Ministry for Primary Industries
Manatū Ahu Matua

Investigating a multi-purpose aerial method for surveying inshore pelagic finfish species in New Zealand.

New Zealand Fisheries Assessment Report 2015/36

P.R. Taylor

ISSN 1179-5352 (online)
ISBN 978-0-908334-92-6 (online)

July 2015

New Zealand Government

Growing and Protecting New Zealand

Requests for further copies should be directed to:

Publications Logistics Officer
Ministry for Primary Industries
PO Box 2526
WELLINGTON 6140

Email: brand@mpi.govt.nz
Telephone: 0800 00 83 33
Facsimile: 04-894 0300

This publication is also available on the Ministry for Primary Industries websites at:
http://www.mpi.govt.nz/news-resources/publications.aspx
http://fs.fish.govt.nz go to Document library/Research reports

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Taylor, P.R. (2015). Investigating a multi-purpose aerial method for surveying inshore pelagic finfish species in New Zealand.

***New Zealand Fisheries Assessment Report 2015/36*. 92 p.**

A multi-purpose method for aerial survey of a range of schooling pelagic species and ecologically related species such as pelagic sharks and marine mammals was investigated under MFish Project PEL2006/01. This included consideration of aerial survey methods used worldwide, which are summarised as five case studies from the literature.

The case studies were examined in the New Zealand context and the two methods of distance-sampling and photogrammetry provided a basis for discussing possible components of a survey method. The distance-sampling methodology provides a highly developed system of data collection and abundance estimation for transect sampling; the photogrammetric method was developed for an aerial survey of sardine on the West Coast USA. Currently in New Zealand, aerial survey is limited to observational sightings data from spotter pilots working in the domestic purse-seine fishery, which are used for annual relative abundance stock indices for two species in a single Fishstock. These pilots have developed reliable methods of determining species composition and tonnage of observed schools.

A key issue in developing a survey design for New Zealand target purse-seine species is to standardise the methods of species identification and estimation of school size. Because peak harvest season coincides with the time a survey should be carried out, commercial spotter pilots are unable to contribute to aerial surveys of these species. Therefore a method of determining species composition based on, but independent of, the pilots' method is fundamental to development of any survey method.

The photogrammetric approach largely comprises a method of estimating school biomass from school surface area. One addition to the original method suggested here, based on an analysis of the West Coast USA sardine data, is that school height be included in the estimation method. By contrast, distance-sampling does not include methodology for estimating school biomass, but this could be resolved by including that component of the photogrammetric method within the distance-sampling approach.

The two methods were compared and contrasted in terms of their relative ability to provide reliable estimates and their associated costs. A large component of the cost of an aerial transect survey is related to the amount of flying time. Because of the dynamic nature of schools of these species and the reliance of species-composition determination on multiple visual cues, it is concluded that photography or video cannot be used reliably for determining species composition. Maximum working altitude for species determination is 2000 ft, which ultimately results in a differential in flying time between the two methods such that flying costs of the photogrammetric method are twice those of the distance method.

Observational data from the MPI database *aer_sight* include observations and school-size estimates by domestic fish-spotter pilots and were used to investigate the relative spatio-temporal distributions of the main purse-seine target species. This work produced broad summaries that suggested that the peak seasonality of presence at the surface was similar for these species thus supporting the concept of a multiple-species survey. The observational aerial sightings data were also used to investigate the precision of abundance estimates using a simulated survey under Project SAP2008-26. The results of this work yielded CVs that were very high and it was concluded that these data cannot be used for such analyses.

A methodology with associated costs is suggested for a single-transect and a pilot study to collect data under survey conditions for investigating this issue further. The main aim is to determine whether the sightings encounter rate is high enough to allow acceptable CVs on relative abundance estimates using these methods. This is a critical first step requiring resolution before an aerial survey method for these species can be considered further.

1. INTRODUCTION

1.1 General background

Data from monitoring the abundance (biomass) of finfish species is an essential input to assessing their stocks, estimating yield, and determining whether catch limits are sustainable or will allow a stock to grow towards a size that will support the maximum sustainable yield (MSY) (see Ministry of Fisheries 2007). There is an obvious need for a survey method designed specifically to determine the abundance of the fourteen inshore pelagic species currently managed under the quota management system (QMS).

The method most often used to produce indices of abundance in New Zealand, that of standardised catch per unit effort (CPUE), is not appropriate for these species for at least three reasons. Firstly, blue mackerel (*Scomber australasicus*), the three jack mackerels (*Trachurus declivis, T. murphyi, T. novaezelandiae*), kahawai (*Arripis trutta*, *A. xylabion*), and trevally (*Pseudocaranx dentex*) are fished by purse-seine, where targeting is by fish size and there is a tendency for catches to remain high after abundance has declined (i.e., "hyperstability" — see Cochrane 1999). Secondly, pilchard (*Sardinops neopilchardus*), anchovy (*Engraulis australis*), sprats (*Sprattus antipodum*, *S. muelleri*), garfish (*Hyporhamphus ihi*), and yellow-eyed mullet (*Aldrichetta forsteri*) currently support very small commercial fisheries. And thirdly, kingfish (*Seriola lalandi*) is taken mostly as bycatch by several different fishing methods.

Existing information on inshore pelagic species that can provide input to stock abundance is therefore largely limited to aerial sightings data. These observational data are currently collected as part of the purse-seine fishing operation and are restricted, in practice, to the main species exploited in that fishery — trevally, blue mackerel, jack mackerels, and kahawai. Potentially, they can provide relative abundance indices for these species in certain areas over a medium time frame (since 1976), but they are limited in that they cannot provide estimates of absolute abundance at any level of precision, and they do not include information on the other inshore pelagic species listed above.

The aim here is to investigate the possibility of a multi-purpose survey method that can be used to survey a range of species. In addition to the inshore species mentioned above, the method should also include the highly migratory skipjack tuna, inshore schooling species for which there is no commercial fishery such as koheru (*Decapterus koheru*) and pink maomao (*Caprodon longimanus*), and ecologically related species such as pelagic sharks and marine mammals.

With a multi-purpose survey method, it would be useful to be able to perform multiple-species surveys of more than one inshore pelagic finfish species at a time. The "multiple" aspect is a way of maximising return for cost, but it is dependent on the species of interest having similar seasonality in their presence at the surface and the geographic range that they occupy. Examining these types of issues using the opportunistic aerial sightings dataset allows us to determine spatio-temporal distributions for the various species and is a necessary first step in survey design. One likely specialisation for pilchards and anchovy might be the need to perform aerial surveys at dawn and dusk, which, according to previous discussions with fishers, are the times that highest numbers of these two species are at the surface.

This report is a record of work completed under MFish project PEL2006-01, *Design of a multi-purpose aerial survey for pelagic fisheries*. Because it is not a record of completed work, but an investigation preliminary to developing a survey method, this document does not follow the usual structure of a New Zealand Fisheries Assessment Report. The structure has developed from the approach taken to meet the specific project objective: *to design a multi-purpose aerial survey for pelagic fisheries*. The main sections are:

1. Executive summary.
2. Introduction, including a brief discussion of the New Zealand situation (Section 1).
3. Detailed discussion of several example aerial survey methods (Section 2).
4. A summary of these methods and their potential in the present context (Section 3).
5. An examination of possible components for inclusion in survey design (Section 4).
6. Suggestions for preliminary work including costs (Section 5).
7. Conclusions (Section 6)
8. Acknowledgements (Section 7).
9. References (Section 8).
10. Appendices (Section 9) (Appendix A provides a glossary of terms).

Also documented here are the methodology and results of a simulation study completed under MFish project SAP2008-26 as extra work related to MFish project PEL2006-01. Documentation of the work is included as Appendix C; results are discussed with reference to development of the aerial survey method in Section 3.6.

1.2 Aerial surveys for finfish — an historical perspective

Aerial survey using small aircraft has been used to monitor the stocks of a number of pelagic finfish species. Agenbag (1980) described a method used off the southwest African Coast for determining the "frequency-of-fish-occurrence" of pilchard (*Sardinops ocellata*), anchovy (*Engraulis capensis*), and horse mackerel (*Trachurus trachurus*). Hara (1986) described a method in which aerial survey based on a line transect design was used to estimate stock size of the Pacific population of Japanese sardine (*Sardinops melanosticta*). Squire (1993) described development of "apparent abundance indices" off California and Baja California, Mexico, for northern anchovy (*Engraulis mordax*), Pacific sardine (*Sardinops sagax*), Pacific bonito (*Sarda chilensis*), chub mackerel (*Scomber japonicus*), jack mackerel (*Trachurus symmetricus*), and bluefin tuna (*Thunnus thynnus*). The term "apparent abundance" refers to that portion of the total abundance that is available to the fishery (Marr 1951).

Strip transect aerial surveys are flown in the Great Australian Bight each summer to provide an estimate of the relative abundance of juvenile southern bluefin tuna (SBT) (*Thunnus maccoyi*) as a fishery-independent index of recruitment (Chen et al. 1995). Davis & Stanley (2002) suggested that the largest source of variance in these estimates is from "environmental factors that influence both surfacing behaviour and aerial detection" and reported on a study that used ultrasonic telemetry to investigate "surfacing behaviour and short-term horizontal and vertical movement patterns that might influence sightings from the air". Associated with this work was the archival tagging programme of Gunn et al. (1995) that was designed to provide long-term information on behaviour. Since 2000, further development of this work has been documented by a number of workers including Cowling (2000), Bravington (2003), and Eveson et al. (2006). A detailed summary is presented in Section 2.1.2 below.

In the Mediterranean, Fromentin et al. (2003) used the experience of the team working on SBT in the Great Australian Bight to survey Atlantic bluefin tuna (ABT) (*Thunnus thynnus*) in the Western Mediterranean Sea. ABT have also been the subject of aerial survey methods using aerial photography in the Atlantic, as described by Lutcavage & Kraus (1995), Lutcavage et al. (1997a, 1997b), and Newlands et al. (2006), and discussed by Lutcavage & Newlands (1999). Photographic aerial surveys for capelin (*Mallotus villosus*) have been described by Carscadden et al. (2004).

Alternatives to the line transect approach have been employed, mainly to capitalise on the presence of airborne commercial fish spotters working in areas where aggregations of pelagic species occur, by collecting observational data with the objective of deriving estimates of relative abundance. Squire (1993) used opportunistic data collected by spotter pilots selecting schools for targeting by Californian purse-seiners to produce “apparent abundance indices” computed by dividing the tonnage observed by the number of “block areas” (i.e. areas of 10 seconds of latitude by 10 seconds of longitude) searched, expressed as tons per block area flown (T/BAF).

The distribution of pelagic schools is usually contagious i.e., fish aggregate in some areas but are scarce in others. Consequently, stratum counts by pilots following flight paths through a number of strata can contain a high number of zero values. Lo et al. (1992) developed a delta-lognormal linear model to standardise indices of relative abundance for northern anchovy (*Engraulis mordax*) from fish-spotter data. Their approach incorporated a logistic linear model and a lognormal linear model. The first estimated the proportion of flights during which fish were spotted; the second estimated the density (tons per area) of fish from flights when fish were spotted. The final index of relative abundance was based on the product of the two quantities, adjusted for the size of the survey area.

A similar approach has been used in New Zealand to develop a method for estimating time series of annual (i.e., by fishing year, 1 October to 30 September) relative abundance indices for two of the main purse-seine species (kahawai and trevally) based on opportunistic fish-spotting data collected by pilots working in the domestic purse-seine fishery (Taylor 2014, Taylor & Doonan 2014). Historically, these data were referenced to a grid of half-degree squares (30 n. mile squares) (Figure 1), but, with the advent of the Global Positioning System (GPS), pilots have recorded positions of sightings. Several predictor variables have been included in the generalised additive model (GAM) approach including moonphase, sighting time (time of day), and a measure of effort recorded by pilots as 10–15 minute periods spent searching in half-degree squares.

The most recent aerial survey method to come to hand is that developed for estimating relative abundance of sardine on the west coast of USA in 2010 (Jagielo et al. 2011). The method employed a two-stage sampling design with stage 1 comprising aerial transect sampling of sardine schools using photogrammetry to estimate school surface area and stage 2 employing “point set” sampling of sardine schools at a range of sizes. The point set sampling included photographing the schools as in stage 1, then targeting and landing the school using a purse-seine vessel, and recording details of the school (tonnage, species composition). Data from stage 2 were used to quantify the relationship between school surface area and biomass for the range of schools sampled during stage 2 and these standard samples were then used to quantify the schools recorded during stage 1 from their estimated surface areas. A detailed summary is presented in Section 2.1.6 below.

1.3 The aerial survey method — general aspects

Essentially, aerial surveys are based on the methods of quadrat/transect sampling where randomly-defined search paths are placed within what is usually two-dimensional space, and numbers of the subject of interest are counted (Burnham et al. 1980); other parameters of interest such as environmental conditions can also be recorded. Densities of the subject of interest are estimated for the area of the transect strips, a mean-weighted density is calculated for the total area, which is then scaled up to the total area to provide an estimate of the total abundance at the surface. Where necessary, strata are identified and the additional step of adding the total abundance for each stratum is incorporated into the estimation method.

Data collection for a simple census takes place using a standardised set of criteria to ensure that the sighting path is consistent throughout the survey and between surveys. Often, a

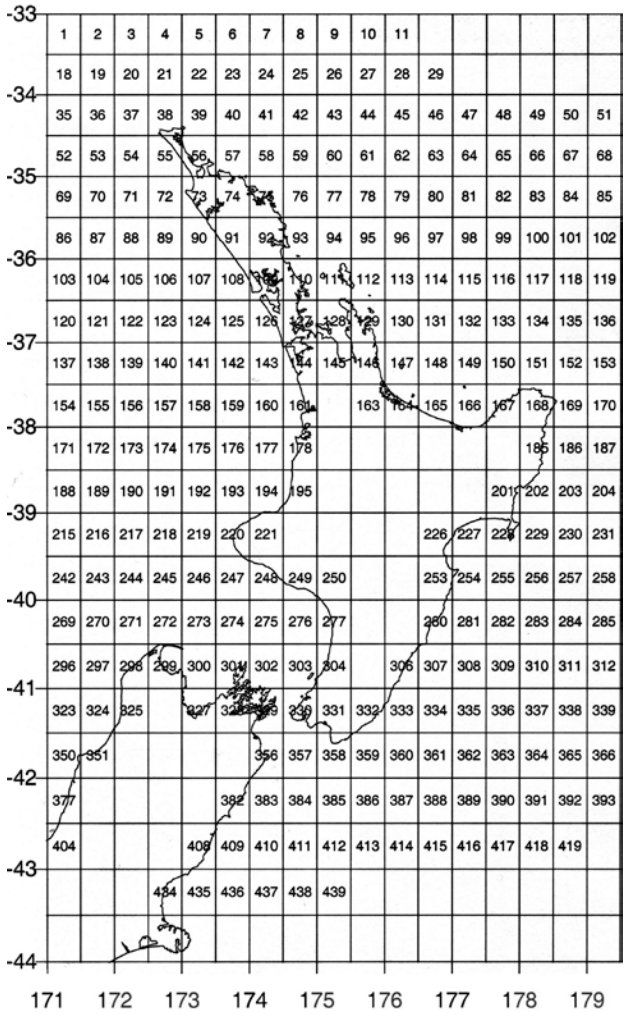

Figure 1: Northern and central grid squares and their codes.

sighting "window" is constructed with markings on the cockpit and strategically positioned rods attached to the wing struts through which the strip transect is viewed, with a defined flying altitude ensuring that the area of view is constant. The aircraft then flies a systematic or random line transect (see Caughley 1977) and the spotter counts all the sampling units, in this case schools of fish, that lie within the strip transect created by the moving window.

Aerial surveys for estimating abundance of small schooling fish are complicated by the need not only to count the schools, but also to estimate the size in tonnes based on aspects of the school's appearance. This is in addition to having first identified the species composition of the school, both of which require a high level of skill in the spotter or spotting team.

A number of potential sources of bias in the sightings data are evident (Krebs 1989). Their effect is to reduce sightability, which is defined as the probability that an animal or school will be seen by the observer. Caughley (1974) suggested that the three most important factors are as follows.

- Transect width — as the width of the strip is increased, mean distance between observer and sampling unit increases, decreasing the time available to locate each unit, which is confounded by environmental factors that reduce fish sightability (wind disturbance causing chop on the water, height and direction of the sun, presence of rain or mist).

- Altitude — as altitude increases, the mean distance between the observer and sampling unit increases, which can prevent sampling units from being observed, but may increase visibility in some cases by reducing glare or allowing more time to observe the school.
- Speed — as speed increases the amount of time available to observe the sampling unit decreases.

However, as was observed by Krebs (1989), this list is not exhaustive. The presence of fish schools at the surface is known to be correlated with environmental factors such as sea surface temperature (SST), and the variables "pilot" and "time of day" have been shown to be significant predictors of fluctuation in indices of relative abundance from aerial sightings data (Eveson et al. 2006, Squire 1993).

Such uncertainty has been referred to as *visibility bias*, and has been a topic of investigation for aerial surveys of populations of large birds, terrestrial mammals, and marine mammals. Pollock & Kendall (1987) defined visibility bias as resulting from animals being missed and suggested that it was exacerbated by factors such as dense vegetation, bad weather conditions, and observer fatigue. Estimation of visibility bias has been examined for manatees (Packard et al. 1985, Lefebvre et al. 1995), aquatic fauna (Marsh & Sinclair 1989), waterfowl (Smith et al. 1995, Gabor et al. 1995, Prenzlow & Lovvorn 1996), Arctic geese (Bromley et al. 1995), American alligators (Woodward et al. 1996), loons (Groves et al. 1996), Canada geese (Walter & Rusch 1997), bottlenose dolphin (Carretta et al. 1998), cetaceans generally (Kingsley & Reeves 1998), and polar bears (McDonald et al. 1999).

On their own, aerial surveys of fish cannot provide an estimate of the total abundance of the stock. To do this an assumption must be reached about the proportion of the stock beneath the surface, beyond the range of observation by the data collector. Without such an assumption (or a direct measure using some other approach such as acoustic survey that is not limited by the "sightability" of the fish) aerial survey can only provide an estimate of the relative abundance of the species of interest, and this only under the assumption that the proportion of the population at the surface is constant. Little is known about the validity of this assumption.

Some aerial survey methods have been based on viewing fish schools during the dark phase of the lunar cycle when schools can be detected by the bioluminescence caused by their movement through the water (Squire 1976, Agenbag 1980, Agenbag et al. 1984). This may improve sightability, but it seems unlikely that species identification can be made with any certainty in the New Zealand situation where schools of various species can be within several hundred metres (Paul Taylor, personal observations from fish-spotter aircraft). Nor can it remove the uncertainty associated with the proportion of the stock that is cryptic.

1.4 Estimation methods

After an extensive literature search as a preliminary to the work presented here, it was concluded that the distance-sampling approach of Buckland et al. (2001) is the most up-to-date, mathematically-robust, generalised method for transect sampling, comprising a well-defined data-collection method and data analysis using the custom-built software DISTANCE. Distance-sampling is under widespread use for aerial surveys, though not necessarily of small-to-medium schooling fish. Applications of transect theory are the basis of the method developed by fisheries scientists at the Australian Commonwealth Scientific and Research Organisation (CSIRO) for juvenile southern bluefin tuna in the Great Australian Bight, and similarly by French scientists for juvenile Atlantic bluefin tuna in the Mediterranean.

Because of its widespread use in surveying a wide variety of "objects of interest", the distance-sampling approach is used as a point of reference for the discussion developed here. However, it is only one of several methods being considered completely or in part for incorporation into a possible survey design. The approach followed here has been to examine the methods used in fisheries globally and to summarise the salient features of the data collection from a sample of these methods. This sample is referred to as a set of case studies in this document.

In considering an appropriate method of data analysis, the methods used to analyse the data collected in the case studies were also examined, including the DISTANCE software. Choice of an approach depends to some extent on the sampling method, but one is not limited by the sampling-analysis packages used in these studies. For example, CSIRO scientists use a data-collection method that is a variant of the distance-sampling approach, but model their data using a customised GLMM-based approach instead of the DISTANCE software.

1.5 The New Zealand situation

1.5.1 Current use of aerial finfish monitoring

Until recently, no aerial survey of finfish had been undertaken in New Zealand. In 2013 a survey was funded by the Ministry of Primary Industries (MPI), but this has not yet been reported and is not discussed here.

Since 1976, near the beginning of the domestic purse-seine fishery, data on the quantity and geographical position of schools of inshore pelagic finfish species have been collected by fish-spotter pilots working with the domestic purse-seine fleet. These data are not collected according to any sampling method and are therefore referred to as observational data. They are stored in the MPI *aer_sight* database and represent the longest series of information on our most commercially important inshore pelagic species, including skipjack tuna, kahawai, blue and jack mackerels, and trevally.

Recently these data have been used to develop an estimation method and produce time series of annual relative abundance indices for kahawai and trevally in the Bay of Plenty (BoP) for 19 of the fishing years (1 October to 30 September in the following year) from 1986–87 to 2012–13 (Taylor 2014, Taylor & Doonan 2014). Results from the development phase indicated that similar methods could not be used for blue and jack mackerel species: high inter-annual variability for blue mackerel suggested an unstable local population, possibly as a result of immigration/emigration to and from the area; and jack mackerel comprise several species, each with its own geographical distribution and biological characteristics, which cannot be separated in the aerial sightings data.

Other results showed that there were too few data for the estimation method to be extended to areas outside the Bay of Plenty.

1.5.2 Reasons for considering aerial survey methods

A study was carried out under MFish project PEL2002/01, *Survey methods for small pelagics*, in which the international literature was reviewed to compile comprehensive information on the survey methods for estimating abundance/relative abundance for small inshore pelagic species worldwide to use as a basis for developing a method of producing abundance/relative abundance estimates for inshore pelagic finfish species in New Zealand. A number of methods and combinations of methods were identified, described and discussed in terms of their benefits, disadvantages, special features, and costs (Taylor 2004). The list included acoustic methods, gear surveys (e.g., trawl survey), egg and larval methods including the daily egg production model (DEPM), aerial survey, lidar (i.e., laser light ranging and detection), and tag and release with reference to several different tag types.

The study highlighted the advanced level of expertise currently available within the domestic fishery, with at least two very experienced fish-spotter pilots working within the purse-seine industry, and pointed out the attraction of incorporating some form of aerial survey in the method to be developed. Also in favour of the aerial survey method was its low relative cost and the high speed with which the survey area could be covered. All survey methods, including aerial survey, would rely on meeting the assumptions of surveying the entire range of the species of interest and without double counting, which is complicated by the high mobility of pelagic species and the high probability that their aggregations would persist for short periods only. Given these characteristics, it was necessary that any survey method proposed for estimating the abundance of inshore pelagic species based on densities of post-larval fish be able to cover the survey area quickly to minimise their effects.

1.5.3 Objectives and features of an appropriate aerial survey method

According to Buckland et al. (2001, Section 7.2), the following elements are essential to developing a successful survey method using transects.

- A clear definition of the study population in time and space.
- A clear definition of the survey objectives.
- A clear determination of the transect layout using replication (i.e., multiple lines or points), randomisation, sampling coverage, stratification, and sampling geometry.
- Determination of the sample size.
- Determination of the length of line transects.

Defining the *what*, *where*, and *when* of the biological population is a necessary co-requisite to the survey objectives and must also be based upon an understanding of whether the population is closed during the sampling period or whether the location that the population inhabits changes, as would be the case for a migrating population. Once these elements are decided, factors defining the transect lines can be considered and prescribed.

The required objective of an appropriate aerial survey method would be to provide reliable indices of relative abundance for members of the inshore schooling pelagic finfish assemblage. Obviously the method would need to be cost effective, the main key to its successful application being its ability to deal with the issues of species identification and providing accurate estimates of the biomass of observed schools. These issues, and strategies for resolving them, are discussed later in this document with reference to features of the case studies and the proposed method for investigating aspects of a possible survey design.

Defining the survey objectives provides a basis for the amount of sampling required and how it should be organised spatio-temporally. Buckland et al. (2001) suggest that “the smallest temporal and spatial scales of interest should be specified and the level of precision needed at each scale should be defined to allow selection of an adequate sample size.” For distance-sampling, these workers recommend the use of a transect line length great enough to ensure detection of at least 60–80 observations, but point out that sample size should also be based on the degree of precision required to meet the research objectives, and that considerably fewer observations per year may suffice in the case of a monitoring programme that uses annual sampling with consistent protocols and employing the same observers.

2. CASE STUDIES

Following extensive literature searches, six published works describing the use of aerial survey methods for estimating abundance or relative abundance were examined and used to guide discussion on development of a survey design. They are referred to here as case studies.

2.1 Descriptions of the case studies

The case studies varied considerably, from close fidelity to the distance-sampling method (Case 1), to use of a strip transect sampling method for data collection similar to that discussed by Buckland et al. (2001), while analysing the data with custom-built modelling techniques (Case 2), the use of transect design without inclusion of distance-sampling techniques (Cases 3a, 3b), and to the methods incorporating aerial photography for estimating school size (Cases 4 and 5). For cases 3a and 3b, a reading of both is required to derive a full understanding of the method used, which appears to be similar in both cases.

2.1.1 Wyoming pronghorn (*Antilocapra americana*) survey (Case 1)

References: Guenzel (1997 and 2007).

The following comprises almost verbatim text extracts from Guenzel (1997).

Sampling

The Wyoming technique involves the accurate marking of struts and windows on certain high-winged aircraft. This allows observations to be accurately assigned to distance bands corrected for actual height above ground level (AGL) using a digital radar altimeter, GPS and onboard computer.

Two observers are used on most surveys. Each observes from separate sides of the plane. Usually one observer sits in the front (copilot seat) while the other sits on the opposite side in the back seat. Because of the different seat positions, each side of the plane has to be marked specifically since the eye position for each side of the plane will be different (front compared to back seats).

For some two-place airplanes (e.g. SuperCubs, Scouts), only one observer can be used requiring that the observer scan from only one side of the plane. Both sides of the plane can be marked the same as long as the observer only searches from one side during a transect traverse. To optimise detection, the observer may alternate surveying sides of the plane from one transect to the next so that the observer is usually watching with the sun instead of looking into the sun. The analysis has to be adjusted to account for there being only one observer. Currently, surveys in Wyoming are not performed with single observers. On rare occasions, a survey has been flown with only one observer when the other observer could not continue, requiring adjustment of the survey effort in the analysis.

The pilot's role is to safely fly the airplane, follow the design, and enter observations into the computer. The observer's responsibilities are to properly search for animals of the target species out to the defined outer distance limit (focusing most effort on and near the line), to count the number of animals in the cluster, to assign the location on the ground where the cluster was first observed to the correct distance band when the plane was perpendicular to that location, and to relay the distance band and cluster size to the pilot through the intercom so that he can capture the data onto the computer. Observers should not perform other tasks (e.g. writing down data, looking at maps, trying to obtain composition data, etc.) which would divert their attention from surveying. Pilots and observers should be trained prior to conducting the survey.

The number and placement of markers to define prescribed distance bands depend in part on characteristics of the species to be surveyed and its habitat. While safety will be the primary concern dictating how low to fly the survey, one also needs to consider the angle of view needed to cover the desired ground distance intervals, airspeed, and disturbance to wildlife. Ideally, surveys should be flown as high above the ground as possible while still being able to see all animals of the target species in and near the line and most in the next inner bands.

The set-up currently used for Wyoming's pronghorn surveys includes the following design:

1. Two observers on opposite sides of the plane (front and back).
2. Onboard computer for data acquisition linked to a GPS.
3. A digital radar altimeter.
4. A prescribed survey height above ground level (AGL) of 91.4 meters (300 feet).
5. Dowels attached to the struts at specific positions to mark the defined offset (blind area) and four perpendicular distance bands (Figure 2) when the plane is flown at the prescribed height of 91.4 meters AGL:
    - Blind area 0–65 meters,
    - "A" Band (defines the line in a 25 meter wide first interval) 65–90 meters,
    - "B Band (defines another 25 meter wide band) 90–115 meters,
    - "C Band" (defines a 50 meter wide band) 115–165 meters,
    - "D" Band (defines a 100 meter wide band and the outer distance limit) 165–265 meters.
6. Two window marks that align the first distance band.
7. Pilot enters data into the computer [more recently a personal digital assistant (PDA)].

Criteria are provided to define a cluster of pronghorn (e.g., are there two clusters or just one big one?) and whether or not a cluster is in or out of a particular distance band when the cluster overlaps bands. These criteria should allow decisions to be made more consistently among observers.

Biologists are encouraged to give greater attention to the desired sample sizes and layout of surveys when designing them. There has been confusion over what constitutes an adequate sample. Too often, biologists attempted to only obtain a minimal sample of 100 clusters. As a result, confidence intervals were often wide and estimates were less reliable. The general recommendation for a sample size of 100 is generally only adequate for estimating the detection function from which density is corrected. Many other factors contribute to the accuracy and overall variance of the estimates, including the encounter rate (number of clusters/length of transect) and the mean cluster size. Surveys should generally be designed to obtain considerably larger (e.g., at least 200 clusters) samples. This is particularly true for moderate to large populations occupying large geographical areas with relatively low densities and/or having fairly clumped distributions. Positional data from prior surveys should be used in designing future surveys and in determining whether or not a stratified or other special design would provide a significant improvement.

Analysis

Guenzel (1997) strongly advocates the use of the DISTANCE programme (Laake et al. 1996). Although TRANSECT (Laake et al. 1979) is easier for novices to use, we prefer DISTANCE because it includes many new or improved numerical procedures such as new estimators with more robust and objective model selection criteria. DISTANCE will calculate densities and totals for clustered populations directly. TRANSECT estimated the density of

Figure 2a: **Left-hand image[1] shows dowels attached to wing struts; inter-dowel distances are carefully calibrated to ensure that the viewing bands so formed provide distance categories of known width when the aircraft is in level flight at the prescribed height of 91.4 m; right-hand image shows window marks which are also positioned as part of the calibration and ensure correct alignment of the observer's eye with the viewing bands between the dowels.**

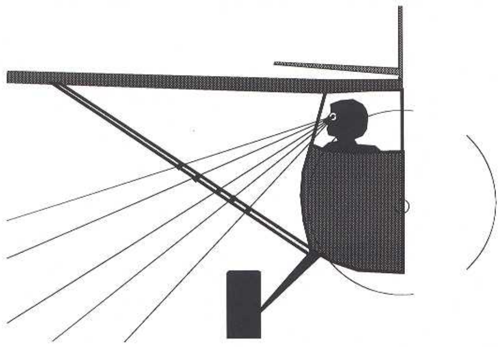

Figure 2b: **Schematic representation of an observer looking through the combination of window markings and viewing bands on the starboard side of the plane.**

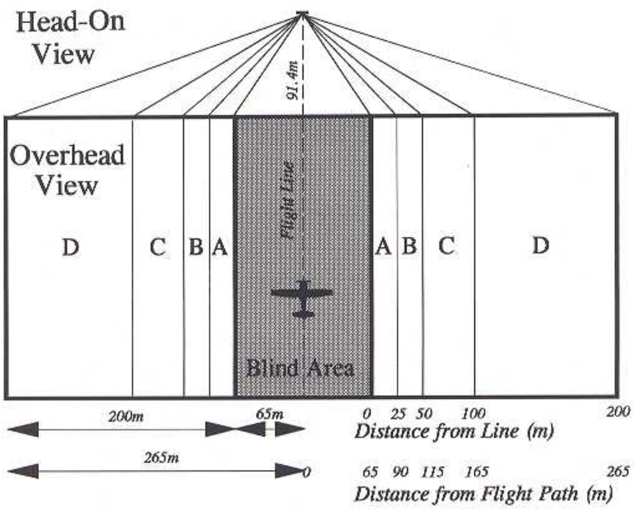

Figure 2c: **The geometry of the Wyoming Technique for aerial line transect surveys, showing relative widths of ground distance zones formed by the viewing bands when the aircraft is in level flight at the prescribed height of 91.4 m.**

---

[1]**All images on this page reproduced from Guenzel (1997, 2007) with the kind permission of Rich Guenzel, formerly of Wyoming Game & Fish, Laramie.**

clusters, which then had to be manually corrected for mean cluster size and multiplied by hand to get a total. DISTANCE includes robust procedures for correcting for cluster size bias. DISTANCE accommodates more sophisticated survey designs and allows for bootstrapping confidence intervals.

2.1.2 Southern bluefin tuna (*Thunnus maccoyi*) surveys in the Great Australian Bight (Case 2)

Background

A bilateral Recruitment Monitoring Program (RMP) between Australia and Japan was begun in the early 1990s (Davies et al. 2007). One of the key features of the RMP was the development of a fishery-independent index of juvenile southern bluefin tuna (SBT) recruitment using a scientific aerial survey in the Great Australian Bight (GAB) (Eveson et al. 2006). This survey was carried out between 1991 and 2000, but was suspended in 2000–01 because of difficulties finding trained, experienced spotters and spotter/pilots. The suspension resulted in further data analysis and an evaluation of the effectiveness of the survey being carried out. This data analysis was completed in 2003 and showed that the scientific aerial survey provides an acceptable indicator of SBT abundance in the GAB (Bravington 2003).

The full scientific line-transect aerial survey in the GAB was re-established in 2005 (Eveson et al. 2011) and has been conducted each year since until at least 2011. New analysis methods were developed and have subsequently been refined. Based on these methods, an index of abundance across all survey years was constructed and reported by Eveson et al. (2011). A method that accounted for variations in the number of sightings, as the number of observers varied between 1 and 2 had been developed based on calibration experiments in 2007, 2008, and 2009, was refined for the analysis reported by Eveson et al. (2011).

Field procedures

The 2011 line-transect aerial survey was conducted in the GAB between 1 January and 31 March (Eveson et al. 2011). Two Rockwell Aero Commander 500S were chartered for the survey. Each plane contained one observer and a non-spotting pilot. The same observers employed for the 2007 to 2010 surveys were used in the 2011 survey. In addition, a spotter-pilot used in the 1993–1998 and 2008–2010 surveys was used as an observer in one of the planes in January.

The survey followed the protocols used in the 2000 aerial survey regarding the area searched, plane height and speed, environmental conditions, time of day the survey was conducted, and data collection protocols (Cowling 2000). The survey area lies between 128°E and 135°E, running from the coast to just off the continental shelf. Fifteen north-south transect lines (Figure 3) were searched by the observers (i.e. spotter and spotter-pilot). A complete replicate of the GAB consists of 12 lines divided into 4 blocks. The remaining 3 lines in a replicate were not searched to save on time, and SBT abundance is historically low in these areas. The blocks were flown from west to east, and the lines within each block were flown in a pre-set order (sequence and direction).

The survey was only conducted on days when certain environmental conditions were met (see Eveson et al. 2006). The minimum environmental conditions required were: less than 1/3 cover of cloud at or below 1500 ft, visibility at 1500 ft must be greater than 7 nautical miles (n. miles), and wind speed at the sea surface must be 8 knots or less. However, once the survey had started, it continued as long as the wind speed did not exceed 10 knots.

A Garmin 176 GPS was used to log the position of the plane (at 15 second intervals) and waypoints during the survey (see Eveson et al. 2006). Transects were flown at 120 knots and at an altitude of

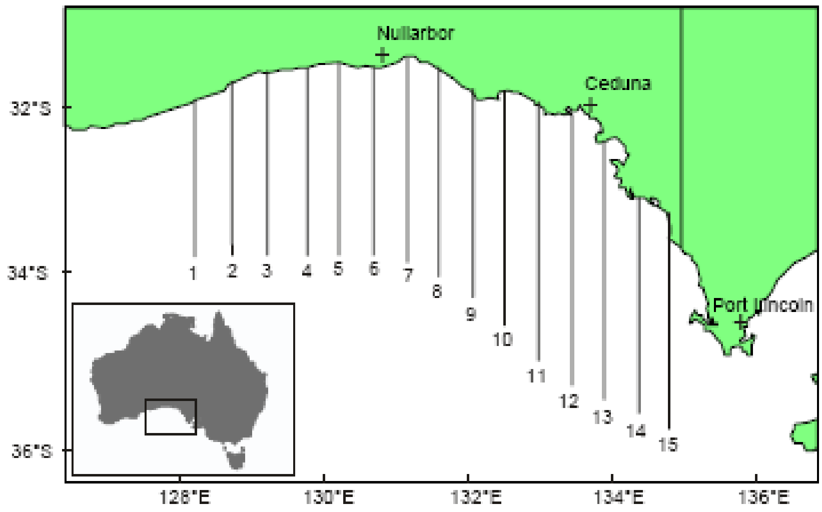

Figure 3: Location of the 15 transect-lines for the scientific aerial surveys in the Great Australian Bight. (Reproduced from Eveson et al. 2006 with the kind permission of Dr Paige Eveson of CSIRO, Hobart).

1500 ft. Each observer searched the sea surface from straight ahead through to 90° on their side of the plane (abeam of the plane) for surface patches (schools) of SBT.

When a sighting of SBT was made, a waypoint position (with time) was recorded in the GPS (see Eveson et al. 2006). The plane continued along the transect line until the observer judged that the sighting was at 90° to the plane. At that point, the plane left the transect line and flew directly to the sighting and circled it. Each sighting can contain one or more schools (or patches) of SBT. The two observers independently estimated a range for the size of individual fish in each school (in kilograms) and the size of each school (in tonnes). Another waypoint was recorded over the school, and then the plane flew back to the point where it left the transect line to resume searching.

Information was collected only on those sightings for which some part of the grouping was within 6 n. miles of the transect line. While flying out to a sighting, the observers refrained from looking at the areas that had not yet been searched. This reduced the possibility of additional (secondary) sightings. If secondary sightings were made when flying off the transect line, they were only recorded if they were within the 7 n. mile limit, and were in areas not already searched. If the secondary sightings could be seen from the transect line (when the plane returned), that was recorded. Only secondary sightings that could be seen from the transect line were included in the analysis.

Environmental observations were recorded at the start and end of each transect and at 30 minute intervals during the transect flight, or when the conditions changed significantly. The observations included wind speed and direction, air temperature, amount of high and low cloud, glare, haze and swell.

Analyses

Two components of observed biomass were described using different models. These were the biomass per patch sighting (BpS) and the sightings per nautical mile of transect line (SpM). For the purposes of analysis, 45 area/month strata were defined, based on 15 areas (5 longitude blocks and 3 latitude blocks (Figure 4) and 3 months (Jan, Feb, Mar). The latitudinal divisions were chosen to correspond roughly to the three depth strata, inshore, mid-shore and shelf-break.

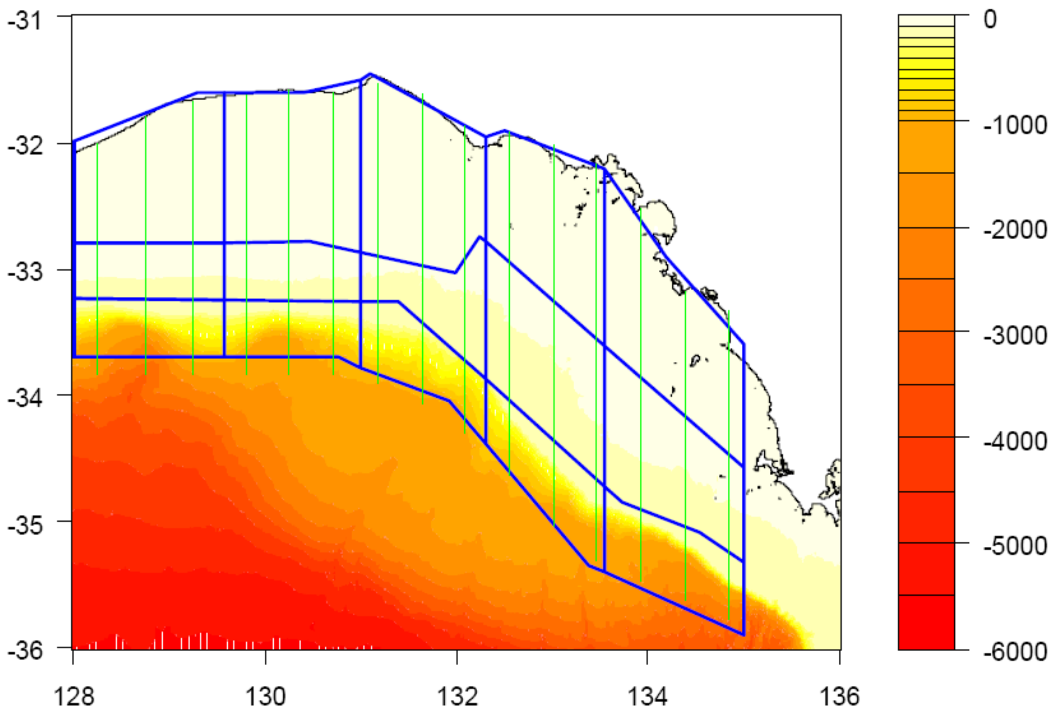

Figure 4: Plot showing the 15 areas (5 longitudinal bands and 3 latitudinal bands) into which the aerial surveys were divided for analytical purposes. From the depth profile it can be seen that the latitudinal bands correspond approximately to depth strata (inshore, mid-shore and shelf-break).The green lines show the official transect lines for the surveys conducted in 1999 and onwards. (Reproduced from Eveson et al. 2006 with the kind permission of Dr Paige Eveson of CSIRO, Hobart).

For the BpS model, the relative differences between observers in their estimates of patch size (using the same methods as described in Bravington 2003) were estimated first, which showed that there was good consistency between observers such that patch size estimates made by different observers tended to be within about 5% of each other.

A GLMM (generalized linear mixed model) with a log link and a Gamma error structure was used to fit the BpS model. The model was fitted with 3-way interaction terms between year, month and area. Essentially, the 3-way interaction model simply corrects the observation (in this case, the total biomass of a sighting) for environmental effects, which are estimated from within-stratum comparisons (i.e. within each combination of year, month and area). The 2-way and 3-way interaction terms between Year, Month and Area were fitted as random effects, whereas the 1-way effects were fitted as fixed effects.

Exploratory plots and model fits indicated that two environmental covariates had a significant effect on biomass per sighting. These were wind speed and, particularly, SST, resulting in the following final model:

$$\log \mathrm{E}[Biomass] \sim Year * Month * Area + SST + Windspeed$$

where *Year*, *Month*, and *Area* are factors, *SST* and *Windspeed* are linear covariates, and $\mathrm{E}[Biomass]$ denotes the expected value of *Biomass*.

For the SpM model, the pairwise observer analysis described in Bravington (2003) was first updated, based on within-flight comparisons of sighting rates between the various observers.

The (logged) estimates of relative observer pair efficiencies were included in the model as an offset (i.e., as a predictor variable with a known, rather than estimated, coefficient).

The data used for the SpM model were accumulated by flight and area, so that the dataset used in the analysis contained a row for every flight/area combination in which search effort was made (even if no sightings were made). Within each flight/area combination, the number of sightings and the distance flown were summed, whereas the environmental conditions were averaged. The SpM model was fitted using a GLMM with the number of sightings as the response variable, as opposed to the sightings rate. The model could then be fitted assuming an overdispersed Poisson error structure with a log link and including the distance flown as an offset term to the model (i.e. as a linear predictor with a known coefficient of one).

As was done for the BpS model, terms for year, month and area, as well as all possible interactions between them, were included in the SpM model, and the 2-way and 3-way interaction terms were fitted as random effects. Determination of which environmental variables to include in the model was based on exploratory plots and model fits. The final fitted model was:

$$\log \mathrm{E}\left[NumberOfSightings\right] \sim offset(\log(Distnce)) + Year * Month * Area + \\ \log(ObsEffect) + SST + Windspeed + Swell + Haze + MoonPhase$$

where *Year*, *Month*, and *Area* are factors, *MoonPhase* is a factor (taking up one of four levels from new moon to full moon), and all other terms are linear covariates.

Results from the BpS and SpM model fits were used to predict the number of sightings per mile and the average biomass per sighting in each of the 45 area/month strata in each survey year under standardised environmental/observer conditions. These predicted values were then used to calculate an abundance estimate for each stratum as ‘standardized SpM’ multiplied by ‘standardized average BpS’. The weighted sum of the stratum-specific abundance estimates over all area/month strata within a year, where each estimate was weighted by the geographical size of the stratum in square nautical miles, were then used to produce an overall abundance estimate for that year. And finally, the annual estimates were divided by their mean to get a time series of relative abundance indices.

2.1.3 Atlantic bluefin tuna (*Thunnus thynnus*) surveys in the US (Florida) incorporating aerial photography (Case 3a)

Key reference

Lutcavage et al. (1997a)

Methods

Two tuna-spotting pilots, each with more than 20 years of experience in the commercial bluefin, yellowfin, and tropical tuna purse-seine fisheries, sighted and counted bluefin tuna. Standard practice for spotters is to identify species and estimate average size, weight, and total tonnage before the set is made. The two spotter pilots had participated in the 1994 New England bluefin tuna survey (Lutcavage & Kraus 1995). They flew two single-engine fixed-wing aircraft (Supercub and Cessna 172, defined as “transect” and “discovery” aircraft respectively, except on one day) that had viewing from both sides. The origin of flights meant that transit to the survey area at the Great Bank near Bimini was approximately 40–55 min. The pilots began spotting fish upon reaching the Florida Straits. The timing of the survey was for 11.00–13.00 h, similar to the time of day when previous surveys in 1974–76 were held. The data acquisition system (Tunalog, Cascadia Research, Inc) comprised a global positioning system (GPS), a laptop computer (for marking events), and a 35-mm camera to photograph schools. The position of the aircraft was recorded automatically every 15 seconds. Daily flight tracks were constructed, including the plotting of bluefin tuna positions, using OPCPLOT, version 7.0.

The transect aircraft surveyed a zigzag transect line each day that was approximately 70 n. mile in length along Tuna Alley. Surveys began at a southernmost point near 24°45'N and zigzagged north to approximately 25°48'N. Setting of the starting point was far enough south to include the southernmost limit of the presumed migration route on the Great Bahama Bank where bluefin tuna can be be observed from the air (Rivas 1954, Mather et al. 1995). An observer was on board the transect aircraft on the first day to establish and verify survey protocol. The transect start point was staggered each day to ensure that daily transects were not identical. Surveys were conducted at a height of 750–1000 ft and at a true airspeed of 80 kt. Transect legs following the zigzag pattern were flown to points approximately 3 n. mile west of Tuna Alley and bounded by the the shallows of the Great Bahama Bank. Transects were repeated unless rain squalls and strong winds greatly reduced visibility. The spotter noted any bluefin tuna observed during transit to the starting point.

The discovery aircraft did not fly dedicated transects, but searched Tuna Alley and adjacent areas to determine the general limits of bluefin tuna movement patterns, and to locate, photograph, and observe the behaviour of any bluefin located there. An observer was on board for six of the survey days and the spotter was free to follow whatever search patterns deemed appropriate. Two aircraft were present in the survey area on 14 of the 17 survey days. Pilots remained in radio contact except when the transect aircraft was occupied flying a transect line. Pilots recorded their estimation of wind strength and direction, visibility, cloud cover, and water colour at the beginning of each survey, and at the end of each transect leg. Pilots used the mouse to mark the location of all bluefin encountered and documented them with photographs when possible. General information on SST, sizes of landed fish, and additional sightings were collected through radio contact with local sport fishing boats targeting bluefin tuna.

The index, sightings per unit of effort (SPUE), was estimated as the number of sightings of ABT per 100 n. miles; the number of bluefin per 100 n. miles was also estimated. The distance travelled (n. miles) was estimated from flying time and velocity of the aircraft.

Results

A total of 158 hr (11 910 n. mile), including transit time, was flown by the spotters. Bluefin tuna were encountered on 10 of the 17 survey days. Approximately 115 hr (7126 n. mile) were flown over the Great Bahama Bank. A total of 53 bluefin tuna schools were documented, in which a total of 839 individual fish were counted. Although a number of other species including turtles, sharks, dolphins, and flying fish were sighted during transits over the Florida Straits, no bluefin tuna were observed. Most sightings of bluefin tuna occurred north of 24°30'N within the migratory roué of Rivas (1954) and Mather et al. (1995).

Bluefin tuna sightings ranged from observations of individual fish to loose aggregations of 20 to 100 individuals, and all were categorised by spotters as large giants (greater than 226 kg, approximately 196 cm). Sightings peaked in the first week of June, followed by a gradual decline to 9 June, the last day of the survey, when only one giant was seen. Interviews with charter boat captains indicated that aerial sightings were consistent with the general location and timing of sightings by recreational vessels. By contrast, aerial sightings were more extensive, covering a much greater area than the recreational vessels, which limited their activity to an approximately 12 n. mile strip. The last bluefin tuna sighted in Tuna Alley was on 11 June, with all fishing ending by 12 June. SSTs measured by charter boats ranged between 26 and 29 °C. Prevailing winds were mainly from the east and southeast sectors.

2.1.4 Atlantic bluefin tuna (*Thunnus thynnus*) surveys in the US (New England) incorporating aerial photography (Case 3b)

Key reference

Lutcavage & Kraus (1995)

Methods

According to Lutcavage & Kraus (1995), this study was based on a simple technical framework that included only voluntary participation by the nine commercial spotter pilots involved and the use of two cameras, one to photograph tuna schools (for enumeration), the other to document school location. Participation by spotters was during the 1993 seasonal fishery. All spotters flew single engine, fixed wing aircraft (Cessna 172 and 182, Citabria, SuperCub). Five pilots were involved with harpoon or general category fishing (hook and line), four spotted for seining operations, and at least two participated in all three methods. Photographing bluefin tuna was carried out between 23 July and 13 September after pilots had completed participation in fishing operations because fishing quotas were filled.

Each pilot was allocated a hand-held 35-mm camera and autofocus zoom lens to photograph tuna schools. Time and date were imprinted directly onto exposed film with synchronised databacks. Aircraft positions were recorded from the onboard GPS or LORAN unit using a second camera mounted overhead in the cabin. The two cameras were triggered simultaneously via a cable link when pilots operated a remote shutter control. This provided a record of position for each tuna school documented photographically. Further verification of sequence linkages between tuna school images and locations were necessary because of imperfectly matched film-advance speeds. This was provided by a digital clock synchronised with the 35-mm camera databack and mounted within range of the second camera.

Tuna schools were photographed with colour slide film selected for contrast characteristics and depth of penetration. A circular polarising filter or haze filter was fitted to lenses for glare reduction. Aircraft positions were read directly from black and white film.

Pilots mailed film immediately it was finished in labelled film canisters and stamped and coded direct mailers.

Analysis

The numbers of tuna were determined by projecting selected slides of tuna schools and visually counting individual fish. Enlargement of images was by projection to a standard size (78 × 52 cm) onto a sheet of drafting-quality tracing paper marked with 10 × 10 cm square gridlines. The positions of clearly identifiable fish were marked on the sheet and totalled per grid square and per slide frame. Then each sheet was labelled with the film identification code, frame number, time, and total fish count. Estimation of the total number of fish in school was not attempted.

Care was taken to avoid double counting. A method was developed using estimates of the distance travelled by schools, based on a swimming speed of 10 kts. The rule required that the positions of schools in subsequent images must be far enough apart for them not to be photographed more than once on a particular day.

2.1.5 Capelin (*Mallotus villosus*) surveys in Canada based on aerial photography (Case 4)

This study (Carscadden et al. 1994) examined “the comparability of indices of abundance” of a single stock of Northwest Atlantic capelin (that in NAFO Div. 3L), during 1982–89. The work compared biomass trends from acoustic surveys with indices of abundance from an aerial survey and a commercial trap catch-rate series. It was concluded that "trends in the two inshore indices of abundance were significantly correlated with each other but were not significantly correlated with the Canadian [acoustic] series". Although the study is interesting in its entirety, only the aerial survey component is described here.

The following is a verbatim extract from Carscadden et al. (1994).

Methods

All aerial survey flights were along the coastline following a defined survey track in Conception and Trinity Bays, Newfoundland (Figure 5). These bays were chosen as the study sites because they are in the central area of the Div. 3L stock, the fishery has consistently high landings in these bays and both are within 1 hour of flying time from the nearest airport at St. John's, Newfoundland.

All surveys used fixed wing aircraft with a large format camera and 228 × 228 mm aerocolour negative 2 445 film, which allows penetration in water to a depth visible to the naked eye. An anti-vignetting filter was used in all years.

Two observers along with a pilot and navigator/photographer were present on all flights. One observer spotted capelin schools and directed the pilot during the survey while the other recorded relevant information. Optimal photographic conditions were on sunny days with light wind conditions. To minimize glare, reduce the effect of land shadows along the coastline, and increase visibility, photographs were generally taken when the sun angle was between 20° and 45°. The optimal flying altitude was set at 457 m (1500 ft) above sea level. An accurate measurement of altitude is essential to estimate the scale of each photograph and consequently, a radar altimeter has been used for all surveys since 1983.

Because the distribution of capelin varied somewhat within and between bays, the survey track was subdivided into four transect lines (Figure 5). One transect in Trinity Bay encompassed the route from the Horse Chops to Gooseberry Cove including Southwest Arm, while the second ran from Gooseberry Cove to Hopeall. One transect in Conception Bay included the shoreline from Caplin Cove to Harbour Grace Islands and the other transect went from Harbour Grace Islands to Portugal Cove. It was impractical to survey the entire coastline of both bays within the optimal time period each day. Thus difficult areas to survey, areas with low landings, and places with no fixed gear fishing were excluded from the survey track. The flight path represented the maximum area which could be covered on an ideal day under optimal photographic conditions, when capelin was abundant and widely dispersed inshore.

We attempted to complete at least one transect on each flight. Flights generally alternated between bays. When a school was observed, it was photographed and location, altitude and time of day were recorded. Photographic frames overlapped by 10–20% and contained some shoreline as a reference point for later identification. The frequency of flights was increased subject to weather to cover the peak periods of capelin abundance inshore.

Each photograph was visually scanned to identify capelin schools against a background of kelp beds and rock formations. Capelin schools were usually easily identified because of their greyish colour and distinctive shapes. School surface area was measured using a compensating polar planimeter. The scale (RF) of the photography was estimated by the

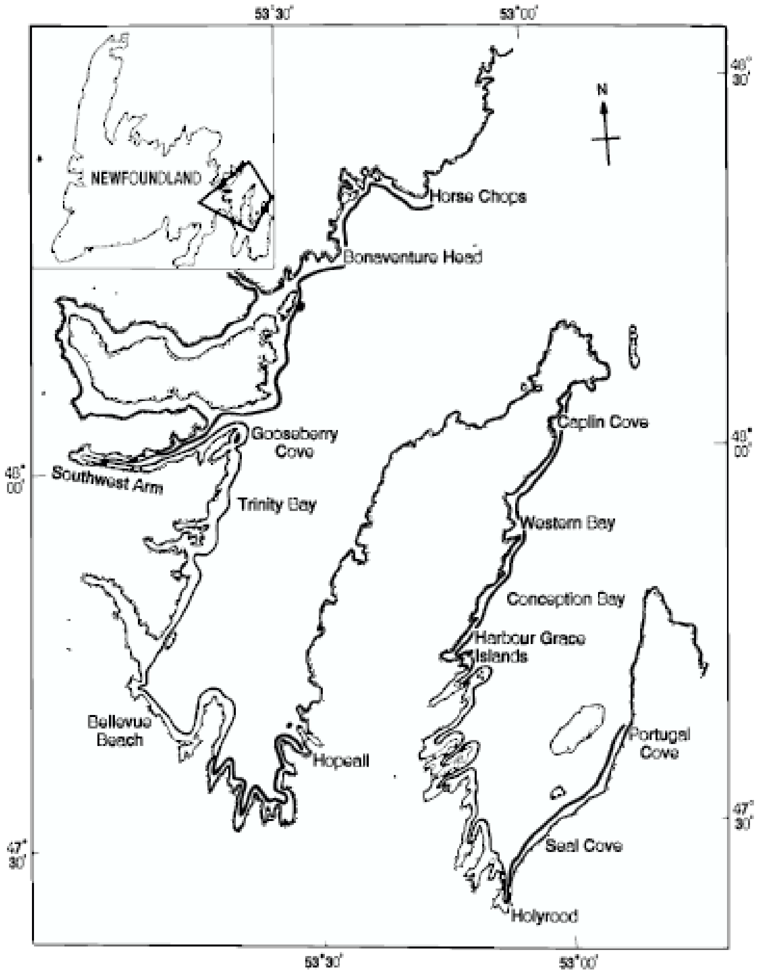

Figure 5: Aerial survey transects in Conception and Trinity Bays. Transects are from Horse Chops to Gooseberry Cove to Hopeall in Trinity Bay and from Caplin Cove to Harbour Grace Islands, Harbour Grace Islands to Portugal Cove in Conception Bay. (Reproduced from Carscadden et al. 1994 with the kind permission of Dr Brian Nakashima, formerly of the Science Branch, Department of Fisheries and Oceans, Canada).

equation RF = F/A where F is focal length (cm) and A is the altitude (cm). Each school was measured three times by the same person and the average of the three measurements was accepted as the estimated school size. Only complete transects were included in the analysis. The total observed surface area was calculated per transect and assumed to represent a minimum estimate of available school surface area. No density or school depth measurements are available, and in this analysis it is assumed that all schools were of uniform density.

An annual relative abundance index was calculated by summing the highest total capelin surface area observed along each of the four transects.

Results

Annual coverage by the aerial survey has been variable due to changing flying conditions. The worst year was 1986 when weather conditions were consistently bad resulting in only 5 days of survey totalling 13.4 hr compared to the 1983–89 (omitting 1986) average of 9 days and 28.7 hr of survey. Also, no estimate was available for one transect during 1986.

Since the highest value of school surface area in each transect is summed to provide the annual index, the 1986 index is likely an underestimate of the true capelin abundance in 1986.

Based on the school surface area indices, abundance of capelin spawning inshore were relatively low during 1982, 1984 and 1986 and highest during 1987.

2.1.6 West Coast USA two stage sardine (*Sardinops sagax caerulea*) 2011 survey (Case 5)

The following has been adapted from Jagielo et al. (2011).

Methods

i. Transect sampling

This survey employed a two-stage sampling design, Stage 1 comprising aerial transect sampling using quantitative aerial photogrammetry for estimating the surface area of individual sardine schools as a basis for biomass estimation, and Stage 2 using at-sea sampling ("point-set sampling") as a basis for quantifying the relationship between individual school surface area and biomass.

For Stage 1 systematic random sampling was done according to a belt transect approach with each transect treated as a single sampling unit (see Elzinga et al. 2001). Three replicate sets of transects were defined and the sampling order was chosen randomly, one set at a time without replacement. Transects were parallel and aligned in an east-west orientation, originating three miles from the shoreline and extending westward for 35 miles. The segment from the coastline to the transect east end (3 miles offshore) was also photo-documented for future evaluation. Two strata were established for sampling and transects were spaced 7.5 nautical miles apart in the northern stratum (n = 31 transects) and 15 nautical miles apart in the southern stratum (n = 10 transects).

The sampling direction was from north to south, against the summertime migratory direction of the sardine schools. Three pilots participated in the survey, with two pilots working as a coordinated team at any time, adopting a "leap-frog" approach to maintain the southward movement and minimise the likelihood of double counting. Skipping transects or portions of transects if conditions required it was allowed, but skipped transects could not be revisited during sampling of a transect set.

Once a transect set was begun, the aim was to complete sampling in the least number of days possible. A nominal survey altitude of 4000 ft (1219 m) was maintained and transects could be flown in either an east-to-west or a west-to-east direction. Survey pilots conferred at the beginning of each potential survey day, considering factors such as sea condition, and the presence of fog or cloud cover to jointly determine whether safe and successful surveying could be achieved, based on the aim of having clear visibility of sardine schools from 4000 ft.

Each aircraft carried similar equipment to that used for previous survey work in 2008, 2009, and 2010: an Aerial Imaging Solutions photogrammetric aerial digital camera mounting system integrated with a data acquisition system designed to capture digital images and to log transect data. Data recorded included altitude, GPS position, and spotter observations, which were directly referenced to the time stamped quantitative digital imagery. The approximate transect width swept by the camera with a 24 mm lens at the nominal survey altitude of 4000 feet was 1829 m (1.13 mi). For work in previous years, digital images were collected with 60% overlap to ensure seamless photogrammetric coverage, but in 2011 the overlap was increased to 80%.

ii. Transect data analysis

Taking photogrammetric measurements

To provide a basis for ground truthing digital images and making cross comparisons between survey aircraft, digital images of objects of known size (e.g. aeroplane hangars) were collected at a series of altitudes from 1000 ft. to 4000 ft. The observed vs. actual sizes of the objects were then compared to determine photogrammetric error. Features of images collected during calibration flights by the three survey pilots were measured by six photograph analysts which provided estimates of average deviation that ranged between -0.059 and 0.074 for the three camera systems employed in the study. The tendency for deviations to increase with altitude was confirmed.

Photogrammetric calculations

Digital images collected during the work provided data for determining the number, size, and shape of observed sardine schools. Resolution was maximized using Adobe Photoshop Lightroom 3.0; the two key school metrics of circularity (shape) and area (size) (m^2) were recorded using Adobe Photoshop CS5-Extended. Transect width was calculated using the photogrammetric relationship

$$\frac{I}{F} = \frac{W}{A}$$

$$W = \frac{I}{F} A$$

where I is the image width of the camera sensor (e.g. 36 mm), F is the focal length of the camera lens (e.g. 24 mm), A is the altitude when the image was captured, and W is the width of the field of view of the digital image. Transect width was calculated as the average W for all images collected.

Photographic analysis

Photographic analysis comprised the three steps of preliminary analysis, school measurement, and analysis of between-reader differences.

Preliminary analysis "was conducted by a well seasoned member of the analysis team" who reviewed all transect photographs and determined which would be used for collecting school measurements. Transects were classified according to readability criteria.

School measurement was carried out independently without conferring by two analysts who recorded school detection and measurement from a set of transect photographs.

Analysis of between-reader differences was where two sets of transect school measurement records were compared to determine variability in the detection and measurement of schools. Transects with the largest deviation in total school area were compared school-by-school to identify where schools were not detected or objects were mistakenly identified as schools, or any double counting had occurred.

Transect readability

A three-point scoring system was applied to the transect photographs and the resultant scores used to classify each transect. The scores were defined as 1 for few impediments to readability, 2 for moderate impediments, or 3 for substantial impediments. Other conditions were also recorded, including cloud cover, water turbidity, sea-surface chop, and excessive glare.

School species identification

Species identification of schools observed along the transects was carried out in real time by experienced fishery spotter pilots whose observations were recorded on a Transect Flight Log Form. Other conditions such as sea state, weather, and sea surface anomalies (e.g., tidal rip, fresh-water bodies, turbidity plumes) were also recorded by pilots for use in interpreting transect photographs.

iii. Point-set sampling

Point-sets are where sardine schools are captured in their entirety by a survey purse-seine vessel after identification of the school by a survey pilot at 4000 ft. Point-sets were used to determine the relationship between individual school surface area and their quantity or biomass. The sampling design for point-sets was stratified by size with the aim of providing a range of sizes that were representative of schools photographed during the survey as well as a geographic distribution of school size. Sampling was constrained to a range of school sizes that ensured safe operation of the vessels involved, so point-sets were restricted to school size of 130 tonnes and less.

An exempted fishing permit made allowance for 2700 tonnes of sardine. Based on this amount, 76 point-sets were included in the survey plan.

Point-set data

School height data were collected at sea with the purse-seine sonar and down-sounder and recorded on Point-set Vessel Log Forms. Individual schools were stored in separate holds and the landed weight of the individual schools as recorded at the dock was used to infer landed weight.

A series of photographs of each point-set school were recorded before the fishing vessel was close enough to influence the behaviour of the fish. The best available image was used for school size measurements. The same method as that described above for taking measurements from photographs was used here. Observations by the pilot arising during the photographing were recorded on the Point-set Log Form.

Samples from each school were collected at the dockside and used to determine species composition and sardine biological parameters. Samples were taken systematically from the unsorted catch at the start, middle, and end of unloading from the hold. These three samples were combined and a random subsample taken. Weight, sex, and maturity (female 4 point scale, male 3 point scale) were recorded for each fish using the Biological Sampling Form.

iv. Analytical methods

Total biomass

Total sardine biomass for the survey area was estimated using a three step process and incorporating individual school surface area measurements, individual school biomass estimates (from the surface area – biomass relationship), and transect sampling design theory for estimating population total. The R statistical programming language was used to implement the following calculations.

Surface area (a_i) of the school was estimated using the measurement feature of *Adobe photoshop,* employing the photogrammetric relationships described above. Surface area density (d_i) was determined from the surface-area:biomass relationship obtained from the point-set sampling. Individual school biomass (b_i) was estimated as the product of school surface area density and surface area ($b_i = d_i\, a_i$). Total biomass (b_u) was calculated for each transect (u). The mean sampled biomass for the study area was given by

$$\overline{b} = \sum_{u=1}^{n} b_u / n$$

where n is the number of transects sampled. The total biomass for the study area was given by

$$\overline{B} = N\overline{b}$$

where N is the total number of transects available in the study area without overlap and $\overline{B}$ is the unbiased estimator for a population total (Stehman & Salzer 2000).

Two readers completed the school measurement process, thus producing two estimates of total biomass. The mean of these values provided the final biomass estimate.

School biomass

Biomass of the individual school (b_i) was calculated from the measurements of school surface area and the surface-area:biomass relationship obtained from the point-set sampling.

The surface-area:biomass relationship was described using the three parameter Michaelis-Menten (MM) model, assuming log-normal errors:

$$d_i = (yz + xa_i)/(z + a_i)$$

where d_i is the school surface area density (tonnes/m^2), a_i is the school surface area (m^2), y is the value at the intercept, x is the asymptote as a_i approaches infinity[2], and x/z = slope at the origin. Individual school biomass (b_i) was then estimated as the product of school surface area density and surface area ($b_i = d_i\ a_i$).

Coefficient of variation for total biomass

A bootstrapping method implemented with the R statistical programming language was used to estimate the CV of the total biomass from the three components:

- The surface-area:biomass relationship;
- Reader measurements; and
- Transect random sampling.

The bootstrapping method comprised several steps:

1. Fit the MM model to the point-set data;
2. Derive the variance-covariance matrix for the MM model fit using the R package MSBVAR[3];
3. Extract matrix of simulated parameters from the MSBVAR output using the R function rmultnorm [a function within MSBVAR];
4. For 100 000 bootstraps:
   a. Select one realization of the MM parameters from the matrix of simulated parameters;
   b. Calculate the predicted MM curve;
   c. Estimate biomass for the transects (Reading 1 and Reading 2);
   d. Select either Reading 1 or Reading 2 at random for each of the *n* transects;
   e. Randomly sample with replacement from the set of selected transects; and
   f. Calculate total biomass for the study area from the sampled transects and store as the bootstrap estimate of biomass ($\hat{B}$).
5. Calculate standard error (SE) from the stored bootstrap estimates of biomass at 4e;
6. Calculate CV as $SE/\hat{B}$.

2.2 Summaries of methods from the case studies

2.2.1 Method used

As a means of standardising the various aerial survey methods used in the case studies, each was summarised in terms of a set of common salient features which were then used as a tool in the initial step of defining salient features for the New Zealand method (see Section 4.1). The summary features are as follows.

[2] This phrase was corrected from "as *x* approaches infinity" which was undoubtedly a typo in the original text, based on consideration of publications such as Bolker (2008, p 81).
[3] http://www.rdocumentation.org/packages/MSBVAR

a. Objective of survey.
b. Dates of survey (i.e., years).
c. Basis for survey design: distance-sampling or other.
d. Data-collection method: field recording, photographic etc.
e. Data-collection medium: laptop, PDA, paper forms etc.
f. Timing of survey flights: day, night, etc.
g. Seasonal timing and area of survey.
h. Environmental constraints: brief description of optimal conditions as defined.
i. Unit for object of interest: single objects, clusters.
j. Flightpath descriptor: transect grid randomly positioned; other.
k. Flightpath recorded: yes/no.
l. Number of observers.
m. Seating arrangement of pilot and observers.
n. Pilot's role/tasks
o. Observers' role/tasks
p. Species identification method: data recorder and person identifying.
q. Method for measuring perpendicular distances.
r. Prescribed survey altitude.
s. Method of measuring altitude.
t. Number of aircraft on transect and number of pilots at any time.
u. Environmental data collected.
v. Modelling environment — DISTANCE software or any other.
w. Major changes to method (for a method used over a long term).
x. Aircraft type.
y. Total flying/search effort.

2.2.2 Discussion of the case studies in the New Zealand context

Features of the case studies

The case studies have been included to illustrate the types of method that have been used for aerial survey. Each of the methods has provided useful insights as background for investigating an appropriate method for the New Zealand inshore pelagic schooling finfish situation. Each case study included the two main components of data collection and data analysis. Three methods of data collection were used: distance-sampling or a variant on its usual line-transect approach (Cases 1 and 2 respectively) and using photographic images (Cases 3a, 3b, 4, and 5). In all cases the data collection method was applied while traversing a system of transects, although there was some variation in the way that transects are defined.

Data analysis in the case studies is a little more varied than data collection. Although distance-sampling provides the DISTANCE software which was used in Case 1, custom-written software was used in Case 2. Photographic images were used for data collection in the remaining cases, but their analytical methods differed: Cases 3a and 3b used methods designed to enumerate individual fish and Case 5 provided the R code developed to calculate the relevant estimates using data from the images and the point-set sampling. Case 4 appeared to use a similar, though more simplistic, method for data analysis to that of Case 5, and there was no attempt at standardisation of school size using point-set or similar methods.

In summarising the two components of data collection and data analysis in terms of their relevance to the New Zealand situation there are two data-collection methods to be considered (transect sampling as is formalised in the distance-sampling method, and the use of photographic images) and three data-analysis methods (DISTANCE, the custom modeling from the Australian SBT method, and the photogrammetric approach from the West Coast USA sardine survey).

Although the Wyoming pronghorn method may appear to be irrelevant here in that it was developed for surveying a terrestrial species, it was included because it contains a well illustrated, detailed description of what has been a standard method for preparing a small aircraft for collecting data using the distance-sampling method, thus providing a useful demonstration of the distance-sampling data collection method in its original form. It also provides reference to a large proportion of documented aerial surveys that use the distance-sampling method, and the more recent document (Guenzel 2007) includes useful discussion and demonstration of electronic data collection and software.

As has been discussed elsewhere, the Australian SBT method provides an innovative survey approach for fish, utilising transect sampling with some reference to the methods of Buckland et al. (2001) (see Bravington 2003) but employing the strip transect instead of the line transect which seems more standard with the distance-sampling method, and a custom-built estimation procedure. It includes extensive background information on sampling design and an alternative modeling approach. It also contains discussion providing insights for developing a similar method while avoiding the pitfalls discovered in the SBT case.

The two ABT studies were included because they contain useful information on aerial photographic techniques. The Canadian capelin study and the west coast USA sardine study also utilise photographic techniques as well as similar methods for estimating school size using school area from aerial photographs. The capelin study highlights the need to carry out photographic work under optimal photographic conditions; it uses a series of transects that generally follows the coastline at an approximately constant distance rather than a grid design (see Figure 5). The sardine survey method provides an integrated approach for a purse-seine fishery with aerial support, and a method for relating photogrammetrically measured school surface area to school biomass.

The Californian sardine survey method described by Lo et al. (1992) was also considered for inclusion as a case study but omitted because the literature suggests that the method has been replaced with that described under Case 5 (see Hill et al. 2012). An approach similar to that of the Australian SBT survey has been published by Fromentin et al. (2003) for Atlantic bluefin tuna in the Mediterranean, but it is less detailed and was also omitted from the list but with little loss in information given that the approach is adequately represented by the SBT method. Also omitted was the online report by Sulikowski et al. (2012), which documents what could be a useful contribution here but is presented as a feasibility study and currently remains unpublished. Its method incorporates aerial photography into standard transect sampling similar to the distance-sampling method using hand-held cameras, but does not include motion compensation.

Species identification and school size

To be effective in the present context an aerial survey method must sample from the population of interest and provide reliable data for estimating relative abundance indices. Fundamental to this are the two essential elements of species identification and a method for collecting the data from which the quantity of fish in each school can be estimated. For any of the methods described in the case studies to be useful, they would need to satisfy these requirements. However, in several cases simple enumeration of the observed animals is the approach taken, which probably provides an adequate basis for biomass estimation in the SBT case, but, because of the relative fish size, cannot be effective in estimating biomass of large schools (about 10 t to over 100 t) of small-to-medium finfish species as the case in the New Zealand situation.

Most of the case studies allocate responsibility of species identification to the pilot. In a few cases it is a task of an observer. Currently in New Zealand there is a high level of expertise for species identification — when working in the purse-seine fishery, spotter pilots are required to make accurate assessment of species composition of schools. Species identification is a complex task, requiring knowledge of the species being observed and the visual cues used to distinguish between them, including dynamic factors such as swimming motion or the brief reflection of light in the form of “flashes”. A description of these cues is included in Appendix B and comparing them for the various species indicates that the observation process is dynamic, often gathering information on several aspects of fish movements before comparing them with what is known. Frequently several cues require a positive sighting before a positive species identification can be made. This set of cues is a highly tuned practical knowledge base that has been generated and modified over many years.

Developing expertise in species identification is part of the training when a spotter pilot begins working in the purse-seine fishery (Red Barker, senior spotter pilot, pers. comm.). It is possible that similar training could be given to survey observers (i.e., observers working in an aerial survey), although it is unlikely that the key feature of feedback from the purse-seine vessel could be sustained because of the extended time-frame this would require for the trainee to be present during purse-seine fishing operations and the cost that would incur. As an alternative, depending on the overall nature of the survey design, it might be considered more efficient to always employ spotter pilots for flying the aircraft and use their expertise for identifying the species composition of the observed schools. However, there are reasons why this approach should not be used which are discussed in the following section.

What may be possible, at least in the shorter term, is professionally recorded footage of a full set of the visual cues used for each species. This could be achieved using a moving picture format with commentary added in consultation with the senior pilot. The footage could then be used to train observers and remove reliance on the spotter pilots. As is discussed below (see Section 3.1.4), the pilot or observer factor has been shown to be an important source of variability, particularly in the Australian SBT survey. If it can be done, standardisation of species identification using training video would go some way to reducing this observer variability. Clearly, the difficulty would be to record the full set of cues required to distinguish schools of a particular species, but achieving it once to a high standard using professional expertise is sure to be a lot more cost effective than attempting to have an observer do it as a matter of course for each school encountered during a survey to a standard that would produce acceptable estimates of species composition.

The second element mentioned above, that of providing reliable data on the biomass of observed schools, also currently requires the expertise of the spotter pilot. Pilots are able to accurately assess the school size in tonnes and use this as part of normal operations within the fishery to select from a group of schools the one that is best for targeting in terms of available storage capacity for a particular vessel. An important factor for pilots developing this accuracy, including accuracy in determining species composition of the school, is the immediate feedback they receive from the crew once the targeted school has been landed onto the vessel.

Two of the case studies provide methodologies for estimating school size using the surface area of the school as recorded with photographic images. The Canadian capelin survey assumes fish density to be constant between schools. By contrast, the West coast USA sardine survey method includes a “point-set” component in which schools of sardine of a range of sizes are photographed, using the same approach as in the transect surveys, followed by their being landed by a survey purse-seine vessel. The densities estimated from the landed weights for the range of schools are then used for estimating tonnages of schools observed in the transect survey. The key factor linking the density of the point-set schools to those photographed along the transect lines is the surface area of the two school types.

Both of these methods used recorded photographic images for calculating surface area of each observed school. The capelin study used a compensating polar planimeter for the calculation and the sardine survey, which is more recent, used the measurement feature of Adobe Photoshop CS5-Extended. Both methods allowed for the effects of variations in altitude, but only the sardine survey method included a component for estimating photogrammetric error, which was based on a series of calibration photographs of objects of known size taken at several altitudes.

However, both of these methods seem to include a further assumption that is not discussed in either case – they both use school surface area as an index of school size without taking account of probable variation in school height (the distance between the top and bottom of the school), thus assuming a constant school height for a given surface area. There is explicit reference in the sardine survey method to collection of school height data using vessel sonar as having been carried out, but there is no mention of how the data are used and it is absent as a variable from the equations presented in the methodology. If this assumption was made it is unlikely to be valid because any variation in school height for a given surface area confounds the assumption and introduces error into the estimation method.

Employing spotter pilots for aerial surveys

Previously, discussion related to aspects of a possible aerial survey by members of the Northern Inshore Working Group was based on the availability of spotter pilots to carry out particular tasks including the single transect study described below in Section 5.1. However, such an approach has been discussed with the senior pilot and is considered too difficult in its present form to pursue further. Pilots cannot have their primary function within the fishery compromised by other tasks.

This also applies to pilots being involved in any survey proper. The main issue here is that the optimum time (i.e., season) for an aerial survey of the inshore pelagic species coincides with the time that the purse-seine fishery is at its annual operating peak, so that pilots' involvement in the survey operation would clash with their involvement in the purse-seine operation. For these reasons it is necessary that any aerial survey method be developed as an operation that does not require the involvement of the purse-seine spotter pilots, apart from their input during the setting-up phase to particular parts of the design such as the training of observers in identifying species and determining the species composition of schools or perhaps early investigation of CVs etc. using the single transect study (see Section 5.1).

Conclusions

The case studies provide methodologies for two different approaches to aerial survey design — the distance-sampling approach, with two options for data analysis, and the photogrammetric approach. The photogrammetric approach includes a method for converting observations to biomass, which could also be applied in the distance-sampling context. This conversion method probably needs some revision to account for variation in school height.

3. DISCUSSION ON AVAILABLE RELEVANT INFORMATION

3.1 Examining aspects of the available survey methods

3.1.1 Introduction

Essentially, two variations on aerial survey are available: distance-sampling as described by Buckland et al. (2001) and a photogrammetric method similar to that used in the West Coast USA sardine survey described by Jagielo et al. (2011). These methods can be described in terms of two components, those of data collection and data analysis. For distance-sampling the data collection component provides a well-defined approach that accounts for the reality that not all objects of interest within the viewing range will be seen, and a clear system for collecting the data necessary for taking this approach. Certain technical details of the distance-sampling method are discussed in this section to provide some additional background information on the technique. Similar discussion is not required for the photogrammetric method whose details are described in Section 2.1.6.

3.1.2 Data collection using distance-sampling

For the distance-sampling method to be adopted as the basis for data collection in a survey design, some modification to the method is appropriate, particularly with respect to measurement of perpendicular distances from the centre line to the sighting. Rather than adopting the approach used in the pronghorn surveys of Guenzel (1997) where “viewing windows” attached to the wing struts are used to collect grouped data, distances in the New Zealand situation are probably best achieved by following the Australian SBT survey approach and flying the aircraft to a position that is central to the group of schools making up the sighting. At least two possibilities exist for recording the perpendicular distance once this position is reached. The first is to record the distance flown from the point at which the centre line was relinquished, that is, the point from which the shortest distance to the sighting was perpendicular to the centre line, to the sighting — this constitutes the “manual method”. A second, more automated method is to fly directly to the point central to the schools making up the sighting and then record the waypoint representing this position — simple software can then be used to equate the shortest distance to the centre line, perhaps at the data manipulation stage when data are error checked and loaded onto a database — this is referred to below as the “direct method”.

There are other factors requiring consideration here. Australian scientists (Eveson et al. 2006, Bravington 2003), provide clear directions for sighting schools, warning that, to comply with the distance-sampling method, sightings can only be made from the centre line. Their method requires that the pilot fly from the centre line to the sighting (as is described in the previous paragraph), but that the pilot must return to the centre line, continuing along the transect line from the point of “perpendicular departure” for the previous sighting before “spotting” the next sighting. In situations where a subsequent (or secondary) sighting (called secondary patches by Bravington 2003/Eveson 2006) is made while flying to or returning from a sighting, the pilot is instructed to “forget” its presence or at least to recommence travel along the transect and “check” whether the school could be detected from the centre line before recording it as a new sighting. This only applies to potentially new sightings that lie on a line perpendicular to the centre line from a point further advanced along the centre line than the sighting that was being examined at the time the “new” sighting was detected. Secondary sightings that lie perpendicular from a point on the centre line that precede the point from which the sighting of current investigation lies perpendicular to the centre line, must be considered “missed sightings” and therefore ignored.

Two further points are relevant. Firstly, the Australian method for SBT also sets the maximum distance from the centre line at which a sighting is eligible to be recorded at 7 n. miles[4], and secondly, taking the direct method to measuring perpendicular distances eliminates complexities and sources of error arising from measuring distances and angles during the flight.

3.1.3 Data analysis using distance-sampling

The DISTANCE software offers a standardised system for estimating density and abundance from data collected using the distance-sampling method; its use is recommended by Guenzel (1997). However, there are a number of features of aerial survey as it is applied to schooling fish species that suggest the need for changes to the standard distance-sampling method, with certain considerations being particularly relevant in the New Zealand context.

[4]There is some confusion from the references documenting the Australian SBT work where 6 n. mile and 7 n. mile are both reported for this distance.

Buckland et al. (2001, Section 1.4.3) define cluster as a "relatively tight aggregation of objects of interest, as opposed to a loosely clumped spatial distribution of objects" and refer to schools of fish as an example of clustered data. They also state that "In distance-sampling theory, the clusters must be considered to be the object of interest and distances should be measured from the line or point to the geometric centre of the cluster." It follows that density estimation of the clusters is then straightforward, with n the sample size representing the number of clusters observed during the survey.

Where a measure of the density of individuals is required (e.g., whales or birds) the number of individual(s) in each observed cluster is counted and the expected cluster size for the population, $E(s)$, can be estimated. The density of individuals, D, is then given by

$$D = D_s \cdot E(s)$$

where D_s is the density of clusters.

Although the most simple estimate of $E(s)$ is $\bar{s}$, the mean size of the n observed clusters, detection of the clusters can be a function of cluster size (i.e., smaller clusters are less visible at greater distance from the centre line) which results in the estimator D_s remaining unbiased, but $\bar{s}$ being a positively biased estimator of $E(s)$ and the density being over-estimated.

Buckland et al. (2001) continue with a list of five strategies for size-biased sampling when "the detection probability is dependent on both distance from the line or point [for point transect sampling] and cluster size." For example, one particular strategy is described as "straightforward and generally quite robust" where the distance data are truncated so that the correlation between detection distance and cluster size is reduced followed by the application of robust semiparametric line transect methods with the suggestion that "appropriate data truncation after data collection can greatly reduce the dependence of detection probability on cluster size." A second recommended approach is two-step, comprising an initial estimation of cluster density followed by a regression of cluster size on $\hat{g}(y)$, the detection function (Buckland et al. 2001, Section 1.3), for estimating mean cluster size where detection is certain $(\hat{g}(y) = 1)$. This subject is discussed further in Buckland et al. (2004) with reference to more advanced methods.

The detection function represents the probability of detecting an object at a distance y from the random line (i.e., $g(y) = \mathrm{pr}\{\text{detection}|\text{distance } y\}$. Generally, the value of the detection function lies in the range from 0 to 1 (i.e., $0 \leq g(y) \leq 1$) and decreases with increasing distance from the centre line. The general assumption is that objects on the line (i.e., where the distance y is zero) are detected with certainty, such that $g(0) = 1$. Closely allied is the shape criterion (Buckland et al. 2001, Section 2.3.2) which requires that the detection function has a 'shoulder' near the central line so that detection remains almost certain at small distances from the line, thus excluding spikes near zero.

Within the New Zealand inshore pelagic context the issue relating to a clustered population is not confined to the composition of schools. It is commonly known from discussion with spotter pilots working in the purse-seine fishery and from the data returned by pilots that

schools of these species are not themselves distributed randomly in space. Often multiple schools are observed in clusters (Table 1) which are recorded as sightings, and these sightings are assumed to follow a random distribution. So these populations can be characterised as having two levels of clustering - the first is of fish within the school, the second is of schools within the sighting.

According to Professor Stephen Buckland (University of St Andrews, Scotland, pers. comm.) this is not an uncommon phenomenon, with the distance-sampling method very robust to such effects because the main contribution to variance is variation in the encounter rate. Variance is estimated by examining variation across transect lines so that variation between lines is accommodated for within the analysis. Options within the DISTANCE software allow variance in the detection function and cluster size components of the estimation to also be estimated from the between-line variation. A further option allows density variation through the study area to be estimated, which can help in identifying where clusters of schools occurred during the survey.

This tendency of schools to form clusters means that the sighting becomes the object of interest in a survey employing the distance-sampling method. Consequently, in a manner similar to that taken when "cluster" is defined as a school of individual fish, the perpendicular distances are measured from the central line to the geometrical centre of the group of schools comprising the sighting. In the case where a half-width (*w*) has been set for the data collection, inclusion of these schools in the survey data then becomes a question of the position of the sighting-centre: if it is within *w* then all schools are included, even if some lie outside *w*; but if the sighting-centre is outside *w*, none of the schools should be included. However, it is probably more efficient to include all sightings encountered at data-collection time, and select data according to a preferred half-width after the data-collection phase. That way, choices can be made according to the number of sightings encountered.

When documenting methods used for the Australian SBT survey analysis, Bravington (2003) listed the following three complications that make analysis of the SBT aerial survey data generally difficult and preclude the application of textbook methods including the DISTANCE software.

1. SBT are only at the surface for a proportion of the total time; the proportion of time they are visible to an airborne spotter seems to vary widely with the environmental conditions.

2. "A sighting" of SBT is an imprecise concept because, although a visible patch is easy to define, a loose aggregation may be classed as one sighting or as several, depending on its distance from the centre line; this introduces uncertainty to the conventional analysis methods (e.g., DISTANCE).

3. Observers may differ widely in their ability to spot patches under different conditions and/or in their ability to estimate biomass; consequently, there is a risk that estimates of abundance will be driven by the spotting instead of the fish, unless exactly the same set of pilots and observers is used over time.

To deal with the three points above, several adjustments were made to the standard distance-sampling method for the SBT survey approach. The essential reason for adopting the custom modelling approach (referred to above in Section 2.2.2) was the uncertainty introduced to conventional analytical methods described in point 2. Line transect theory such as the standard distance-sampling approach allows for the tendency of sampling rates to decline with distance from the centre line through the use of a line transect method in which a proportion of objects within a distance *w* of the centre line can be missed (Buckland et al. 2001, Section 1.2.3). On the basis that there is no evidence of a declining sampling rate with

Table 1: Proportions of the total number of schools (*n*) contained in a sighting, for each of the five main purse-seine target species: skipjack tuna (SKJ), trevally (TRE), blue mackerel (EMA), jack mackerel (JMA), and kahawai (KAH). Source: MPI aerial sightings database *aer_sight*

Number					Species
of schools	SKJ	TRE	EMA	JMA	KAH
1	0.42	0.52	0.41	0.25	0.18
2	0.17	0.23	0.19	0.14	0.14
3	0.11	0.11	0.12	0.10	0.11
4	0.07	0.05	0.07	0.07	0.08
5	0.05	0.03	0.05	0.06	0.07
6	0.05	0.02	0.04	0.05	0.07
7	0.02	0.01	0.02	0.03	0.04
8	0.03	0.01	0.02	0.04	0.05
9	0.01	0.00	0.01	0.01	0.02
10	0.02	0.01	0.02	0.04	0.05
11	0.00	0.00	0.00	0.01	0.01
12	0.01	0.00	0.01	0.02	0.03
13	0.00	0.00	0.00	0.01	0.00
14	0.00	0.00	0.00	0.01	0.01
15	0.01	0.00	0.01	0.03	0.03
Totals*	0.98	1.00	0.97	0.86	0.88
Total no. of sightings	21466	7393	7278	6992	21565
Max no. of schools†	100	35	100	275	250

*Where the total proportions for a species is <1.00, additional sightings comprising >15 schools have been recorded for that species, but proportion for each additional number-of-schools category is <0.01.
†Maximum number-of-schools recorded for each species.

distance in aerial surveys for SBT, at least not for distances of up to 6 n. mile, a strip transect approach was adopted instead of a line transect, with its outer boundary 6 n. mile from the centre line (Bravington 2003). Under the strip-transect approach perpendicular distances are not required and all patches encountered along the strip are recorded and simply summed to produce total biomass for that transect.

For the complications of points 1 and 3, model-based estimators rather than design-based[5] estimators were developed, which took into account environmental and observer factors and estimated their effects on the observed biomass. This approach produces corrected indices that can allow for conditions at a preferred temporal level e.g., on an annual basis.

The first of these three complications is relevant in the New Zealand inshore pelagic context. Schooling behaviour of these species is poorly known, including the length of time they are at the surface. The third point also appears relevant — preliminary analysis of the opportunistic aerial sightings data from *aer_sight* has shown large variations in the way spotter pilots record information (Paul Taylor, unpublished data). The second point, however, does not appear relevant — summaries of the opportunistic aerial sightings data and discussions with pilots

[5] "Design-based analyses attempt to deal with environmental and observer effects by ensuring balanced sampling in space and time. However, in practice it is impossible to fix environmental covariates such as sea surface temperature, so most design-based analyses need to include a certain model-based element" (Bravington 2003).

indicate that the loose aggregations reported by Bravington (2003) for SBT occur only very occasionally for the inshore schooling species that are important in New Zealand.

However, a further complication becomes evident when considering the consequences of having to treat the sighting as the object of interest. Because 50% or more sightings for each species comprise multiple schools (see Table 1), relatively large proportions of the total biomass constitute the average object of interest: for skipjack tuna, 30% of sightings contain four or more schools and for kahawai it is almost 50%. Thus, it is clear that the need to treat the sighting as the object of interest could significantly reduce the potential encounter rate and, as was discussed above, variance is largely a function of encounter rate and a critical factor in determining an acceptable sample size. Buckland et al. (2001) set the required sample size for a survey as around 60–80 observations, but, under the constraint imposed for clustered populations it is far from likely that the encounter rate of sightings of any of the species of interest would be high enough to provide sample numbers of this magnitude.

There are two possible solutions to this problem. The first comes from noting that the sample size recommendations are related to fitting a reliable detection function and that, if the surveys are carried out over years, then, as is discussed below (Section 4.2.4), a single detection function model can be fitted across years and the pooled sample size may then be adequate. An option in DISTANCE allows fitting of this model such that detectability can vary across years, depending on the covariates included in the model. It is still possible however, that precision will remain poor if there are large variations in encounter rate from one transect line to another.

The second possible solution may be the adoption of a strip-transect approach, where all the schools encountered on the strip are recorded along with either an estimate of their biomass or the data/images to estimate their biomass at data-processing time. There is something of a trade-off here — the use of strip transects can reduce efficiency because an appropriate strip transect is usually considerably narrower than the observed width sampled in the standard line transect approach — but it seems that the alternative (i.e., when encounter rate varies enormously from one line to another) provides far less reliable results, which is obviously an outcome to be avoided.

Finally, for the New Zealand inshore pelagic case using the distance-sampling approach, it seems that the model based strategy for dealing with Bravington’s (2003) points 1 and 3 above is a valuable addition to the standard distance-sampling methodology because it provides for the inclusion of environmental- and observer-driven variability into the analysis.

3.1.4 Data collection using aerial photography

Case Studies 3a, 3b, 4 and 5 all use aerial photography as a basis for data collection. Of these, the photogrammetric method of Case 5 provides the most complete system for aerial survey of schooling pelagics, using photographic images as a basis for measuring school surface area which in turn is used for biomass estimation. However, species identification is not carried out using photographs, but is the responsibility of an experienced fish spotter recording species composition of schools in real time. This approach is discussed in Section 2.2.2.

Currently spotter pilots working in the New Zealand domestic purse-seine fishery are trained to visually estimate school size and determine species composition. Accurate estimates are important for efficient management of the fishing operation, but within a given level of accuracy pilots will differ to some degree in their ability to carry out these estimates. Error in the estimates for each of the main purse-seine target species can be determined for each pilot working in the fishery using data from the aerial sightings database *aer_sight* collected specifically for this purpose. An examination of the tonnage data for two pilots was carried out under Project PEL2001-01, which showed differences in the accuracy of estimating school size between species that was similar between pilots: i.e., estimates for skipjack tuna schools were the most accurate, while estimates for blue mackerel were the least accurate. It is also clear from the results that estimation accuracy reduces with increasing school size (Taylor 2003).

Only preliminary work has been done in New Zealand examining the influence of environmental conditions on pilot estimates of small-medium schooling species, but discussion by Bravington (2003) suggests that a pilot's ability to collect SBT survey data is influenced by the environmental conditions at the time and that under some conditions this ability is strongly compromised to the extent that there may be a large associated error. Given the multiple-species nature of the New Zealand fishery, this error will differ in its impact depending on which of the two data types is being recorded: species is a categorical variable and will simply be either correct or incorrect, while school size or tonnage of a particular species is a continuous variable whose associated error will be a percentage of its unknown correct value. The question is, which of these would have greater impact on survey results — systematic error in assigning species composition or poor estimation of school size?

For the proposed survey method then, these two components of species identification and tonnage estimation can each be carried out under one of two possible collection methods. Direct estimates by suitably trained observers could be used for either, but photographic-based methods are practically limited to estimates of school size because of the complexities associated with determining species composition (see Section 2.2.2). Adopting a photogrammetric approach for the biomass component seems reasonably straight forward, given the method described for the West Coast USA sardine survey, but there is a need to investigate the issue related to school height.

Difficulties with the use of a photographic method for species identification arise because current methods of species identification require observation of several visual cues to distinguish between species, including the brief reflection of light in the form of "flashes" (see Appendix B). In the case of still photography a series of images would be required in most cases and the timing of shots to capture features such as the flashes suggests a highly specialized task. Moving pictures in some format may be able to provide the necessary information but, given the concentrated attention needed for a human observer to process visual cues in real time, developing a method to provide reliable data would probably require extensive work. The proposed alternative of developing a high quality training video that displays the various cues is discussed in Section 2.2.2.

In light of the strategies available for dealing with these two survey components the solution to the question posed above regarding the impact of erroneous data becomes one related to the effectiveness of these strategies. The photogrammetric method for estimating school size requires measurements being taken from photographic images recorded during the survey, followed by processing of the data using a relatively straight forward approach for biomass estimation (see discussion below); it appears to be an easily activated approach whose effectiveness could be maximised with little extra cost. By contrast, the means for species identification and associated issues is probably too complex to be carried out using images collected during the survey, with comprehensive observer training including the use of expertly collected visual aids the most likely means of realising its full effectiveness.

3.1.5 Data analysis using photogrammetry

The photogrammetric method described in Case 5 includes clearly defined steps for analysing the data and producing an estimate of total biomass of sardine for the survey area, with associated *CV*s. This method was developed for a schooling pelagic species and is directly applicable in the New Zealand context. Included in the document is a series of *R* functions for carrying out the analysis which could be used as a basis for an analysis here and modified where necessary.

Point-set sampling is fundamental to this method. A range of schools are each photographed and subsequently fished and landed. The surface-area:tonnage relationship estimated for the point-set schools then provides the key for estimating tonnage of the schools whose images are recorded during the survey. Although school height (distance from top of the school to the bottom of the school) is recorded for the point-set schools in the sardine survey method, it was not used in the analysis (Tom Jagielo, pers. comm.).

Failing to account for any variation in school height for schools of a given surface area may well be the weakness in the method. If such variation is great, then consistency cannot be assumed and, under such conditions, a measure of school height would be necessary, not only for the point-set schools but also for each school encountered along the survey transects. To examine this issue through the relative influence of school height and school surface area, data published by Jagielo et al. (2011) on sardine schools was used (Appendix C). Scatter plots of school height, surface area, school volume, and school biomass were created and several bivariate linear regressions using these data, both with original values and following log-transformation. The aim was to determine whether including school height showed any improvement over simply using school surface area.

The three-parameter Michaelis-Menten (MM) model was chosen for estimating school density (as a preliminary to determining the surface-area:biomass relationship) because it provided a strategy for fitting the observed empirical relationship that density (school biomass/m^2, estimated as landed tonnage/school surface area) decreased as school size (visible surface area) increased (Jagielo et al 2011) (Figure 6); the rationale was that “an asymptote of zero isn’t logical under that construct” (Tom Jagielo, pers. comm.). It may be however, that an alternative approach provides a method with a less uncertain outcome.

Consideration of the plotted variables used in Figure 6 raises the first question about the integrity of the observed empirical relationship. This concerns the confounding of the two variables: school surface area is present in both, which undoubtedly contributes at least in part to the apparent relationship underlying the choice of the MM model. In addition, examination of the plot suggests that the selected empirical relationship may not be the best expression of the distribution, with certain features (e.g., the two clumps of points centred at about (2300, 0.04) and (500, 0.01)) likely contributors to the result that the fitted smoothed lines provide little support for a decrease in density to an asymptote, either overall or by year.

An alternative approach is to include school height in the analysis. Examination of the Northwest USA sardine data documented in Appendix C shows no relationship between school height and school surface area (Figure C1), with school height ranging from less than 1 m to more than 7 m. This makes unfeasible any assumption that either school height is relatively similar between schools or that there is any systematic variation of height with surface area, although it is interesting that in most cases, school heights in 2011 are consistently lower than for the other two years despite school area in 2011 covering almost the entire range of surface area observed in all three years.

Ultimately, it was concluded that inclusion of school height, particularly in the form of school volume, resulted in a marked improvement in predicting biomass over the use of school surface area (Appendix C). Back-transformation of fitted values from the regression with the two predictors school surface area and school height,

$$\log(\text{school biomass}) \sim \log(\text{school area}) + \log(\text{school height}),$$

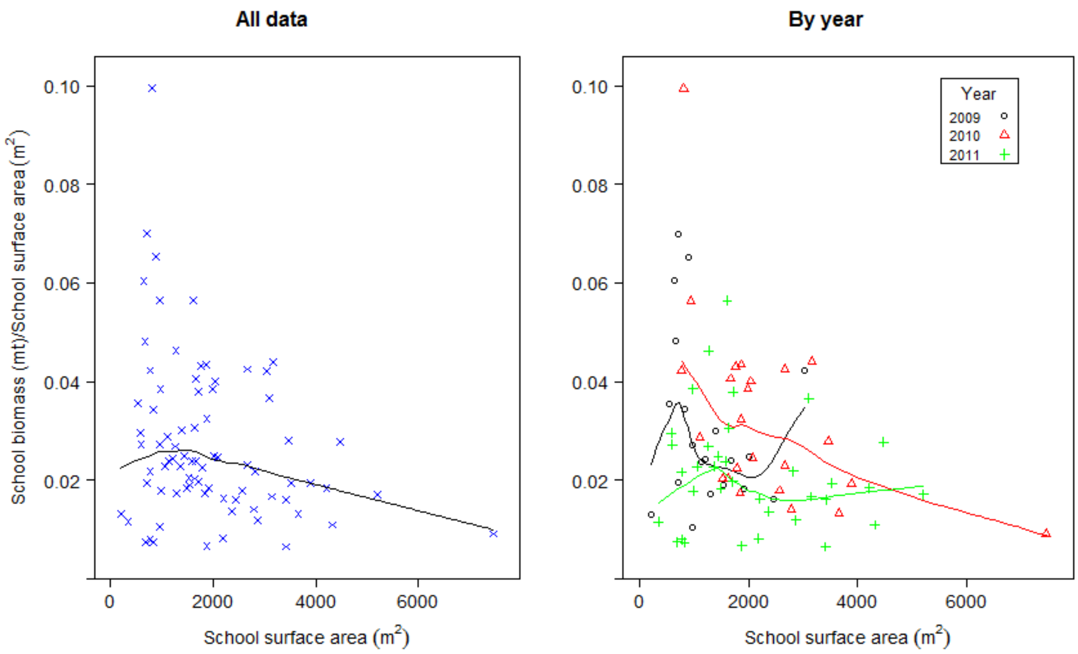

Figure 6: School density (school biomass/school surface area) by school surface area for point-set schools sampled in the Northwest USA sardine aerial survey work from 2009 to 2011, with smoothed lines for all data (left plot) and by year (right plot). Data source: Jagielo et al. (2011).

showed a systematic increase (except for school height = 4 m) in the biomass-surface area relationship with increasing school height (Figure 7).

Avoiding the inclusion of school height in the sardine analysis may have been a cost-cutting strategy — the approach relies on school height being collected for all schools observed during a survey. However, the MM model approach has a number of problems described by

Jagielo et al. (2011) which might be resolved by adopting the simpler approach of using the relationship between school biomass and school volume calculated from the point-set sampling as the basis for estimating biomass from school surface area and school height (i.e., school volume) of the schools encountered during the survey. A vessel deploying side-scan sonar or similar would be required, but this could be achieved with a 25 m runabout (for example) deploying a portable instrument such as the WASSP multibeam sonar developed and marketed by Electronic Navigation Ltd, a New Zealand company situated in Auckland[6]. This instrument has been deployed successfully in New Zealand for observing inshore pelagic finfish species from a small vessel (Paul Taylor unpublished data, O'Driscoll 2006).

3.1.6 Conclusions about the available survey methods

Based on the discussion in this section, numbers 1 to 3 of the following list must be satisfied when developing the proposed survey method; number 4 is probably necessary in developing a method that is independent of professional spotter pilot involvement.

1. Because of the complexity of distinguishing between schools of the various species and because schools of more than one species can occupy space in close proximity to the extent that mixed species schools can be encountered, the use of still or moving imagery

[6] http://www.enl.co.nz/pdfs/WASSP_brochure_(3).pdf

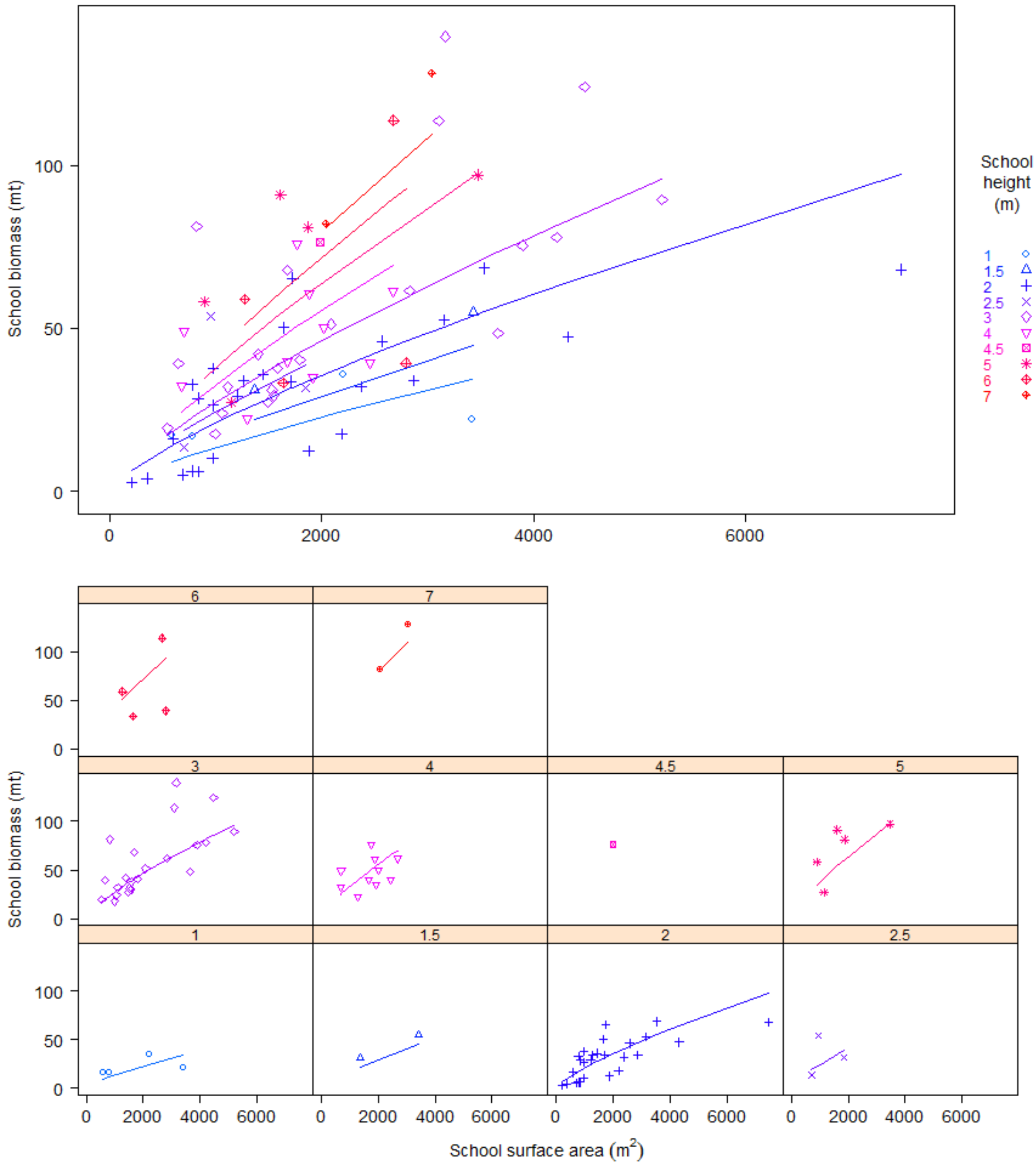

Figure 7: School biomass (metric tons) on school surface area of point-set schools sampled in the Northwest USA sardine aerial survey work during 2009, 2010, and 2011, with lines from the back-transformed fitted values of the log(SclBmss) ~ log(SclArea) + log(SclHt) fit; plotting characters are referenced to school height as are colours for both the plotting characters and the plotted lines which express the increasing biomass with increasing school area at each school height, except for height=4.5 m which comprises a single value only; the upper plot is a scatterplot of all data with lines overlaid; the bottom plot is a series of scatterplots and overlaid lines relevant to each school height. Data source: Jagielo et al. (2011).

for species identification during a survey is unlikely to provide reliable data on school species composition;

2. As a result of 1 above, survey flights must pass directly over all schools or clusters of schools;
3. If photogrammetry is considered a realistic option for estimating school biomass, then, for each species that a survey using the method is planned, preliminary work must be

undertaken to investigate aspects of the relationship between school surface area and biomass to ensure that an appropriate measure of school height is included in the survey analysis; and

4. The use of high quality video of schools of a range of species taken independently of any survey should be investigated as a means of providing a key training aid for observers.

3.2 Implications for adopting a multiple-species approach

As was discussed in the Section 1.1, approximately 13 species make up the inshore schooling pelagic assemblage, although they do not have equal likelihood for inclusion in an aerial survey. Ideally, the choice of candidates should be based on a number of factors, including commercial and recreational fishing value, ecological importance, and accessibility to aerial survey, which, in turn, includes seasonality of presence at the surface, and the timing of their presence at the surface during the day.

The original brief of the work documented here was to investigate the use of a multi-purpose method for surveying inshore pelagic finfish species. “Multi-purpose” implies the application of the method to multiple species which includes its application as a method to surveying multiple species simultaneously. In this sense, a multiple-species method relies on similar seasonal distributions for those species being included in the survey, and, for economic reasons, the spatial distribution of each species needs to be similar within this coincidental seasonality.

In developing a survey method, each of the relevant factors should be investigated as a preliminary to the final setting of survey protocols. While the relative fishery-value of these species is so well understood that selection on this basis is largely a foregone conclusion, some of the other factors require more careful examination. Spatio-temporal distributions for seasonality at two spatial scales is possible from the opportunistic data (i.e. the *aer_sight* database), either as aggregations within a grid of half-degree squares, or, using GPS data from about 1998, by plotting positions of sightings. Distributions of the timing of sightings of each species throughout the day can also be investigated using the opportunistic dataset.

Although others of these species have lower direct commercial fishery value, their importance to fishing indirectly becomes clear when other factors are considered, and this ultimately provides good reason for including them in surveys. For example, the ecological importance of small pelagics (i.e., pilchard and anchovy) in ecosystems associated with marine upwelling circulation systems has been well documented overseas (Bakun & Parrish 1980, Parrish et al. 1989, Schwartzlose et al. 1999, see review in Paul et al. 2001 and discussion by several workers in Checkley et al. (eds) 2009). Their occupation of the “wasp-waist” niche (Rice 1995, Bakun 1996, Cury et al. 2000) provides a conduit for energy flow between primary production and upper trophic levels and is critical to ecosystem function, but we have little understanding of this mechanism in a New Zealand context. Monitoring spatio-temporal distributions of these species would provide insight into the extent and variations of these resources and a preliminary estimate of their trophic value for groups higher on the food chain, including more commercially-important finfish species.

3.3 Geographical limits of the survey

It is proposed that initially the aerial survey method be restricted to one relatively small area such as the Bay of Plenty. As a first step in determining geographical limits for a survey, the spatial distribution of the species of interest could be summarised using opportunistic data from *aer_sight* — recent data (since 1998) that includes GPS positions would be best. However, the survey area should include all potential habitat for the species of interest, which is likely to be more extensive than the spatial extent of the opportunistic data. Determining final survey limits could include the use of a simple environmental model incorporating information such as water depth and sea surface temperature, referenced to the distributions of species of interest, and extended as necessary. Given the level of information currently available, any useful stratification of the survey area should be postponed until initial surveys have been completed and information is available to determine whether such an approach is appropriate.

3.4 Identifying potential species for aerial survey

3.4.1 Relevant biological information

The spatio-temporal distribution at the surface of each member of the pelagic finfish group being considered here is a complex question, being the result of a number of behavioural characteristics that are poorly understood. However, the essential information we require in this context is to understand the extent of their migratory patterns — how widely they range geographically and what pattern of vertical migration they follow diurnally — and how these vary with time. Summaries from the opportunistic aerial sightings data can provide some information, but to get a thorough view all known information is summarised below.

Trevally

Trevally occur around the North Island and the north of the South Island (James & Stephenson 1974) in surface, mid-water, and bottom schools, and are dispersed over the bottom, usually in depths of less than about 70 m (James 1994). Trevally exhibit both pelagic and demersal phases, with juvenile fish up to about age 2 y inhabiting shallow inshore areas including estuaries and harbours, and young fish entering a demersal phase from about age 2 y until they reach sexual maturity. Once mature, adult fish move between the demersal and pelagic habitats and are often associated with reefs and rough bottom. Schools are sometimes mixed with other species such as koheru and kahawai. The occurrence of trevally schools at the surface appears to be correlated with settled weather conditions rather than time of year.

Summary distributions from the aerial sightings datasets by Bagley et al. (2000) showed that most sightings occur on the east coast of the North Island between North Cape and the Bay of Plenty, with good representation from Hawke Bay and Golden-Tasman Bay; some sightings have also been recorded from west Northland and North and South Taranaki Bights.

A summary of bottom trawl data from the MPI *trawl* database, by Anderson et al. (1998) showed that trevally were represented all around the North Island, and around the South Island including Golden-Tasman Bay to about 44°S on the west coast with one record from about 42°S on the east coast. Highest representation for this dataset was around the northern North Island from the North Taranaki Bight to Hawke Bay. Most were caught at less than 100 m depth.

Blue mackerel

Blue mackerel are widespread in North Island and northern South Island waters (Robertson 1978). Jones (1983) described the areas in New Zealand during summer where “blue mackerel are found in abundance” as Northland, Bay of Plenty, South Taranaki Bight, and Kaikoura and observed that in winter they “all but disappear except for occasional ones in Northland and the Bay of Plenty”.

Summary distributions from various datasets by Bagley et al. (2000) showed records from midwater trawl catches (MPI scientific observer database, *obs_lfs*, MPI research trawl survey database, *trawl*) in the North and South Taranaki Bights, west coast South Island southwards to the Hoki Trench, and around Mernoo Bank—most were caught over bottom depth shallower than 250 m; aerial sightings (MPI aerial sightings database, *aer_sight*) throughout most of the range covered by pilots supporting purse-seine vessels, from the Three Kings Islands around the entire coastline of the North Island, and from Kahurangi Shoals, outer Golden-Tasman Bay, to Kaikoura—the majority of sightings are on the east coast from North Cape to Hawke Bay, and in the area including the South Taranaki Bight to Kahurangi and the outer Golden-Tasman Bay.

A summary of bottom trawl data from *trawl* by Anderson et al. (1998) showed that blue mackerel were represented all around the North Island, and around the South Island including Golden-Tasman Bay to about 44°S on the west coast and about 45°S on the east coast. Highest representation for this dataset was from the inner and outer Hauraki Gulf. Most were caught at less than 120 m depth.

Shuntov (1969) suggested that the inshore distribution of juvenile blue mackerel is related to the abundance of suitably sized prey. Stevens et al. (1984) observed that most blue mackerel taken in nine research cruises using a variety of fishing gears (pelagic, midwater, and bottom trawl) in the Great Australian Bight between January 1979 and December 1980 were taken at 50–150 m depth and that no relationship between fish length and depth was found over this range. Kingsford (1992) showed that larval and juvenile blue mackerel are more likely to be found in open water than associated with drift algae, whereas for early life history stages of a number of other pelagic species the reverse was true.

Jack mackerel

From work by Horn (1991), the three *Trachurus* species have different geographical distributions, with some overlap in their ranges: *T. novaezelandiae* predominates in waters shallower than 150 m and warmer than 13°C, and is uncommon south of latitude 42°S; *T. declivis* generally occurs north of 45°S in deeper waters than *T. novaezelandiae*, but shallower than 300 m and in temperatures less than 16°C; and *T. murphyi* occurs over a wide latitudinal range (e.g., from 0°S to 50°S off South America) to depths of at least 500 m. Based on this information for the two New Zealand species, we can conclude that, while there is overlap in their ranges, *T. novaezelandiae* follows a more northerly, onshore distribution than *T. declivis*. For *T. murphyi*, the situation is less clear, but we do know from other sources (see Taylor (2002) for summary) that this species prefers cooler water than the New Zealand species. This, coupled with anecdotal information from the fishery, indicates that its distribution is more southerly than that of the two New Zealand species.

Summary distributions from various datasets by Bagley et al. (2000) showed records from midwater trawl catches (MPI scientific observer database, *obs_lfs*, MPI research trawl survey database, *trawl*) of *T. declivis* in the South Taranaki Bight, west coast South Island southwards to the Hokitika Trench, and around Mernoo Bank—most were caught over bottom depths shallower than 250 m; *T. murphyi* records from these sources had a similar distribution; there were no records for *T. novaezelandiae*. Most aerial sightings (MPI aerial sightings database, *aer_sight*) records were for the aggregate jack mackerel, although there were some records collected of *T. murphyi* during the first half of the 1990s, which showed a distribution from North Cape to the Bay of Plenty. Separating *T. declivis* and *T. novaezelandiae* from the air is not possible — sightings of jack mackerel (*Trachurus* spp.) occur mainly on the east coast from North Cape to the Bay of Plenty and in Golden-Tasman Bay and off Kaikoura, although there are sightings all around the North Island.

A summary of bottom trawl data from *trawl* by Anderson et al. (1998) showed records of all three species around both the North and South Islands, but there were well-defined patterns for each species. *T. novaezelandiae* was most highly represented in tows from the Hauraki Gulf to the Bay of Plenty, in the North and South Taranaki Bights, and in Golden-Tasman Bay; records further south were sparse and did not extend beyond about 43°30' S on the west coast and 45° S on the east coast, apart from two records near Stewart Island. The distribution of *T. murphyi* showed some marked omissions in this dataset with no records from the South Taranaki Bight or Fiordland and only a total of three records around the North Island from the North Taranaki

Bight to East Cape. The *T. declivis* distribution was most heavily populated between Raglan and almost Jackson's Bay on the west coast, including the South Taranaki Bight, Pegasus Bay to just south of the Canterbury Bight, a reasonable frequency in the outer Hauraki Gulf immediately south of East Cape, and in Hawke Bay and some of the Wairarapa coast.

Kahawai

Kahawai occurs throughout the coastal waters of New Zealand (Baker 1971), including harbours and estuaries, and will enter rivers (McDowall 1978). It is most abundant around the North Island and the northern part of the South Island (Kilner 1988).

Summary distributions from the opportunistic aerial sightings data by Bagley et al. (2000) showed sightings from the Three Kings Islands around most of the coastline of the North Island, and from Kahurangi Shoals, outer Golden-Tasman Bay, to Kaikoura. The density of sightings was quite consistent throughout this range except between the Kaipara and Raglan Harbours, where few sightings of kahawai have been recorded. No records were available from the midwater dataset.

A summary of bottom trawl data from *trawl* by Anderson et al. (1998) showed that kahawai were represented around most of the North Island, and around the South Island including Golden-Tasman Bay to about 44°S on the west coast and about 45°S on the east coast. Highest representation for this dataset was from the inner and outer Hauraki Gulf. Most were caught at less than 120 m depth.

Pilchard

Pilchards are widely distributed around New Zealand. They now appear to be least common off southeastern New Zealand, although Graham (1956) recorded large quantities in the Otago region during the early decades of the 20th century, but inferred that they were not regularly abundant there. Robertson (1973) reported on ichthyoplankton sampling around much of New Zealand in 1969–72 which failed to reveal any evidence of pilchards between Banks Peninsula and Dusky Sound.

Anchovy

There is little information available for anchovy, but a summary of bottom trawl data from *trawl* by Anderson et al. (1998) showed that this species was represented around some of the North Island, throughout Golden-Tasman Bay, and to about 44 °S on the west coast. Highest representation was from the inner and outer Hauraki Gulf and Golden-Tasman Bay. Most were caught at less than 120 m depth. Few records were available from east Northland north of 36°30' S, on the Wairarapa coast, and south of the North Taranaki Bight to Cape Palliser.

3.4.2 Seasonal distributions of species

To determine seasonality in sightings of the main purse-seine species, monthly totals were extracted from the opportunistic dataset (*aer_sight*) and plotted. These summaries included monthly sightings in all areas (Appendix D, Figure D1), monthly totals in east Northland (North Cape to approximately Great Barrier) (Appendix D, Figure D2), and monthly totals in the Bay of Plenty (Appendix D, Figure D3), and included plots of each of the main species in mixed schools with any other species, monospecific or "pure" schools (i.e., schools containing the species of interest only), and plots of all schools (mixed and monospecific schools aggregated).

Generally these plots suggest a peak in the presence of these species at the surface during Spring–Summer, but there is a difference in the relative predominance of particular species between areas. In east Northland, blue mackerel is the predominant species, particularly from September to December, while kahawai is the species most frequently sighted in the Bay of Plenty. In east Northland, jack mackerel and blue mackerel exhibit the highest degree of mixed schooling, following very similar patterns and thus suggesting preference for mixing with one another. By contrast, the highest degree of mixed schooling in the Bay of Plenty is exhibited by jack mackerel and kahawai, with a high level of fidelity between these two species obvious from the plots. Generally the plots suggest a longer season in the Bay of Plenty than east Northland, but this is likely to be, at least in part, a function of the greater amount of flying effort in the Bay of Plenty.

A further plot was produced using the opportunistic sightings dataset with sightings of the main purse-seine species in the Bay of Plenty summarised by grid square (for individual grid squares covering the Bay of Plenty — see Figure 1) and the aim of determining the degree of seasonal variation in their presence at the surface within each square (Figure 8). To achieve this, all sightings of each species or, in the case of jack mackerel, species aggregate, in each half-degree square were summed by month throughout the data series and plotted onto a grid of cells where each cell represented one grid-square-month. The first assumption underlying this summary is that areas of high aggregation frequency will be most highly represented in the data, thus providing a picture of spatio-temporal peaks of their presence at the surface. The corollary is that areas where low numbers of fish occur will be poorly represented.

Grid squares were included in the summary if any sightings of any of the target species had been recorded there. The summary shows that sightings have been minimal in grid squares 131, 149, 150, 163, 166, and 167. Based on this result, these squares can probably be omitted from any aerial survey. Some seasonal variation in particular squares is evident. For example, kahawai sightings have been rare in square 146 from January to April but have occurred more frequently throughout the remainder of the year. There is also evidence for seasonal differences between species — sightings peak in September for kahawai and jack mackerel, and in November for blue mackerel, while trevally sightings seem quite consistent from May to October.

A feature of squares 164 and 165 is the predominance of kahawai coupled with good representation of trevally and jack mackerel, and low representation of blue mackerel. By contrast, blue mackerel follows a more northerly distribution, being represented throughout the year in square 147 and from September to about March in square 130.

Generally then, there are a number of inter-species variations in the spatio-temporal distributions. A further feature of the summary is the overlapping period from August to November when all species are represented throughout the four main grid squares — 130, 147, 164, and 165. This overlap suggests that a multiple-species approach could be possible.

3.4.3 Diurnal distributions of species

To examine the diurnal pattern of the main purse-seine species, sightings from the Bay of Plenty were plotted by pilot and half hour time slot between 8.30 am and 8.00 pm (Figure 9). Often there was a greater volume of sightings in the morning than in the afternoon, especially for kahawai and, for Pilots 1, 2, and 6, trevally. A number of pilots filter the data by omitting from records fish they spotted earlier in the day, thus introducing bias into the distribution.

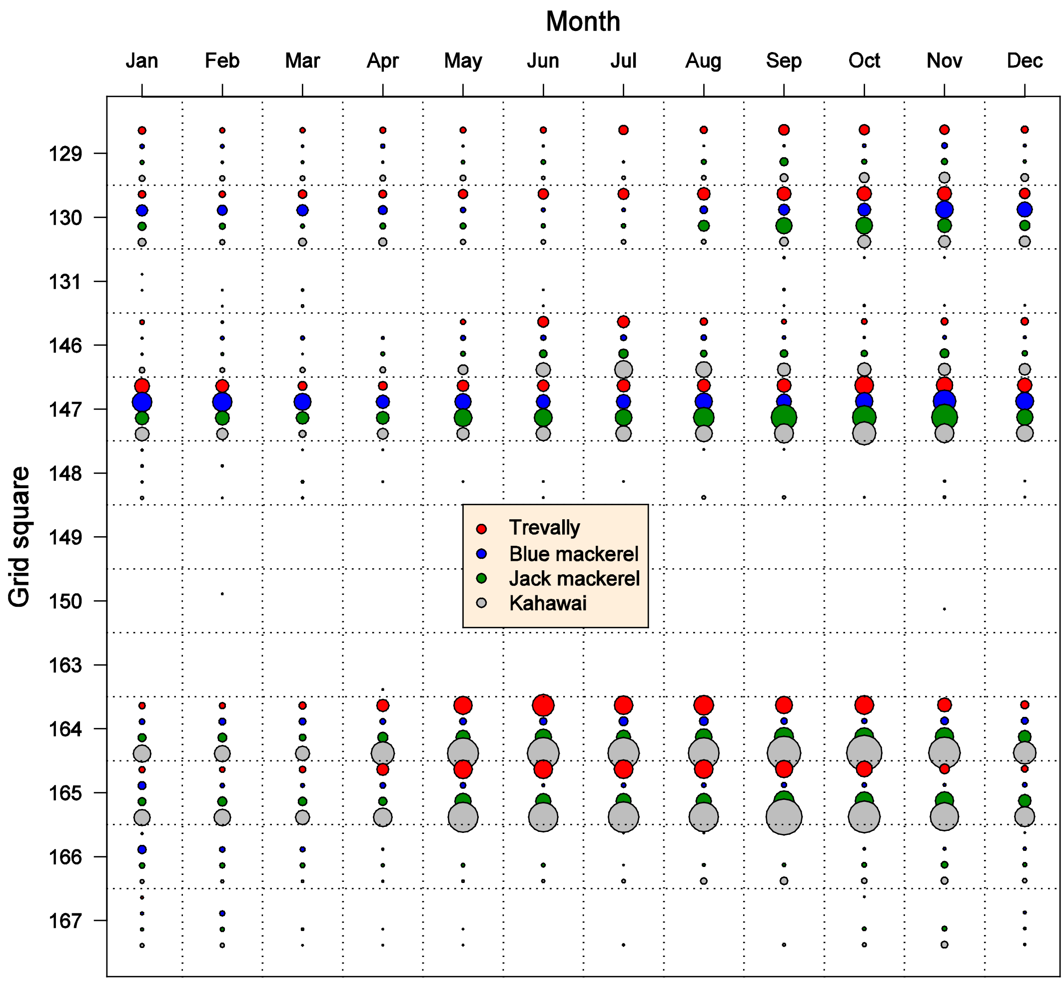

Figure 8: Spatio-temporal distributions of all sightings of trevally, blue mackerel, jack mackerels, and kahawai in grid squares comprising the Bay of Plenty south of latitude 36°30'; circle diameters are proportional to the number of sightings; cells represent 1 grid-square-month; circles centred within a cell belong there; the top down species order shown in the legend is consistent throughout the cells. Source: MPI aerial sightings database, *aer_sight*.

However, there is enough evidence to suggest that the frequency of afternoon sightings is high enough for the survey operation to continue throughout the day.

There are few sightings data available for pilchards and anchovy, but anecdotal information from the pilchard fishery suggests that their presence at the surface and, hence, period of accessibility to aerial survey, is morning and evening.

3.4.4 Migratory behaviour

Little is known about local migrations of the six species discussed above. The following brief summaries represent all the information available from Ministry of Fisheries (2011).

Blue mackerel

At least three spawning centres are apparent for this species based on sampling of eggs, larvae, and spawning blue mackerel, but nothing is known of their migratory patterns or their fidelity for particular spawning areas.

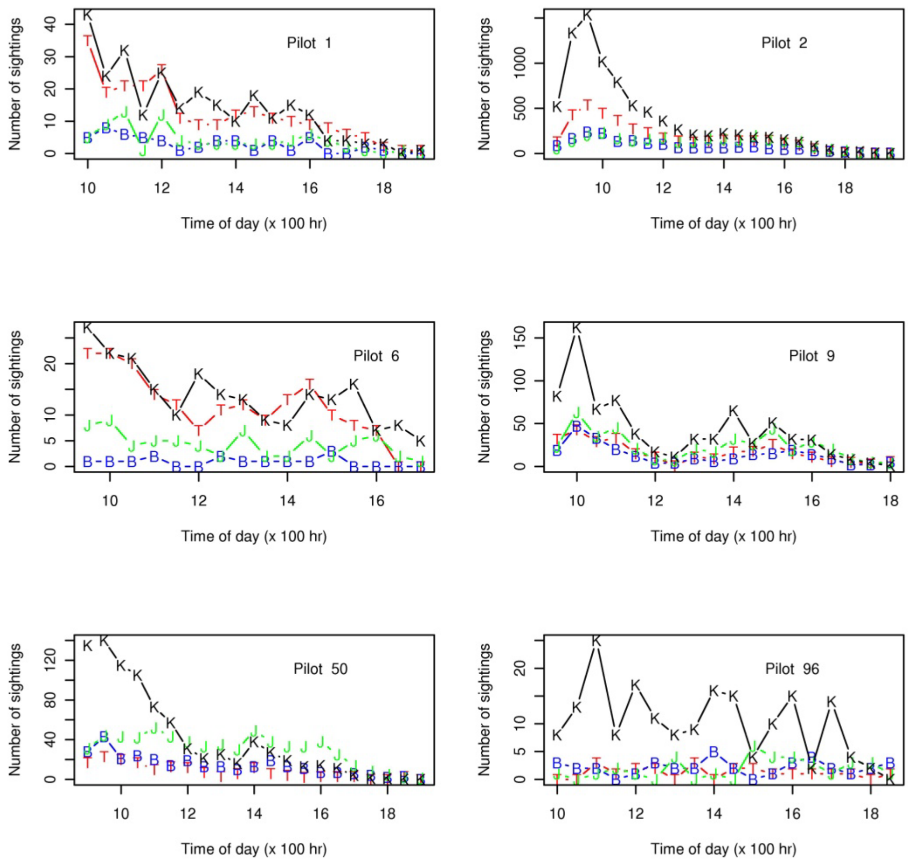

Figure 9: **Distribution of sightings of kahawai (K), trevally (T), blue mackerel (B), and jack mackerel by pilot and half hour time slot between 6 am and 8 pm. Source MPI aerial sightings database *aer_sight.***

Kahawai

Tagging returns indicate that the majority of the single kahawai species *A. trutta* population remains in the same area for at least several years, but that some follow a far more extended migration pattern circumnavigating much of New Zealand. However, there is little known about the pattern of movement around New Zealand although regional differences in age structure and abundance suggest limited mixing between regions. Work by Smith et al. (2008)using 0-group kahawai from two well separated regions resulted in neither meristics nor stable isotopes providing any discrimination, and magnesium and barium concentrations providing only weak discriminatory power.

In conclusion, it seems possible that at least two stocks of *A. trutta* exist within New Zealand with centres of higher concentration around the Bay of Plenty and the north of the South Island. Tagging data suggest limited mixing between these areas. Because of the shared QMA boundaries in the lower North Island and South Island, more mixing is likely between the southern QMAs than with the northern QMA.

3.4.5 Concluding remarks — potential species for survey

The information summarised here includes all the relevant details on spatiotemporal distributions for the six species listed above. It is proposed elsewhere in this document that a preliminary survey should be limited to the Bay of Plenty. Recent work by Taylor (2014) using the opportunistic aerial sightings data from the Bay of Plenty only, disregarded jack mackerel and blue mackerel as candidates for relative abundance index estimation. This was because, in New Zealand the jack mackerel genus (*Trachurus*) comprises three species that are characterised by distinct distributions and biological parameters but cannot be separated in the sightings data; and blue mackerel displayed high variability in interannual indices suggesting varying levels of immigration/emigration. It seems unlikely that they would be good candidates for preliminary testing of any survey method and should only be included where component tasks are being developed.

It should also be noted, however, that this caveat only applies to blue mackerel in as much as a survey is limited to the Bay of Plenty. Where a survey is designed to cover a range similar to that of the blue mackerel population or a known sub-population, then the species could be considered a viable candidate for applying aspects of any survey method.

3.5 Developing a storage database

It is proposed that data collected during the proposed aerial survey be permanently stored in an MPI administered, EMPRESS relational database. The first step in the planning should be definition of the database structure with an Entity Relationship Diagram (ERD), and could consider structure of the existing MPI opportunistic aerial sightings database, *aer_sight* as a basis for development. This would provide useful definitions for tables and a range of data fields comprising the tables. Using EMPRESS would allow for extract codes developed for *aer_sight* to be used in the survey database.

3.6 A simulated aerial survey study

3.6.1 Background

A simulation study was carried out using data from the MPI aerial sightings database *aer_sight*. There were two main objectives to this work. The first was to estimate the amount of flying required to complete a generic aerial survey of the main target species of the domestic purse-seine fleet and use this to produce indicative costs for such a survey. The second aim was to determine whether school density in the Bay of Plenty is likely to be high enough to provide estimates with acceptable precision and was carried out as a preliminary to proposing a survey method (Notes of Northern Inshore Technical Working Group meeting, 4/2/09). A description of the work including methods and results is included as Appendix E.

3.6.2 Summary of results

The results show that a sightings index using 7 transects has reasonable *CV*s (20–30%), but only if the number of surveys is 10 or more. For the biomass index, *CV*s are high (about 40%) even at 20 days of flying, therefore failing to achieve the levels of precision likely to be considered satisfactory in a survey even at the maximum/most ideal conditions examined.

Inclusion of the sightings index was somewhat academic and performed out of interest rather than practical application. Any aerial survey would require estimates of biomass as a basis for indices of relative abundance. The level of uncertainty from sightings is too great to provide reliable estimates of relative abundance. Sightings contain variable numbers of schools of varying size and little if anything is known about which factors drive variations in school size.

3.6.3 Conclusions — simulation study

It is clear that the results from the simulation study are inconclusive and suggest that the opportunistic aerial sightings data are not useful in this context. A meeting of the NINSWG (NINSWG 2009/58) concluded the following:

"It is possible that CVs determined from simulations using commercial sightings data may be higher than would actually [be] achieved using a designed survey. Investigating this further requires collection of new data according to a survey design. These data could be gathered in two ways: 1) Conduct a pilot survey and 2) Arrange for commercial pilots to conduct one random transect during each flight. An independent pilot survey to test the variability both within and between flights (on different days) was considered by many to be the more feasible, although neither option had yet been developed in detail".

3.6.4 Resolution

The suggestions from the NINSWG are discussed below in Section 5 as a preliminary to the two approaches above being implemented to capture the appropriate data.

4. EXAMINING COMPONENTS FOR AERIAL SURVEY DEVELOPMENT

This section contains discussion on the components that might be used in designing an aerial survey method for schooling inshore pelagic finfish species with the conditions necessary for utilising them. The discussion is focused on the two possible methods (i.e., distance-sampling and photogrammetry) and aims to conclude with the components that could be incorporated into the final proposed survey design and a recommendation for which of those require investigation under preliminary tasks.

4.1 Salient features of the two potential methods

Based on consideration of the case studies in the context of the New Zealand situation, salient features of a possible survey design were defined according to the method outlined in Section 2.2. Two approaches were included, one based on distance-sampling, the second on the photogrammetric method used in the West Coast USA sardine survey. The features of the two approaches are shown in Appendix F.

A number of the factors considered in this section apply to both of the possible survey approaches. Where the discussion refers specifically to one of the approaches, clear reference is made to that approach in the text.

4.2 Survey method

Five requirements of Buckland et al. (2001) essential to developing a successful survey method were listed above in Section 1.5.3. They are repeated here for easy reference:

- A clear definition of the study population in time and space.
- A clear definition of the survey objectives.
- A clear determination of the transect layout using replication (i.e., multiple lines or points), randomisation, sampling coverage, stratification, and sampling geometry.
- Determination of the sample size.
- Determination of the length of line transects.

These considerations are necessary for both the distance-sampling approach and the photogrammetric approach. The final three points are closely related and part of the survey objectives but are discussed separately below.

4.2.1 The biological population

Depending on the objective of a particular survey, any one (or combination, if a multiple-species survey were planned) of several biological populations could be sampled. Within their simplest definitions these are trevally (the population comprising the single species *Pseudocaranx dentex*), jack mackerel (i.e., the population comprising the three species of the genus *Trachurus*: *T. declivis*, *T. murphyi*, and *T. novaezelandiae*), blue mackerel (the population comprising the single species *Scomber australasicus*), and kahawai (the population comprising the two species of the genus *Arripis*, *A. trutta* and *A. xylabion*). Note however, the probable exclusion of jack and blue mackerel and associated conditions as discussed in Section 3.4.5.

With regard to inclusion of life history stages and which might be included in the survey of a given species, reference is made to the information on distributions of early life history stages summarised above in Section 3.7.1. It is clear that for most species little information is available. Only the larvae and juveniles of trevally and blue mackerel are mentioned and the only comprehensive information available indicates that a trevally survey could target only the sexually mature fraction of the population.

For some of the other species it might be possible to develop definitions of life history information in some broad sense using a nominal scale (e.g., small, medium, large). The species of interest here tend to school by size and discussions with pilots have indicated that schools are chosen by aerial observation for targeting by the purse-seine fleet according to the sizes of the fish comprising them. Measurements of fish size from photographs, perhaps with some ground truthing using data from recently landed schools taken on board purse-seine vessels (i.e., from the point-set sampling of the photogrammetric approach), with reference to size-based biological information, could provide the basis for these definitions.

As was proposed in Section 3.3 above, the geographical boundaries of the populations should initially be defined generally as the Bay of Plenty. To accommodate the set of transects discussed below, this extends more to the north than might be normal convention, referring to that area of coastal shelf bounded by latitude 36° S, and the continuation of longitude 176° E, the east coast of Great Barrier Island, and the eastern coastline of mainland New Zealand from latitude 36° S in the north to longitude 178° E in the east (Cape Runaway).

Information presented above shows that seasonal patterns of sightings from existing data for the four main purse-seine species are similar. However, there are inter-annual variations in the first appearance of these species at the surface and some delay is usual before their presence is in any way consistent in a particular season. Although the plot of the aggregated data (see Figure 8) indicates coincidence between the various species, for any particular year it is difficult to predict which of these species will be present simultaneously and when this might occur. A better interpretation might be found in reworking the data at a finer temporal scale, say annually, to determine whether there are particular patterns that occur.

While information on diurnal patterns is inconclusive to some degree, the data also suggest similarity in the four main species and that survey flights operating throughout the morning could simultaneously provide representative sampling data for each. Once again, further, temporal exploration at a finer scale (e.g., comparing seasons) might provide a better understanding, but is outside the scope of the present work. It is also important to note that there is a bias in the data towards the morning.

4.2.2 The survey objective

For a survey of the main purse-seine species, trevally, jack mackerel, blue mackerel, or kahawai, the objective would be to provide an index of relative abundance for that year. The ultimate aim is to use annual estimates of relative abundance from a time series of surveys performed at some frequency (i.e., perhaps not every year) to produce a time series of indices.

For uses of the multi-purpose method where relative abundance indices are not required, there would be no need to define the survey objective within the criteria of distance-sampling.

4.2.3 Determining the transect layout

Buckland et al. (2001 Section 7.2.1) stress the requirement of using an objective method for sample selection and discuss the five components of sampling design: replication, randomisation, sampling coverage, stratification, and sampling geometry. They recommend: the use of 10–20 replicate lines, at a minimum, "to provide a basis for an adequate variance of the encounter rate and a reasonable number of degrees of freedom for constructing confidence intervals; that transect selection should be based on some form of random probability sampling with a strong recommendation to avoid subjective placement of the lines for any reason, although this randomisation can be invoked in tandem with a systematic grid of lines to provide better spatial coverage than a set of lines placed in a purely random manner; that the main benefit of stratification of the study area is to improve precision, with post stratification according to habitat or some other criterion a possible strategy; and that sampling geometry refers to "the configuration and orientation of a the set of lines" with discussion examining various sampling geometries and their benefits.

It is proposed that the Australian SBT model be used as a basis for the transect layout, with features requiring input from the New Zealand situation being set after reasonable consideration and using as a basis for discussion the five criteria of Buckland et al. (2001) listed above.

To investigate the rationale of restricting an initial survey to the Bay of Plenty, a grid of parallel transects with approximately 12 n. mile separation was plotted over a map of the Bay of Plenty with depth contours 50, 100, and 200 m included (Figure 10). To ensure adequate variance of the encounter rate and an acceptable number of degrees of freedom for estimating confidence intervals, Buckland et al. (2001) suggest at least 10–20 replicate lines or points should be surveyed. The test grid in Figure 10 includes 10 transects, which meets the minimum suggested criteria, and provides a separation of about 12 n. miles, which would allow for a maximum effective half-strip width[7] of 6 n. miles. There is some room for expansion to the north and south, which could ultimately provide an effective half-strip width of some 7 or 8 n. miles. Based on the criteria that there should be no sighting of the same fish from neighbouring transects, this is near the limit but satisfactory for an initial survey.

Placement of the grid in Figure 10 was chosen because it covers the full width of the survey area (coastline to shelf break), avoids overlapping transects, and its orientation is designed to minimise the degree to which transects lie parallel to depth contours or any bathymetric features (see Figure 10, detail in depth contours) that might have some influence on the distribution of fish at the surface. Because the lines cover the entire width of the survey area there is no need to predetermine line length.

[7] The distance *w* either side of the centre line (Buckland et al 2001, Section 1.2.2).

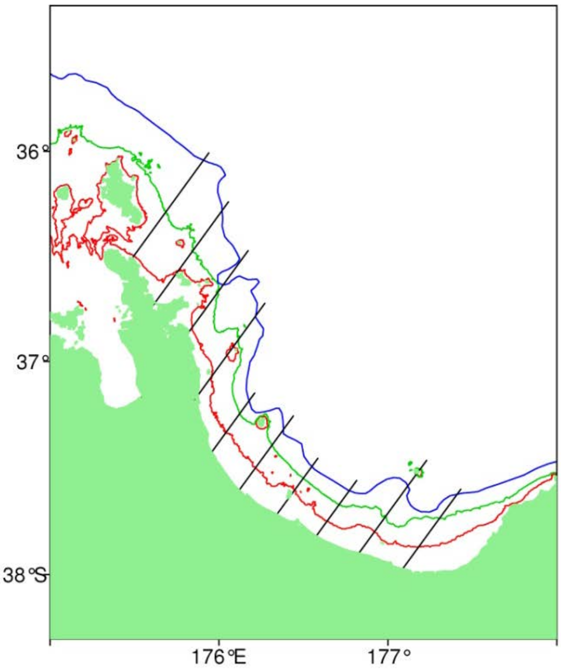

Figure 10: Placement of a grid of 10 parallel transect lines with 12 n. mile separation on the Bay of Plenty coast; depth contours of 50 m (red), 100 m (green), and 200 m (blue) are shown.

The Australian SBT model uses 3 latitudinal and 5 longitudinal bands as a basis for stratification (see Figure 4), with the latitudinal bands roughly corresponding to the depth strata *inshore*, *mid-shore*, and *shelf break*. A similar approach is proposed here, although the equivalent to their longitudinal bands (i.e., perpendicular to the shoreline) would be fewer in number given that the Australian case covers about 7 degrees of longitude or 420 n. miles, compared with a shoreline distance of less than one half of that in the Bay of Plenty case.

An alternative transect layout was used as part of the simulation work described in Appendix E (Figure E3), which was based on the distribution of kahawai sightings in the opportunistic dataset. A common boundary for all species was identified (Figure E1) which might provide a more appropriate basis for a survey area. However, decisions should be based upon updated summaries of the opportunistic data which would illustrate any variations in species' distributions that may have occurred since the simulation study was carried out.

In the case of the photogrammetric method, the required transect density would be considerably higher because of the narrower width possible from a working altitude of 2000 ft (see Section 4.8.2 for transect coverage).

4.2.4 Determining sample size (*n*) in distance-sampling

For distance-sampling, Buckland et al. (2001, Section 7.2.2) recommend a sample size of 60–80. Given the requirement of treating clusters (i.e., sightings) as the fundamental unit in the present context, this means that the minimum number of sightings recorded on a survey should be in this range — it does not refer to 60–80 *schools*. It is also suggested that a larger sample size may be necessary for a clustered population to produce similar precision for the abundance estimates than for a non-clustered population; and furthermore, sample size should be increased still further where cluster size is highly variable, although, if this becomes extreme, distance-sampling methods may not be appropriate for the population during periods that such conditions persist.

Sample size may also be reduced to considerably less than the recommended 60–80, but only where the assumption for a constant detection function holds from year to year in a monitoring programme with annual sampling. According to Buckland et al (2001, Section 7.2), this relies on interannual consistency in sampling protocols including ongoing employment of the same observers.

A further recommendation is that the half width, w, be set large relative to the expected average perpendicular distance $E(x)$. The rationale is that the data can be truncated at analysis time, but that no observations should be ignored. This is particularly true in the case of a relatively sparse population where the recommended sample size will not be met, a situation that may well be true for some of the New Zealand species of interest. Note that sample size dictates the amount of available information on density and as this decreases so will precision of the estimate of abundance.

It is proposed that an examination of the sighting rate of the various species of interest be carried out as part of a pilot study to determine what level of sample size might be available.

4.2.5 Packaging survey protocols within an operation manual

The value of first developing a clearly defined survey protocol (Buckland et al. 2001) is highlighted when comparing the approach taken by Guenzel (1997) with the Australian SBT survey, which has gone through several major iterations since its inception. The Wyoming pronghorn survey manual contains well-defined protocols and has been in place for about 15 years. The Australian SBT survey has been operational for a similar period, but, by contrast, there are instances in Eveson et al. (2006) where changes in protocols (in one case, with respect to the definition of secondary patches) can only be inferred from analysis of the data. A document containing the full range of information for the survey is critical to the future life of the survey method, and must be updated with any revisions while still containing the previous protocols, or at least reference to them in previous, archived, available documents, to provide guidelines to understanding the entire dataset.

4.3 Data collection details — species, environmental, and operational data

4.3.1 Measurement of perpendicular distances in distance-sampling

Based on discussion throughout this document, direct measurement of perpendicular distances is the best approach; benefits are (in no particular order) (1) data are not grouped and therefore carry more information, (2) there is less difficulty in setting up the aircraft, (3) direct observation of each school in a sighting ensures greater precision in species identification and school size, (4) the tendency to underestimate distances at sea is avoided, and (5) heaping[8] in the data is avoided. Furthermore, because of the need to record species composition of each school, all schools must be examined individually. Thus, direct measurement of perpendicular distances is proposed for the method being developed here.

4.3.2 Environmental data

The Australian SBT survey collects data on wind speed and direction, air temperature, amount of

[8] The tendency to “round” to convenient values when estimating, for example, distances or angles.

high and low cloud, glare, haze, and swell (Eveson et al. 2006). An examination of Farley & Bestley (2003) showed that swell refers to swell height, but there is no clarification for "haze" in the extensive relevant literature. In the earlier GLM analysis, SST, wind-speed, swell, haze and moon phase were significant covariates (Eveson et al. 2006).

It is proposed for the New Zealand survey, irrespective of the approach taken, that a digital temperature sensor be mounted on the aircraft wing to supply SST to the onboard PDA/laptop. This would provide local SST directly from the ocean surface and avoid the need to use remote-sensing satellite data, which is comparatively coarse. Wind speed and direction, air temperature, amount of high and low cloud, glare, haze, and swell could all be recorded at a similar frequency to that used in the Australian survey, though some discussion with Australian scientists may help in determining which of these should be collected and clarifying other details such as "haze". Moon phase can be downloaded from http://aa.usno.navy.mil/data/docs/MoonFraction.php in several forms including calculating a series as the fraction of the moon illuminated for all days in any year between 1700 AD and 2100 AD inclusive.

4.3.3 Aerial photography

At a meeting of the Northern Inshore Technical Working Group on February 4, 2009 (NINS-TECHWG-2009/05) it was noted that *Photographs and/or video should be recommended to provide for standardization and consistency*.

Photography is central to the photogrammetric method where data collection requires a sustained altitude with overlapping images taken along the transect line. For this method the central piece of equipment would be something equivalent to the single-camera Forward Motion Compensating (FMC) Mount system supplied by Aerial Imaging Solutions[9] used in the West Coast USA sardine surveys. This is a mount system for digital cameras that reduces image blur caused by forward motion of the aircraft while the shutter is open. The total system (Appendix G) comprises the forward-motion-compensated camera mount, GPS/AHRS[10], software that controls the camera and logs pertinent flight and GPS data each time the camera fires, a Canon 5d Mark III camera, Zeiss lens, and notebook computer. The system is usually deployed in an aircraft with a dedicated camera port.

Transect width is a function of altitude, camera lens focal length (F), and image diameter (I) of the camera sensor (see Method ii of Section 2.1.6). For the sardine survey an altitude of 4000 ft with $F = 24$ mm and $I = 36$ mm provided a transect width of about1850 m. Records of aircraft-height will be critical to determining area of school, if this approach is deemed appropriate. In the early phase, while investigating feasibility of the photographic component, a strategy is required for linking photographs of each school to the field-estimate of school size. Digital images can be stored on the onboard laptop at the time they are recorded.

It is suggested above that the part of the photogrammetric method that deals with estimating biomass of individual schools (including photography, estimation of school surface area, point-set sampling etc.) could be used to estimate individual school biomass for the distance-sampling method. This is similar to the approach used by Sulikowski et al. (2012) (see Section 2.2.2).

4.4 Equipment list and current costs (at May 2015)

The following is an initial list of items required for a survey method employing the distance-sampling method.

[9] http://www.aerialimagingsolutions.com/home.html
[10] Global Positioning System/Attitude and Heading Reference System

- [11]PDA with CYBERTRACKER (about $1000).
- Laptop with internet access and flash-drives for data storage and return to a central point for database entry ($1000–1500).
- A wing-mounted digital radar altimeter linked via Bluetooth to the PDA.
- A wing-mounted digital temperature sensor for SST linked via Bluetooth to the PDA.
- Digital camera(s).

The following is an initial equipment list for a survey using the photogrammetric method.

- A single-camera FMC Mount system or equivalent (New $US20K, used $US14.5K).
- A three-camera FMC Mount system or equivalent (New $US35K).
- A wing-mounted digital radar altimeter linked via Bluetooth to the laptop.
- A wing-mounted digital temperature sensor for SST linked via Bluetooth to the laptop.

4.5 Personnel

A successful survey hinges on involvement of personnel capable of performing the key activities of species identification and estimation of school size. Initially this can be done by experienced spotter pilots, but attention must be focused on developing strategies to standardise these tasks so that sources of error/bias are minimised.

The critical and most demanding issue is that of species identification or, more specifically, determining the species composition of schools. For mixed schools (i.e., schools comprising more than one species) the exercise becomes even more demanding, because it must also estimate the proportion of each species in the school.

Determination of school size using photogrammetry is relatively simple by comparison, but hinges on the collection of reliable data. What is required here is a clearly defined data-collection plan that can then be implemented without confusion by the technical personnel.

Overall, the technical tasks for data collection in such a survey are highly specialized and the training programme must be designed to reflect this. Adequate resources must be developed for training personnel in the fine art of species composition of schools, or else the level of unknown uncertainty could be very high.

For personnel carrying out analysis of data there should be the experience required to synthesise an appropriate analytical method based on the methods described by Buckland et al. (2001), Bravington (2003) and Eveson et al. (2011), and Jagielo et al. (2011). The final method will depend on which components discussed above are included in the survey design.

4.6 Data processing and storage

4.6.1 Returning data for database entry

It is proposed that, where components of the distance-sampling method are utilised, data collection be by PDA with regular download to a laptop. The download frequency will depend on the volume of the data stream and the capability of the PDA. For aerial components of the photogrammetric method using the FMC mount system, data is recorded by the system's laptop. Point-count data collection may be onto paper forms and require manual entry into electronic

[11] A discussion on the use of this equipment and software is available from Guenzel (2007).

format. Collection of school-height data from the purse-seiners' sonar would probably be most easily recorded onto paper forms and would also require manual data entry.

Following completion of survey flights, transport of data to a central point for error checking and database entry could be by one of several methods, including email attachment and flashdrive. Paper forms would be transported by technical personnel or mailed to a central point for data entry, error checking and database entry.

4.6.2 Error checking

Error checking programmes should be based on those currently in place for the opportunistic data collection. These are mainly range checks with some data massaging (e.g., the perpendicular distance could be calculated from recorded waypoints).

4.6.3 Database details

A relational database should be set up, with its structure based on the existing MPI database *aer_sight* and appropriate revisions included.

4.7 Modelling approaches

The discussion above has considered three possible approaches for the analysis of aerial survey data: DISTANCE software (Buckland et al. 2001), custom built software for SBT data collected using a strip transect (Bravington 2003 and Eveson et al. 2011), and the photogrammetric approach used for the West Coast USA sardine survey (Jagielo et al. 2011).

The Distance Project[12] offers free DISTANCE software for the design and analysis of distance-sampling surveys. There are two versions of the software: a Windows-based program and a suite of packages for use within the statistical programming environment R. The software can be downloaded directly from the website which also provides a history of the development of the method and a reference list for key books and journal articles along with a useful graphic illustrating the relationship between the relative spatial arrangements of transect lines and the objects of interest, and construction of the detection function. Introductory and advanced training courses in the use of DISTANCE are advertised on the website.

The Australian SBT method uses a generalised linear mixed model (GLMM) written in R. R programming is used commonly in New Zealand fisheries science but not the GLMM, which provides a powerful tool for analysing correlated data such as those comprising clustered or repeated measures data, by specifying a covariance structure based on relating common random effects to observations in a given group. Key texts on the theory of GLMMs include McCulloch et al. (2008), and Jiang (2007); and for the use of the GLMM in fisheries research a good starting point is the special issue of Fisheries Research (Xiao et al. 2004), which contains papers on field-based studies as well as theoretically-based papers where modelling and associated methodologies are presented in the context of fisheries research.

The photogrammetric method described by Jagielo et al. (2011) includes a series of software functions used in their analysis which are quite straight forward, incorporating the three parameter Michaelis-Menten model (see, for example, Bolker 2008). These functions are also written in R and could easily be revised to incorporate suggestions discussed above in Section

[12] http://distancesampling.org/

3.1.5. Note that, while the R functions are included as appendix III in Jagielo et al. (2011), details of data structures are not included.

4.8 Comparing and contrasting the two potential methods

4.8.1 Overview

As candidates for the proposed survey design, the two potential methods have been discussed above in terms of the two features of data collection and analysis. The distance-sampling method requires that groups of schools comprising a sighting be treated as clusters and provides for the abundance of the clusters in the population of interest to be estimated. Because school size and therefore sighting size varies in an unknown way, clusters do not provide a valid measure of population abundance. Consequently, distance-sampling on its own cannot provide a means of estimating the abundance of the fish in the population. By contrast, the photogrammetric method does provide a method for estimating the abundance of the fish comprising the population of interest.

We are interested in the abundance of fish, not of the sightings. For the distance-sampling method to satisfy our needs, we would need to add a technique for estimating abundance of fish in the population of interest from the schools constituting the sightings observed during a survey. One way of achieving this would be to utilise the photogrammetric approach and use the estimated surface areas of the observed schools. A second solution would be to employ spotter pilots for surveys and utilise their skill at visually estimating school size but this would not produce a method independent of the pilots' involvement.

Addition of the estimation of school-size to the distance-sampling method results in it being a four-step process: collect perpendicular distances, collect school size data, collect point-count data, and estimate relative abundance of the population of interest from the data. On the other hand, the photogrammetric method is a three-step process: collect images of schools encountered during the survey, collect point-count data for a sample of schools, and estimate relative abundance of the population of interest.

Based on this somewhat rudimentary summary one might conclude it is better to adopt the photogrammetric method because of its relative simplicity. However, there are complications to that method caused by the need for a visual assessment of each school's species composition. The recommended maximum flight altitude for reliable species identification is 2000 ft (Red Barker, pers. comm.), but the logistical requirement for the photogrammetric method as utilised for the West Coast USA sardine survey is a working altitude of 4000 ft, a setting that provides a strip-transect width of about 1850 m. By contrast, an altitude of 2000 ft would produce a transect width of about 925 m which would radically reduce the efficiency of the survey if it were adopted.

A design in which there was a need to regularly vary the working altitude would require more flying time and greater cost. This problem would need some preliminary investigation to determine whether a working height could be defined at which both an acceptable transect width and effective species identification could be achieved. The only way to achieve the same coverage at half the altitude with a single camera is to halve the focal length of the lens. The West Coast USA sardine survey uses a 24 mm lens, so a 12 mm lens would be necessary to realise the same footprint, but that would introduce considerable distortion to the images (Don LeRoi, Aerial Imaging Solutions, pers. comm.). An alternative would be to use the 3-camera mount available from Aerial Imaging Solutions, and stitch the frames together using Photoshop. An example is shown in Figure G3, and the 3-camera FMC mount system is shown in Figure G4.

With this complication in mind, distance-sampling using a line transect approach may provide an attractive alternative. Under this design, transect width is largely immaterial so a working altitude can be adopted that maximises the reliability of determining school species composition. Perpendicular distances could be measured directly by flying from the transect line to the geometric centres of the sighting clusters, where the waypoint, the species composition, and photographic images of component schools could be recorded before the aircraft returns to the perpendicular origin of the sighting on the transect line and continues searching for sightings.

However, the success of this scenario is dependent on the factors relating to an acceptable sample size. These factors include encounter rate and may hinge on whether a particular detection function is viable between years (see Section 3.1.3 for details). Failure could mean that the only available recourse is use of the distance-sampling method with a strip transect, which may return us to the complication caused by the double working altitude discussed above.

4.8.2 Quantifying the differences

With the aim of quantifying the overall difference between the two methods, the essential differences are summarised here.

Transect coverage is a function of transect length and width. While there may be some difference in total transect length between the two methods, the essential difference in comparing transect coverage is transect width. Observer notes from a flight and discussion with the senior spotter pilot arguably suggest a reliable half-width of about 3.5 n. miles (about 6500 m) for the distance-sampling method. For the photogrammetric method utilising the 3-camera system at 2000 ft, the transect width is about 2000 m[13].

Width of the photogrammetric transect is fixed, but width of the distance-sampling transect can be doubled by using an observer on each side of the aircraft. Under this scenario, transect width becomes 13000 m.

Under the approach of developing a survey method that is independent of the involvement of spotter pilots, the distance-sampling method requires that observers complete two main tasks — spotting schools along the transect, and recording the species composition of observed schools. In addition, it might be necessary for the observer to ensure that photographic images are being recorded satisfactorily. For the photogrammetric method, the observer would not be required to record schools according to the distance-sampling protocols, but only to record species composition and monitor the equipment as necessary.

Each method requires one pilot and at least one observer. The tasks for the observer on flights for the photogrammetric method are less demanding than for the observer on flights for the distance-sampling method. Because such concentration is needed for the distance-sampling fish spotting task, it might be necessary to have a second observer present to carry out the species composition determination.

Ultimately we might conclude that, if each method requires one observer then the photogrammetric method will be more expensive to run than the distance-sampling method, by a factor of about 3–3.5. This factor is a consequence of the difference in transect width achievable by each of the methods and the amount of flying each requires. However, this factor will be reduced by the extra flying required in the distance-sampling method, from the centre line to the centre of the sighting cluster to collect data on perpendicular distance and school species composition. By contrast, no extra flying will be required for the photogrammetric

[13] The 3-camera system may allow a maximum width greater than the 1850 m referred to elsewhere.

method — at an altitude of 2000 ft determination of species composition should be achievable, and with the 3-camera system images of schools will be recordable without course deviation.

Overall then it seems that the relative cost of the data collection phase for the two methods is driven by the amount of extra flying required to complete a distance-sampling survey. Given the half-width of about 6 km, this extra flying could be considerable, depending on the number of sightings encountered (see estimates in Table 2 and discussion in Section 5.2.2). Other factors that require consideration are whether a single observer can complete the required tasks during a distance-sampling survey, and certain issues related to the camera systems. No further discussion will be presented here on the observer question because of the absence of practical experience with the tasks that are necessary to provide reliable information.

The rationale behind the proposed use of the 3-camera system for the distance-sampling method is based on two factors — the need to maintain a working altitude no higher than 2000 ft while maximising the transect width. These constraints are not relevant to the distance-sampling method. Consequently, the 1-camera system would probably satisfy requirements in that case. Using the 3-camera system for the photogrammetric method would eliminate the need to vary altitude, thus removing the associated cost while maintaining the 1850 m transect width, although there would be some increase in time at the image-processing stage with the need to stitch images together. Stitching time for a single 3-camera shot is 30 sec on a mid-range computer running 32-bit Windows (Don LeRoi, Aerial Imaging Solutions, pers. comm.). Automated stitching for the 3-camera system is possible — it has been done previously by clients of Aerial Imaging Solutions.

A final comment is made regarding the data analysis phase. The time cost for the distance-sampling method is probably greater than the photogrammetric method. Attaining proficiency in the use of the DISTANCE software would take considerably longer than revising and testing the R code used for the West Coast USA sardine survey.

5. PRELIMINARY WORK

It was recorded in the Northern Inshore Working Group Draft Note of Meeting from the 31 August 2009 meeting (NINSWG 2009/58) that the CVs determined from simulations using commercial data (Appendix E) may be biased high, suggesting that this can be tested either by conducting a preliminary (i.e., pilot) survey or arranging for commercial pilots to conduct one random transect during commercial fish-spotting flights, thus constructing an "aggregating survey" dataset over time. Further discussion determined that a good approach would be to treat the two methods as a two-step strategy, the first being the single-transect study, which offers a more cost-effective approach than a full pilot study method of investigating sources of error and determining whether sufficient data can be collected to produce more acceptable CVs. If the single-transect approach is successful, then undertaking a full pilot study becomes a more feasible option.

Note that this work was proposed by the NINSWG before the discussion with the senior spotter pilot reported in the penultimate subsection of Section 2.2.2 took place. This discussion suggested that such a study may not be possible, at least not during periods when the purse-seine fishing season is at its peak. However, some pilots do work a shift system on a week on-week off basis and might be available to contribute to this study when not required for the fishing operation. Such a study constitutes a considerably lower time commitment than being involved with a full-blown survey.

5.1 Single transect study

5.1.1 Method

Distance sampling method

The essential feature of the single-transect method is to employ spotter pilots to fly a series of single transects. As a rough rule-of-thumb, the aim would be to fly about two transects per week for three months, totaling about 30 transects overall. Ultimately, the total number of transects would be dependent on the number of sightings observed.

To clarify this further, transect flying time consists of two components — flight along the transect centre line, and perpendicular flight from the centre line to the sighting to establish the species content and size of the sighting. The amount of perpendicular flight required is dependent on the number of sightings observed. Thus, the number of transects possible under a given budget will be determined by the density of the sightings and the consequent proportion of budgeted flying time expended in perpendicular flight.

It is proposed that under this method a single transect be chosen that runs approximately parallel to the coastline (to avoid elbows of around 90°) and is of a length that takes about 1 hr to complete. The transect line should be positioned in such a way that it intersects areas where species of interest are known to aggregate at the surface. The same transect line should be used for all flying under this method with the aim of minimising the sources of variation arising from varying its position. It is also important that data collection be carried out under average conditions to minimise the likelihood of collecting widely varying contributions to the analysis.

The single-transect method is an opportunity to investigate the relationship between the inshore pelagic fish population and the aerial survey method design. One subtlety in considering factors contributing to sightability is size of the sighting. Obviously, larger volumes of fish will be more visible than smaller volumes. It is unknown how the visibility of school size and/or the size of sighting (aggregate of schools) varies with distance. One requisite of distance-sampling is that the object of interest must initially be sighted from the transect centre line. It is therefore proposed that data on sightings initially sighted during perpendicular flight also be collected with the aim of using them to produce an estimate of the amount of fish not captured by the sampling method.

The single-transect study will allow sightability to be examined in some detail. The largest component of variance in the aerial sightings data is the result of variations in sightability. Sightability is a measure of how “observable” the fish are and is defined by a combination of the ability/skill of the pilot or observer and the environmental conditions at any particular time, which include sea condition (swell and wave height), cloud cover, wind speed and direction, time of day (relative position of sun), atmospheric conditions (rain, mist). In addition to recording information on the sightings themselves, data collection must also include records of the factors contributing to variations in sightability.

Photogrammetric method

A similar single transect study could be applied with the aim of determining whether sufficient data could be collected to ensure acceptable estimates according to a photogrammetric approach. Such would require the use of narrower transects (about 1850–2000 m) than the distance-sampling approach, which would be strip transects rather than line transects. Data collection would be carried out using the pilots’ method of direct school observation to determine school size and species composition. This approach would allow investigation of the central analytical method of the photogrammetric approach without committing funds to photographic and associated equipment before some confidence is reached about the level of success that might be expected from a photogrammetric survey.

5.1.2 Costs

A single-transect study would comprise the following activities.

- Preparation (identify "best" transect, program PDA and laptop, coordinate with pilot, discuss and finalise data collection method e.g., waypoint recording).
- Aerial data collection (fly transects, record data).
- Data processing (define database, modify error checking and process data, enter data to database).
- Data analysis (develop data analysis method, complete analysis, produce inputs to report e.g., plots and tables).
- Report writing (write text around plots and tables etc.).
- Presentation of results (present results to the stock assessment working group).

Flying costs (including travel time to and from the transect line):

30 transects × 2.5 hr × $350 = $26 250.00 (inc).

Other costs (see tasks in parentheses above):

$35 000 + GST (without observer in aircraft);
$50 000 + GST (with observer in aircraft).

5.2 Pilot study

5.2.1 Methods

A pilot study would comprise the following activities.

- Preparation of equipment (program PDA, laptops, mounting and linking temperature sensor, camera(s), sighting "windows" for observers).
- Aerial data collection (fly 7 transects for the required number of surveys, record data using pilot and two observers).
- Data processing (error-check data and load to database).
- Data analysis (investigate CVs, produce indices of relative abundance).
- Write up (develop and finalise report).
- Presentation of results (present results to the stock assessment working group).

5.2.2 Costs

Distance-sampling method

Flying costs. For simulations using observational sightings data of kahawai, two levels of transect-and-survey combinations were considered, the first based on a normalisation to 6 sightings and 1200 t biomass and the second based on a normalisation to 21 sightings and 4000 t biomass. These simulations examined the variation in CVs at 5, 10, 15, and 20 surveys (i.e., days flying); in each case 7 transects were used.

For a single 7-transect survey the calculated transect flying time was 3.24 hours, which, at $350.00 per hour, totals $1134.00. There are also three components of travel time: 1) from the pilot's home airfield to the beginning of the first transect; 2) from the end of each completed transect to the beginning of the next; and 3) returning from the end of the last transect to the pilot's home airfield. The amount of flying associated with identifying species is based on the two normalising levels used in the simulations, 6 and 21 sightings. Given that the detection function was based on a maximum distance of 5 n.mile from the centre line of the transect to the schools comprising the sighting, and that 40% of the schools present are actually observed, and assuming that sightings occupy this distance in an average way, and knowing that the aircraft must fly from the centre line to the sighting and back to the centre line, the estimates of distances for a single survey are either $6 \times 0.4 \times 2.5 \times 2 = 12$ n.mile or $21 \times 0.4 \times 2.5 \times 2 = 42$ n.mile. Table 2a summarises flying costs at the various survey numbers when employing the distance-sampling approach.

Table 2a: Estimated dollar cost of a pilot study based on 7 transects, four numbers of surveys or days flying (i.e., 5, 10, 15, 20), and two levels of sighting density; 1 survey is the completion of 7 transects on any day.

Flying	No of				No of surveys
Type	sightings	5	10	15	20
Transects		5 670	11 340	17 010	22 680
Travel		5 359	10 719	16 078	21 438
Spp ID	6	263	525	788	1 050
	21	919	1 838	2 756	3 675
Totals	6	11 292	22 584	33 876	45 168
	21	11 948	23 896	35 844	47 793

Other costs. The following is based on 10 days flying over 7 transects; it includes initial setting up of electronic gear and re-setting for each day's flying, travel to and from point of departure, time for 2 observers in the aircraft (i.e., in addition to the pilot), processing and loading of data into database, data analysis, report writing, and presentation of results to the WG. Note that costs related to data collection do not include processing digital photographs.

Total indicative for "Other Costs": $98 000 + GST.

Photogrammetric method

Flying costs. The factor expressing relative cost in terms of transect flying time for the methods was roughly estimated as 3–3.5 greater for the photogrammetric method (see Section 4.8.2), but this did not include the amount of extra flying time spent recording perpendicular distance data and species composition data under the distance-sampling regime. Table 2b summarises flying costs at the various survey numbers when employing the photogrammetric approach for which the extra flying is not required. Generally flying costs for the photogrammetric method are a little over twice the flying costs for the distance-sampling method.

Table 2b: Estimated dollar cost of a pilot study based on the distance-sampling costs of 7 transects, four numbers of surveys or days flying (i.e., 5, 10, 15, 20), and two levels of sighting density shown in Table 2a, by applying a factor of 3.25 (see text, Section 4.8.2).

Flying	No of				No of surveys
Type	sightings	5	10	15	20
Transects		19 845	39 690	59 535	79 380
Travel		5 359	10 719	16 078	21 438
Totals	NA	25 204	50 409	75 613	100 818

5.3 Other issues requiring resolution

Several other features of the two possible survey methods will require examination before a full-blown survey is undertaken. While they could be examined as part of the single-transect study, it would be expedient to postpone this work until the pilot study given that moving to the pilot study is dependent on acceptable CVs being estimated from data collected during the single-transect study. These features include the following.

- Determining an appropriate sample size.
- Examining the effectiveness of the point-set sampling, including photographing schools, processing the images, and determining the relationship between school biomass and school volume using data from the point-set sampling.
- Determining a clear task list for pilots and observers.
- For the distance-sampling method — determining the minimum number of observers required for the collection of reliable data.
- Investigating best deployment of equipment including a method for coordinating the digital temperature sensor, altitude sensor, and PDA/laptop using Bluetooth.
- Ensuring that the framework for all the elements of a survey is in place and functioning correctly — data-collection equipment, personnel, cameras, data-return method, error checking programs, database development, familiarity with DISTANCE etc.'

Restricting the survey to the Bay of Plenty is working to the minimum limits of the criteria suggested by Buckland et al. (2001) (i.e., 10–15 transects). It is unknown at this stage what sample size is possible with "sighting" as the fundamental unit. It may be discovered quickly that the area of the Bay of Plenty is too small to provide the data required to make reliable estimates. However, to include east Northland too early would be undertaking more than can be handled before the survey protocols are developed. Evidently the Bay of Plenty is a reasonably homogeneous area with a high density of data available from the opportunistic dataset. Including east Northland would require a further set of strata in addition to those proposed for the Bay of Plenty. Ultimately, lessons learned from the early Bay of Plenty survey(s) would be used to expand into other areas as is seen fit. Very little is known about these species outside the areas of commercial fishing.

Thus, the overall plan might be to begin by surveying the Bay of Plenty only for one or two years and then look to incorporating east Northland where a substantial proportion of the inshore pelagic populations reside. The aim be to eventually include all of New Zealand by dividing the coastline into several blocks: east Northland, Hauraki Gulf, Bay of Plenty, East Coast, Wairarapa coast, South Coast, west Northland, North Taranaki Bight, South Taranaki Bight, Marlborough-Kaikoura, Pegasus Bay, Canterbury Bight, north Otago coast, south Otago coast, Foveaux Strait, Golden-Tasman Bay, Kahurangi-Karamea, Buller, Westland, Fiordland.

6. CONCLUSIONS

6.1 Challenges in method development

The key issues in developing a successful, ongoing aerial survey method for New Zealand inshore pelagic species relate to standardising the methods of species identification and estimating school size. Unlike methods such as the Australian SBT survey, where species are easily identified and individual fish are counted, abundance of our smaller species must be based on estimates of school tonnage, with unknown but potentially high levels of variance caused by the between-observer variation that is sure to exist in estimating these data. Developing a method for standardising the estimates is an important step in reducing this variance to an acceptable level.

This would not, however, eliminate all between-observer variation in the distance-sampling approach. A second source is the varying ability between observers to successfully observe the fish that are present at the surface out to the maximum width of strip. This source of variance is common to these analyses. It is dealt with in the Australian GLMM by including an observer effect as a covariate and similarly in the DISTANCE software.

It is clear that this issue requires special resolution within the New Zealand context. Once resolved, there remain issues such as the visibility of the population of interest, which have been considered as part of distance-sampling in the context of surveys such as the Wyoming pronghorn case or the Australian SBT survey and present certain difficulties, but also provide a well-debated basis for developing a successful survey here.

The problem that must be resolved before development of a survey method can proceed is that of determining whether the density of sightings of the species of interest is high enough for the estimation methods to produce acceptable CVs. Sighting-density will be species specific, so any investigation of the issue will require species-specific data, which could well result in a species related ability to achieve or fail gaining the desired result. Therefore, we may develop a multi-purpose method capable of surveying multiple species, but only be able to apply it with reliable results to a subset of the species of interest.

The original aim of this work was to develop a multi-purpose survey method that included its having the facility to survey a range of species, including, in addition to the inshore commercial species listed in Section 1.1, the highly migratory, oceanic skipjack tuna, inshore schooling species for which there is no commercial fishery, such as koheru and pink maomao, and ecologically related species such as pelagic sharks and marine mammals. While the discussion has focused on the commercial inshore schooling species, that has been mainly the result of the fact that these are the species for which we have data and are therefore the ones we understand best. Essentially any of these species can be included as candidates for a method based on the discussion above, under the condition that density of sightings is high enough for estimates to carry reliable CVs, and reliable species composition protocols can be defined for the schools containing them. For larger species that can be counted individually, the method could be defined to allow for clusters of individuals only, without the added complexity of sighting clusters required for the small schooling species.

6.2 Implications for stock assessments

Within the MFish tender document for PEL200601, the current research was considered necessary and therefore a high priority because:

- Kahawai, jack mackerel, blue mackerel, trevally and skipjack tuna support important, commercial, recreational and customary fisheries;
- Stock status of many of these species is currently unknown, and the information required to undertake an assessment is not currently available;
- Relative indices of abundance are needed for stock assessments of all these species; and
- The project has been identified as integral to the Pelagic Fisheries Medium Term Research Plan.

Currently, the capability for producing stock indices for inshore schooling pelagics is limited to annual relative abundance indices from the opportunistic dataset for trevally and kahawai in the Bay of Plenty only. From the discussion presented here it is clear that several challenges would need to be met before development of an aerial survey method could be undertaken. Given the lack of stock status information and the discussion that has focused on the viability of aerial survey, it is clear that the preliminary investigation regarding acceptable CVs should be undertaken using some form of the single transect method discussed above. This was the recommendation of the NINSWG and results from a species specific study would provide the guidance required for continuing or abandoning the aerial survey approach for each of the species of interest. Ignoring it means that the discussion continues without resolution and that there is no progress on improving knowledge of their stock status.

6.3 Other possibilities

6.3.1 A tandem approach

The term "tandem approach" refers to what could be a second objective of the work, though not specifically of a single survey. The idea here is to investigate the possibility of using the survey results to test the validity of indices of abundance estimated using the opportunistic aerial sightings data (see Taylor & Doonan, 2014), with the aim of improving their reliability. A strategy of occasional years where data are collected both from aerial surveys and using the current opportunistic approach, interspersed with several years collecting only the opportunistic data would minimise costs while providing an opportunity to investigate some of the unknowns in the opportunistic data.

The timing of aerial surveys could follow a similar pattern to monitoring methods adopted for various pelagic species, where age and size structure are produced for several years at the beginning of the series, and then reduced in frequency to once every three or so years. In the years where a survey is not carried out, the opportunistic data could provide what would then be "calibrated estimates" of relative abundance.

6.3.2 Surveys using alternative "aerial" technology

The use of Lidar for survey of schooling finfish species has undergone some investigation. Churnside et al. (2003) compared the performance of lidar with echosounder measurements of seven fish schools — striped mullet (*Mugil cephalus*), Spanish sardine (*Sardinella aurita*), Atlantic thread herring (*Opisthonema oglinum*), blue runner (*Caranx crysos*), and scaled sardine (*Harengula juguana*) — in the Gulf of Mexico. The conclusion was that lidar does not exhibit the biases from fish avoidance potentially affecting acoustic and trawl surveys, and is a suitable tool for rapid survey of distribution and abundance of epipelagic fish stocks. However the difficulty appears to be species identification. Churnside et al. (2003) address this, suggesting that lidar survey of small fish would require direct sampling from the recorded schools by some alternative method to establish species composition. Similarly, Tenningen et al. (2003) describe species identification as "one of the lidar's major limitations". It seems likely that this remains the case — a summary by Churnside (2014) does not mention the issue although it is noted that this is a paper published in Optical Engineering.

It seems likely that there could be some discussion on the use of drones or satellite imagery to carry out an aerial survey of inshore pelagic finfish. While one can make suggestions about the details of particular components such as photography/video in this context, the difficulty will always remain identification of species composition, because of the variety of species that are potentially present and the ways in which they mix together. It seems unlikely that in the near future any method will overcome the need for a human observer to know where to look for the visual cues required to provide a certain result, recognise and process the combination of cues correctly, and record the result with any contributing conditions. Ultimately, with developing technology it could prove that some means of identification other than visual is possible, and will result in a paradigm shift for this kind of work as has proved to be the case in so many fields of practical application.

6.3.3 An innovative funding strategy

Partial funding for the West Coast USA sardine work has been under exempted fishery permits. The following is a passage verbatim from Jagielo et al.(2011).

"Full-scale surveys were subsequently performed by NWSS and the California Wetfish Producers Association (CWPA) in the coastal waters off Washington, Oregon, and California in the summers of 2009 and 2010 under Exempted Fishery Permits (EFPs) approved by PFMC and granted by the National Marine Fisheries Service (NMFS). Results from the 2009 and 2010 aerial sardine surveys were incorporated into the Pacific sardine stock assessment models used to set harvests for the 2010 and 2011 fishing years (Hill et al 2009; 2010)."

7. ACKNOWLEDGMENTS

Many thanks to the current spotter pilots Red Barker, John Reid, Brian Decke, and Garth Shaw, who continue to provide the opportunistic data on a voluntary basis, and to the other pilots who over the years have contributed to a dataset that makes possible a number of inputs to the discussion presented here. Thanks also to Harold Henderson (AgResearch), Mark Bravington (CSIRO, Hobart), Paige Eveson (CSIRO, Hobart), Rick Guenzel (formerly Wyoming Game & Fish, Laramie), Nancy Lo (Southwest Fisheries Centre, La Jolla), Mark Maunder (IATTC, La Jolla), and Nathaniel Newlands (Agriculture and Agri-Food Canada, Lethbridge) for discussion on the subjects of aerial sightings and surveys, and the modelling of their data. Thanks also to Rick Guenzel, Paige Eveson, and Brian Nakashima for permission to reproduce Figure 2, Figures 3 and 4, and Figure 4 respectively; and to Marc Griffiths and Paul Starr for comments on an earlier version of the manuscript. This work was funded under MFish Projects PEL2006/01 and SAP2008/26.

8. REFERENCES

Agenbag, J.J. (1980). General distribution of pelagic fish off southwest Africa as deduced from aerial fish spotting (1971–74 and 1977) and as influenced by hydrology. *Fish Bulletin of South Africa 13*: 55–67.

Agenbag, J.J.; Kruger, I.; Le Clus, F. (1984). Environmental factors associated with a distinct decline in pelagic fish abundance as detected by aerial fish spotting in February and March 1982 off northern southwest Africa. *South Africa Journal of Marine Science 2*: 93–107.

Anderson, O.F.; Bagley, N.W.; Hurst, R.J.; Francis, M.P.; Clark, M.R.; McMillan, P.J. (1998). Atlas of New Zealand fish and squid distributions from research bottom trawls. *NIWA Technical Report 42*. 303 p.

Bagley, N.W.; Anderson, O.F.; Hurst, R.J.; Francis, M.P.; Taylor, P.R.; Clark, M.R.; Paul, L.J. (2000). Atlas of New Zealand fish and squid distributions in midwater and at the surface. *NIWA Technical Report 72*. 171 p.

Baker, A.N. (1971). Food and feeding of kahawai (Teleostei: Arripididae). *New Zealand Journal of Marine and Freshwater research 5(2)*: 291–299.

Bakun, A. (1996). Patterns in the ocean; ocean processes and marine population dynamics. California Sea Grant College System.

Bakun, A.; Parrish, R.H. (1980). Environmental inputs to fishery population models for eastern boundary current regions. pp. 67–104 *In* Workshop on the effects of environmental variation on the survival of larval pelagic fishes, Lima, Peru, 20 April–5 May 1980. *IOC Workshop Report 28*. UNESCO, Paris.

Bolker, B.M. (2008). Ecological Models and Data in R. Princeton University Press.

Bravington, M. (2003). Further considerations on the analysis and design of aerial surveys for juvenile SBT in the Great Australian Bight. CSIRO Marine Research Appendix 4 in: Davis, T.L.O. (2003). Southern Bluefin Tuna Recruitment Monitoring Program

2002/2003. Report RMWS/03/03 for Australian Fisheries Management Authority Project R02/1096. 43 p.

Bromley, R.G.; Heard, D.C.; Croft, B. (1995). Visibility bias in aerial surveys relating to nest success of Arctic geese. *Journal of Wildlife Management 59(2)*: 364–371.

Buckland, S.T.; Anderson, D.R.; Burnham, K.P.; Lakke, J.L.; Borchers, D.L.; Thomas, L. (2001). Introduction to distance sampling, estimating abundance of biological populations. Oxford University Press, Oxford, New York.

Buckland, S.T.; Anderson, D.R.; Burnham, K.P.; Lakke, J.L.; Borchers, D.L.; Thomas, L. (2004). Advanced distance sampling. Oxford University Press, Oxford, New York.

Burnham, K.P.; Anderson, D.R.; Laake, J.L. (1980). Estimation of density from line transect sampling of biological populations. *Wildlife Monographs 44(2)*: 202 p.

Carretta, J.V.; Forney, K.A.; Laake, J.L. (1998). Abundance of Southern California coastal bottlenose dolphins estimated from tandem aerial surveys. *Marine Mammal Science 14(4)*: 655–675.

Carscadden, J.; Nakashima, B.; Miller, D.S. (1994). An evaluation of trends in abundance of capelin (*Mallotus villosus*) from acoustics, aerial surveys, and catch rates in NAFO Division 3L, 1982–89. *Journal of Northwest Atlantic Fisheries Science 17*: 45–57.

Caughley, G. (1974). Bias in aerial survey. *Journal of Wildlife Management 38*: 921–933.

Caughley, G. (1977). Sampling in aerial survey. *Journal of Wildlife Management 41*: 605–615.

Checkley, D.M.; Alheit, J.; Oozeki, Y.; Roy, C. (Eds) (2009). Climate change and small pelagic fish. Cambridge University Press.

Chen, S.A.; Cowling, A.; Polacheck, T. (1995). Data analysis of the aerial sightings (1991–95) for juvenile southern bluefin tuna in the Great Australian Bight. *1995 Southern Bluefin Tuna Recruitment Monitoring Workshop Report RMWS/95/6*. 57 p. CSIRO Marine Laboratories, Castray Esplanade, Hobart, Tasmania, Australia 7000.

Churnside, J.H. (2014). Review of profiling oceanographic lidar. *Optical Engineering*, *53*(5), 051405-051405.

Churnside, J.H.; Demer, D.A.; Mahmoudi, B. (2003). A comparison of lidar and echosounder measurements of fish schools in the Gulf of Mexico. *ICES Journal of Marine Science, 60*: 147–154.

Cochrane, K.L. (1999). Review of the Western Australian pilchard fishery [Report of a workshop held] 12–16 April 1999. *Fisheries Western Australia, Fisheries Management Paper No. 129*. 28 p.

Cowling, A. (2000). Data analysis of the aerial surveys (1993–2000) for juvenile southern bluefin tuna in the Great Australian Bight. RMWS/00/03.

Cury, P.; Bakun, A.; Crawford, R.J.M.; Jarre, A.; Quiñones, R.A.; Shannon, L.J.; Verheye, H.M. (2000). Small pelagics in upwelling systems: patterns of interaction and structural changes in “wasp-waist” ecosystems. *ICES Journal of Marine Science 57(3)*: 603–618.

Davies, C.R.; Farley, J.; Eveson, P.; Basson, M.; Bravington, M (2007). Proposal for continued monitoring of southern bluefin tuna recruitment via scientific aerial survey of juveniles in the Great Australian Bight. Report prepared for the CCSBT 7th Meeting of the Stock Assessment Group (SAG7) and the 11th Meeting of the Extended Scientific Committee (ESC11) 4–11 September, and 12–15 September 2006, Tokyo, Japan. CCSBT-ESC/0609/Info02. 4 p.

Davis, T.L.O.; Stanley, C.A. (2002). Vertical and horizontal movements of southern bluefin tuna (*Thunnus maccoyii*) in the Great Australian Bight observed with ultrasonic telemetry. *Fishery Bulletin 100*: 448–465.

Elzinga, C.L; Salzer, D.W.; Willoughby, J.W.; Gibbs, J.P. (2001). Monitoring Plant and Animal Populations. Blackwell Science, Inc., Maiden, MA.

Eveson, P.; Bravington, M.; Farley, J. (2006). The aerial survey index of abundance: updated analysis methods and results. Report prepared for the CCSBT 7th Meeting of the Stock Assessment Group (SAG7) and the 11th Meeting of the Extended Scientific Committee (ESC11) 4–11 September, and 12–15 September 2006, Tokyo, Japan. CCSBT-ESC/0609/16. 25 p.

Eveson, P.; Farley, J.; Bravington, M. (2011). The aerial survey index of abundance: updated analysis methods and results for the 2010/11 fishing season. Report prepared for the CCSBT Extended Scientific Committee for the 16th Meeting of the Scientific Committee 19–28 July 2011, Bali, Indonesia. CCSBT-ESC/1107/15. 32 p.

Farley, J.; Bestley, S. (2003). Aerial survey indices of abundance: comparison of estimates from line transect and "unit of spotting effort" survey approaches. CSIRO Report RMWS/03/01. 40 p.

Fisher, D.; Taylor, P. (2001). Database documentation: *aer_sight*. NIWA Fisheries Data Management Database Documentation Series. 44 p.

Fromentin, J.-M.; Farrugio, H.; Deflorio, M.; de Metrio, G. (2003). Preliminary results of aerial surveys of bluefin tuna in the western Mediterranean Sea. Collective Volume of Scientific Papers ICCAT 55, 1019–1027.

Fromentin, J.M.; Powers, J.E. (2005). Atlantic bluefin tuna: population dynamics, ecology, fisheries and management. *Fish and Fisheries 6*: 281–306.

Gabor, T.S.; Gadawski, T.R.; Ross, R.K.; Rempel, R.S.; Kroeker, D.W. (1995). Visibility bias of waterfowl brood surveys using helicopters in the great clay belt of northern Ontario. *Journal of Field Ornithology 66(1)*: 81–87.

Graham, D.H. (1956). A treasury of New Zealand fishes. AH & AW Reed, Wellington. 2nd ed. 424 p.

Groves, D.J.; Conant, B.; King, R.J.; Hodges, J.I.; King, J.G. (1996). Status and trends of loon populations summering in Alaska, 1971–1993. *Condor 98(2)*: 189–195.

Guenzel, R.J. (1997). Estimating pronghorn abundance using aerial line transect sampling. Wyoming Game and Fish Department, Cheyenne, USA. 174 p.

Guenzel, R.J. (2007). Procedures for Estimating Pronghorn Abundance in Wyoming Using Aerial Line Transect Sampling. *Wyoming Game and Fish Department, Cheyenne 60-86.* 100 p.

Gunn, J.T.; Davis, T.; Polacheck, T.; Betlehem, A.; Sherlock, M. (1995). The application of archival tags to study SBT migration, behaviour and physiology. Progress Report — 1994–95. Southern Bluefin Tuna recruitment, monitoring and tagging programme workshop, 7–10 August 1995, Hobart Australia. Rep. RMWS/95/8. 17 p. CSIRO Marine Laboratories, Castray Esplanade, Hobart, Tasmania, Australia 7000.

Hara, I. (1986). Stock assessment of Japanese sardine in the waters off the southeast coast of Hokkaido using line transect method. *Bulletin of the Japanese Society of Scientific Fisheries 52(1)*: 69–73.

Hill, K.T.; Crone, P.R.; Lo, N.C.; Demer, D.A.; Zwolinski, J.P.; Macewicz, B.J. (2012). Assessment of the pacific sardine resource in 2012 for U.S. management in 2013. Technical report, Pacific Fishery Management Council, 7700 NE Ambassador Place, Portland, OR 97220, USA. 51 p.

Hill, K.T.; Lo, N.C.H.; Macewicz, B.J.; Crone, P. (2009). Assessment of the Pacific Sardine Resource in 2009 for U.S. Management in 2010. STAR Panel Review Draft, September 21–25, 2009. NOAA National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, California.

Hill, K.T.; Lo, N.C.H.; Macewicz, B.J.; Crone, P.; Felix-Uraga, R. (2010). Assessment of the Pacific Sardine Resource in 2010 for U.S. Management in 2011. NOAA National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, California.

Horn, P.L. (1991). Trawl survey of jack mackerels (*Trachurus* spp.) off the central west coast, New Zealand, February-March 1990. New Zealand Fisheries Technical Report No. 28. 39 p.

Jagielo, T.; Howe, R.; Mikesell, M. (2011). Northwest Aerial Sardine Survey Sampling Results in 2011. Report prepared for Northwest Sardine Survey,LLC. Available at www.pcouncil.org/wp.../F2b_ATT3_AERIAL_SRVY_NOV2011BB.pdf

James, G.D. (1994). Trevally, *Caranx georgianus* Cuvier: age determination, population biology, and the fishery. *Fisheries Research Bulletin No. 25.* 50 p.

James, G.D.; Stephenson, A.B. (1974). *Caranx georgianus* Cuvier, 1833 (Pisces: Carangidae) in temperate Australasian waters. *Journal of the Royal Society of New Zealand 4(4)*: 401–410.

Jiang, J. (2007). Linear and Generalized Linear Mixed Models and Their Applications. Springer Series in Statistics. Springer

Jones, J.B. (1983). The poor man's tuna. *CATCH '83 10(2)*: 11–12.

Kilner, A.R. (1988). Kahawai *(Arripis trutta).* New Zealand Fisheries Assessment Research Document 88/42. (Unpublished report held in NIWA Greta Point library, Wellington.)

Kingsford, M.J. (1992). Drift algae and small fish in coastal waters of northeastern New Zealand. *Marine ecology progress series. Oldendorf, 80*(1): 41–55.

Kingsley, M.C.S.; Reeves, R.R. (1998). Aerial surveys of cetaceans in the Gulf of St. Lawrence in 1995 and 1996. *Canadian Journal of Zoology/Revue Canadien de Zoologie No. 8*: 1529–1550.

Krebs, C.J. (1989). Ecological methodology. Harper & Row, New York. 654 p.

Laake, J.L.; Buckland, S.T.; Anderson, D.R.; Burnham, K.P. (1996). DISTANCE user’s guide version 2.2. Colorado Cooperative Fish and Wildlife Research Unit, Colorado State University, Fort Collins. 82 p.

Laake, J.L.; Burnham, K.P.; Anderson, D.R.; (1979). User’s Manual for Program TRANSECT. Utah State University Press, Logan, UT, USA.

Lefebvre, L.W.; Ackerman, B.B.; Portier, K.M.; Pollock, K.H. (1995). Aerial survey as a technique for estimating trends in manatee population size — problems and prospects. In: O'Shea, T.J.; Ackerman, B.B.; Percival, H.F. (eds) Population biology of the Florida manatee. *National Biological Service: Information and Technology Report, No. 1*: 63–74.

Lo, N.C.-H.; Jacobson, L.D.; Squire, J.L. (1992). Indices of relative abundance from fish spotter data based on delta-lognormal models. *Canadian Journal of Fisheries and Aquatic Sciences 49*: 2515–2526.

Lutcavage, M.; Goldstein, J.; Kraus, S. (1997b). Distribution, relative abundance, and behaviour of giant bluefin tuna in New England waters, 1995. *Collective Volumes of Scientific Papers, International Commission for the Conservation of Atlantic Tunas 46*(2): 332–347.

Lutcavage, M.; Kraus, S. (1995). The feasibility of direct photographic assessment of giant bluefin tuna, *Thunnus thynnus*, in New England waters. *Fishery Bulletin 93*: 495–503.

Lutcavage, M.; Kraus, S.; Hoggard, W. (1997a). Aerial survey of giant bluefin tuna, *Thunnus thynnus*, in the Great Bahama Bank, Straits of Florida, 1995. *Fishery Bulletin 95*: 300–310.

Lutcavage, M.; Newlands, N. (1999). A strategic framework for fishery-independent aerial assessment of bluefin tuna. *Collected Volumes of Scientific Papers International Commission for the Conservation of Atlantic Tunas 49*: 400–402.

Marr, J. (1951). On the use of the terms abundance, availability and apparent abundance in fishery biology. *Copeia 1951*: 163–169.

Marsh, H.; Sinclair, D.F. (1989). Correcting for visibility bias in strip transect aerial surveys of aquatic fauna. *Journal of Wildlife Management 53(4)*: 1017–1024.

Mather, F.J.; Mason Jr., J.M.; Jones, A.C. (1995). *Historical document: life history and fisheries of Atlantic bluefin tuna* (No. 8986). US Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, *NOAA Technical Memorandum NMFS-SEFSC-370*, 165 p.

McCulloch, C.E.; Searle, S.R.; Neuhaus, J.M. (2008). Generalized, Linear, and Mixed Models. Wiley Series in Probability and Statistics. John Wiley & Sons, Hoboken, New Jersey, second edition.

McDonald, L.L.; Garner, G.W.; Robertson, D.G. (1999). Comparison of aerial survey procedures for estimating polar bear density: results of pilot studies in northern Alaska. *Marine Mammal Survey and Assessment Methods*: 37–52.

McDowall, R.M. (1978). New Zealand freshwater fishes: a guide and natural history. Heinemann, Auckland. 230 p.

Ministry of Fisheries. (2007). Report from the Fishery Assessment Plenary, May 2007: stock assessments and yield estimates. Ministry of Fisheries, Wellington, New Zealand. 1015 p.

Ministry of Fisheries (2011). Report from the Fisheries Assessment Plenary, May 2011: stock assessments and yield estimates. Ministry of Fisheries, Wellington, New Zealand. 1178 p.

Newlands, N.K.; Lutcavage, M.E.; Pitcher, T.J. (2006). Atlantic bluefin tuna in the Gulf of Maine, I: estimation of seasonal abundance accounting for movement, school and school-aggregation behaviour. *Environmental biology of fishes 77(2)*: 177–195.

O'Driscoll, R.L. (2006). Sea trials to evaluate the use of swath mapping technology to quantify pelagic fish in aquaculture areas. Final Research Report for MFish Project SSFA065 (FRST Contract C01X0507). (Unpublished report held by MPI, Wellington.)

Packard, J.M.; Summers, R.C.; Barnes, L.B. (1985). Variation of visibility bias during aerial surveys of manatees. *Journal of Wildlife Management 49(2)*: 347–351.

Parrish, R.H.; Serra, R.; Grant, W.S. (1989). The monotypic sardines, *Sardina* and *Sardinops*: their taxonomy, distribution, stock structure, and zoogeography. *Canadian Journal of Fisheries and Aquatic Sciences 46(11)*: 2019–2036.

Paul, L.J.; Taylor, P.R.; Parkinson D.M. (2001). Pilchard (*Sardinops neopilchardus*) biology and fisheries in New Zealand, and a review of pilchard (*Sardinops, Sardina*) biology, fisheries, and research in the main world fisheries. *New Zealand Fisheries Assessment Report 2001/37*. 44 p.

Pennington, M. (1983). Efficient estimators of abundance for fish and plankton surveys. *Biometrics 39*: 281–286.

Pollock, K.H.; Kendall, W.L. (1987). Visibility bias in aerial surveys: a review of estimation procedures. *Journal of Wildlife Management 51(2)*: 502–509.

Prenzlow, D.M.; Lovvorn, J.R. (1996). Evaluation of visibility correction factors for waterfowl surveys in Wyoming. *Journal of Wildlife Management 60(2)*: 286–297.

Rice, J. (1995). Food web theory, marine food webs, and what climate change might do to northern fish populations. In *Climate Change and Northern Fish Populations*, ed R.J. Beamish. *Canadian Special Publication of Fisheries and Aquatic Sciences 121*: 561–568.

Rivas, L. R. (1954). Preliminary report on the spawning of the western North Atlantic bluefin tuna *(Thunnus thynnus)* in the Straits of Florida. *Bulletin of Marine Science 4*:302–321.

Robertson, D.A. (1973). Planktonic eggs and larvae of some New Zealand marine teleosts. Ph.D. Thesis, University of Otago.

Robertson, D.A (1978). Blue mackerel, pilchard, anchovy, sprat, saury and lanternfish. Pp. 85–89 in: Habib G.; Roberts, P.E. Proceedings of the Pelagic Fisheries Conference July 1977. *Fisheries Research Division Occasional Publication 15.*

Schwartzlose, R.A.; Ahleit, J.; Bakun, A.; Baumgartner, T.R.; Cloete, R.; Crawford, R.J.M.; Fletcher, W.J.; Green-Ruiz, Y.; Hagen, E.; Kawasaki, T.; Lluch-Belda, D.; Lluch-Cota, S.E.; MacCall, A.D.; Matsuura, Y.; Nevarez-Martínez, M.O.; Parrish, R.H.; Roy, C.; Serra, R.; Shust, K.V.; Ward, M.N.; Zuzunaga, J.Z. (1999). Worldwide large-scale fluctuations of sardine and anchovy populations. *South African Journal of Marine Science 21*: 289–347.

Scott, D.W. (1992). Multivariate density estimation. Theory, practice, and visualisation. John Wiley and Sons, New York.

Shuntov, V.P. (1969). Some features of the ecology of pelagic fishes in the Great Australian Bight. *Problems of Ichthyology 9*: 801–809.

Squire, J.L. Jnr. (1976). Apparent abundance of some pelagic marine fish off the southern and central California coast as surveyed by an airborne monitoring program. *Fishery Bulletin 70*: 1005–1019.

Squire, J.L. Jnr. (1993). Relative abundance of pelagic resources utilized by the California purse-seine fishery: results of an airborne monitoring program, 1962–90. *Fishery Bulletin 93*: 348–361.

Smith, D.R.; Reinecke, K.J.; Conroy, M.J.; Brown, M.W.; Nassar, J.R. (1995). Factors affecting visibility rate of waterfowl surveys in the Mississippi Alluvial Valley. *Journal of Wildlife Management 59(3)*: 515–527.

Smith, P.J.; Hartill, B.; Hamer, P.; McKenzie, A. (2008). Stock structure of kahawai, *Arripis trutta*. *New Zealand Fisheries Assessment Report 2008/20*. 42 p.

Stehman, S.; Salzer, D. (2000). Estimating Density from Surveys Employing Unequal-Area Belt Transects. *Wetlands 20 (3):* 512–519. The Society of Wetland Scientists, McLean, VA.

Stevens, J.D.; Hausfeld, H.F.; Davenport, S.R. (1984). Observations on the biology, distribution and abundance of *Trachurus declivis*, *Sardinops neopilchardus* and *Scomber australasicus* in the Great Australian Bight. Report. *CSIRO Marine Laboratories. Hobart, No. 164*. 29 p.

Sulikowski, J.; Morgan, A.; Carlson, A.; Butterworth, D. (2012). Inferences from aerial surveys on the abundance of Atlantic menhaden from outside the normal fishery range: implications for improved management of this resource. Unpublished Report for aerial surveys completed in 2011; PDF from uct.ac.za downloaded at: https://scholar.google.co.nz/scholar?q=Sulikowski+Inferences+from+aerial+surveys&btnG=&hl=en&as_sdt=0%2C5

Taylor, J.K.D.; Kenney, R.D.; LeRoi, D.J.; Kraus, S.D. (2014). Automated vertical photography for detecting pelagic species in multitaxon aerial surveys. *Marine Technology Society Journal 48(1)*: 36–48.

Taylor, P.R. (2002). Stock structure and population biology of the Peruvian jack mackerel, *Trachurus symmetricus murphyi*. *New Zealand Fisheries Assessment Report 2002/21*. 83 p.

Taylor P.R. (2003). Refining the aerial sightings data, their collection, and the method using them to estimate relative abundance of coastal pelagic fish species. Final Research Report for MFish Project PEL2001/01. 45 p. (Unpublished report held by MPI, Wellington.)

Taylor, P.R. (2004). A summary of survey methods for small inshore pelagic finfish species. Final Research Report for MFish Project PEL2002/01. 66 p. (Unpublished report held by MPI, Wellington.)

Taylor, P.R. (2014). Developing indices of relative abundance from observational aerial sightings of inshore pelagic finfish; Part 1, exploring the data. *New Zealand Fisheries Assessment Report 2014/34*. 66 p.

Taylor, P.R.; Doonan, I.J. (2014). Developing indices of relative abundance from observational aerial sightings of inshore pelagic finfish; Part 2, expanding the dataset and producing annual indices for KAH 1 and TRE 1. *New Zealand Fisheries Assessment Report 2014/35*. 45 p.

Tenningen, E.; Godø, O.R.; Iversen, S.A.; Slotte, A.; Hjellvik, V.; Torkelsen, T. (2003). Comparison of Northeast Atlantic mackerel (*Scomber scombrus*) distribution patterns in the Norwegian Sea using lidar, sonar, and trawl. ICES CM 2003/V: 04. 16 pp.

Venables, W.N.; Ripley, B.D. (1994). Modern applied statistics with S-Plus. Springer-Verlag, New York.

Walter, S.E.; Rusch, D.H. (1997). Visibility bias on counts of nesting Canada geese. *Journal of Wildlife Management 61(3)*: 768–772.

Woodward, A.R.; Rice, K.G.; Linda, S.B. (1996). Estimating sighting proportions of American alligators during night-light and aerial helicopter surveys. *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies*: 509–519.

Xiao, Y.; Punt, A.E.; Millar, R.B.; Quinn, T.J. (2004). Models in Fisheries research: GLMs, GAMs and GLMMs. *Fisheries Research 70*:137–139.

9. APPENDICES

Appendix A: Glossary of definitions and terminology

ABT:	Atlantic bluefin tuna.
aer_sight:	the MPI aerial sightings database.
AGL:	above ground level.
BoP:	Bay of Plenty
CSIRO:	(Australian) Commonwealth Scientific and Research Organisation.
Detection function:	$g(y)$ = the probability of detecting an object, given that it is at a distance y from the random line or point; central to distance-sampling.
DISTANCE:	the software package developed for use in the context of distance-sampling.
GAB:	Great Australian Bight.
GLM:	generalised linear model.
GLMM:	generalised linear mixed model.
GPS:	global positioning system.
n. mile:	nautical mile.
Opportunistic data:	observational aerial sightings data collected opportunistically by spotter pilots working in the domestic purse-seine fishery since 1976; the dataset resides in the MPI relational database, *aer_sight*.
PDA:	personal digital assistant, or a handheld or palmtop computer.
Patch:	group of aggregations of SBT used in the Australian survey; includes both schools and loose aggregations.
SBT:	southern bluefin tuna.
Sighting:	a spatially integrated (i.e., in close proximity) group of schools of similar species composition; a sighting is the fundamental unit in the opportunistic aerial sightings data comprising the existing MPI database *aer_sight*.
Half width:	w, the width either side of the transect centre line.

Appendix B: Visual cues used for school species composition

The following was recorded during a meeting with Red Barker at his hangar at Tauranga airport on 27 November 2014.

1. Blue mackerel

Tend to show areas of white — come up and push a lot of water and streak from the front of the school. Tend to be large schools. Show shines (i.e., a flash) underneath when they stop foaming, which could be barracouta[14] but not usually seen with blue mackerel. This species often has gannets diving into them but this is not failsafe because they [gannets] also dive into small jack mackerel schools. If small jacks were mixed in with the blues you would see their brown colouration.

2. Small jack mackerel (300–500 gm)

Tend to be dense schools with darker colour than blue mackerel (though not always) with well-defined parameters e.g., outline is well-defined because the fish [= grain size] are small. They are similar to bait in this respect, but bait will come up, fizz, and go down again, whereas small jacks will come up and stay up showing the well-defined outline.

3. Gannets

Gannets will dive into bait and small jacks but not into *T. murphyi*. If gannets are diving into big jacks then the school is probably mixed with small jacks underneath. Gannets are looking for the 300–500 gm fish. If gannets are diving into a kahawai school or around the edges then there are small jacks underneath; if they dive for a while then leave, there are no small jacks.

4. Jack mackerel

T. murphyi look a little green when they go down. *T. Murphyi* and Northland jacks *T. Novaezelandiae* are more difficult to call. Generally rely on the size of the ripples which can only be seen when the school is up, not when it's sub-surface.

5. Kahawai

A greenish glow when they go down. Tend to show a silvery colour, and individual fish can be seen. Can be mixed with *T. Murphyi* and/or small jacks.

6. Trevally

Initially look like kahawai, but the school's surface looks grey when at the surface. Show lazy flashes (turquoise) that roll down the side of the school. Small kingfish can be with them so the boat has to refine the pilot's identification by deploying the camera to determine presence/absence of the kingies.

7. Baitfish (anchovy or pilchard)

Will come up, fizz, and go down again, but the foaming (fizz) is not like the streaking of the blues.

[14] Only during August–September.

Appendix C: Examining the relevance of school height

The aim of the following work was to determine whether including school height as a predictor of school biomass, either as school volume or simply as school height, improved the simpler approach of using school surface area as the single predictor of school biomass.

An analysis was carried to investigate the relationship between school surface area (SclArea) (m^2), school height (SclHt) i.e., the difference between depth of the bottom of the school and depth of the top of the school (m), school volume (SclVol) i.e., SclVol = SclArea x SclHt (m^3), and school biomass (SclBmss), the landed tonnage of the school (mt), using data on schools of sardine collected during several years of sardine survey work — 2009, 2010, and 2011, on West Coast USA and published by Jagielo et al. (2011). Sardine schools were sometimes mixed with up to about 1% by volume of pacific mackerel, which was ignored here.

Scatterplots were created (Figure C1) and simple bivariate linear regressions were carried out in R of the following relationships:

- SclHt as a function of SclArea (Plot A);
- SclBmss as a function of SclArea (Plot B);
- SclBmss as a function of SclVol (Plot C);
- SclBmss as a function of SclHt (Plot D);
- The log of SclBmss as a function of the log of SclArea (Plot F);
- The log of SclBmss as a function of the log of SclVol (Plot G); and
- The log of SclBmss as a function of the log of SclHt (Plot H).

Each of the regression lines were plotted onto the relevant scatterplot, along with the back-transformed fitted values from each log regression (Plots B, C, D). Regression outputs and residual plots for the regressions were examined and compared along with the scatterplots with the aim of determining the importance of including school height in the form of school volume.

Observations from the plots

- Plot A (school height on school area), shows no relationship between school area and school height.
- Plot B (school biomass on school area), suggests a linear relationship between school biomass and school area but with relatively wide scatter and a degree of heteroscedasticity; the plot of back-transformed log values appears to account better for small values than the line from the non-transformed regression.
- Plot C (school biomass on school volume) suggests a linear relationship; scatter of points is reduced compared with Plot B, and heteroscedasticity is less pronounced, arguably absent; the back-transformed log values appear to account better for small values.
- Plot D (school biomass on school height) suggests a linear relationship that is spoilt somewhat by several higher biomass values at 3 m and lower biomass values at 2 m.
- Plot E (log of school height on log of school area) provides little additional information to Plot A.
- Plot F (log of school biomass on log of school area) provides a better basis for regression than the untransformed data in plot B with no hint of increasing variability.
- Plot G (log of school biomass on log of school volume) provides a better basis for regression than the untransformed data in plot B with no hint of increasing variability; as with plot C (compared with plot B), nett variability is less than in the school surface area relationship (plot F) i.e., points are distributed more tightly around the fitted lines.
- Plot H (log of school biomass on log of school height) was included for completeness but log transformation is not really required – range is less than one order of magnitude.

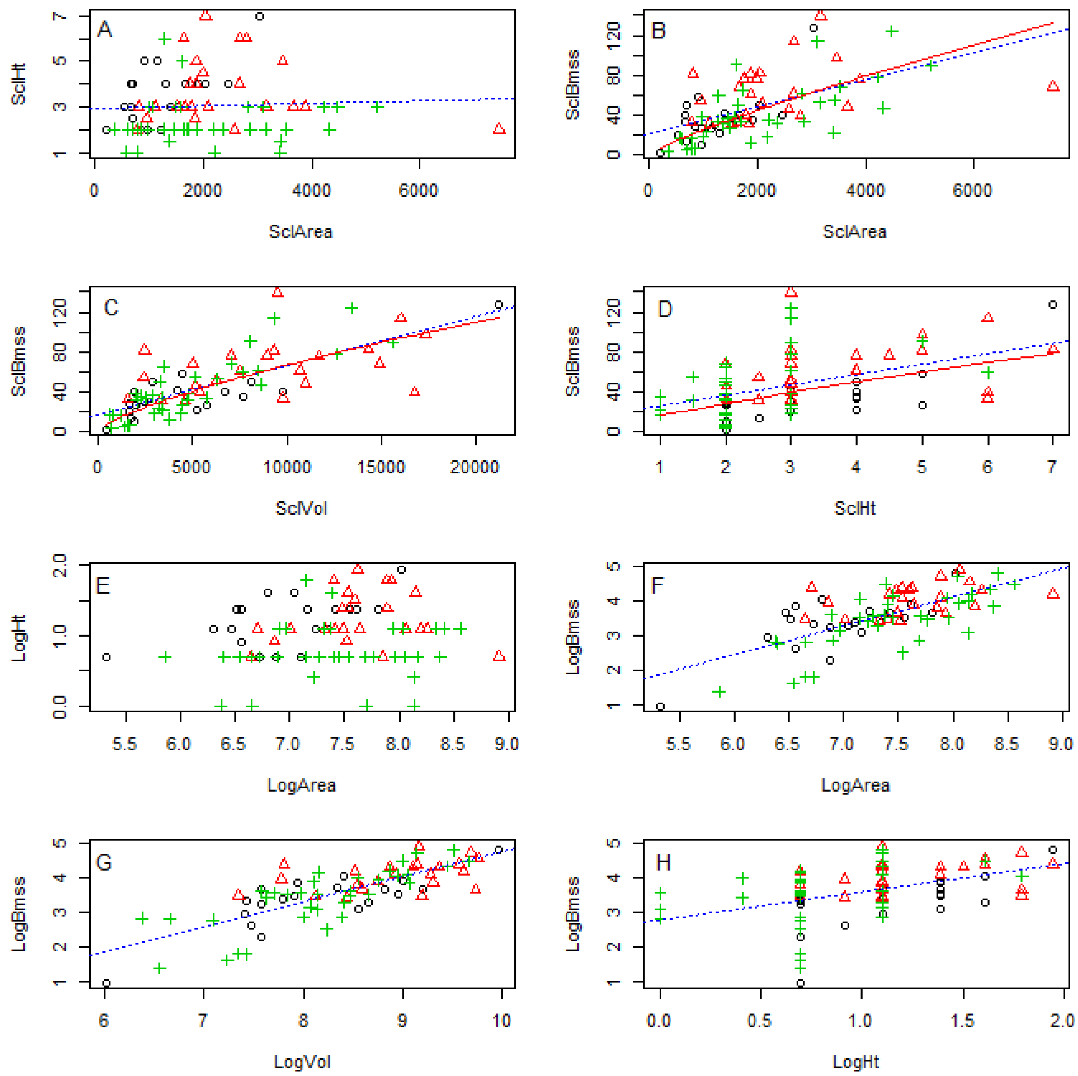

Figure C1: Graphical analysis of the relationship between school surface area (SclArea) (m^2), school height (SclHt) i.e., the difference between depth of the bottom of the school and depth of the top of the school (m), school volume (SclVol) i.e., SclVol = SclArea × SclHt (m^3), and school biomass (SclBmss), the landed tonnage of the school (mt), using data on schools of sardine collected during sardine survey work in 2009 (black o), 2010 (red ∆), 2011(green +) on West Coast USA and published by Jagielo et al. (2011); the blue broken line is a plot of linear regression of the scatter-plotted variables in each case, the dependent variable being that on the y axis; the red solid line plots the back-transformed fitted values from the linear regression of the logarithms of the plotted variables; plots E–H are scatterplots of the logged variables shown in plots A–D, such that log of school height is LogHt etc.

Observations from the regression outputs

Regressions including school height, both as school volume and in the raw form, produced better results than those based on school area (Table C1). This applied both outside and within log space: residual standard errors of the fits were lower, with R^2 and F statistic values higher.

Residual plots for the log regressions (Figures C2, C3) indicate no increasing variability or other important issue requiring resolution. Several points were flagged by R for further examination, but that was not carried out here.

Table C1: Parameters for linear model fits; residual standard error (RSE), degrees of freedom (DF), multiple R^2 (Mult R^2), adjusted R^2 (adj R^2), F statistic (F stat).

Fit	RSE	DF	Mult R^2	Adj R^2	F stat	p-value
SclBmss~SclArea	24.95	1, 77	0.3226	0.3138	36.68	4.771e-08
SclBmss~SclVol	20.28	1, 77	0.5526	0.5467	95.09	4.319e-15
log(SclBmss)~log(SclArea)	0.5711	1, 77	0.4780	0.4712	70.50	1.751e-12
log(SclBmss)~log(SclVol)	0.4987	1, 77	0.6020	0.5968	116.5	< 2.2e-16
log(SclBmss)~log(SclArea)+log(SclHt)	0.5002	2, 76	0.6047	0.5943	58.14	4.806e-16

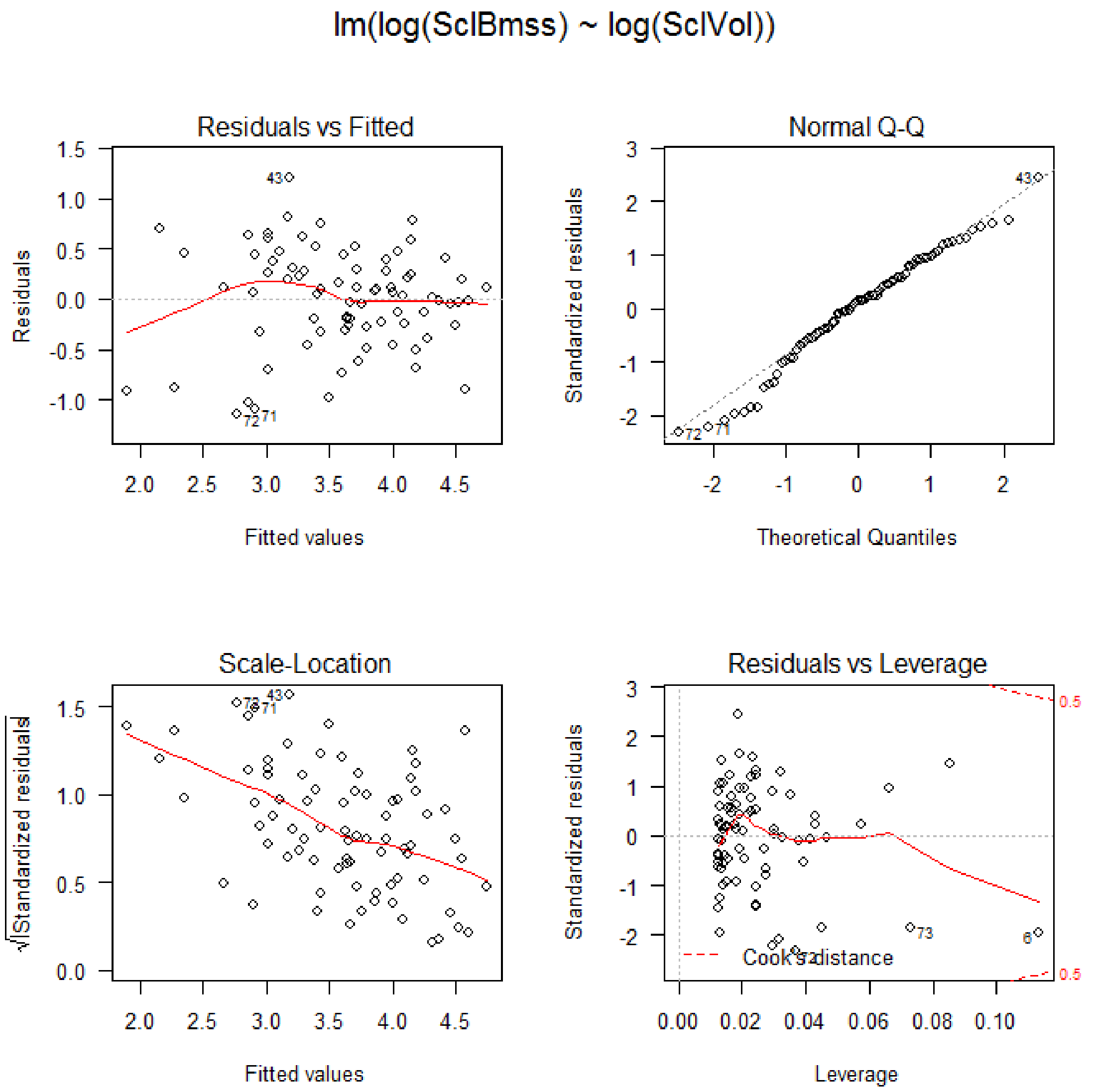

Figure C2: Residual plots for the log school biomass, log school volume linear regression.

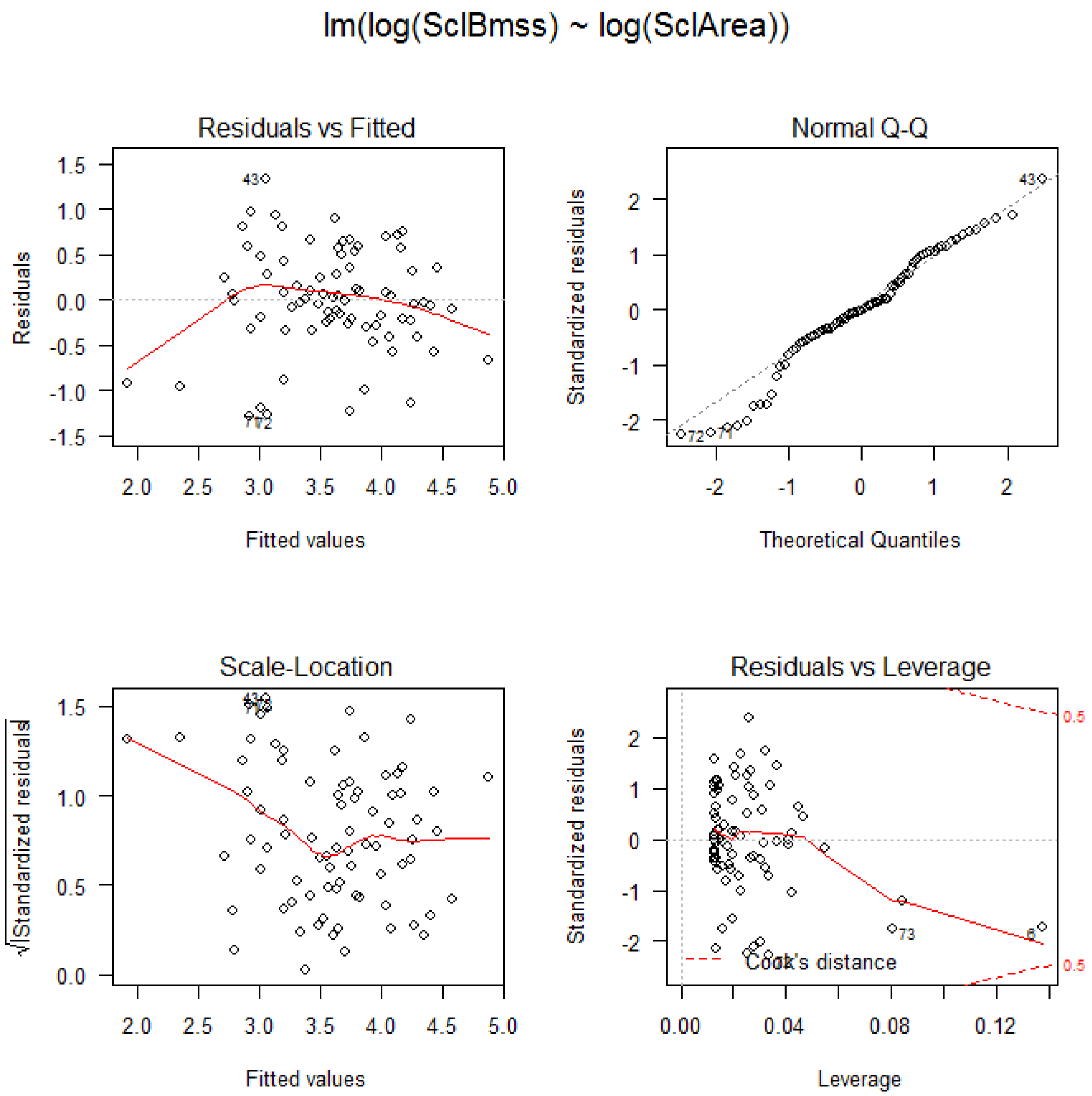

Figure C3: Residual plots for the log school biomass, log school area linear regression.

Conclusions

Because of heteroscedasticity in the raw data, the log-transformed fits provided a better basis for the analysis. A comparison of the regressions carried out in log space showed more acceptable results when school height was included, although the use of volume as the single predictor of biomass performed far better than using both area and height as predictors. It is concluded that the most accurate estimator of school biomass would include school volume as the product of school surface area (from aerial photographs) and school height (from side-scan sonar or similar).

Appendix D: Temporal distributions of sightings

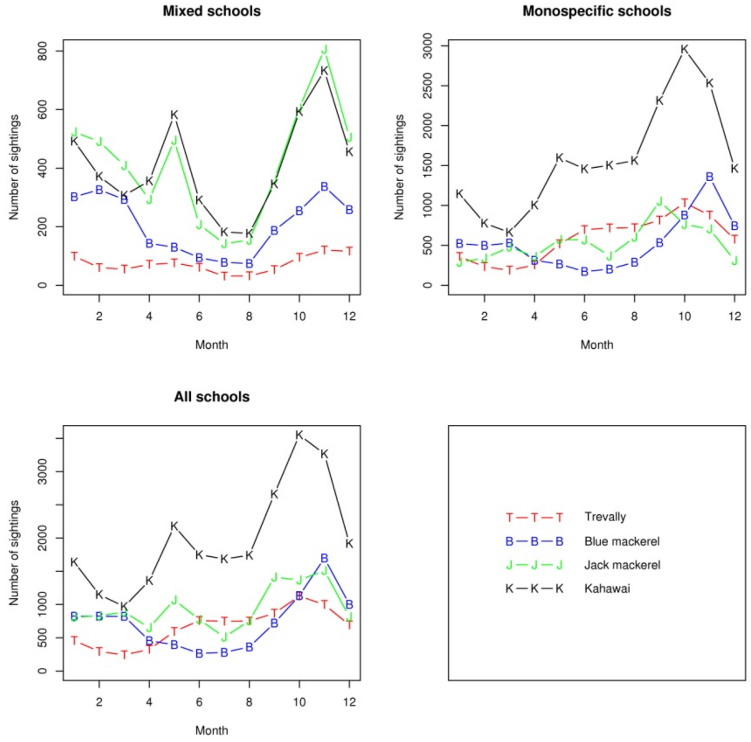

Figure D1: Monthly distributions of all sightings of trevally, blue mackerel, jack mackerel, and kahawai from all areas.

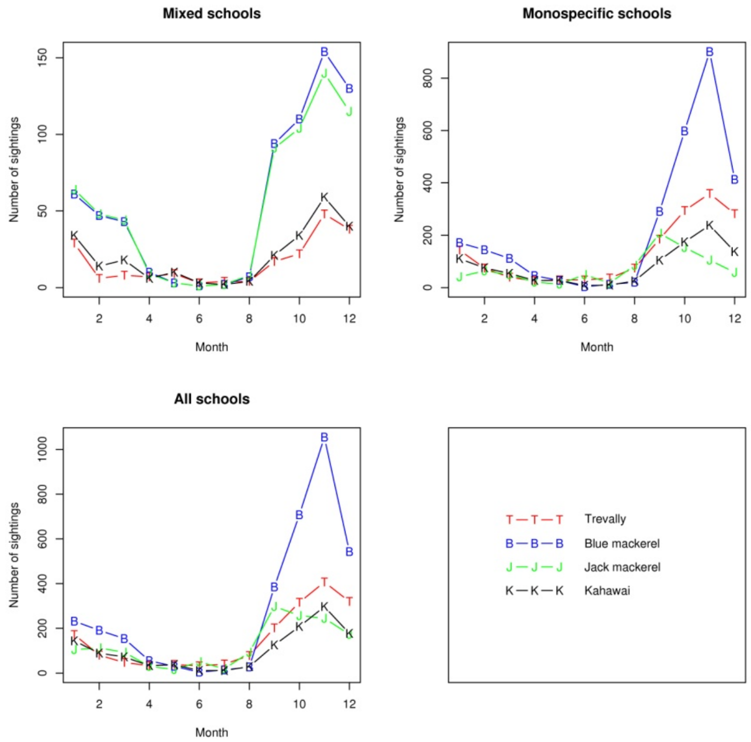

Figure D2: Monthly distributions of all sightings of trevally, blue mackerel, jack mackerel, and kahawai from east Northland.

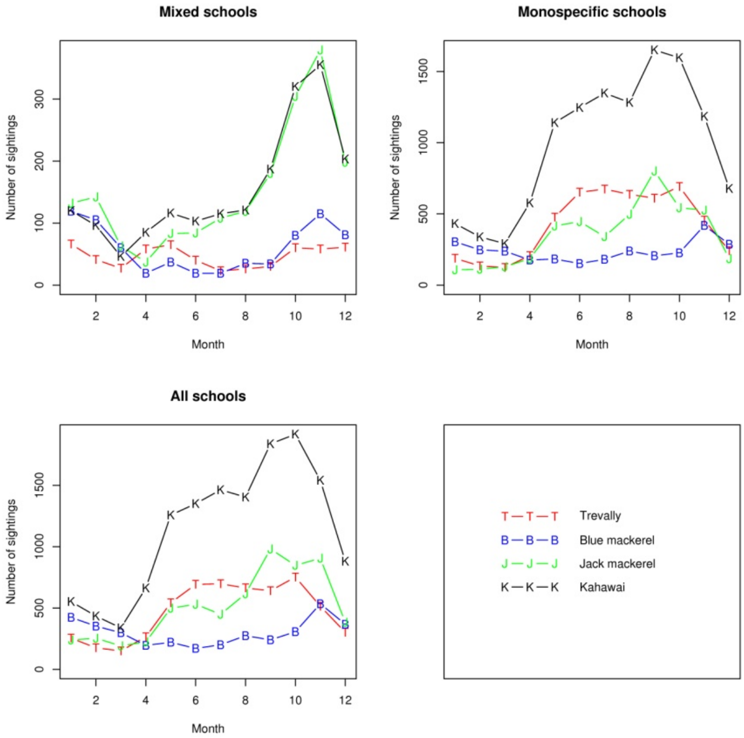

Figure D3: Monthly distributions of all sightings of trevally, blue mackerel, jack mackerel, and kahawai from the Bay of Plenty.

Appendix E: A simulated aerial survey method using observational aerial sightings data of inshore schooling pelagic finfish species.

Authors: Ian Doonan & Paul Taylor.

1. Introduction

This appendix describes additional work for the MFish project PEL2006-01 carried out under SAP2008-26 as a result of discussion during a Northern Inshore Technical Working Group meeting held at MFish Wellington on 4 February, 2009.

Objective:
To carry out a simulation study using sightings data from the MFish (now MPI) aerial sightings database *aer_sight*, to estimate the amount of flying required to complete a generic aerial survey of the main target species of the domestic purse-seine fleet and indicative costs for such a survey.

2. Methods

2.1 General

The simulation was carried out using a set of customised functions written in *R*. Commercial sightings data were used to form the spatial distribution of sightings and also to give the variability of the total number of sightings in the area by day. For a simulation, the random total number of sightings was picked and each sighting randomly positioned in the area via the spatial distribution. Using a specified number of transects, a simulated survey was done over the area. This survey was repeated for specified number of days. The mean number of sightings over these surveys was the index for the year. By varying the number of transects and days surveyed, the precision of the annual index could be investigated.

2.2 Data

Data were selected from the MFish (now MPI) aerial sightings database *aer_sight* (Fisher & Taylor, 2001) for those years since collection first included GPS sightings positions (June 1998); selection was restricted to pilot #2 only. This provided sightings by species from the Bay of Plenty. For this analysis, the Bay of Plenty was defined as the area covered by grid squares 112, 113, 129, 130, 146, 147, 148, 149, 150, 164, 165, 166, and 167 (see Figure 1, main document). This definition applies to all discussion in this appendix unless stated otherwise.

For each species (trevally, blue mackerel, jack mackerel, and kahawai), the data were split into three different yearly groupings — 1999–2001, 2002–2004, 2005–2008. Seasons were assigned to the data based on the following monthly groupings — spring (September, October, November), summer (December, January, February), autumn (March, April, May), winter (June, July, August). Data for these groupings were examined to determine seasons of high sightings and low sightings.

Daily data for each yearly grouping were scaled up to the whole Bay, and these were normalised to eliminate between-year variation in the mean daily sightings and biomass data.

2.3 Scaling and normalising sightings and biomass

BayTime: the time to fly across whole area so that every part is covered once; this value was estimated as 7.8 hr based on a flying speed of 80 kt and a flightpath with legs separated by 10 n. miles.

t_i the flight time for day i.

f_i scaling-up factor for day i (= BayTime/t_i).

s_{yi} sightings in the Bay on day i in year y (= number of sightings$_i$ × f_i).

N_{yi} normalised daily sighting numbers in the Bay for day i in year y

$$= s_{yi} \frac{N}{mean(s_{yi})}$$

where N is the (assumed) true total number of schools in the Bay that can be at the surface. For the simulations here, N was set to 6 and 21.

A similar method was used to normalise the number of tonnes (referred to as biomass).

Seasonal variations in sightability and those due to other factors such as the behaviour of the fish are contained within s_{yi}. No further account of sightability factors was taken except in a crude way to account for seasonal variations with two periods being simulated, a "low" season when sightings were low, and a "high" season when sightings were at a maximum. These seasons were chosen with the aim of using data from a period when sightings were reasonably consistent i.e., did not fluctuate too much.

2.4 The survey area

A survey area was initially defined based on the distributions of the four species of interest. Sighting positions of each of the species were plotted within the Bay of Plenty and a common boundary drawn that included most of the sightings (Figure E1). Once the decision was made to work with the kahawai distribution only, this survey boundary was revised to provide an optimal area for the kahawai distribution (see Figure E3).

2.5 The detection function

Line transect methods use a detection function to account for the decreasing probability of an observer detecting an animal the further away (in a perpendicular direction) from the transect it is. A detection function was created based on discussion with the senior spotter pilot. It was not possible to define the detection function from the *aer_sight* data because distances over which sightings are detected are not recorded in the observational dataset. Any detection function defined here had to be based on the pilot's experience. Information was collected in real-time by an observer during fish-spotting flights (Section 6 below) and used to generate a general detection function. This information-gathering comprised attempts to collect data which ultimately proved to be beyond the scope of casual observations during flights whose primary purpose was part of the fishing operation. Consequently, input data were generated in discussion with the senior pilot. What was required was an estimate of the distance over which the pilot could identify species, which would vary according to the environmental conditions affecting sightability during a flight. The observer's notes indicate that this distance can vary from about 3–4 n. miles under the poorest conditions, to about 10 n. miles when conditions are best.

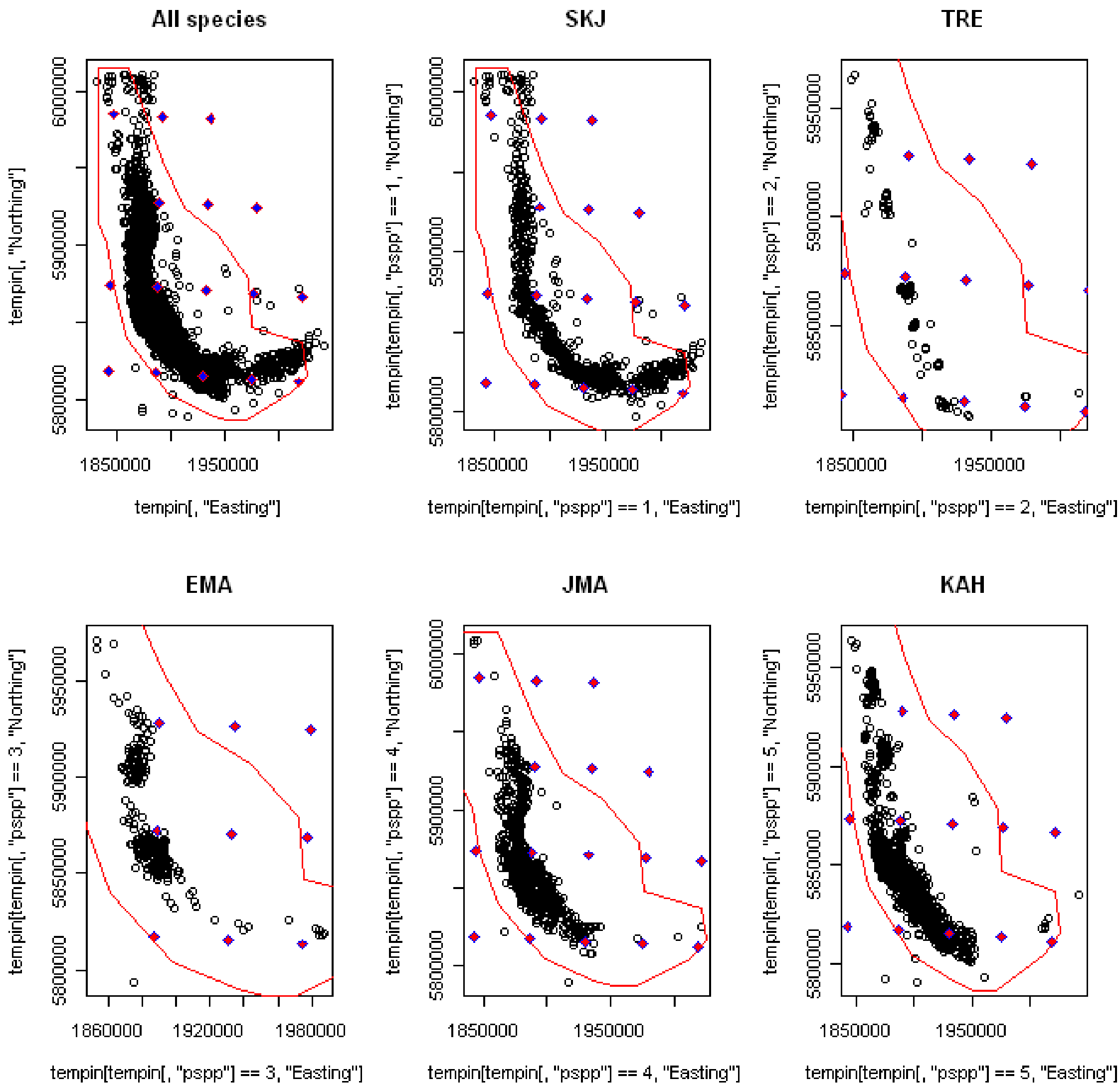

Figure E1: Distributions of sightings of the five main purse-seine target species in the Bay of Plenty (open circles), effort centred by half degree square (diamonds), with a suggested common survey boundary (solid line); axes are Easting and Northing but labels contain species selection code.

In defining the detection function, constant conditions were assumed, such that the probability decreases linearly with distance along the perpendicular axis from the transect to a maximum distance of 5 n. miles (Figure E2), which is the defined half width (d.5) based on a maximum sighting distance of 10 n. miles from the observations discussed above. The factor of interest for the biomass calculation is the effective half width, the area under the detection function curve.

Daily variation in sightability underlies the assumption that a survey will require more than one day of sampling. Sightability can be considered an analogue of catchability and its variations may be the result of a number of components including visibility and behaviour of the fish. In part, this includes variability of the detection function so no explicit variability in the detection function was included in the simulations.

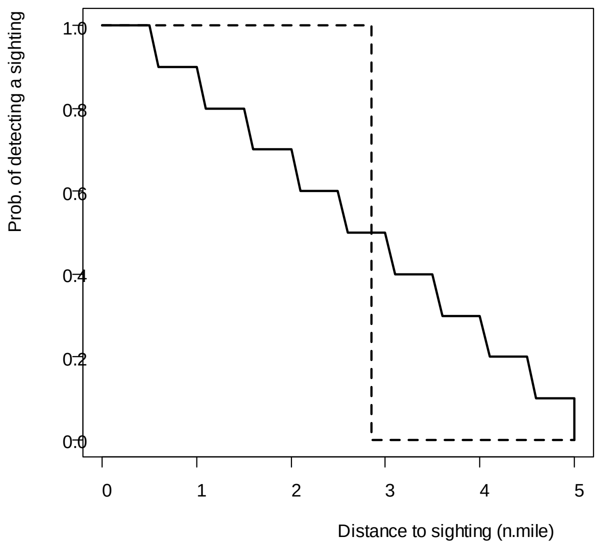

Figure E2: Features of the detection function developed for use in the simulation study; the stepped diagonal curve is the detection function and defines the probability of detecting a sighting at a given perpendicular distance from the centre line; the area under the broken line equals the area under the detection function, thus determining the position of the vertical portion of the broken line and defining the effective or half width (denoted d.5 elsewhere).

2.6 Transects

An *R* function was written to place a transect "grid" within the virtual survey area. A north-south orientation of transects was adopted to allow a simple placement method (Figure E3). The first transect (westernmost) was randomly placed and the others were systematically placed to the west of it. Transect length was determined by its intersection with the northern and southern survey boundaries.

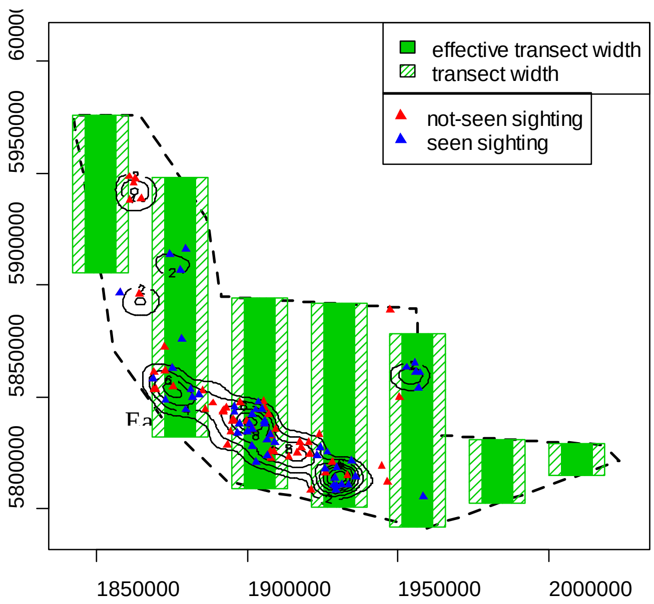

Figure E3: Features of the simulated survey showing the survey boundary (broken line) and 7 transect lines, the total and effective transect widths, an example probability surface and the distribution of observed and unobserved sightings.

Placement of the first transect was determined by the following steps.

a. The width of the survey area was divided by the number of transects being placed (*n*).
b. The first transect (transect 1) was placed randomly (in a horizontal sense) within its space as allocated in a above.

2.7 Effective survey area and total sightings

The effective area surveyed is a product of the total length of the transects (L) and the effective width of the transect. The effective width of the transect is twice the half width ($d.5$). Thus, the effective area surveyed is given by

$$A_e = 2 * d.5 * L$$

and the total sightings (or biomass) in the survey area (A_s) is given by

$$N_{tot} = N_{obs} * {}^{A_s}\!/_{A_e}$$

where N_{obs} is the number of sightings (or biomass) encountered during a single survey and A_s is the survey area.

2.8 The probability surface

The spatial distribution of sightings for a given species-season-yeargroup was used to produce a probability surface where normalised sightings were first distributed and then sampled during each simulated survey (Figure E3). Probability surfaces were produced in *R* using the average-shifted-histogram (ASH) technique (Scott 1992; referenced by Venables & Ripley 1994). In the present context, a three-step process was required to produce a surface for the sightings that was adjusted by flying effort.

a. Produce probability surface for sightings (s_1).
b. Produce probability surface for effort (s_2).
c. Produce effort-adjusted surface ($s_3 = s_1/s_2$).

2.10 Simulations

2.10.1 Annual index calculations

The following steps comprised a simulation run.

a. A season and year was selected from the full dataset.
b. The probability surface was estimated.
c. The number of surveys (*n_surv*) in the season and the number of transects in each survey (*n*) were specified.
d. The *n_surv* surveys were simulated.
e. The simulated index was calculated as the mean of the *n_surv* values.
f. The simulation was repeated up to 500 times.
g. The mean number and coefficient of variation (*CV*) of the simulated indices were estimated.

Simulation runs were repeated for different combinations of season and year group, *n_sury* and *n*.

2.10.2 Simulations

Due to time constraints, simulations were carried out as following:

a. Simulations were restricted to the most recent kahawai, high-sightings season dataset; this provided a dataset with a high volume of sightings.

b. n = 5 transects were used and the normalising constraint was set at 6 sightings; 100 simulations comprised each run. This set was used to explore variance and whether the surveys were biased or not.

c. Initially *n_surv* was set to 1 and *CV*s for other values of *n_surv* were estimated using $CV_{pop}/\sqrt{n\_surv}$, where CV_{pop} is the *CV* from using *n_surv* =1.

d. In the final runs, n = 7 was used and the normalising constraints set to 6 sightings (1200 t) and to 21 sightings (4000 t). *N_Surv* is 1.

3. Results

3.1 Examining performance of the simulated survey

3.1.1 Normalising on 6 sightings

The distribution of daily normalised sightings (Figure E4) shows a range from zero to about 30 with a peak at about 3, which illustrates the wide range of variability in the data. Most data lie between zero and 15.

Scatter plots of estimated sightings on the true number of sightings (Figure E5) indicate little bias but wide scatter throughout the range.

Plots of *CV*s against the true number of sightings show a reducing trend with increasing number of sightings (Figure E6).

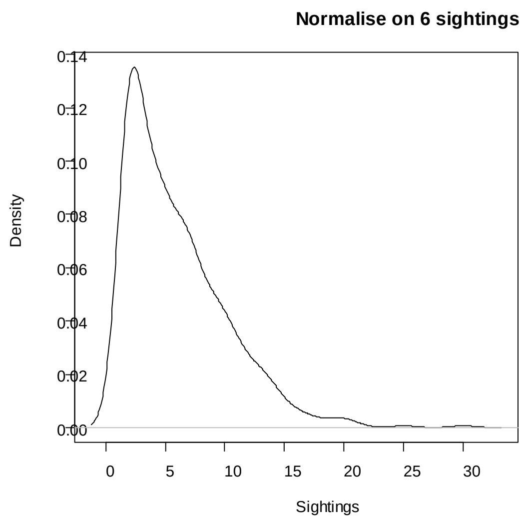

Figure E4: Density of sightings normalised from an assumed true total of 6 sightings in the Bay of Plenty.

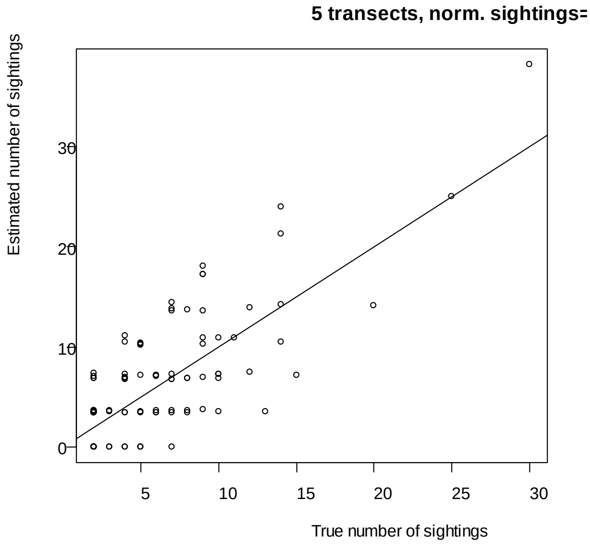

Figure E5: Estimated number of sightings versus "true" number of sightings (with y=x reference plot); sightings normalised from an assumed true total of 6 sightings in the Bay of Plenty; estimated sightings from simulation model using 5 transects.

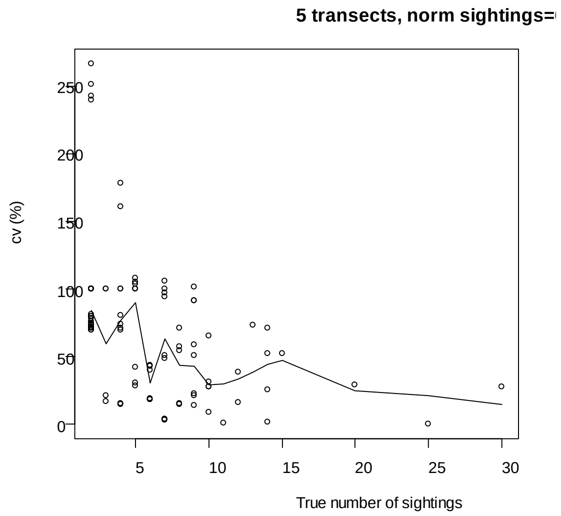

Figure E6: *CV*s of the estimated number of sightings from surveys; sightings normalised from an assumed true total of 6 sightings in the Bay of Plenty; estimated *CV* s from the simulation model using 5 transects.

Table D1a shows the mean and CV_{pop} for the number of sightings estimated from the simulation and the number of sightings from the assumed true distribution. In Table D1b, predicted *CV*s from the simulations are good for sightings when the number of surveys per year is 15 or more (e.g., 21% for 20 surveys), but they are poor for biomass (i.e., 43% for 20 surveys).

Table D1a: Mean number and CV_{pop} of sightings and biomass over days for the data, and 100 simulated surveys using transects; sightings were normalised to 6 over the year and species.

Source		Estimated number of sightings	True number of sightings	Biomass
Normalised sighting data	Mean		6	1238
	CV_{pop} (%)		70	151
5 transect surveys	Mean	7	6	1208
	CV_{pop} (%)	96	80	191

Table D1b: Predicted *CV*s (%) for indices using *n_surv* surveys from population *CV*s in Table 1a.

Source		No of surveys (*n_surv*)			
	CV_{pop} (%)	5	10	15	20
Sightings	96%	43	30	25	21
Biomass	191%	85	60	49	43

3.2 Final results

Simulation *CV*s based on the 6 sightings normalisation approximate the predicted *CV*s but are a little lower (Table D2); simulation *CV*s based on the 21 sightings normalisation consistently have lower values than the 6-sightings *CV*s.

Table D2: Coefficients of variation (*CV*s) — predicted and estimated by simulation based on sampling from two normalising factors and 7 transects; all *CV*s are expressed as percentages: M is the number of simulated iterations. Source: MPI aerial sightings database *aer_sight.*

	No of surveys (*n*)			
	5	10	15	20
1. Predicted *CV* based on √n and 5 transects				
CV_{pop} = 96% (sightings)	43	30	25	21
CV_{pop} = 191% (biomass)	85	60	49	43
2. Simulation *CV*, normalise on 6 sightings and 7 transects				
M*	200	100	133	100
CV, sightings	39/39	27/26	22	19
CV, biomass	79/82	52/58	42	40
3. Simulation CV, normalise on 21 sightings and 7 transects				
M*	400	200	133	100
CV, sightings	34	25	19	17
CV, biomass	71	48	39	36

4. Conclusions

A sightings index using 7 transects has reasonable *CV*s (20–30%), but only if the number of surveys is 10 or more. For the biomass index, *CV*s are high even at 20 surveys.

5. Acknowledgments

Many thanks to Red Barker for assistance with several details including defining the detection function.

6. Appendix 1: Notes from observer's flight with spotting pilot

Notes from discussion during an observer's (Shane Grayling) flight with the senior spotter pilot Red Barker over the Bay of Plenty on August 28 2009.

Here is the brief summary of my flight. Typically the pilot flies at 1000 feet.

Basically he thinks he can predict species 3–4 miles out, although a lot of the prediction is based on depth of species (KAH is typically shallower than JMA and EMA), and also what has been spotted in the area previously, particularly in the weeks/days leading up to that flight.

Generally KAH are easier to predict than the other species, from a distance, JMA can be easier to predict as it is usually a darker colour, although when you get close again it is greens and blues that confirms which JMA species it is. From a distance, if the school "fizzes" then that makes it easier to predict.

It is difficult to predict tonnage from a distance, although you get a good indication from 3–4 mile out, there can be fish deeper, not obvious from a distance, and the school may not be concentrated on the surface.

Mixed schools are harder to predict, particularly proportions. Again a lot of prediction is based on previous findings, if there are 3–4 schools in an area, and the first school spotted is mixed, a lot of the time the others in close vicinity will be also, although the proportions are often different, and can only be confirmed when flying directly over.

Obviously the environmental conditions play a big part in the distance you can accurately predict, everything from light levels, wind, swell, water clarity, cloud cover rain all play a part. On a really good day you could see a school 10 miles away.

Appendix F: Investigating aerial survey methods for schooling pelagic finfish — salient features of two possible approaches

	Feature	Method 1[15]	Method 2
a.	Objective of survey:	to estimate annual relative abundance for several inshore schooling pelagic species.	as with Method 1.
b.	Dates of survey:	species- and season-dependent; to be determined.	as with Method 1.
c.	Basis for survey design:	distance sampling.	photogrammetric sampling.
d.	Data collection method:	field recording.	photographic images for surface area of individual schools, point-set sampling for school surface area:density relationship, school height from vessel sonar/sounder.
e.	Data collection medium:	touch-screen PDA with CYBERTRACKER.	Instruments as for the Aerial Imaging Solutions photogrammetric aerial digital camera mounting system and data acquisition system, see details of the system at: http://www.aerialimagingsolutions.com; various paper data-collection forms for pilot and purse-seine skipper.
f.	Timing & duration of flights:	possibly species dependent considerations — decision based on examination of opportunistic aerial sightings data for diurnal patterns.	as with Method 1.
g.	Seasonal timing and area:	preliminary examination of opportunistic aerial sightings data suggests multi-species approach is feasible; more fine-scale examination may provide basis for species-specific considerations.	as with Method 1.
h.	Environmental constraints:	all efforts are made to perform surveys when conditions are optimal; preliminary work will be carried out to define minimum conditions to provide directions on making decisions under less favourable environmental conditions; essentially, conditions of strong wind, late spring and early summer storms, low cloud and fog might be avoided.	as with Method 1.
i.	Unit for object of interest:	fundamental unit is the sighting (group of schools), with records of school size (tonnes) necessary for relative abundance estimation.	school size estimated from school surface area; the scale (RF) of the photograph was estimated by the equation RF = F/A where F is the focal length in cm and A is the altitude

[15] The suggestion is to incorporate into Method 1 the photogrammetric technique for estimating school biomass from school surface area, though details are not repeated here.

			in cm; the total observed surface area was calculated per transect and assumed to represent a minimum estimate of available school surface area; no information on school density was available — uniform density in all schools was assumed.
j.	Flightpath descriptor:	transect grid positioned at random to the sampling area with care to avoid placement parallel to “some inherent pattern that makes the sample unrepresentative of the population”.	as with Method 1.
k.	Flightpath recorded:	yes.	as with Method 1.
l.	Number of observers:	one might suffice depending on whether the pilot or the observer(s) is made responsible for making the initial observation; observers likely to be responsible for any photography though this would tend to be when the plane is away from the transect.	one would suffice.
m.	Seating arrangement:	several possible contingencies depending on whether one or two observers involved.	observer to have clear view of schools for determining species composition.
n.	Pilot’s role/tasks:	flying aircraft; safety; follow design; properly search for schools out to the defined outer distance limit (focusing most effort on and near the line causes bias); estimate school size; to identify position when the plane is perpendicular to the location of the sighting; and to relay the sightings information to the observer (through the intercom?) for recording; relay environmental data to the observer for recording.	fly plane.
o.	Observers’ role/tasks:	record data onto the computer; monitor altitude; record environmental and any other ancillary data; photography.	record species composition data onto the computer; record environmental and any other ancillary data; maintain/monitor photography instrumentation.
p.	Species ID method:	based on current knowledge this would have to be responsibility of the pilot, but need to standardise this task for the future — use of photographs seems best approach.	Work towards a method for determining school composition independent of spotter pilot’s involvement.
q.	Measuring perpendicular distances:	fly to sighting and directly record position using GPS waypoint, then estimate distance as part of initial data examination.	NA.

r.	Prescribed survey altitude:	to be determined; Guenzel works at 91.4 meters (300 feet); current opportunistic data collected at about 200’.	optimal flying altitude was 4000 feet for sardine survey.
s.	Altitude measure:	wing-mounted digital radar altimeter, linked with Bluetooth to PDA; record at beginning and end of each transect and at 30 min intervals during the transect flight.	the data acquisition etc system to record altitude, GPS position, spotter observations.
t.	Number of aircraft & pilots:	one on transect at any time; one pilot in the short term.	for sardine survey two planes working on separate transects; one pilot per plane; — allowed recording of fast-moving species.
u.	Environmental data collected:	visibility, sea condition, wind speed and direction, SST from wing-mounted IR sensor, linked with Bluetooth to PDA.	at the beginning of each sardine survey and at the end of each transect leg, pilots recorded their estimation of wind strength and direction, visibility, cloud cover, and water colour; radio contact with local sport fishing boats targeting bluefin allowed the spotters and observer to sollect general information on sea surface temperature, sizes of landed fish, and additional sightings.
v.	Modelling environment(s):	DISTANCE and R.	R with custom code.
w.	Major changes to method:	NA.	method developed from pilot study in 2008 – in 2011 geographical range of survey was extended both north and south.
x.	Aircraft type:	Cessna 175.	×2 single engine; ×1 twin engine; makes and models unspecified; dedicated camera port used in USA sardine survey.
y.	Total flying effort:	to be determined.	to be determined.

Appendix G: The Aerial Imaging Systems Forward Motion Compensating (FMC) Mount System for Photogrammetry

The following includes information from the Aerial Imaging Solutions website[16] and information supplied directly by Aerial Imaging Solutions.

The FMC Mount System (Figure G1) is a turn-key aerial mount system for digital cameras that reduces image blur caused by forward motion of the aircraft while the shutter is open. The mount and camera are connected to, and remotely controlled by, a program running on a notebook computer. Flight and camera parameters entered by the computer's operator determine the required forward motion compensation (FMC) and camera firing interval. The system also takes data inputs from its integrated GPS receiver and the aircraft's radar altimeter and will, optionally, use these data to automatically determine the required FMC and firing interval. The system includes a remote viewfinder that displays the image seen through the camera's eyepiece on the computer screen, or on a small monitor, to permit the computer operator to observe camera operation and ensure successful coverage of sites. It also includes a data acquisition system that interfaces with the camera, GPS, radar altimeter, and computer to record position and altitude readings as each frame is collected.

This mount is a single-camera system. There are also three-camera systems available (Figure G4); images from this system can be stitched together using Photoshop. In the US, the NOAA National Marine Fisheries Service uses these systems extensively to monitor protected species. NOAA's Southwest Fisheries Science Center, the Alaska Fisheries Science Center, and the National Marine Mammal Laboratory have published papers regarding methods and results. Additionally, New England Aquarium uses the single-camera mount to perform field survey work for marine resource characterization in waters off the coast of Massachusetts (Taylor et al. 2014).

The systems usually go in aircraft with dedicated camera ports. Figure G2 is a drawing of the single-camera mount assembly to illustrate the dimensions and hole diameter required at various distances above the hole. The diameters shown are for a 24 mm lens on a 35 mm camera. For example, with the mount sitting right on the floor above the camera hole, the hole should be 5" for this lens. Narrower angle lenses can get by with smaller holes, but never less than about 4" because of the motion compensation.

[16] http://www.aerialimagingsolutions.com/home.html

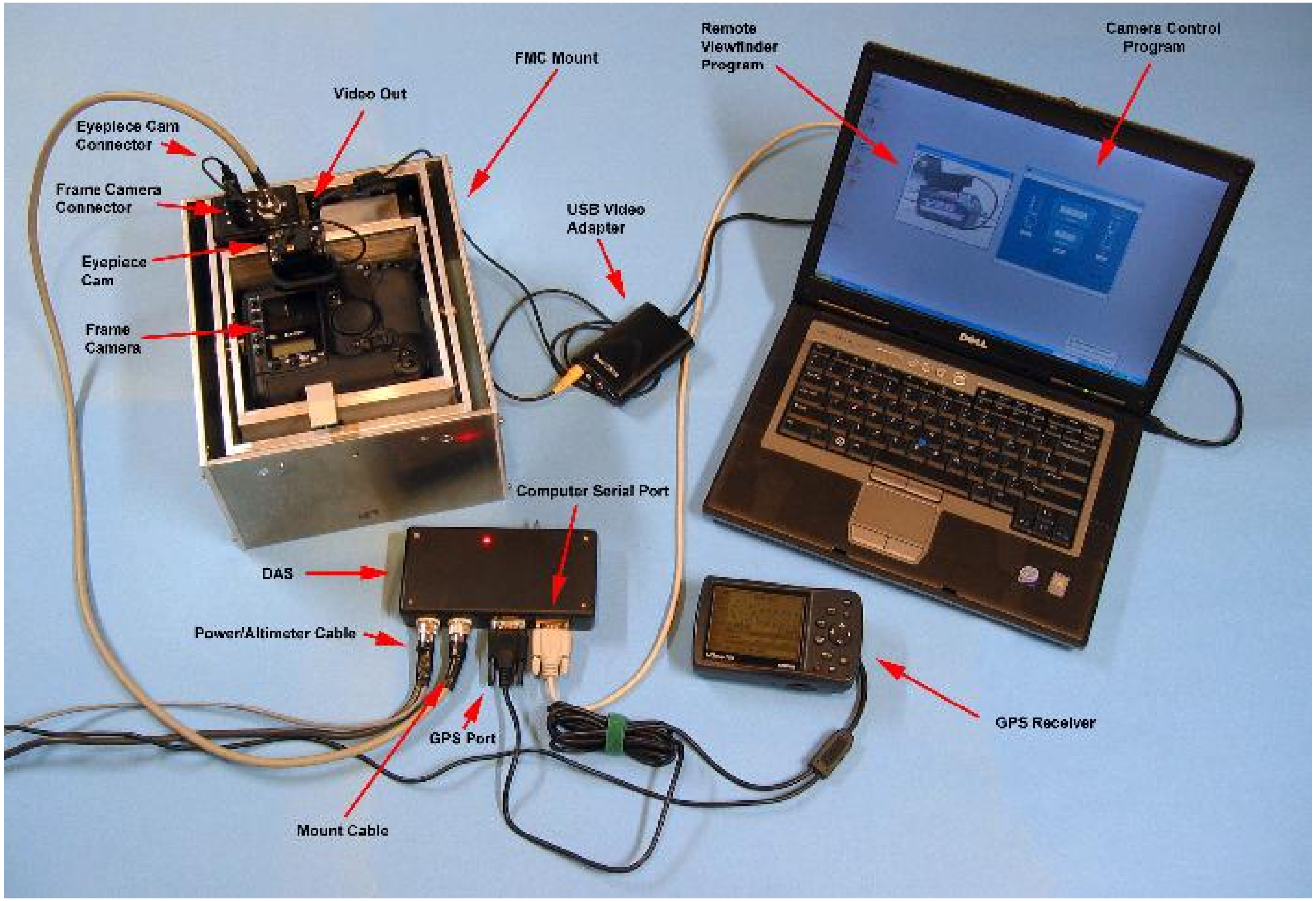

Figure G1: The FMC Mount System.

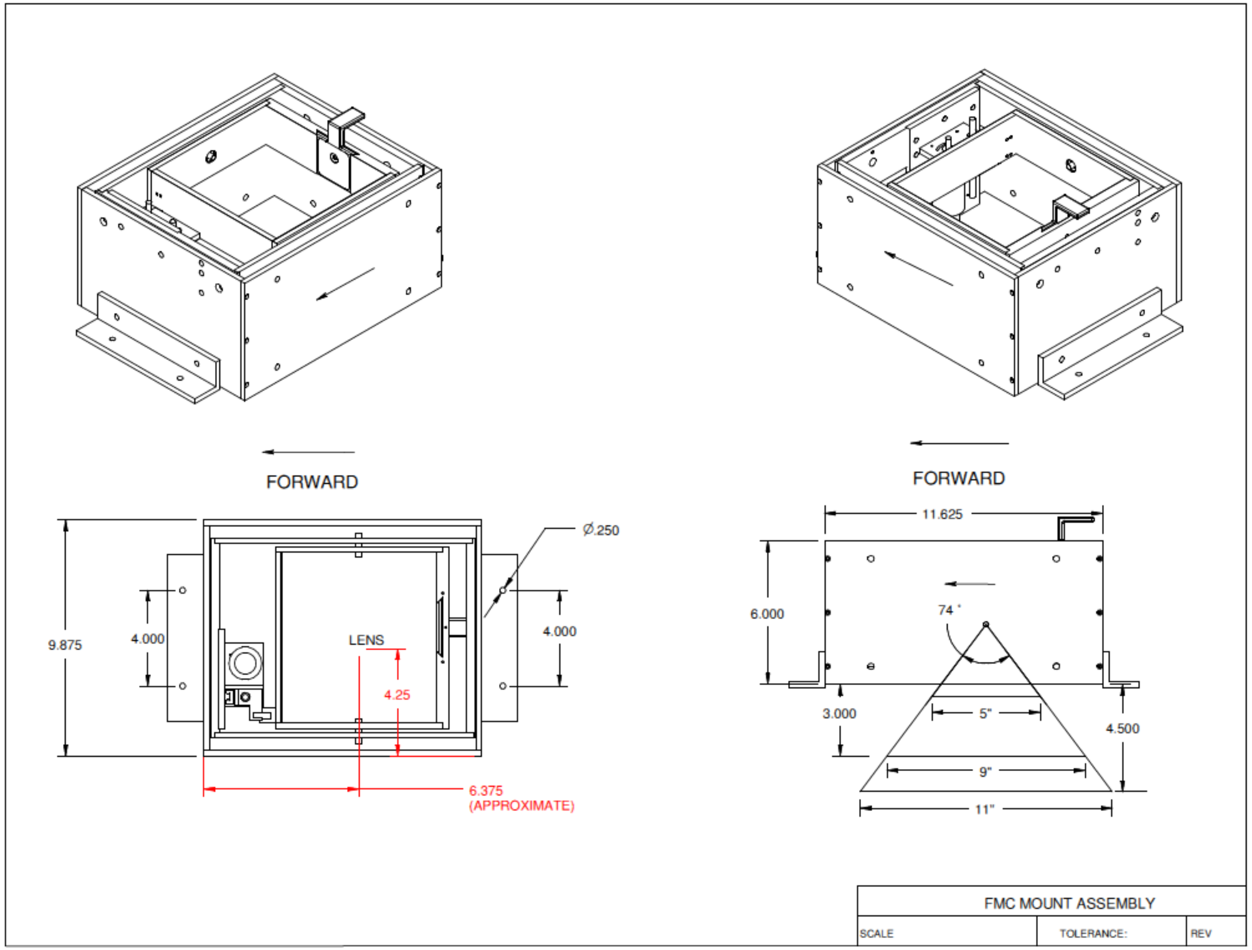

Figure G2: Dimensions and perspective of the single-camera FMC Mount assembly and camera port.

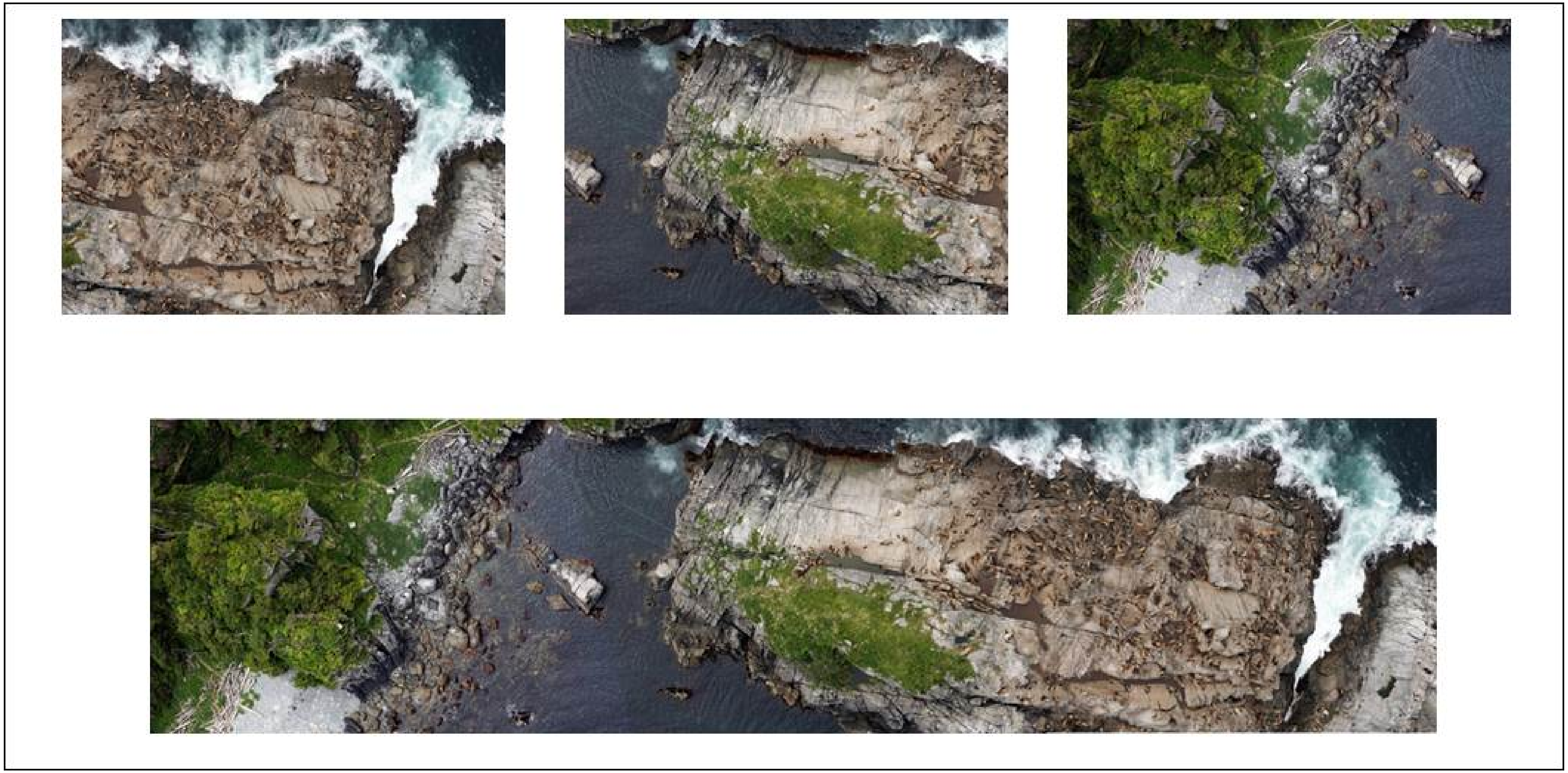

Figure G3: Three images recorded using the 3-camera FMC mount (top) and the three images stitched together using Photoshop (bottom).

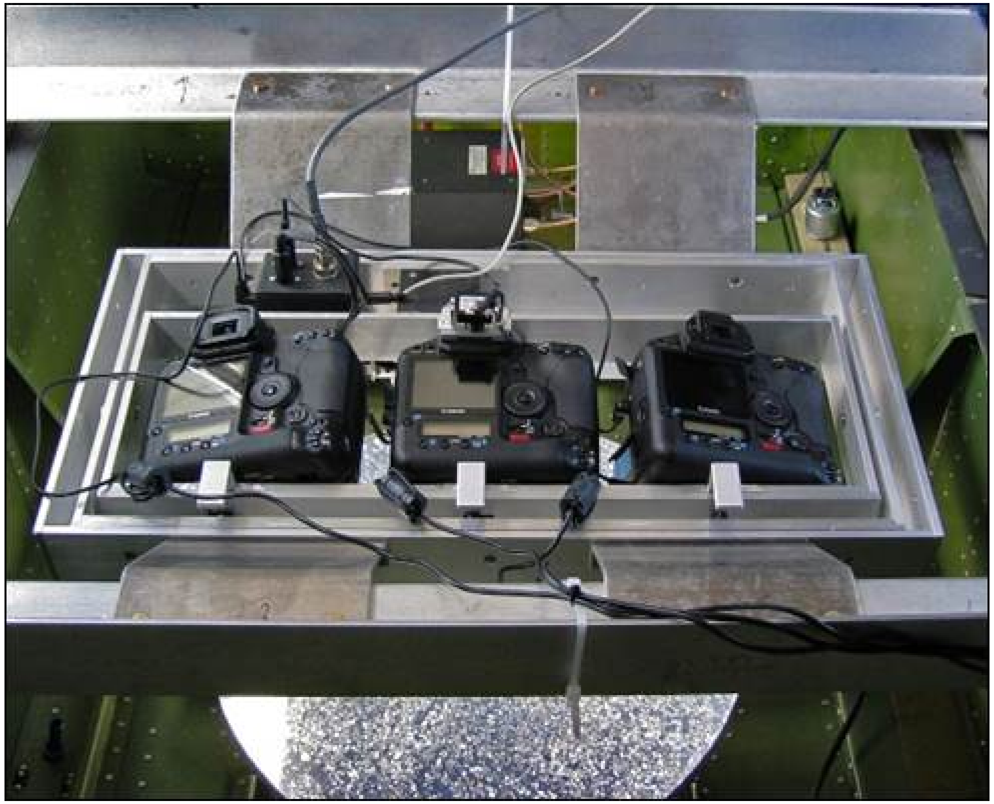

Figure G4: The 3-camera FMC Mount assembly.