver Island, with visual identification of schools in the same area. These we identify as 'positive' sightings. Five small features with areas around 100 m^2 or less were not counted as fish schools.
Fourteen features were labelled as 'probable' schools. Nine of these were on the west coast of Vancouver Island. Two were seen in Transect 3 on the central coast in Fitz Hugh Sound. Two were seen on transect 4 in Queen Charlotte Strait off Port Hardy and one was seen in northern Johnstone Strait. Two small features with areas around 100 m^2 or less were not counted as fish schools.

About 70% of the schools were less than 500 m^2 in area (20 to 25m diameter), with a small number of larger more irregularly shaped schools - one of which reached approximately 44m diameter (Figure 13). The frequency histograms in Figure 13 are similar to those reported by Jagielo et al. (2011) off Washington and Oregon. They found the relationship between school area and tonnage reported on point sets to be highly variable. Our data should probably be regarded as presence/absence. However, using their area to tonnage conversion factor (0.02 tons/$m^{2)}$ most of the schools off Vancouver Island were between 6 and 10 metric tonnes. This is similar in size and tonnage to the slow moving 'dinner plate' sardine schools described by fishermen (Lenic, 2010). Also using this factor and assuming a constant density, the 23 positively identified schools, totalling 11,274 m^2 surface area equals about 225 tonnes. The 14 'probable' schools totalling 9509 m^2 surface area equals about 190 tonnes. The largest schools were seen on the outer coast of Vancouver Island between Esperanza and Kyoquot Inlets, and off Port Hardy in Queen Charlotte Strait. Although we had positive visual confirmation of the schools seen in some CASI imagery, we can not confirm that they were in fact sardines other than by the fact that DFO was seeing sardines in the same region further offshore (Figure 14).

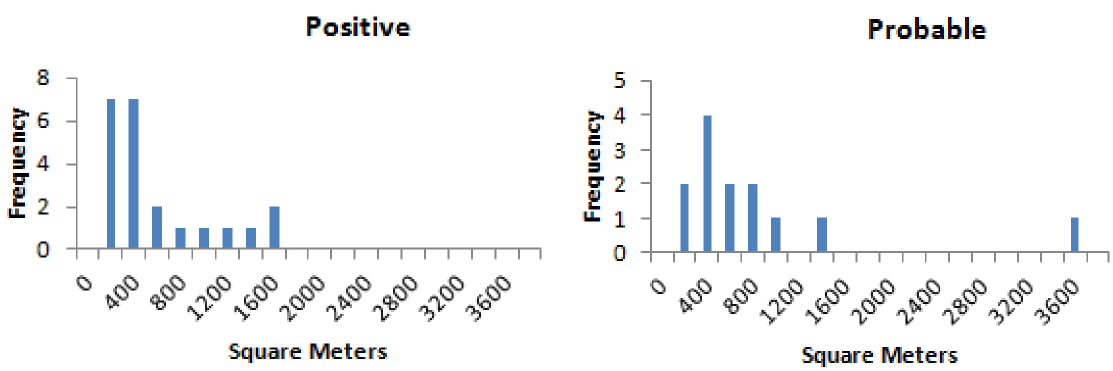


Figure 28. Frequency histograms of schools identified in CASI imagery.

Correlations with Ocean Colour and Chlorophyll

The air crew observed a clear correlation between water colour and the presence or absence of schools. All positive aerial fish sightings were made on Transect 1 in green waters off the west coast of Vancouver Island, on the first day when we were flying at 1500 ft altitude. No positive sightings were made on any other transects. Transect 2 was mostly over impoverished dark blue-black water, acquired late in the afternoon with low sun angles. Only one probable school was seen in Fisher Channel in blue water. Transects 3 and 4 were acquired earlier in the day, under brighter conditions, and in greener phytoplankton rich waters, but no fish schools were positively identified.

While outside the scope of this project, we include a preliminary comparison of the distribution of schools with chlorophyll and temperature derived from satellite. Although the dates of the available chlorophyll imagery (July 18 and 27) do not perfectly match the dates of either survey, the distribution of schools in both the aerial data and in the Ricker surveys, does appear to be related to chlorophyll distribution (Figure 15). The largest sardine catches by the MV Ricker were in waters with chlorophyll of about 10 mg/M^3, with no sardines taken in waters with satellite chlorophyll less than about 1 mg/M^3. Sardine feed on phytoplankton and small zooplankton (Emmett et al 2005) and thus it is reasonable to expect to find them in less oligotrophic waters. Zwolinksi et al 2011 et al have used satellite chlorophyll, SST and SSH to map sardine habitat off the west coast of North America. In their model sardine were most common in waters with chlorophyll between 0.3 and 1 mg/M^3, avoiding freshly upwelled waters with low SST and very high chlorophyll. They can however occupy waters with chlorophyll up to >10 mg/M^3 provided SST is >13 C. Schweigert and McFarlane (2001) found that sardines in Canadian waters avoid waters less than about 12 C.

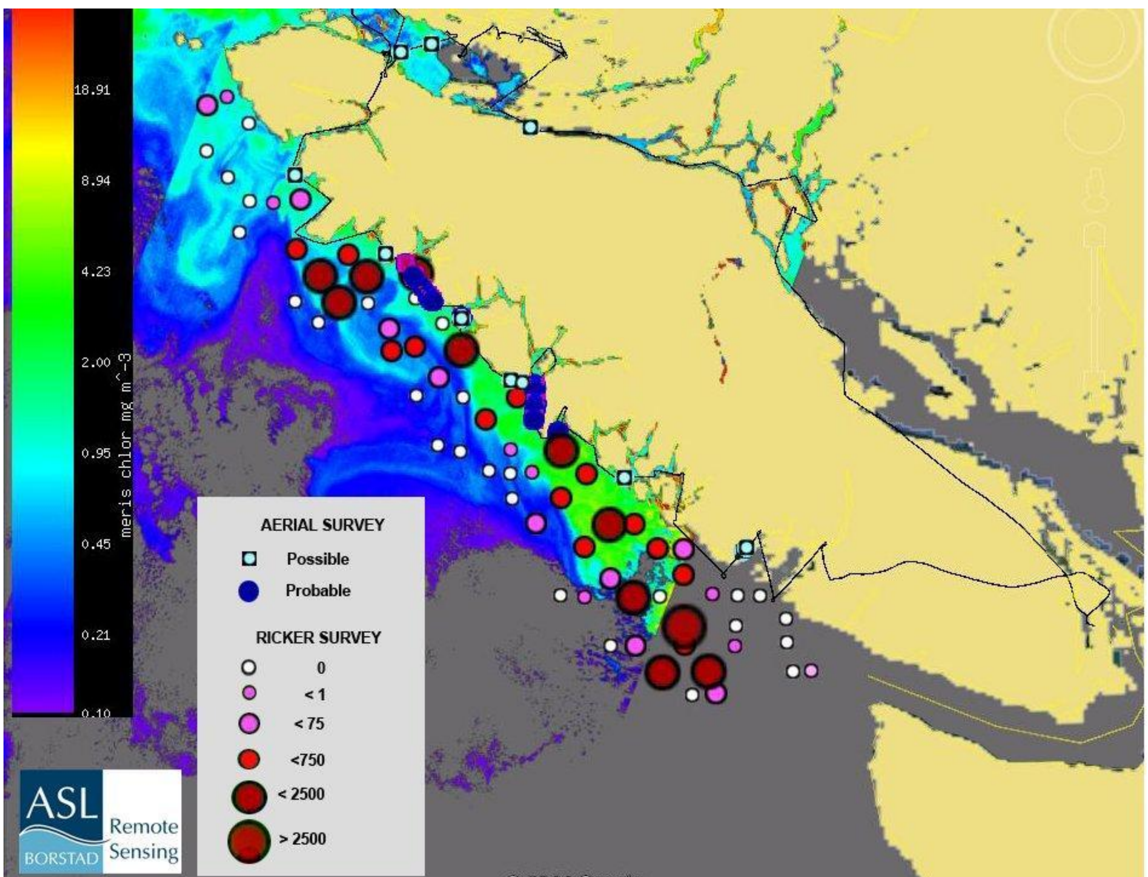


Figure 29. Comparison of aerial sardine school observations July 26 and 27 with sardine catch densities estimated from trawl net sampling from the RV W.E. Ricker (L. Flostrand, DFO *pers comm*), and satellite chlorophyll for July 18, 2011. Sampling from the Ricker began in the north on July 20 and ended in the south on July 31.

Correlations with Sea Surface Temperature

Sea Surface Temperature for July 25 (left) and 27 (right) 2011 (from the St Lawrence Observatory at http://slgo.ca/en/remotesensing/data.html) is shown in Figure 16. Very cold 8 to 10 C water can be seen exiting Queen Charlotte Strait and then passing around the north end of Vancouver Island on both days. Cool water (<12 C) can also be seen exiting the Strait of Juan de Fuca. Cool water along the Vancouver Island coast on the 27th suggests the beginning of upwelling.

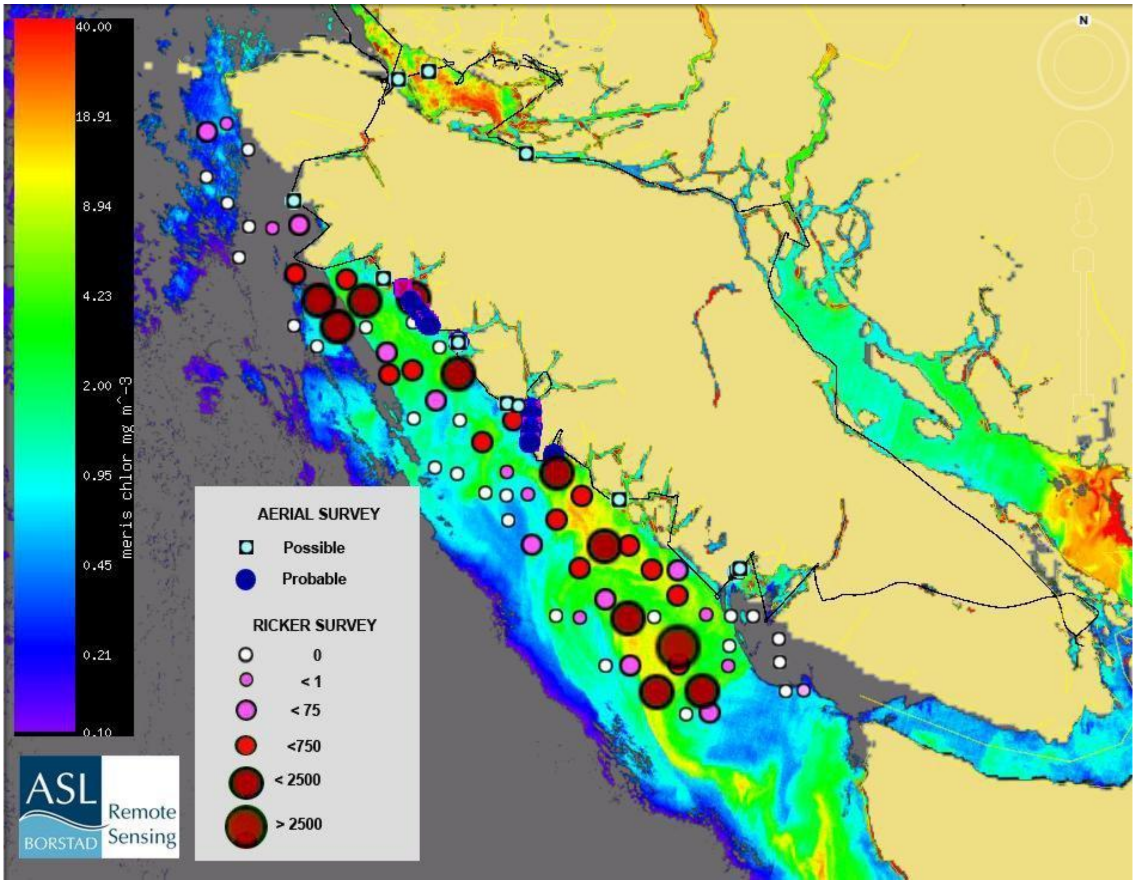


Figure 30. Comparison of aerial sardine school observations July 26 and 27 with sardine catch densities estimated from trawl net sampling from the RV W.E. Ricker (L. Flostrand, DFO *pers comm*), and satellite chlorophyll for July 27, 2011. Sampling from the Ricker began in the north on July 20 and ended in the south on July 31.

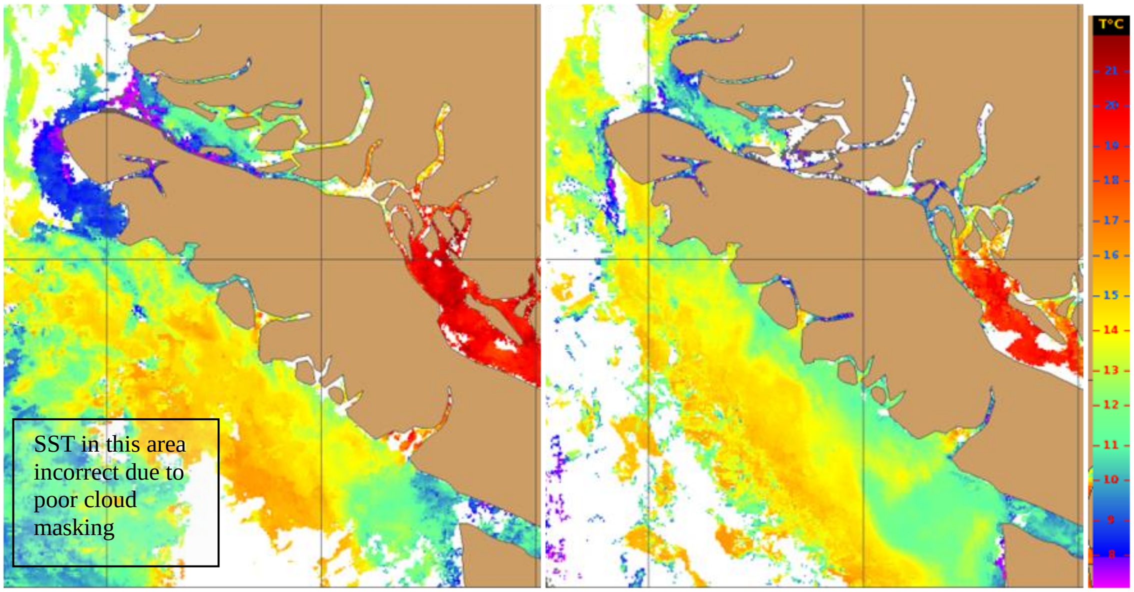


Figure 31. SST for July 25 (left) and 27 (right), 2011.

These temperature patterns suggest the sardine habitat at this time was limited to the west coast of Vancouver Island by cold waters at either end of the island. Further, the distribution of chlorophyll and temperature around Cape Scott may explain why sardines migrating from the south extend onto the Central coast in some years and not others. Borstad et al (2011) found that conditions in southeastern Queen Charlotte Sound and at Triangle Island (off NE Vancouver Island) are closely related to wind patterns in this area.

Available RapidEye Satellite Data

High resolution multispectral imagery was acquired by the RapidEye satellite on August 4, about a week after our surveys (Figure 17) and in the area where fish schools were spotted. This imagery is suitable for imaging of fish schools and could be analyzed at some future time. The data cost for the region of interest outlined in white below is approximately 1100 Euros.

Figure 32. Multispectral RapidEye satellite imagery acquired August 4, 2011 is available for the area outlined above.

Anecdotal Report of Sardine in Shearwater Harbour

During refuelling on the morning of July 27, 2011 at the Shearwater Marine Centre, the fuel dock operator commented on large schools of sardines (pilchard) in Shearwater Harbour about the same time in 2010. The sardine remained in and around the harbour for about a month attracting large numbers of seals and humpback whales that fed extensively and were seen broaching very close to the marina. Anecdotal comments such as these might be a useful index of the presence of forage fish on the north coast.

CONCLUSIONS

In order to keep costs down, a single engine deHavilland Beaver aircraft on floats was used for this experimental survey. This high wing aircraft permitted visual observations and made possible an emergency water landing along most of the survey route should it have been necessary. However, the single engine and very poor weather at the time of the survey limited the distance we could safely fly offshore. A twin engine wheeled aircraft could have been used at higher cost, but with no possible landing areas along most of the survey route, and without the possibility to make visual observations.

In spite of very poor survey conditions, the CASI provided usable multi-spectral image data from which school areas could be extracted. The aerial survey found schools in waters off the west coast of Vancouver Island adjacent to those in which schools were found by the MV Ricker acoustic survey. A preliminary comparison with satellite SST and chlorophyll suggests that sardine habitat in this area is related to these parameters in the same way as seen by Zwolinski et al 2010 further south along the US coastline. The currents and water mass distribution around Cape Scott may determine whether or not sardines appear on the Central coast in any particular year.

RECOMMENDATIONS AND LESSON LEARNED

1. Where weather permits, CASI aerial sardine surveys should be flown at a higher altitude so as to cover more area. Whether or not to use a twin engine aircraft to make more systematic surveys is open to debate. We think it inadvisable to fly a single engine aircraft outside of gliding distance from shore.
2. A nadir mounted video camera with real time monitor could be added to future surveys. More time is required to get the fixed mount Nikon D90 working properly.
3. Multispectral RapidEye satellite image data acquired on August 4 in the region where fish schools were observed could be purchased and analyzed for wider area coverage, more direct comparison with the Ricker surveys, and to determine the offshore extent of the schools.
4. It would be possible to systematically compare the distribution of sardine densities recorded by acoustic surveys to satellite derived SST and chlorophyll, with the objective of understanding habitat requirements in Canadian waters, and explaining interannual variations in distribution.

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