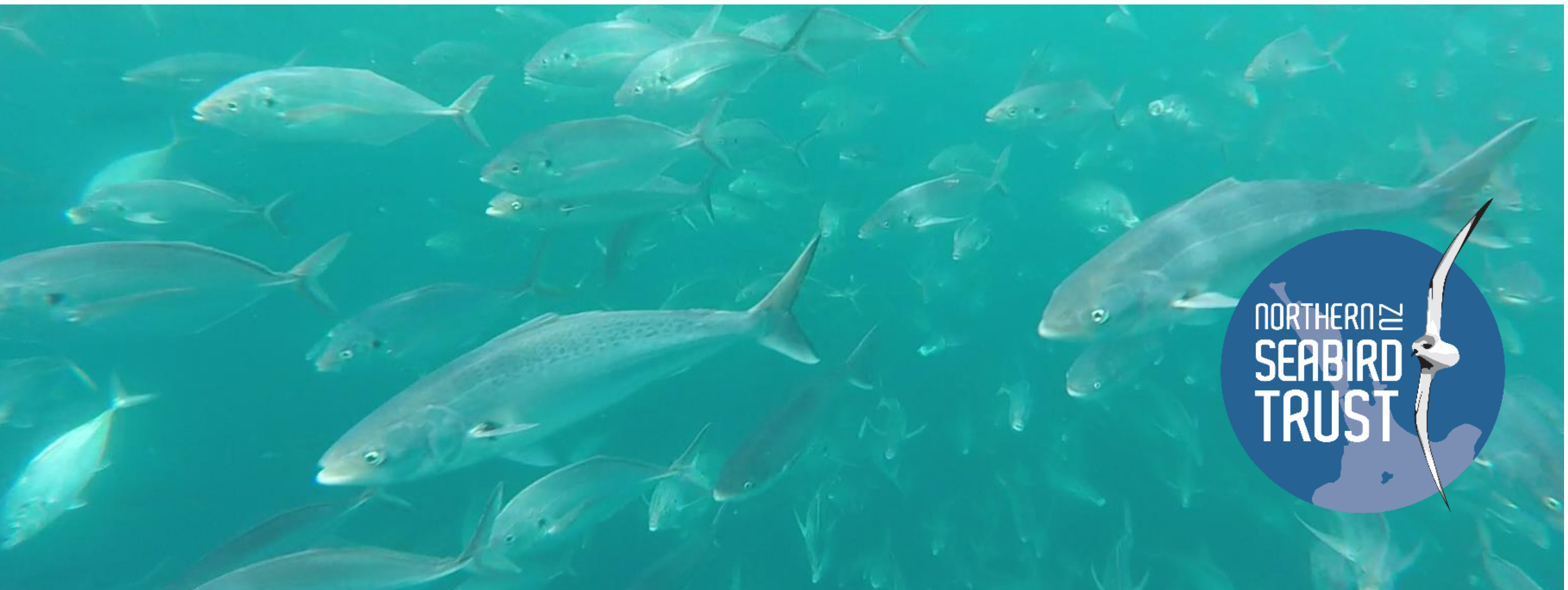
Fish shoal dynamics in north-eastern North Island

POP2019-02

Milestone 1: Proposed methodology



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Cover images: (top) Buller's shearwaters and fairy prions feeding in association with blue mackerel. Photo: Edin Whitehead; (middle) Drone image of a tightly packed trevally school, Hauraki Gulf. Photo: Richard Robinson, Depth NZ; (bottom) Screenshot from underwater videography of kahawai and trevally school, Hauraki Gulf. Image: NNZST

Figure 1 (this page): Drone image of trevally school and launch, Hauraki Gulf. Photo: Richard Robinson, Depth NZ

Contents

1 OBJECTIVE ONE

Identify zooplankton and other prey foraged by different fish shoal species and compare with previous data to better understand how interspecific differences in temporal and spatial fish shoal foraging affects dietary requirements of seabird populations.

1.1 Introduction

A notable feature of north-eastern North Island waters, from the Three Kings Islands to East Cape, are the large numbers of seabirds feeding in association with concentrations of zooplankton and fish. These multi-species feeding aggregations are colloquially known in New Zealand as 'fish shoals', 'workups', 'boil ups', or 'bait balls'. Within this report, they will be termed 'workups'. While the marine megafauna feeding activity has been described to varying degrees, the zooplankton and fish responsible for these events and the dynamics which drives them is poorly understood in New Zealand.

There is a need to understand the processes that drive workup formation and dynamics as many seabird species, predominantly red-billed gull (*Larus novaehollandiae scopulinus*), white-fronted tern (*Sterna striata*), Australasian gannet (*Morus serrator*), fairy prion (*Pachyptila turtur*), Buller's shearwater (*Puffinus bulleri*), and fluttering shearwater (*P. gavia*), are potentially dependent on shoaling fish to drive prey to the sea surface, making them accessible as a food source. There is poor knowledge of both the relationship between the diet of surface-foraging seabirds, and what prey items are being made available to seabirds from workups. This is limiting our understanding of the mechanisms through which any changes in the distribution and/or abundance of fish workups may be driving seabird population changes (population status and annual breeding success). For several seabird species that interact with fish workups, their recent population abundance data are also incomplete or unknown which limits our assessment of population trends over time.

North-eastern North Island waters also support extensive purse-seine fisheries, due to the presence of the aforementioned large shoals of fish. Fish species include kahawai (*Arripis trutta*), trevally (*Pseudocaranx georgianus*), skipjack tuna (*Katsuwonus pelamis*), jack mackerel (*Trachurus declivis*), blue mackerel (*Scomber australasicus*), saury (*Scomberesox saurus*), pilchard (*Sardinops sagax*) and anchovy (*Engraulis australis*). By targeting fish species which are also part of workups utilised by various seabird species, purse-seine fisheries potentially negatively impact these seabird populations. However, the degree to which this may occur is unknown, therefore it is important that we better understand the relationship between seabird population trends and changes in abundance and distribution of fish shoals.

1.1.1 Aim

This research project (POP2019-02: Fish shoal dynamics in north-eastern New Zealand) builds on previous work from INT2016-04 (Indirect effects of commercial fishing on Buller's shearwater and red-billed gulls), and POP2017-06 (Indirect effects on seabirds in north-east North Island region). Previous findings have elucidated the types of prey foraged by seabirds during workups. However, little is known about; (1) the mechanisms that drive the occurrence of fish shoaling activity that is frequently associated with specific pelagic fish species, (2) the nature of the link between fish shoaling activity and seabird feeding, or (3) the potential impact from purse seine fisheries on seabird feeding and population success. To continue to address the shortfall in current knowledge, field research in the Hauraki Gulf for 2019-2020 will focus on the first two of these areas and will be conducted in similar locations to the previous projects, allowing comparison with this previous data.This report details the methodology that will be used for the at-sea surveying and sampling of shoaling fish and zooplankton and associated workup activity, the laboratory analysis of samples, and the subsequent analysis of data obtained.

The aim of this study is to characterise the biological composition of workups by determining the associations among the presence of zooplankton, shoaling fish, and feeding seabirds. This will be achieved by looking at the associations between zooplankton prey, such as euphausiids, and their fish and seabird predators. Some key environmental parameters that potentially affect the spatial and temporal distribution of zooplankton and also their predators will be analysed.

1.1.2 Goals for Objective One

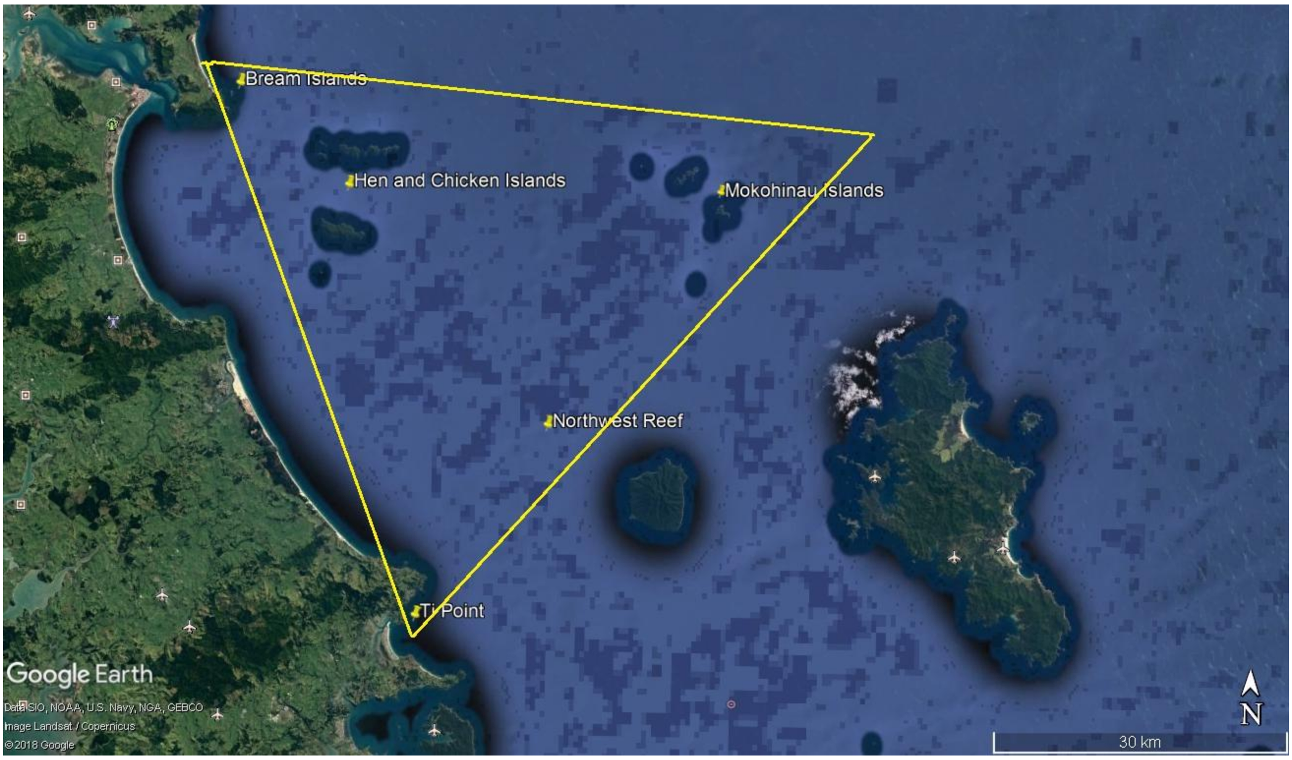
- Design and test a high-speed zooplankton net that will capture both large zooplankton, such as euphausiids, as well as smaller zooplankton via a finer mesh net nested inside, from fish shoaling workups. The performance of the net will be compared with the fine mesh zooplankton net used previously to determine the comparative ability of the two types of net to capture larger zooplankton. This net will also be evaluated for its capacity to sample small fish species associated with workups. From previous work, euphausiids, of various life stages, appear to be a key prey item of both seabirds and shoaling fish, but may not have been representatively captured in the previous years of study because of avoidance of the slowly towed fine mesh net.
- Conduct horizontal, surface high-speed zooplankton net tows both within as many fish shoaling workups as resources allow and also in nearby areas without workups to produce quantitative data on zooplankton composition and abundance. Compare differences in the zooplankton composition and abundance, inside and outside of workups, and temporally and spatially to determine the influence of workups on the availability of seabird prey.
- Sample environmental variables within as many fish shoaling workups as resources allow and also in nearby areas without workups. Compare these environmental variables inside and outside of workups, and temporally and spatially to determine if environmental variables may play a role in initiating workups.
- Record the presence of seabird species during workups and their feeding behaviour to determine potential links between species seen feeding and zooplankton composition and abundance.
- Capture fish from workups, both the smaller baitfish and the larger fish species in order to analyse their stomach contents. Determine the types of zooplankton present and the relative numerical proportions of each type. Compare the stomach content data among different fish species and with the composition and abundance of zooplankton sampled by net tows.
- Conduct energy analysis of potential seabird prey items caught – zooplankton and small fish. Look for potential differences in energy content, such as spatial and temporal variation and inside versus outside workups.

1.2 Field work methods

1.2.1 Study area

Field research will be undertaken in similar locations to the previous projects (INT2016-04 and POP2017-06) in order to make comparisons between data sets. This study area forms a roughly triangular area between Ti Point, Mokohinau Islands and Bream Islands (Fig. 2).

Figure 2. Study area.



1.2.2 Survey trips

The field research period will run from October 2019 – April 2020. During this time, survey trips will be undertaken to cover spring (Oct-Nov), early summer (Dec), late summer (Jan-Feb) and autumn (Mar-Apr). These will be conducted on 'volunteer' vessels operating from either the Whangateau or Whangarei Harbours. Two additional trips will also be undertaken, each of three day/two-night duration aboard the University of Auckland, Leigh Marine Laboratory's Research Vessel *Hawere*. Where possible, trips will be conducted during calm conditions (Beaufort 3 or less).

On each occasion the vessel survey route will be determined by finding areas in which workups are occurring. While underway, observers will continually scan the horizon using binoculars and naked eye to search for workups by looking for the presence of seabirds, marine mammals or disturbances at the sea surface by shoaling fish. Specific locations will be targeted where workup activity has been previously located and by searching other likely areas. Finding workups can be challenging and high-speed vessels, capable of covering large areas will be used.

On arrival at a workup, the following information will be recorded:

- Position using handheld GPS (record waypoint number in sample sheet then download at end of trip to enter coordinates).
- Any movement at the water's surface (i.e., appearance and disappearance) of the workups.
- The number and approximate area covered by workups, including if multiple workups occur at one location.
- The fish activity occurring and species present if possible, to be observed from the vessel.
- Species of seabirds present and provide abundance estimates. Record the extent and nature of feeding behaviour for each species. Note the identity of any prey seen in bird beaks.
- Any other marine megafauna present: e.g., marine mammals: species, abundance estimates and behaviour.

- Weather conditions (i.e., wind speed and direction, swell, sea state).
- Oceanographic data (i.e., sea surface temperate, salinity, water clarity, water samples for chlorophyll *a*).

The following sampling will be undertaken in workups (more details given in separate sections below):

- Zooplankton tows
- Underwater videography
- Topside photography
- Fish capture

1.2.3 Zooplankton sampling

A high-speed zooplankton net will be designed to more efficiently capture the larger, more mobile zooplankton that were likely under-represented in previous years of zooplankton sampling. This net will have a larger mesh (~5 mm) to the previous net and will be able to be towed at ~5 knots. A smaller net comprised of a finer mesh (~0.3 mm) will be nested inside the high-speed net to sample smaller zooplankton types. A flow meter will be integrated into the design to measure the water flow passing through the net and allow subsequent quantitative analysis of zooplankton samples. The addition of a tow camera (GoPro inside a PVC tube, closed at one end, open at the camera end) attached to the tow line, positioned to record the degree of zooplankton patchiness and net avoidance, will be trialled. However, the presence of the camera may cause or increase avoidance behaviour of zooplankton.

Avoidance of zooplankton nets by euphausiids is a common problem in zooplankton studies. In the previous work related to this project, when underwater video footage (of euphausiid swarms) was compared with what was captured in the plankton net, there were often considerable differences. The net used previously had a fine mesh (250 µm) and was towed at approximately 1.5 knots. The data obtained on the zooplankton composition and percentage numerical abundances of different types of zooplankton showed almost no differences between tows conducted inside and outside of workups, and the abundance of euphausiids in the sampled zooplankton was relatively low. The time taken in the laboratory to analyse the zooplankton samples was also considerable due to the presence of huge numbers of small zooplankton present, the abundance of which was found to not significantly differ inside and outside of workups. From the small amount of analysis of seabird regurgitations and fish stomach content undertaken previously, it was found that Malacostraca zooplankton, predominantly euphausiids, comprised the majority of the diets of seabirds and fish feeding in workups.

Horizontal surface tows (<2 m depth) using the high-speed zooplankton net will be undertaken both in workups and in the same vicinity once the workup has moved on/dissipated or nearby the workup area. Within each workup encountered, at least two zooplankton tows will be attempted. Positioning of the net to obtain a representative sample can be difficult due to the highly mobile and patchy nature of the zooplankton within the workup so repeat sampling may not always be possible. The tow duration, speed and start time and GPS position will be recorded.

On completion of a zooplankton tow, the contents of the cod end will be washed into a large sieve, fish will be removed, some killed for gut content analyses, and the remainder released alive. Several fresh zooplankton specimens will be removed from the tow sample, placed in a labelled ziplock bag and stored on ice for energy content analysis. The remaining sample will be subsampled if the sample is very large and then placed in a labelled sample container containing 90% ethanol for subsequent identification and enumeration. It will be important to ensure sufficient ethanol is present to preserve the sample. Subsampling will involve stirring the sample in a large jug until it is evenly distributed and then pouring a representative subsample into a container for storage, with a label recording the extent of the subsampling.

1.2.4 Fish sampling

Fish will be caught from workups in order to obtain stomach content and tissue samples. From previous observations, fish species occurring in workups are expected to include, but not be limited to:

- Pilchard, *Sardinops sagax*
- Trevally, *Pseudocaranx georgianus*
- Jack mackerel, *Trachurus declivis*
- Kahawai, *Arripis trutta*
- Skipjack tuna, *Katsuwonus pelamis*
- Blue mackerel, *Scomber australasicus*
- Saury, *Scombersox saurus*

The larger fish species (e.g., kahawai, trevally and skipjack tuna) will be caught using a hooked lure towed behind the vessel (Fig. 3). The smaller fish species (e.g., jack and blue mackerel, saury, pilchard) may be caught in the zooplankton net, but if this is not possible, a small surface hauled net and/or a sabiki rig deployed from a fishing rod will be tried. When fish are caught, they will be recovered to the boat as quickly as possible. The length and species of all fish landed will be recorded and any not required for stomach contents analysis will be released alive immediately. Fish required for sampling stomach contents will be euthanised immediately by pithing with a spike into the brain cavity. The stomach contents of each fish will then be removed individually and preserved in ethanol for later laboratory analysis (Figs. 4 & 5). A small sample of fish muscle (10 g) will be sampled for later stable isotope or energetic analyses and stored on ice.

Figures 3-5: Skipjack tuna school, screenshot from underwater videography. *Image: NNZST*; Sampling skipjack tuna stomach. *Photo: Edin Whitehead*. Sample from fish stomach, predominantly euphausiids. *Photo: Edin Whitehead*.



Fish captures are covered under the following permits:

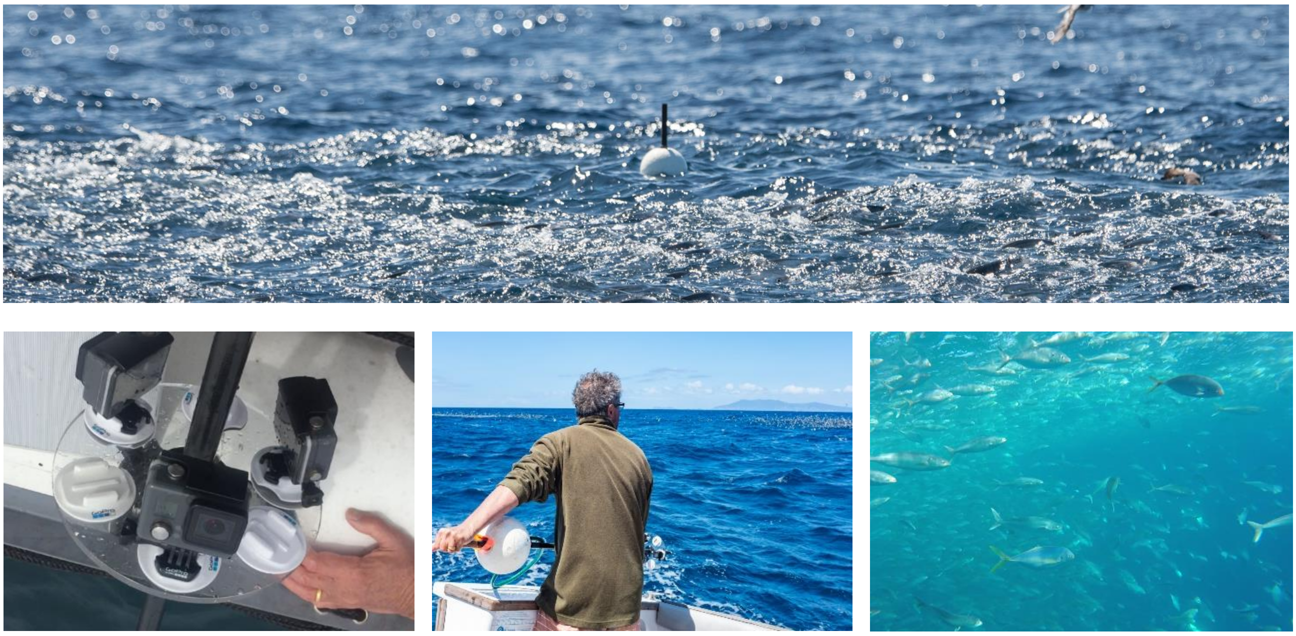
- Special permit 679, Fisheries New Zealand which allows the taking of marine life for the purpose of research.
- Animal Ethics Application 14829, AgResearch where the maximum number of fish captured and killed during the whole research period is capped at 440.

1.2.5 Underwater videography

A floating camera rig was developed during previous projects that can be deployed into a workup (fig. 6). This setup will be used to obtain underwater video footage of fish shoals in order to identify the fish species present, their general behaviour, general size estimations and presence of larger zooplankton such as euphausiids. The rig consists of a long carbon fibre shaft with a buoy at one end, an array of GoPro cameras mounted on an acrylic disc (Fig. 7), and a weight at the other end. This rig is deployed either from a launch or an inflatable dinghy. Timing of deployment is crucial as fish shoals can be fast moving with frequent changes in direction. The aim is to deploy the rig in front of the fish shoal so the fish pass by it and can be filmed from all angles (Figs. 6 & 9).

The underwater videography together with visual observations of fish at the sea surface will be undertaken to identify the species involved in the shoal, their behaviour, including feeding events, the potential prey species involved in large fish aggregations, and to estimate the size range of individual fish. Fish shoals are predominantly phenotypically assorted based on size and therefore, can be quantified as consisting of either juvenile or adult fish based on species-specific biology. This will provide important information on the size make-up and life stages of these fish shoals.

Figures 6-9: Camera rig surrounded by a fish school; GoPro set up; deploying camera rig. *Photos: Edin Whitehead*. Screenshot from videography of a trevally and kahawai school. *Image: NNZST*



1.2.6 Topside photography

The use of high-resolution topside photography (cover image, top) has proved very useful in previous projects, e.g., POP2017-06, to obtain images of species composition (predator and prey), foraging behaviour and general activity around fish schools, as well as other situations where birds where observed feeding. It has been possible to take photos of prey caught by seabirds and visible in their bills before swallowing in the case of gannets and shearwaters to identify prey types. For example, white-fronted terns will carry prey in their bills – either for display purposes or when feeding chicks.

1.2.7 Environmental parameters

Various environmental parameters will be recorded while at sea, both inside and away from workups. This will provide information on factors which can influence the spatial and temporal distribution and composition of the larger zooplankton prey such as euphausiids and therefore that of workups.

Sea surface temperature and salinity will be recorded using a digital handheld device (YSI multiprobe) and this information used to determine the water mass characteristics, i.e., coastal or oceanic water. A Secchi disc will be used to measure water clarity which may be important in determining the visual feeding methods used by seabirds. Three water samples will be taken for chlorophyll *a* measurement in the laboratory as a measure of phytoplankton abundance. Weather conditions will be recorded as these can affect the effectiveness of sampling methods. Record bathymetry (depth to seafloor) using charts and sounder after the trip.

1.3 Laboratory methods

1.3.1 Zooplankton identification and enumeration

Zooplankton and fish stomach content samples will be stored and processed at the Leigh Marine Laboratory (University of Auckland). Zooplankton will be counted into seven groups as was undertaken for POP2017-06: Copepoda, Malacostraca, Nauplii, Appendicularia, Thaliacea, Fish eggs and Other.

Laboratory analysis will include:

- Quantifying the numerical abundance of zooplankton groups in zooplankton tow samples and fish stomach contents. For the zooplankton tows, this can then be calculated as zooplankton numbers per m^3 of water and compared quantitatively against other tow samples from this year.
- Measuring the settled volume of each zooplankton tow sample.
- Recording size ranges of zooplankton types in samples
- Determination of the energy content of potential prey species collected in the zooplankton tows – zooplankton and fish.
- Recording any larval/juvenile fish and plastics present in samples and placing in separate containers for later analysis by third parties.

All zooplankton samples obtained from net tows and fish stomach contents will be counted into the seven groups defined above. This will be undertaken using a dissecting microscope and Bogorov trays. Samples will be subsampled as required in order to reduce the time taken for enumeration. The aim being to have at least 200 individuals from the most abundant groups. The total zooplankton numerical abundance per group, per sample, will then be estimated by scaling the counts for subsampling and water volume filtered by the zooplankton net (where appropriate) and defined as numbers per m^3.

1.3.2 Zooplankton biomass

An estimation of the biomass of each zooplankton sample will be determined by a volumetric method. The settled volume will be obtained by making up the sample to a known volume in a measuring cylinder. The zooplankton will be left to settle for 24 hours before recording the settled volume. The settled volume in ml will then be converted into volume (ml/m^3) by accounting for the volume of water filtered by the zooplankton net.

1.3.3 Energy composition

A micro-bomb calorimeter will be used to measure the energy density (the amount of energy per unit mass) of each prey type by measuring the heat released when that sample is completely oxidised. This will be used to determine the energy values of different types of zooplankton and fish prey from the tows and energy values will be found from samples collected throughout the year to look at seasonal differences.

1.4 Data analysis

The following data will be obtained from field and laboratory work:

- GPS locations of workups and zooplankton tows undertaken.
- Comparative zooplankton sampling performance of the high-speed net versus the previously used 250 µm mesh net.
- Qualitative data on workups: description of activity, estimated area of occurrence, fish species identified (from underwater videography, surface observations, and fish caught).
- Quantitative data on workups: approximate numbers and type of megafauna predator species (seabirds and other), size ranges of fish species (from underwater videography and fish caught)
- Environmental data (collected at sea) at each workup location: SST, salinity, water clarity, chlorophyll *a*, weather and sea conditions.
- Total zooplankton numerical abundance per group, per net tow (inside and outside of workups), individuals per m^3 water volume filtered.
- Total zooplankton numerical abundance per group, per fish stomach contents sample.
- Energy content of different zooplankton types from net tows, and fish muscle samples.

Statistical analyses will be undertaken to:

- Determine if and what differences there are between zooplankton abundance and composition sampled inside and outside of workups using either paired t-tests or ANOVA, depending on final sample set.
- Determine selectivity of fish species for zooplankton prey by comparing relative abundance in stomach contents with zooplankton hauls, and comparing among fish species, for individual work up events using chi-square comparisons of relative proportions.
- Determine associations among the presence of zooplankton, fish species, and feeding bird species in work ups using chi-square comparisons, or nonparametric multivariate analysis using Primer-e, or Permanova methods.

1.5 Added value

Additional aspects that could be added to this project but are not currently included in the contract include:

- Obtaining drone footage of workups in order to determine the workup size (m^2) relative to the research vessel. This would require an experienced drone operator with their own equipment.
- Analysis of seabird regurgitations collected this year to be compared with previously collected samples and zooplankton samples collected this year.

2 OBJECTIVE TWO

Analyse fish shoal data from purse seine fishery database (aer_sight) and develop a model of East Northland, Hauraki Gulf and Bay of Plenty oceanography to explore relationships between fish shoal abundance and the physical and biological aspects of the marine environment to better understand fisheries pressures on seabird population trends.

2.1 Introduction

The work proposed here and the accompanying quotation are concerned with the use of data from the MPI aerial sightings database (*aer_sight*) to investigate questions related to changes in the schooling behaviour (e.g. school size, school number) of inshore schooling finfish species that might affect the effective foraging of seabirds.

The *aer_sight* database contains the longest available time series of information for the six main inshore schooling pelagic species taken by purse-seine: trevally (*Pseudocaranx dentex*), blue mackerel (*Scomber australasicus*), jack mackerel (*Trachurus declivis*, *T. murphyi*, and *T. novaezelandiae*), and kahawai (*Arripis trutta*), and for the highly migratory species skipjack tuna (*Katsuwonas pelamis*), on which the domestic purse-seine industry was founded. Flying effort has been quite consistent although some variation is evident particularly since 2004 (Taylor, unpublished results) and there is a difference in coverage throughout the dataset between the Bay of Plenty (most coverage) and East Northland north of Great Barrier. Other, more minor species from a commercial perspective are recorded in the database, but sightings of these are very inconsistent. Because these species have not provided extensive enough data they have not been considered for previous studies.

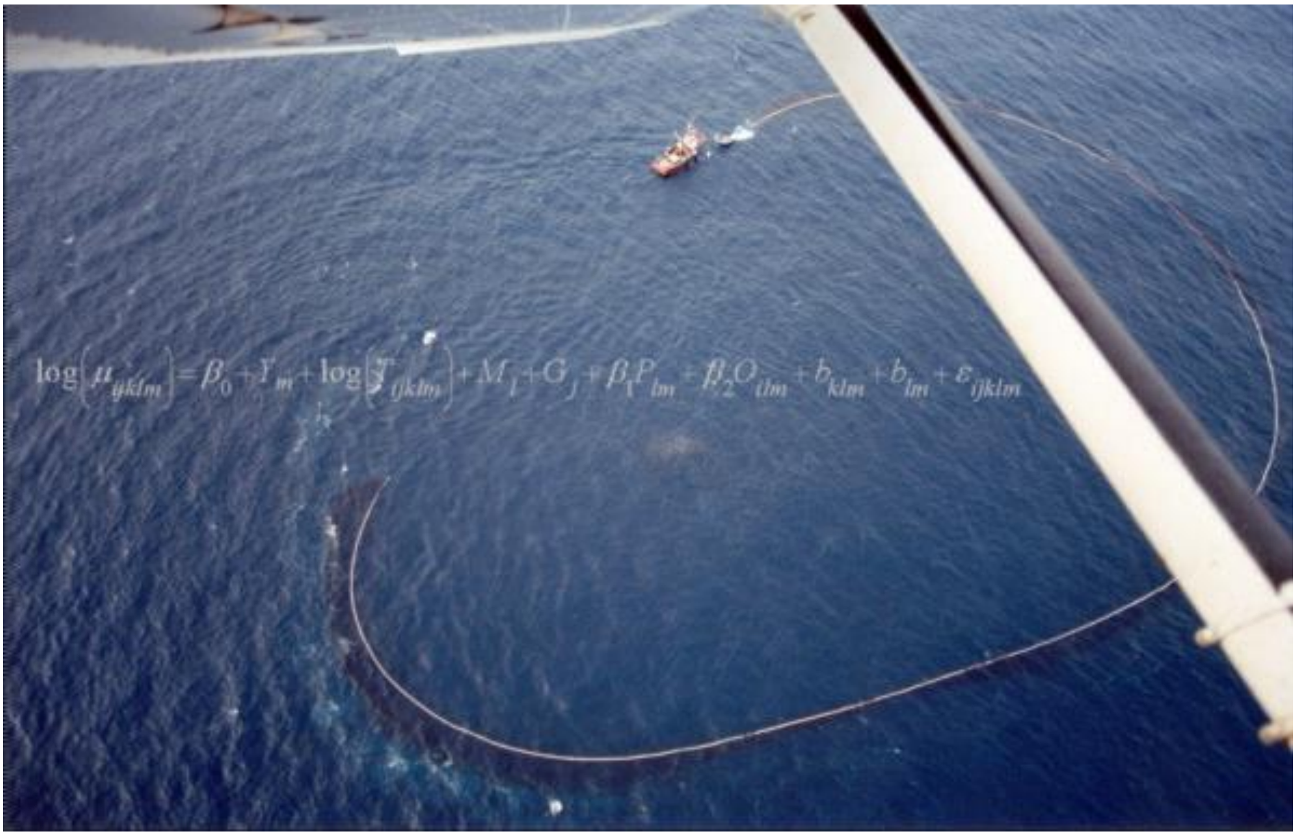
Fish-spotter pilots working in the domestic purse-seine fishery provide the data on a voluntary basis. However, no standard sampling method like transect or quadrat design is employed. In terms of standard sampling methodology this opportunistic approach to data collection violates the assumption of random encounter — pilots search areas where the probability of encounter of the target species is expected to be high. Any method to produce relative abundance indices from these data aims to overcome the effect of this weakness while capitalising on the low cost of collection.

The *aer_sight* database has been maintained by agencies of the Minister for Fisheries from 1976 to 2013. It contains data on schooling pelagic species recorded by pilots assisting in the purse-seine fishing operation and dates almost to the beginning of this fishery in 1974. The database is in electronic format and contains data to the end of the 2012–13 fishing year (i.e., 30 September 2013). Data collection has been managed by Statfishtics Ltd since 2013, but these data only exist as records on paper forms. They have not been entered into electronic format.

Data from *aer_sight* cannot be used to summarise commercial purse-seine fishing activity or the amount of fish taken in the fishery. The only records within the dataset that relate to fishing events are designed to provide the raw material for calculating the error in pilots' estimates of school size (see Panel 4 in Figure 2).

The *aer_sight* database is managed within a relational database environment. Its structure reflects the five panels on the data collection form (Figure 1, Appendix A). Previous work using this dataset has been focused on producing indices of relative abundance for use in the stock assessment of particular species, which has required a complex method of multiple queries to extract the required data (Figure 2). The complexity of data extracts in the work proposed here is dependent on what index is required, and whether it requires standardisation using flying effort (Panels 5 & 5a). Data for each sighting on average school size, number of schools, and location of the sighting are recorded on Panel 3.

Figure 10. Aerial photograph of a purse-seine fishing vessel setting a net around a fish school; modelling equation overlaid. *Composite image: Paul Taylor (Statfishtics NZ)*



Two methods of recording flightpath have been employed during the history of the data collection. Before January 1986[1], separate flightpaths were recorded for each flight. In this, the earliest dataset, flightpath comprised a chronological record of the geographical features visited or passed over during the flight, or a note indicating the vicinity the pilot occupied during the flight (e.g. *worked area 12–15 nmi 060 M from Great Barrier*). These features included islands (e.g. Mayor, Aldermen Islands), rocks (Schooner), reefs (e.g. Astrolabe), shoals (e.g. Penguin), headlands (e.g. Reef Point, Cape Brett), towns (e.g. Te Kaha, Whitianga), bays (Great Exhibition Bay) etc.

The revised data-collection form used since January 1986[1] has instead included a map or outline of the New Zealand coastline with a grid of half degree squares (Figure 1 and Panel 5a in Figure 2). This form is the basis of the second method of recording flight-path — the pilot has entered a tick or stroke into each square flown over during the day's flying to represent each 10–15 min period spent within that square. Thus, multiple ticks have been recorded in squares where about 20 minutes or more have been spent. The direction given the pilot is that the time spent searching for fish is to be recorded here.

The data-collection form underwent a second revision in April 1998[2], which included two major changes to the data. Firstly, global positioning system (GPS) positions were recorded for sighting positions and,

[1] The revised data-collection form first appeared in October 1985, but it was not until January 1986 that database records consistently included the new flightpath information.
[2] GPS data were first recorded on the forms about this date, but it was not until June 1998 that fine-scale position data were represented in an appreciable proportion of records (approx 0.75), and not until January 1999 that representation was near 100%.

secondly, summaries were recorded of the pilots' estimates of size and species composition of the individual schools "shot" by the vessels, and the skippers' final estimates after the school was landed onto the vessel (Panel 4 in Figure 2). Before April 1998, position of the sighting was most often recorded as a bearing and distance to a known landmark and was entered into the database as a grid-square code. Since then pilots have used portable GPS units to record latitude and longitude, which have been entered into the database.

This component of POP2019-02 will explore changes in aggregations of pelagic schooling finfish species over time by investigating relationships between environmental features and distributions of sightings of these species from the *aer_sight* database, along with other characteristics (e.g., school size, school number) of the sightings recorded in the database, and determine whether these changes reflect known changes in seabird abundance. Success with this work could provide the first step to later investigating whether a relationship can be demonstrated between fishing activity using commercial and recreational catch data, and trends in seabird population size.

2.2 Scope of the work

1. Finalise methodology including the hypotheses to be tested within the limitations of the data available from *aer_sight* data
2. Determine relevant *aer_sight* data; request extract from MPI; organise into appropriate data structure.
3. Characterise changes in schooling aggregations over time i.e., size of schools, tonnage of sightings, number of schools.
4. Identify relevant bathymetric, oceanographic and environmental factors; gain access to the data and organise into appropriate data structure. This is the first step towards developing a model of the East Northland, Bay of Plenty and outer Hauraki Gulf bathymetry (reefs, channels, shelf edges), topographical features (islands, island groups and headlands), temporal changes (annual, seasonal), and SST and Temperature Fronts.

2.3 Methods

2.3.1 Finalise methodology within the limitations of data from *aer_sight*

The success of this project largely rests with which questions the data from *aer_sight* can be used to answer. The first step here is to propose a suitable hypothesis or group of hypotheses for testing. Questions related to species abundance may be difficult or expensive to resolve where they are standardised according to the amount of fish recorded per amount of flying time, whereas the use of measures based on the size of aggregations within a sighting or group of sightings is more tractable and can probably be summarised in both time and space.

A number of features of the *aer_sight* data have imposed constraints on their use in previous work (see §1.6 in Taylor 2014 for full discussion). For example, not all flying time is search time, which can be problematic where tonnages sighted by pilots must be standardised by flying effort. In addition to searching for fish, pilots spend time identifying species composition of the schools comprising each sighting, determining the size (tonnage) of the schools, and assisting the vessel(s) to set on the chosen school. This component of non-search time is referred to here as process time. To accommodate the process time idea, flight time (*feff*) was regressed against both the number of fishing operations (*nops*) and the total sightings (*totsit*),

$$\text{feff} = b * \text{nops} + c * \text{totsit}.$$

The estimated slopes from this regression were used to adjust flight time into search time (*efft*). This or a similar strategy may be adopted in the present context where such standardisation is necessary.

Figure 11: Northern and central grid squares and their codes. Red line defines study area.

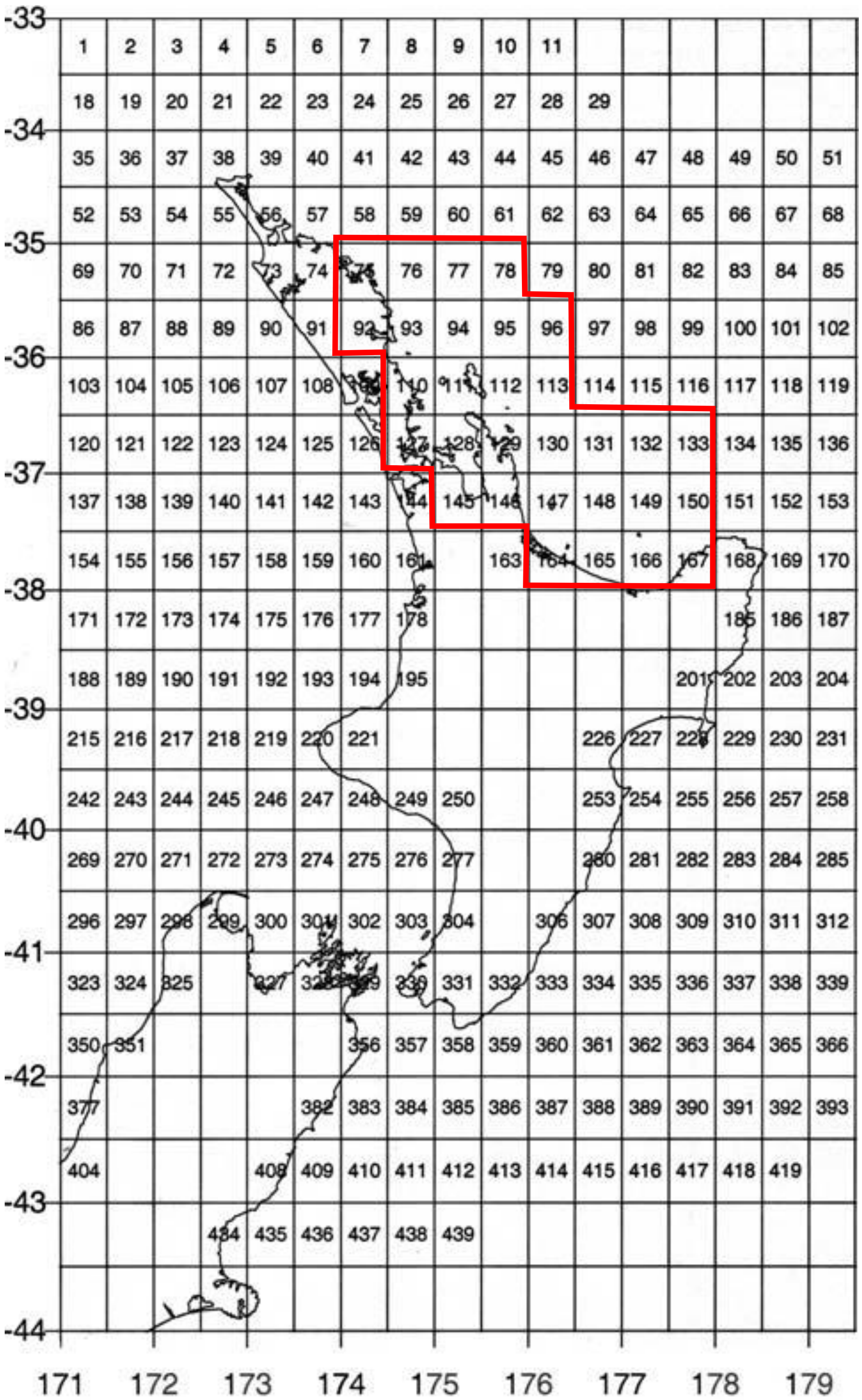
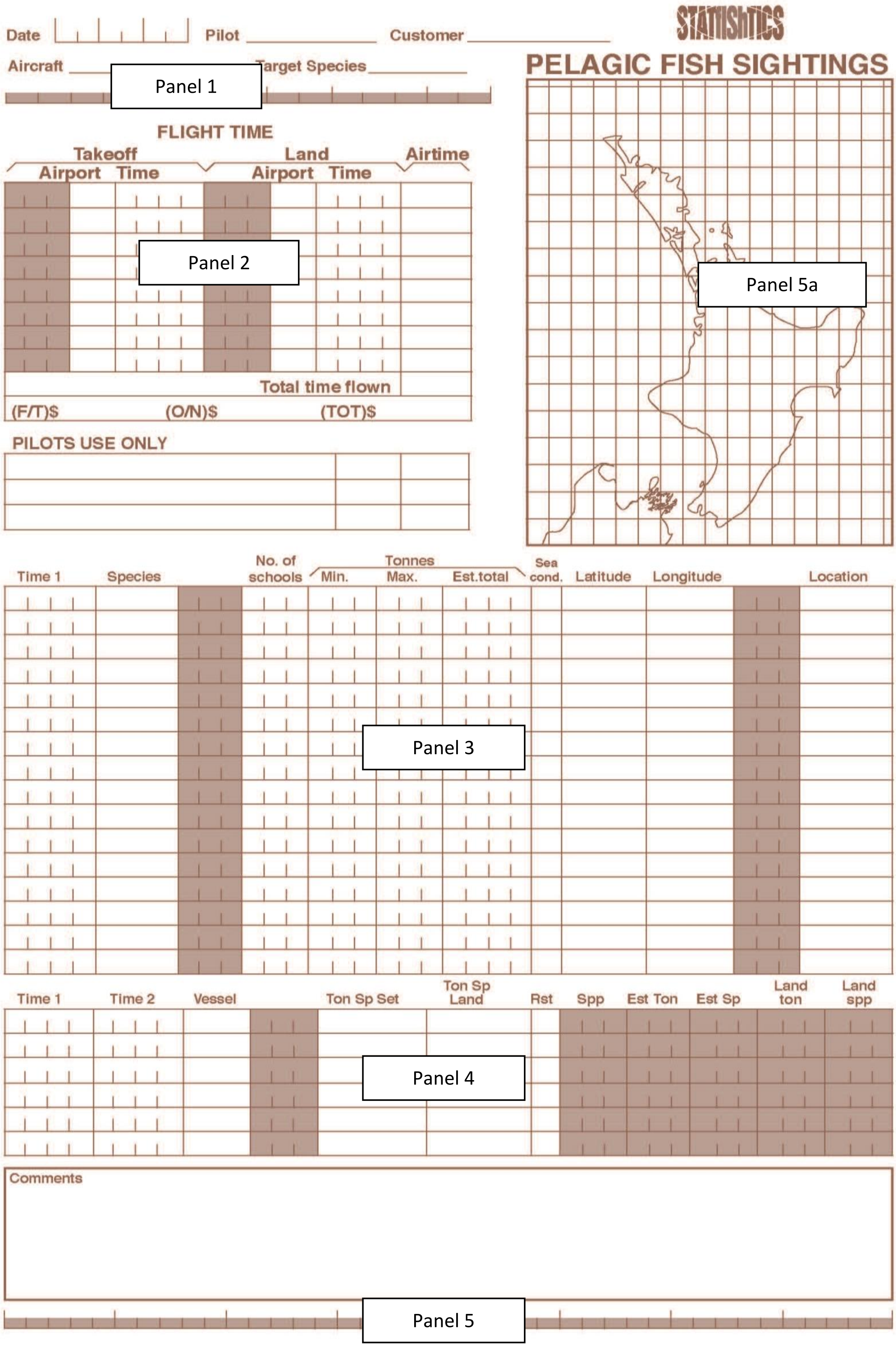


Figure 12: Current aerial sightings data collection form; see explanation in Appendix A.



2.3.2 Identify and organise aer_sight data

This follows from decisions made in the previous stage.

2.3.3 Characterise temporal changes in schooling aggregations

This task could be where the statistical modelling is applied and graphical summaries of trends in features of fish aggregation are produced. Trends in relative abundance could also be explored here, possibly using a similar approach to the sightings per unit effort index adopted in previous studies, but there are caveats on this suggestion related to area and the amount of available data.

2.3.4 Identify and organise environmental data

Geographic/bathymetric features, such as the position of islands and reefs, will not change appreciably over the time frame considered here. Other features such as SST and the associated feature of the ocean front will follow temporal variations, as will measures of *el niño* (i.e., southern oscillation index, SOI). Moon phase will vary, but in a more predictable way than some of the other factors. While it is reasonable to consider developing a 2d model (i.e., map) for stable features, mapping ephemeral features, particularly those undergoing relatively rapid change is unlikely to be practical. This task requires some literature searching.

2.4 Follow up stages

The following stages are not included in POP2019-02.

2.4.1 Investigate relationships between fish distribution and environmental factors

The methodology needs some discussion. The suggested overlay approach may not be practical for ephemeral factors or may need summaries over some time frame. Depending on decisions at Task #1, resolution may require a two-pronged approach with some mapping and some statistical modelling. Consideration of this issue may inform decisions at 2.3.1 above.

2.4.2 Determine how temporal changes in schooling aggregations reflect changes in seabird abundance

This depends on what data are available on seabird abundance trends, which should be clarified early in discussions.

2.4.3 Update database with data collected since 2013 until 2018

This task requires several specific tasks:

- code data collection forms;
- punch data into electronic format using double punch method to minimise punch errors;
- run data through error-checking programmes (mainly range checks);
- resolve any identified errors;
- transfer data into MPI database.

Then rerun 2.3.4, 2.4.1, 2.3.3 with data from this stage. This is mainly re-running 2.3.3, but there may be some updating of tasks completed under the other two.

2.4.4 Investigate the effect of fishing on seabird population trends

This task requires fish catch data and cannot be explored with data from *aer_sight*.

Relevant publications (Objective Two)

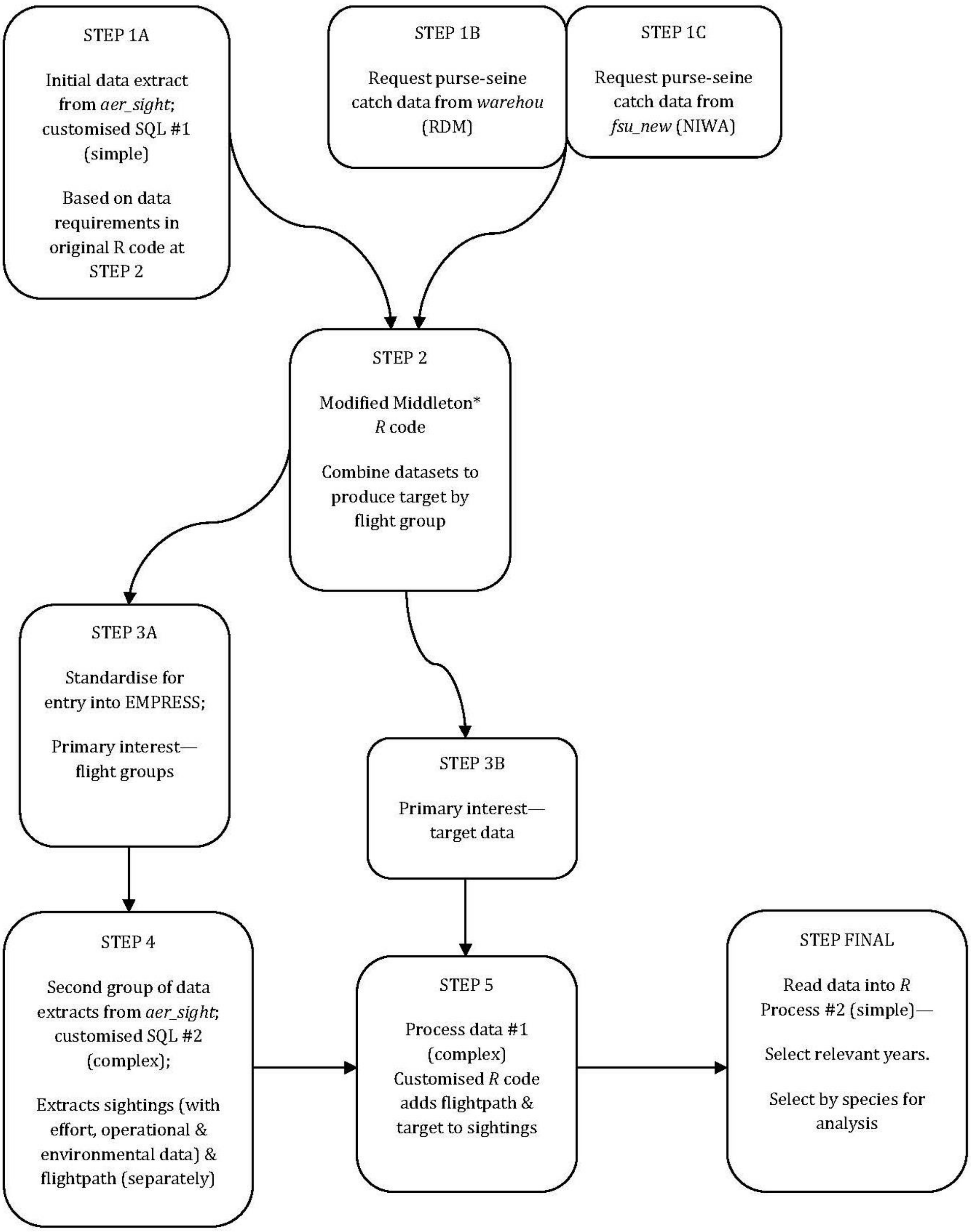
Taylor, P.R. (2015). Investigating a multi-purpose aerial method for surveying inshore pelagic finfish species in New Zealand. *New Zealand Fisheries Assessment Report 2015/36*. 96 p.

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.

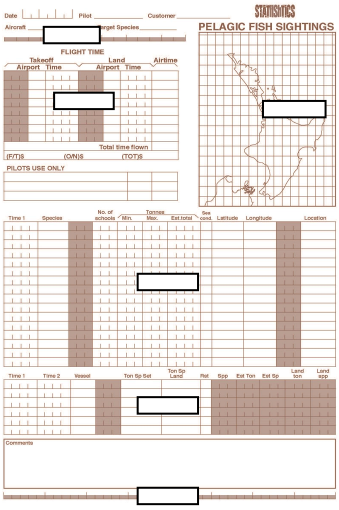
Taylor, P.R.; Doonan, I.J. (2014). Developing indices of relative abundance from observational aerial sightings of inshore pelagic finfish; Part 2, expanding the dataset and producing annual indices for KAH 1 and TRE 1. *New Zealand Fisheries Assessment Report 2014/35*. 45 p.

Appendix

Steps required for data extracts in previous studies using *aer_sight* database.



Explanation of components of the aerial sightings data collection form



The aerial sightings data reside in a relational database that comprises five main relational tables and several ancillary tables. The latter contain environmental data, definitions for codes used in the main tables, and other information to facilitate grouping during data extracts (e.g., temporal periods — calendar year and month, fishing year and month). The main tables reflect the five main panels on the data-collection form (see Figure 1). The following is a brief description of the information recorded on each panel, including the database table in which each group of data are stored.

Panel 1

Description: meta-data for a group of flights.

Specific data: date, pilot, customer, aircraft call-sign.

Database table: *t_flight_group*.

Panel 2

Description: takeoff and landing data.

Specific data: takeoff airfield, takeoff time, landing airfield, landing time.

Database table: *t_flight*.

Panel 3

Description: various data on the sightings made while observing the group of flights comprising a sighting.

Specific data: time of the sighting (Time 1), species (or species mix) in schools comprising the sighting, number of schools in the sighting, the size of the smallest school in the sighting (ton_min), the size of the largest school in the sighting (ton_max), the pilots estimate of the total tonnage (Est. total), sea condition at the time the sighting was made, latitude and longitude (from GPS).

Database table: *t_school_sight*.

Panel 4

Description: operational data.

Specific data: original time of the sighting (Time 1; Note that this is the same time as in Panel 3 and allows position of the school and other information to be accessed), time that fishing on the school began (Time 2), the vessel name, the tonnage and species composition estimated by the pilot (Ton Sp Set), the tonnage and species composition determined by crew on the vessel after the school has been landed to the hold (Ton Sp Land), result of the fishing (Rst) — options are caught, saved, skunked, unknown, caught unknown amount (unavailable from the vessel), let go, burst net.

Database table: *t_set*.

Panel 5

Description: effort data — strokes recorded by pilots into the squares on panel 5a represent 10–15 min periods spent in particular grid squares, which are summed and recorded on panel 5 at the time of form processing.

Specific data: number of ticks (first two spaces), grid square code (spaces 3–5).

Database table: *t_flightpath*.