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Developing indices of relative abundance from observational aerial sightings of inshore pelagic finfish; Part 1, exploring the data

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EXECUTIVE SUMMARY

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The aerial sightings database contains information about schools of inshore pelagic finfish species that has been collected by fish spotter pilots working in the domestic purse-seine fishery targeting these species since 1976. The data used in the analysis include date, pilot, information on the length of flight and the airfields used, the flightpath followed during a day's flying, information on the sightings recorded on individual flights, the species composition and size of the schools making up each sighting, and data characterising the size and species composition of individual schools fished by the purse-seiners as estimated by both the pilot when the set begins and by the vessel following completion of the fishing operation.

The aim of the work described here was to determine whether the aerial sightings data could be used to provide annual indices of relative abundance of the main purse-seine inshore target species, trevally (*Pseudocaranx dentex*), blue mackerel (*Scomber australasicus*), jack mackerel (*Trachurus* spp.), and kahawai (*Arripis trutta*). Because jack mackerel are not separated by species in the data they were removed from the list. Blue mackerel were also removed when preliminary analyses indicated high interannual variation in relative abundance indices, suggesting that the indices were reflecting only part of a much larger stock that had migrated onto the survey area. For the analyses, data were restricted to flights exclusive to the Bay of Plenty where the greatest density of data was centred, to fishing years since 1998 during which information on the number of fishing operations was readily available from the database, to a single pilot who had collected most of the data in the area since 1976, and to the first real working flight of the day to avoid problems of double counting. The proxy for target species in the model was target species in the catch-effort logbook.

Effort was considered an important factor in the analyses because the approach adopted here was based on the two-component, binomial-lognormal approach often used for catch-per-unit-effort standardisations. Because data selection was restricted to the first flight of the day, and because the flightpath data could not be applied to individual flights, the fundamental unit of flying effort was the flight length. It was known from the pilots that not all flying time was search time, so flight length was not an accurate representation of search effort. To account for non-search time, flying time was adjusted by number of fishing operations and the total number of sightings using a linear model fit outside of the main modelling method. Values of adjusted effort were estimated for each flight and its performance was compared with the unadjusted effort by forcing each into individual model fits. These two effort regimes were compared with a third in which the adjusted effort was offered for selection to a third model fit, rather than being forced.

The main analyses were performed using a generalised additive model (GAM) to standardise observed tonnages of each of the two inshore schooling pelagic species, trevally and kahawai. Modelling adopted a two-component approach for each species: a binomial GAM to model the presence-absence of sightings of the species of interest on each flight, and a lognormal GAM to standardise observed tonnages. Predictors included each of the three effort variables along with fishing year, month, time of day, southern oscillation index, sea surface temperature, target species, and moonphase.

Results of the standardisations showed reasonable fits with no clear violations of model assumptions. Levels of variability explained by the selected models ranged from 20.4 to 23.8% for the trevally binomial, 19.4 to 26.4% for the kahawai binomial, 50.2 to 51.6% for the trevally lognormal, and 39.5 to 44.6% for the kahawai lognormal. Comparisons of results from the three effort regimes showed no clear advantage of using one over another although effort was only included as a covariate when it was

forced into the model. An unusual outcome within the trevally binomial fit occurred with pilchard as the target species. This was shown to result from the fact that no trevally was sighted when pilchard was the target species.

The models were re-run using purse-seine catch as a proxy for target species to inform discussion on whether the research should be extended further. This was necessary because modal target is not available for aerial sightings data earlier than 1998. The results of this analysis showed little difference from those produced using the modal target data, and it was concluded that catch provided an acceptable proxy for target in analyses of earlier data.

The results documented here show that reasonable indices can be expected for trevally and kahawai. The method was accepted by the Northern Inshore Working Group and recommendations have been made to extend the work with the aim of producing annual indices of relative abundance for trevally and kahawai within QMA 1 over the longest possible period. The ultimate aim is to use these series as stock indices in stock assessment models for these two species in QMA 1.

1. INTRODUCTION

1.1 Overview

Stock assessments of inshore schooling pelagic species are hampered by our inability to produce a measure of annual relative abundance. The main target fishery for these species in QMA 1 is by purse-seine, and, for reasons discussed below, using catch per unit effort from purse-seine fisheries as a stock index is unlikely to be reliable. Aerial sightings data offer a source of information with the potential to provide cost effective annual relative abundance indices.

The aerial sightings database has been maintained by agencies of the Minister for Fisheries since 1976. 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 is currently administered by NIWA for the Ministry of Primary Industries (MPI) using the relational database environment, Empress.

The aerial sightings 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 oceanic 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). By contrast, purse-seine catch and effort data have been collected only since 1982, and are unreliable during the period of transition (1988–89) from the Fisheries Statistics Unit (FSU) to the present Quota Management System (QMS). Therefore, the aerial sightings data are the longest and most consistent time series of information for some species of schooling pelagic species in New Zealand waters.

The most important commercial species in the fishery has been skipjack tuna, which is taken mainly in summer–autumn in New Zealand waters. Kahawai was the second most important commercial target, being fished mainly in the winter–spring when skipjack was unavailable. Since catch limits were set for this species in 1990–91, more attention has been given to jack mackerel and what was the preferred option, blue mackerel. Blue mackerel have been more valuable as a commercial species than jack mackerel, although jack mackerel have been important as a high volume, low value catch. More recently the market price of jack mackerel has increased and stabilised, resulting in closer parity in the preference for mackerel species. Trevally was fished consistently through early years of the fishery, but catches declined rapidly and total TACs are now relatively low (3932 t total for all Fishstocks).

1.2 Aim of the study and scope of the report

The aim of the present study was to complete an investigation into whether data from the Ministry's Aerial Sightings Database *aer_sight* could be used to produce indices of relative abundance for the main target species of the domestic purse-seine fleet: kahawai, blue mackerel, trevally, and jack mackerel. This work proceeded under a number of Research Projects, including PEL2003/02, JMA2004/02, EMA2005/01, and KAH2005/01. To assist in bringing the work to a useful conclusion, including appropriate reporting milestones, project SAP2006/10 was created. This document has been produced to satisfy the reporting requirements of SAP2006/10 under Milestone 2, Complete FAR/FRR.

At a meeting on 31 August 2009, the Northern Inshore Working Group made the following recommendations regarding the investigation and development of relative abundance indices for small pelagic fishes using aerial sightings data collected by commercial spotter pilots.

- The development of an aerial sightings index for the northern purse-seine fishery should be undertaken in three progressive stages.
- <u>Stage 1</u>
  The first stage to be based on the following data set:

a. data collected on the new form (i.e., since April 1998);
b. data collected by Pilot #2 only (who collected most of the data);
c. data collected during the first flight of each day and from flights exclusive to the Bay of Plenty (BoP).

- Stage 2
  If the first stage appears to have been successful (based on diagnostic tools) the analysis will be expanded to include all years for which data exist for the BoP.
- Stage 3
  In stage three the analysis is to be expanded to include other areas and data collected by all pilots.

The work reported here is for Stage 1 only. Stages 2 and 3 were completed under project SEA2010-17. Note that there may be minor variations between values presented here and those provided to the NINSWG as part of discussion documents, due to minor changes to the dataset at the time of writing this document. Note also that, while Stage 1 is similar to the "Part 1" in the title of this report, "Part 2" in the title of Taylor & Doonan (2014) also includes the production of preliminary annual indices for KAH 1 and TRE 1 in addition to Stages 3 and 4. Thus, the tag "Part" is used in the report titles to simplify their content and provide a link between the two reports.

1.3 Catch per unit effort compared with indices from aerial sightings data

Aerial sightings data can provide useful information for a number of applications, including characterising spatial distributions and examining their variation over time. In stock assessments, aerial sightings data could usefully provide stock indices for the six inshore schooling pelagic species mentioned above. They offer an alternative to the use of catch-per-unit-effort (CPUE) data, which are often used to produce stock indices, although guidelines suggested by Dunn et al. (2000) make clear the inadequacy of this approach in certain cases.

The main danger of using CPUE as a stock index in the purse-seine fishery is that the assumed relationship between CPUE and abundance is confounded by the ability of purse-seine vessels to maintain consistent catch rates until a stock is reduced to low biomass levels. This fits Hilborn & Walter's (1992) category of hyperstability and results from the tendency of these species to be visible either to the naked eye at the surface or on sonar when subsurface, and therefore vulnerable to fishers, even when abundance has reached a low level.

Lo et al. (1992) identified two advantages that even opportunistically collected aerial fish-spotting data have over CPUE data. The first of these involves "saturation", where an increase in fish abundance occurs with no increase in CPUE due to limited hold capacity, trip limits for catch, market demand, or processing capacity. Saturation is not a characteristic of aerial sightings data because pilots can record the size and location of all schools seen without being limited. The second advantage is related to increased efficiency as a result of technological advance. Whereas CPUE data are often confounded by improvements to vessels and fishing gear (Kimura 1981; Jacobson et al. 1987), aerial spotting still relies on fish schools being located visually despite improvements to aircraft and navigation and radio equipment.

1.4 Other methods of analysis and data collection

The study by Lo et al. (1992), which introduced the delta lognormal distribution to these types of analyses, provided the first published solution to difficulties in estimating relative abundance from opportunistic aerial sightings data. Other workers have investigated the use of combined methods of data collection from pelagic fish stocks: Cram & Hampton (1976) proposed a combined aerial-acoustic survey method; Hara (1990) compared ship and aerial surveys of sardine schools.

More recent work provides insight into the use of alternative methods for performing fishery-independent surveys of epipelagic fishes. Churnside & Hunter (1996) and Churnside et al. (1997) described the use of an airborne lidar (light detecting and ranging) system, which produces short pulses of laser light that pass through the water surface, reflect off fish and return to the receiver. This system is being developed by laboratories of the National Oceanic Atmospheric Administration (NOAA) and Lo et al. (2000) modelled its statistical performance using anchovy as the subject.

Line 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 (*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 et al. (2003), and Eveson et al. (2006).

1.5 Some definitions

A number of terms used throughout the document require clear definition. "Fine scale data" is used when referring to latitude and longitude positions, usually as an alternative to the more coarse grid-square location. "Sighting rate" is the amount of fish (usually tonnage) sighted per hour of flying. "Double counting" refers to repeated sightings of the same fish and would be more correctly named "multiple counting". The Bay of Plenty is referred to as BoP. "Half degree squares" are squares with sides of 30 minutes latitude and longitude (which could be considered a misnomer given that whole degree squares have sides of 60 minutes and area of 3600 nmi^2, while squares with sides of 30 nmi contain one quarter the area); the half-degree square is also referred to here as a "grid square". The BoP was defined as comprising grid squares 112, 113, 129, 130, 131, 146, 147, 148, 149, 150, 163, 164, 165, 166, 167 (Figure 1). A fishing year is defined by MPI as beginning on October 1 in one year and finishing on September 30 in the next. The following species codes might be used occasionally: EMA for blue mackerel, JMA for jack mackerel, KAH for kahawai, PIL for pilchard, TRE for trevally, SKJ for skipjack tuna. "Target species" refers to the species that is being targeted by the purse-seine vessels supported by a pilot for a particular period of flying, typically the flying on a given day. Target species can determine where the pilot searches; it is discussed briefly in a particular context in Section 1.6.2, Feature #3.

1.6 The aerial sightings data

1.6.1 Data collection

Data collection by pilots is incidental to the purse-seine fishing operation and is therefore referred to as opportunistic. Data are also referred to as *observational*, a statistical term referring to studies where assignment of subjects into a treatment or control group is outside control of the investigator.

Pilots provide the data on a voluntary basis, so the cost of their collection is minimal. The trade-off is that no standard sampling method like transect or quadrat design is employed. In terms of standard sampling methodology this opportunistic method of 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 interval between takeoff and landing constitutes a "flight". For each flight, the pilot records the time of takeoff and landing, and the airfield used for each. The pilot also records the sightings observed during a flight. A "sighting" is a group of schools with similar species composition seen together. Pilots estimate and record species composition and the range of school sizes for each sighting they observe. The range of school sizes is recorded as the pilot's estimate of minimum and maximum tonnage for the schools in the sighting, along with the number of schools comprising the sighting, the position (using GPS) of the sighted group of schools, and the time of the sighting.

Two methods of recording flight-path have been employed during the history of the data collection. Before January 1986[1], separate flight-paths 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, Aldermans), 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, 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.

1.6.2 Features of the dataset

The following features of the data impose constraints on their use in the present context which are discussed later in this section.

The features

1. Because they are aggregated over the entire day, flightpath data recorded since January 1986 (Panel 5a, Figure 2) can only be used with reference to the entire day; i.e., they cannot be used in the context of the individual flight.
2. Changes related to the two revisions of the data-collection form have resulted in the data naturally falling into three sub-series: the change in flightpath records has caused a dissimilarity between data collected before 1 January 1986 and data collected since; the availability of GPS positions and operational data (represented by the records for individual schools shot by the purse-seiners) from June 1998 provides a more informative dataset thus allowing a more extensive model to be formulated.
3. There was also a change in the way sightings were reported from about 1994. Before this date all sightings were reported, with pilots completing a fly-over to confirm school sizes and species composition. After 1994, no additional flying effort was committed to confirming and recording distant[3] sightings of what were identified as most likely being schools of non-target species.

[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%.
[3] Decisions on sightings of distant (10 nmi or more) schools are based on whether the target is expected to be present in that area.

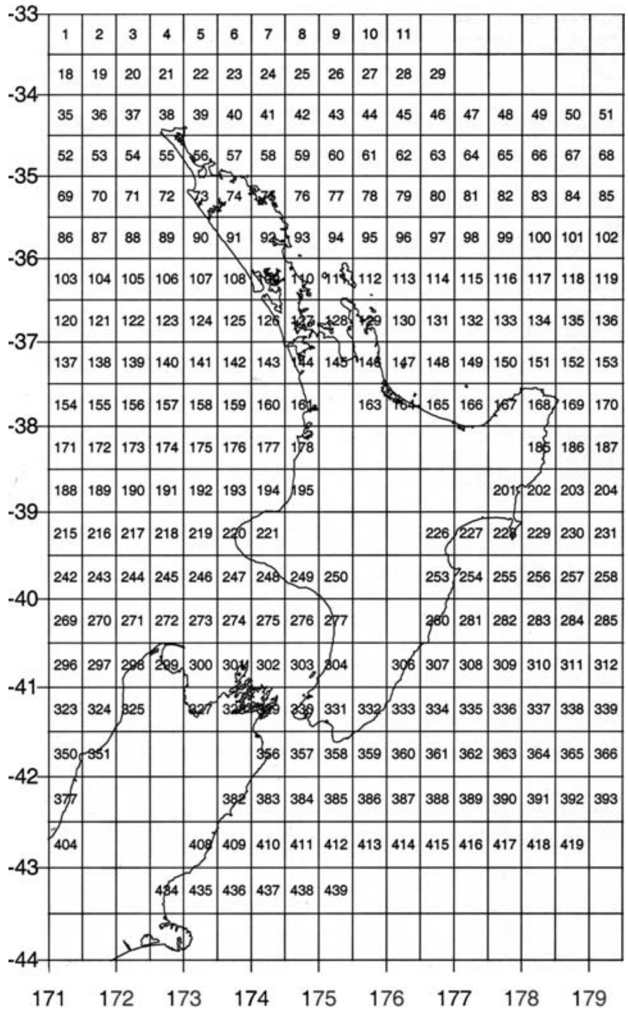

Figure 1: Northern and central grid squares and their codes.

4. Pilot #2 has attempted to avoid double counting by omitting any fish recorded during earlier flights. The frequency with which this occurs could be estimated from comments included on the completed data-collection forms, but data from this part of the form has not been translated into electronic form. Preliminary work was carried out with the aim of testing records throughout the day for the repeated presence of particular bodies of fish, but, because of the assumptions required, it was concluded that robust results could not be achieved (Taylor, unpublished results).
5. Where a sighting is based on multiple schools, pilots always record the number of schools together with estimates for size of the largest and smallest. Although they do not always provide an estimate of total tonnage, Pilot #2 has recorded these data in more than 95% of records in the third series. The pilot's estimate is considered the "best estimate".
6. Not all flying time is search time. 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.
7. As is requested in the instructions for filling out the data collection forms, Pilot #2 "record[s] one mark in the appropriate square on the map [panel 5a, see Figure 2] … [f]or each quarter hour (or part thereof) spent searching for fish … . It is clear on forms from some other pilots that this is not done.
8. Sightings can be divided into two categories based on whether they contain one species (referred to as single species, mono-specific, or pure schools) or more (referred to as mixed schools).

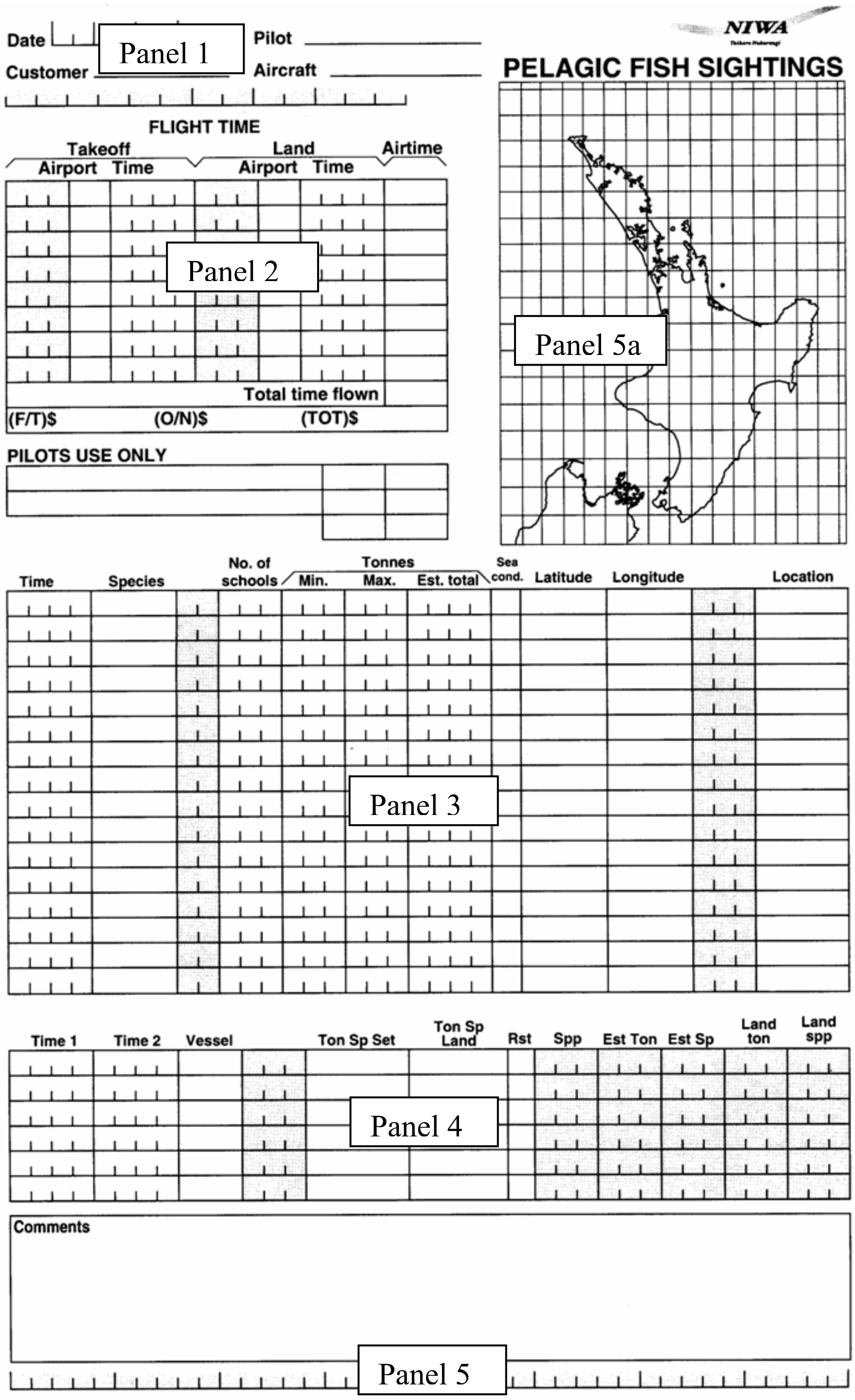

Figure 2: The aerial sightings data-collection form — an explanation of the panels is included in Appendix A.

9. An examination of flightpath information has shown that there are occasions when the pilot loses correct reference to the half degree square grid in Panel 5a and records flightpath data incorrectly in the wrong square. Pilot #2 made available electronic flightpath positions from several days of flying. These were plotted by day on a New Zealand map and compared with flightpath data from the aerial sightings database for the same days, each plotted onto the half degree square grid.
10. Target species is not currently recorded on the forms.

Effects on analyses and strategies for mitigation

Feature #1 is a key weakness in the data, preventing any use of the flightpath data in the context of the individual flight. The flightpath data, i.e., the number of 10–15 min periods spent in each grid square visited while flying is potentially the more accurate source of search effort when it is recorded according to the instructions included with the data-collection forms sent to pilots. The intention was that these data would represent search time, i.e., that here, pilots would only record the time they spent searching for fish, thus eliminating operational time and time waiting for a vessel to arrive. However, it may be true that only Pilot #2 has consistently recorded search time here. Other pilots have interpreted the instructions in a variety of ways, one of which has been to shade the grid squares visited (pilot #50). The alternative source of flying effort is length of flight, which contains various types of non-search flying time and should be adjusted accordingly.

Features #2 and #3 dictate a breakdown of the data into four sub-series: 1976 to December 1985; January 1986 to 1994; 1994 to May 1998; June 1998 to December 2008 (or later, depending on the availability of more recent data). The exact date of the change in sighting/search behaviour during 1994 is unknown but may be identifiable from the data. For the purposes of the work documented here, a system of three periods was defined, based on changes to the collection form. These periods are: first period, 1976 to December 1985; second period, January 1986 to May 1998; third period, June 1998 to December 2008.

Feature #4 implies a potential difference between data collected by pilot #2 during the first flight of the day and subsequent flights. Although it is understood that the frequency at which this occurs is low, it was beyond the scope of the present study to identify actual instances, which are referred to in the notes section of the original data-collection forms. As an added complexity, it should be noted that in some cases the first flight of the day by this pilot was a short flight to refuel and contained no fish-spotting component.

The pilot's estimate of total tonnage described in Feature #5 provides the best estimate of total tonnage in the sighting. When using this estimate in analyses, a strategy is required in cases where it has not been recorded by the pilot. For the work presented here the following approach was adopted. In situations where a sighting is based on more than two schools and no estimate of total tonnage is provided, each additional school was assigned a size equal to the average of the smallest and largest i.e. total tonnage $= (\text{Max}+\text{Min})/2 * \text{number of schools}$.

Feature #7 prevents easy comparison of effort data between pilots. While some pilots clearly have not filled out panel 5a according to the instructions, in addition to Pilot #2 others may have done, but some additional work is required to investigate this possibility and that was not undertaken here.

For Feature #8, preliminary analyses were limited to single-species schools, but pilot-estimates of tonnages of component species in mixed-school sightings have now been entered into the database allowing their inclusion in the analysis reported here.

For Feature #9, the extent of this type of error within the data is unknown. Compensation within the existing dataset is not possible because very few independent electronic flightpaths are available. Future improvements to the data collection should include electronic collection of all data, including flightpaths.

For Feature #10, the absence of target in the data has required the use of target data from the fishing purse-seiners in Stage 1. Target should be included as an improvement in future data collection.

1.7 Target species

Target species has been identified as a potential covariate in models standardising relative abundance indices from the MPI aerial sightings data. With the aim of improving preliminary approaches to the standardisation work presented here, Middleton et al (2010) examined both the setting data from the MPI aerial sightings dataset and the purse-seine catch-effort data to determine the most appropriate method of assigning target species to the flight; flight had been identified in preliminary work as the sampling unit to be used for model runs.

Middleton et al (2010) found that the various methods they had examined differed in the number of flights to which a target could be assigned. In all cases a significant proportion of flights could not be assigned a target species using data from the day on which the flight occurred — usually no fishing had occurred on these days. As would be expected, the greatest numbers of flights were assigned targets when all BoP purse-seine catch-effort data were used. After examining several possibilities, Middleton et al (2010) concluded the best source of a covariate target to be the modal target recorded by the purse-seine vessels on the day of the flight.

2. METHODS

The analysis comprised two components. In the first, several preliminary analyses were performed to explore aspects of the aerial sightings data that required clarification to facilitate choice of input data for the standardisation modelling. This component of the work aimed to answer the following questions.

1. What is the number/proportion of flights that leave the area of interest (the BoP)?
2. What is the level of error, based on the comparison of pilot estimates of school size and composition, with catches made by the purse-seine from each school?
3. What is the effect of adjusting the flying effort for time spent on operational tasks that are not searching for fish?
4. Is the intended modelling approach relevant to all species of interest?
5. To what extent do flights cover the BoP and does this vary with target species?

For the second component, a standard method was used to standardise aerial sightings of the species of interest. Within this component, two additional explorations were made: wide confidence bounds for target pilchard were investigated and an examination was carried out on the ability of catch data to provide a proxy for target species with the aim of informing a decision to extend the analysis into Stage 2.

2.1 Proportion of flights leaving the BoP

Data for all flights where the first sighting occurred within the BoP (see definitions) were extracted from the aerial sightings database. The fields extracted included flight_number, location (grid square code number), and number of sightings.

Records containing locations outside the BoP were selected and the number of unique flight_numbers was determined as the number of flights with their first sighting in the BoP that also contained sightings from grid squares outside the BoP. The number of unique flight_numbers in the original data extract was determined, which provided a count of the total number of flights with their first sightings in the BoP.

2.2 Pilot error

Data collected on Panel 4 of the data collection form (see Figure 2) were extracted from the aerial sightings database for all pilots in the BoP. Fields included pilot_tonnage_estimate, vessel_tonnage_estimate, vessel_species, and pilot. The relationships between these variables were examined using a linear model, a generalised linear model, and a boosted regression tree analysis.

Exploratory data analysis included plotting the data to determine the presence of outliers and any collinearity.

2.3 Adjusting effort

2.3.1 Overview

Preliminary work on the data included the adjustment of flying effort to allow for process time, which is represented in the data by the number of fishing operations and the total number of sightings of all species. To accommodate the process time idea, flight time (*feff*) was regressed against both the number of operations (*nops*) and the total sightings (*totsit*),

feff = b * nops + c * totsit.

The estimated slopes from this regression were used to adjust flight time into search time (*efft*) for the lognormal and the binomial regressions,

efft = feff – nops * b – totsit * c.

Time-of-day was calculated as the time at the mid-point of the flight using the takeoff time plus the flying effort (i.e., flight length) divided by 2.

2.3.2 Definitions

We have the variables:

F total flight time in hours;
N_{op} the number of operations for which a process time must be estimated;
T_{op} time for one operation, on average;
C sightings in tonnes (analogous to catch);
X data that affects a sighting;
a_x factor that accounts for the effect of X;
a_{zi} factor that accounts for a category variable, z_i;
D density of the sightings, or population size;
q sightability (analogous to catchability);
a_F coefficient associated with estimated searching time.

Search time is given by $F-N_{op}*T_{op}$. Here we deal with only one process, but the relationship can be generalised to several processes.

2.3.3 Rationale

For the sightings we have an equation like the following

$$C=qD\left(F-N_{op}*T_{op}\right)^{a_F}e^{\left(a_x*X\right)}e^{z_i}$$

which is used in a log regression

$$\log(C)=\log(q)+\log(D)+a_F*\log\left(F-N_{op}*T_{op}\right)+a_x*X+a_{z_i}$$

The regression will estimate parameters a_F, T_{op}, a_x, and a_{zi}. In this case, the parameter T_{op} enters the equation as a non-linear effect and so cannot be estimated directly in linear regression models. When $a_F = 1$, the usual CPUE variable is formed.

To be precise, variables such as depth, are taken to be of the form $e^{(a_x * Depth)}$ or as $e^{(s(\mathrm{depth}))}$ where $s()$ is a spline function. For categorical variables or terms using $s()$ it does not matter whether an exponential form is used or not, since the parameters will be adjusted to take it into account. However, it does matter for continuous variables like flight time since $e^{(a_x * Depth)}$ and X^{a_x} are different functional forms.

Flight time could enter via an exponential function such as

$$e^{\left\{a_F * \left(F - N_{op} * T_{op}\right)\right\}}$$

so that in the log regression we get the linear terms:

$$a_F * F - a_F * T_{op} * N_{op}$$

This is still non-linear if we want to estimate both a_F and T_{op}. Even if we collapse the $a_F * T_{op}$ term into one parameter, it is non-linear since we would need a constraint to enforce the sense of the negative sign in $-a_F * T_{op} * N_{op}$. In a linear regression, a combined $a_F * T_{op}$ parameter would take any value that helps the regression to predict total tonnage. Any aliasing by N_{op} on tonnage seen (or correlations) that is not due to search time will detract from the process time idea and will estimate something entirely different.

To examine this idea, two regressions were performed. Firstly, positive kahawai catch data were regressed using the model:

log(tons) ~ year + s(month) + flight_time (feff) + no_operations (nops).

Secondly, flight time was regressed on the number of operations.

So, in summary, flight time was regressed against both the number of operations and the total sightings to accommodate the process time idea. The resulting estimated slopes were used to adjust flight time into search time. Outcomes of examining the rationale above are reported in the results section below.

2.3.4 Investigating the effect of adjusting effort

To investigate the influence of processing activities on trends in relative abundance, flying (or search) effort was included in runs of both the lognormal and binomial models (see description below) in three ways:

1. adjusted effort (*efft*) forced into the model as a covariate;
2. non-adjusted effort (*feff*) forced into the model as a covariate;
3. adjusted effort offered to the model as an explanatory variable.

2.4 Investigating relevance of the analysis to each species

The original aim of this work was to produce indices of relative abundance for all the main purse-seine species (see Section 1.1) except skipjack tuna. During initial model runs outputs were examined for patterns indicating any inadequacy in the data to track abundance of the species. While the results of a standardisation cannot alone provide appropriate evidence, inconsistencies in the data can be linked to other knowledge of the species and assist in decision making.

2.5 Density of flights by target species

Flight density plots were created for each target species from the flight path information (Figure 2, Panel 5) to determine the extent to which the BoP was covered by flights, and whether the area flown varied with target species. This was achieved by extracting the number of ticks for each day that target data were available by grid square, and plotting the proportion of total ticks for each target species as expanding circle plots on a background of grid squares.

2.6 Producing the standardised indices

2.6.1 The data

Pilot and time frame

To avoid difficulties arising from the effects of multiple pilots (e.g., different methods of recording effort, see Section 1.6.2 above), only data for pilot #2 were extracted from the aerial sightings database. To utilise operational data for adjusting the flight effort, the extract was restricted to "the third period" (June 1998 to July 2009). This definition is based on the introduction of a revised data-collection form in 1997–98; after June 1998 pilot #2 returned all his data on the revised form. The final dataset included complete fishing years only, thus comprising the period 1 October 1998 to 30 September 2008.

Area and flight number

Data selection for the analysis was limited to the first flight of the day and to flights that were exclusive to the Bay of Plenty (BoP). This was achieved by limiting selection to those days on which flightpath data from Panel 5a (see Figure 2) indicated that flying was exclusive to the BoP. Selected fields included date, fishing year (fsyr), month, flight index (a unique flight identifier), species code, number of sightings of the species of interest, tonnage (pilot's tonnage estimate for about 97% of records, estimate using school number, minimum and maximum tonnage estimates in the remainder), time of takeoff, flying effort (in decimal hours), half degree grid square code, number of fishing operations (nops), sea surface temperature (sst), and moonphase (moon) (percentage of disc illuminated).

The selection method was based on an examination of the dataset by Middleton et al. (2010) followed by selection and contribution to the analysis described here of a data series of the key attribute flt_grp by David Middleton (SEAFIC). The approach made initial access through table *t_flight*, thus constraining selection to those days on which effort was restricted to the BoP. In addition to avoiding several types of error in the *t_school_sight* table, this approach provided two main improvements over the previous method. Firstly, it eliminated the uncertainty associated with the extent of geographical area visited and secondly, it included those flights during which no sightings were made, thus contributing important information by adding to the category of zero flights. Using the flt_grp series as a basis, an improved coding in Standard Query Language (SQL) was written to extract data from the *aer_sight* database and incorporate the improved selection into the analysis.

Target species

Purse-seine catch data were available from 1989 and had been used to provide information on target species for the third period. Middleton et al. (2010) examined the relative benefits of using catch data from the MFish database, *Warehou*, operational data from *aer_sight*, and modal target data from the purse-seine vessels (*Warehou*). They determined that the modal target, which is based on all purse-seine fishing in the BoP on the day of the flight, provided a target value for the greatest number of flight records, and suggested that this be used as the target variable in the standardisations. Modal target was supplied for each flight by David Middleton along with the flt_grp series mentioned above.

Exploratory data analysis was carried out on the resulting dataset, examining the relevance of target species to the purse-seine fishery, the distribution of flights by year, instances where no sightings were made during a flight, and instances where flightpath data were unavailable from the database. In some cases where an omission could not be clarified from the database, reference was made to the data collection form. Where an omission could not be resolved, the record was dropped from the dataset.

Mixed schools

Mixed schools of the species of interest were included in both of the model components used here (log normal and binomial). For the binomial model, mixed schools were simply included as a sighting of the species of interest. The requirement of tonnages for the lognormal model meant an extra link to the newly created database table containing names and tonnages of component species in schools of a mixed sighting. Tonnages of the species of interest were included in sightings comprising the dataset.

2.6.2 The analysis

The analysis was carried out using the generalised additive model (GAM) (Hastie & Tibshirani 1990) within the *R* package *mgcv* (Wood 2006) following a two-component approach. The first used family=binomial to standardise the presence-absence of schools of the species of interest (trevally or kahawai) on the flight; the second used family=lognormal to standardise observed tonnages of each species. The aim was to standardise for each component-species combination at three levels:

1. log normal (family Gaussian) models for the positive sightings;
2. binomial models of zero sightings versus sightings greater than zero;
3. to produce indices based on the Gaussian and binomial models combined.

Because the aim was to produce annual indices of relative abundance, fishing year (fsyr) was forced into all model runs. A forward stepwise approach was used. In the preliminary runs the models were constrained to include explanatory variables accounting for at least 1% of the variability (i.e., those increasing the R^2 by no less than 1%). This was increased to 3% in the standardisations reported here. In addition to fishing year (categorical) and one of the measures of effort (continuous), six explanatory variables were offered to each of the model runs (Table 1).

Table 1: Explanatory variables used in the regressions.

Explanatory variable	Expanded name	Description	Variable type
fsyr	fishing year	Fishing year (see Section 1.2)	categorical
efft	adjusted effort	Flying effort adjusted for operations & sightings	continuous
feff	unadjusted effort	Flying effort	continuous
cmth	month	Calendar month	†continuous
dchr	time of day	Decimal hour of the day	continuous
soi	southern oscillation index	Troup's index — monthly values	continuous
sst	sea surface temperature	Daily temperature collected at Leigh	continuous
targt	target species	Modal target from the purse-seine fleet	categorical
moon	moonphase	Proportion of the disc illuminated	continuous

†Calendar month must be included as continuous data for the cyclic smoother to function.

Terms were added to the model as follows:

```
"~ fsyr + s(cmth,bs=\"cc\") + s(effort) + s(sst) + s(soi) + targt + s(dchr) + s(moon)"
```

where "s()" is a smoother, "cc" is cyclic smoother, and effort is either efft or feff.

2.7 Resolving issues related to pilchard as the target for trevally

The plot of partial effects for the trevally binomial model runs displayed extremely wide confidence bounds for pilchard compared with those for the other target species (Appendix B, Figure B2a). It was not clear from this result whether contrast in pilchard flights had resulted in the acceptance of target by the model as a significant explanatory variable, or whether the wider scale on the y-axis required by the pilchard confidence bounds was obscuring contrast in the plot.

Three steps were taken with the aim of resolving this issue. Firstly, the numbers of flights by target and time (month, year) were summarised for the trevally data, as well as the number of tonnes of trevally sighted, by target species, and the number of flights, by target species, on which zero tonnages of trevally were sighted. Secondly, the model was rerun without the 11 records with PIL as the target. And thirdly, an independent plot of partial effects for *targt* was produced by holding the covariates other than *targt* constant and using the *predict* function in *R*.

The method for estimating and plotting the partial effects as illustrated in Figure B2a uses units on the y-axis that are not related to binomial values and which would usually be between zero and 1. For the y-axis in Figure B2b, a logit transform is used, which should result in interpretation of the -140 value for PIL as indicating that the effect for pilchard is much closer to zero than the values for the other target species. To better illustrate this, an independent plot of partial effects for *targt* was produced by holding the covariates other than *targt* constant and using the *predict* function in *R*.

2.8 Examining catch as a proxy for target

In order to inform a decision on whether the analysis should be extended to Stages 2 and 3, a set of extra model runs were completed with catch species substituted for target species. These runs were completed for all of the effort types (i.e., adjusted effort forced into the model, unadjusted effort forced into the model, and adjusted effort offered to the model). Results of model structures (i.e., covariates in the order they were selected into each model) were then compared with those from a full set of model runs (i.e., including all effort types) for which target species had been used. A comparison was also made of time series of annual relative abundance indices produced by the target species and catch species models. In both cases indices were produced for the binomial model, the lognormal model, and the combined binomial-lognormal.

3. RESULTS

3.1 Proportion of flights leaving the BoP

Output from the analysis was:

Total number of flights with first sighting in the BoP = 12130.
Total number of these with sightings outside the BoP = 2066.

Proportion of flights leaving the BoP = 2066/12130 = 0.17.

3.2 Pilot error

A comparison of pilot estimates of school size with catches reported by vessels (Figure 3) suggested that the pilot's estimates were reasonably accurate and that there was little evidence for bias. Some instances were evident where the pilot estimates were substantially larger than the catch, particularly for large schools. This is explained partly by the fact that vessels sometimes miss schools and that often they take only a portion of very large schools.

Residual plots from a linear model fitted with untransformed data (Figure C1, Appendix C) suggested a systematic increase in variance with the fitted values. Log transforming the response variable (vessel estimate) and the primary covariate (pilot estimate of tonnage) overcame the problem (Figure C2). Inclusion of an interaction between the log transformed pilot estimate and pilot only reduced the residual sum of squares by 0.4% (Tables C3 and C4). A boosted regression tree fit showed that pilot estimates were close to vessel estimates although one pilot consistently overestimated the tonnage of all species (Table C5). Generally pilots slightly overestimated trevally tonnage and underestimated jack mackerel tonnages (Table C6, Figure 3b).

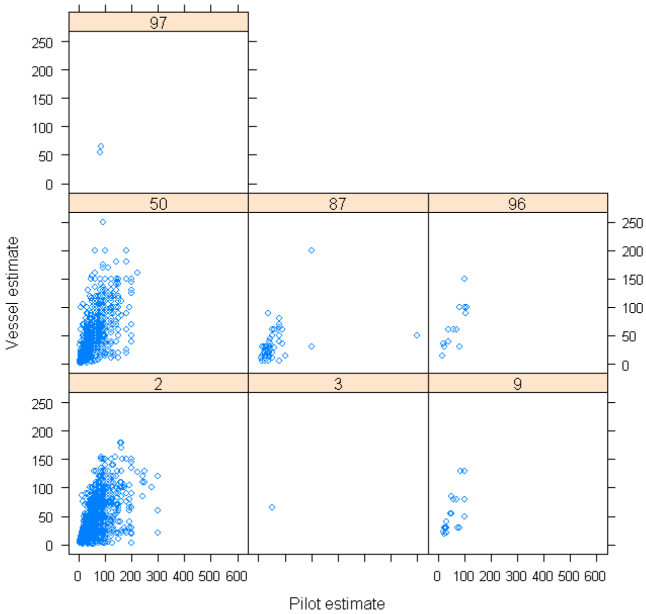

Figure 3a: Plots comparing the vessel estimate of school size with the pilot's estimate, for seven pilots.

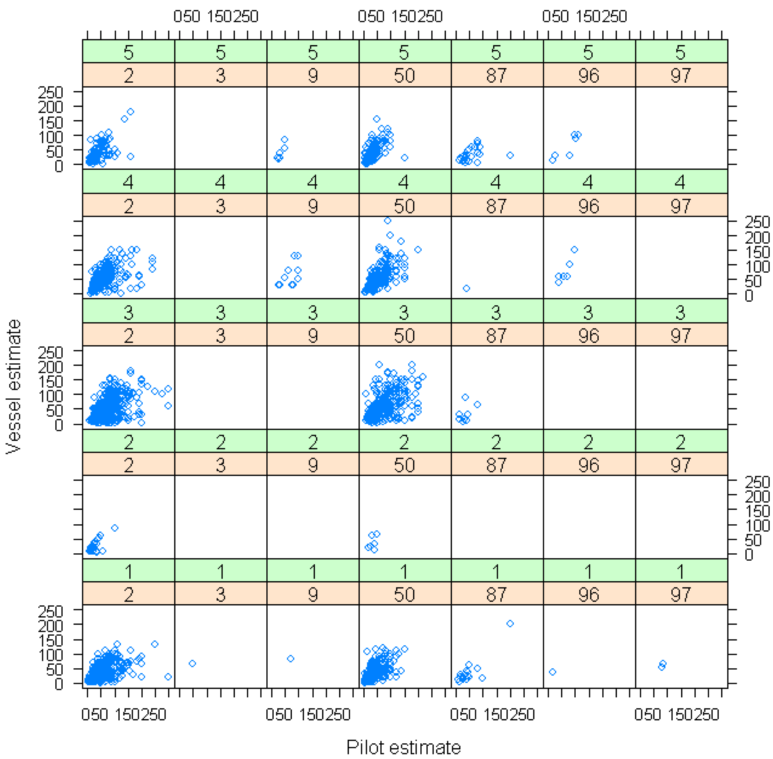

Figure 3b: Plots comparing the vessel estimate of school size with the pilot's estimate, for seven pilots (2, 3, 9, 50, 87, 96, 97) and five species — 1 is skipjack tuna, 2 is trevally, 3 is blue mackerel, 4 is jack mackerel, 5 is kahawai.

3.3 Adjusting effort

3.3.1 Investigating the rationale

Using the model   log(tons) ~ year + s(month) + flight_time (feff) + no_operations (nops)

for kahawai sightings data gave a significant result for flight_time at the 5% level and a non-significant result for no_operations (Table 2a). The coefficient for no_operations was negative, thus implying a process time of 0.25 hours; i.e., process time = 0.040/0.156 = 0.256 hr.

Regressing flight time on the number of operations gave a clear positive slope that suggested a process time of about 40 minutes (Table 2b, Figure 4).

Table 2a: Model outputs for regression of kahawai sightings.

```
Parametric coefficients:
feff      0.15611   0.07604   2.053 0.040609 *
nops     -0.04063   0.07536  -0.539 0.590061
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 2.158 on 478 degrees of freedom
Multiple R-squared: 0.2808,     Adjusted R-squared: 0.2628
F-statistic: 15.56 on 12 and 478 DF,  p-value: < 2.2e-16
```

Table 2b: Model outputs for regression of flight time and number of operations.

Model:	flight_time ~ no_operations
Slope:	0.71 hr/operation
Deviance explained:	49.9%

When the number of total sightings was included, it had a clear positive relationship with tonnage seen (Figure 5) and, consequently, a positive slope in the log(tons) regression. When flight_time was plotted against total_sightings the result was a flattish response indicating that only a few minutes of process time were associated with fly-over time for identifying species and estimating tonnages.

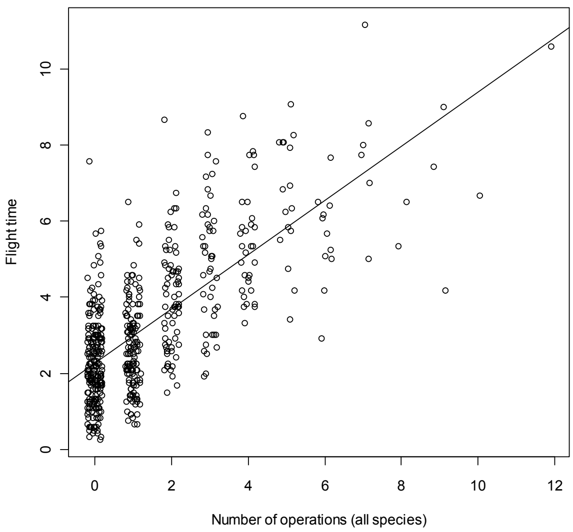

Figure 4: Plot of flight time on the number of operations, including the plotted regression line.

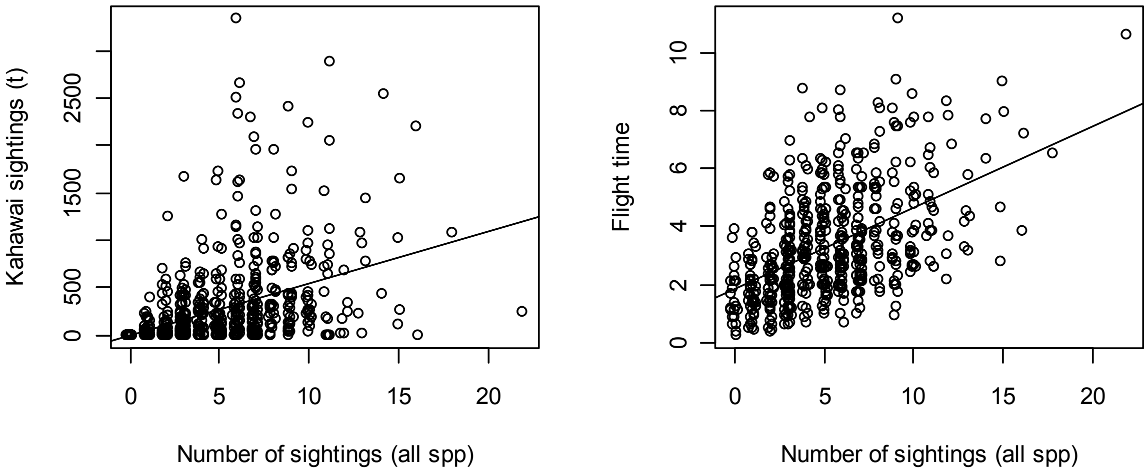

Figure 5: Plots of the tonnage of kahawai observed on the total number of sightings of all species (left plot) and flying time on the total number of sightings of all species (right plot); both include the regression line.

3.3.2 Investigating the effect of adjusting effort

A summary of the outcomes of the four model fits (Table 3) performed in producing the standardised indices documented below (Section 3.6) shows that, in the case of the lognormal fits, the adjusted-effort-forced case accounts for most variability (i.e., total R^2 is highest) for both species. For the binomial fits, the adjusted-effort-offered case provides the largest R^2 for trevally, and the unadjusted-effort-forced case provides the largest R^2 for kahawai.

The range of R^2 values for the various cases of effort is considerably wider for kahawai (i.e., binomial R^2 values range over 7%, lognormal R^2 values range over 5.1%) than for trevally (i.e., binomial R^2 values range over 3.4%, lognormal R^2 values range over 1.4%) and this assists in making a decision for kahawai. Under the covariate selection criterion of "increasing R^2 by 3%", we would choose the unadjusted-effort-forced model for the kahawai binomial and the adjusted-effort-forced model for the kahawai lognormal, but we would be unable to separate the three outcomes for each of the trevally fits.

Table 3: Summarised outcomes from the final model runs to illustrate relative influence of the three variations in effort covariate used in the analyses — adjusted forced (Adj_frcd), unadjusted forced (Un_frcd), and adjusted offered (Adj_offrd); integers indicate selection of covariate into final model for a particular model run, and the order of selection.

Species	Model	Effort type	cmth	effort	dchr	soi	sst	targt	moon	Total R^2
Trevally	Binomial	Adj_frcd	1	2	3					20.4
		Un_frcd	1	2				3		22.7
		Adj_offrd	1		2			3		23.8
	Lognormal	Adj_frcd	1	2			4	5	3	51.6
		Un_frcd	1	2			4	5	3	50.9
		Adj_offrd	1				3	4	2	50.2
Kahawai	Binomial	Adj_frcd	1	2						21.5
		Un_frcd	1	2						26.4
		Adj_offrd	1							19.4
	Lognormal	Adj_frcd	1	2	3		4			44.6
		Un_frcd	1	2				3		39.5
		Adj_offrd	1		3			2		41.8

3.4 Investigating relevance of the analysis to each species

Mackerel species

Currently, there is no way of separating the three jack mackerel species in the data. Therefore, jack mackerel were not included in the analyses. Preliminary analyses of blue mackerel showed high inter-annual variation in estimated relative abundance indices that were unlikely to track abundance (Figure D1, Appendix D). Members of the Northern Inshore Working Group agreed that fluctuations could reflect movements of this widely distributed and highly mobile species, so blue mackerel were also omitted from the analysis.

3.5 Density of flights by target species

There was a major component of flight patterns that dominated the distributions of most species (Figure 6) — the largest proportion of flying occurred in grid squares 147 and 164 with lesser amounts in grid squares 130 and 165. In all cases there was flying in squares 112, 129, and 146, although for most species the proportion of effort expended there was very low; but it was clearly evident for pilchard in all three squares and for trevally in square 129.

Despite the "common" pattern particularly of squares 147 and 165, there were subtle variations that characterised most species individually. However, for skipjack tuna the overall pattern contrasted markedly with that of the other species, with a greater proportion of coverage in the east resulting in a more dispersed coverage over a wider area. The grid squares from which data were recorded is represented by the labelled squares in the plot entitled "Grid square codes" (Figure 6).

3.6 Standardised indices

3.6.1 The data

A total of 539 flights were identified by Middleton et al. (2010) as being exclusive to the BoP within the third period and having an associated modal target available on the day they were flown. Of these, 3 were subsequently identified as having spurious associated modal target (i.e., garfish, paddle crabs, octopus) and 1 was identified as being flown outside the BoP. A further 44 flights were removed (18 in 1997–98 and 26 in 2008–09) when the dataset was restricted to full fishing years only (1998–99 to 2007–08). The total number of flights remaining in the dataset was: 539 – 3 – 1 – 44 = 491.

The total number of flights per year has varied between 22 in 2006–07 and 79 in 1999–00 (Table 4), although numbers were 35 or more in all years except one, and 45 or more in six of the 10 years. The overall monthly mean was 41 flights, but monthly totals over all years were only 25 for March, and 5 for April. The highest monthly mean of 6 flights was for August, when the monthly total (over the entire dataset) was 60 flights.

The number of sightings varies markedly between the two species of interest (Table 5) with a maximum grand total for kahawai of 1127 and 192 for trevally.

A discrepancy is evident for both kahawai and trevally between the number of sightings in the dataset used for the lognormal fit and the number in the dataset used for the binomial fit. These discrepancies are highlighted in Table 5. In all cases the binomial dataset contains more sightings than the lognormal dataset. The disparities are the result of missing mixed tonnage data on the original data collection forms. In the binomial dataset, it is the presence of a mixed school containing the species of interest that is required. These data are available from the *t_school_sight* table in the aerial sightings database. However, tonnages related to sightings of mixed schools are sometimes recorded incorrectly (e.g., two tonnages for a mixed school containing three species) or are missing altogether and, because a tonnage of the species of interest is required for each sighting in the lognormal component of the analysis, some mixed-school sightings (10 for kahawai; 4 for trevally) are missing from the lognormal dataset.

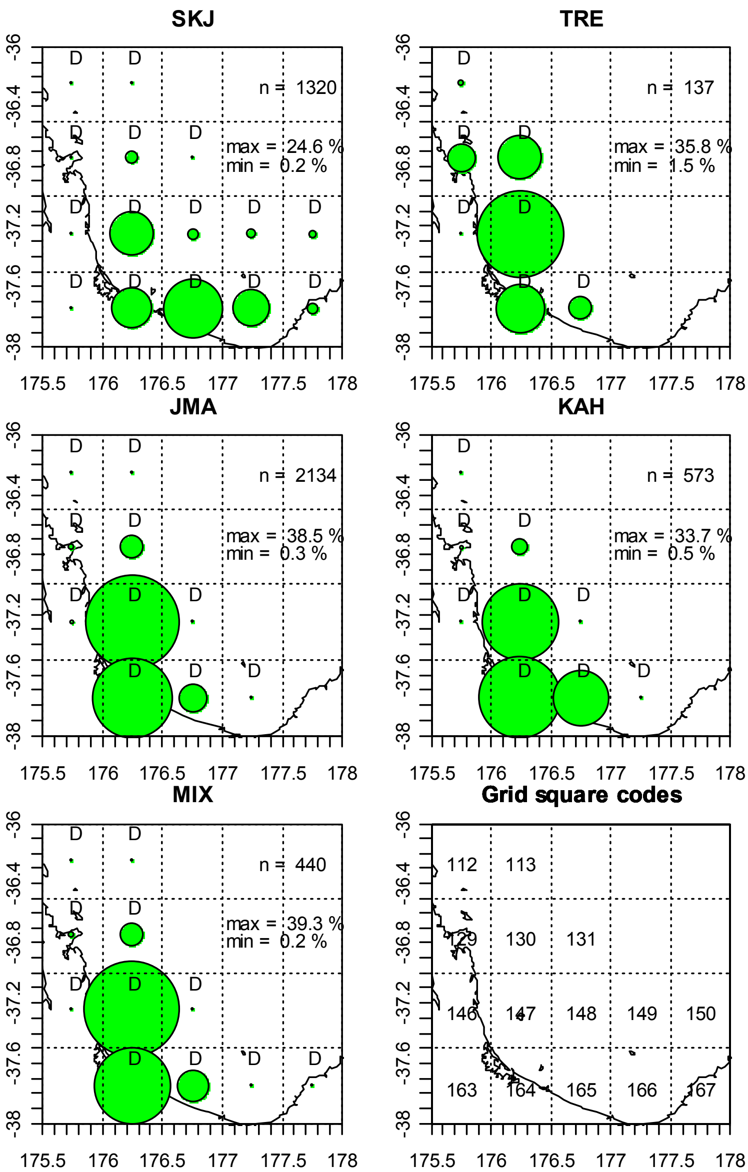

Figure 6: Flightpath density or the proportion of total flightpath ticks (10–15 min periods) recorded in each grid square visited during all flights within the third period (June 1998 to July 2009) in the Bay of Plenty for each modal target species; circles are centred on grid squares, their diameters are relative to proportions of ticks for that species, and the scale is constant for all plots; *n* is the total number of ticks recorded during flights on days a particular target species was assigned, max is the largest proportion plotted for the relevant species, min is the smallest, D denotes squares where data were recorded for that species; EMA is blue mackerel (*Scomber australasicus*), JMA is jack mackerel (*Trachurus* species), KAH is kahawai (*Arripis trutta*), MIX refers to several minor target species, PIL is pilchard (*Sardinops neopilchardus*), SKJ is skipjack tuna (*Katsuwonas pelamis*), TRE is trevally (*Pseudocaranx dentax*); grid square codes are shown in the final plot for squares where data were recorded.

3.6.2 Trevally — binomial fits and indices

The results of the binomial model-fitting are shown in Figure 7 and Table 6. A declining trend in the proportion of flights with trevally sightings is evident in the time series. Target species is significant in all of the fits. The adjusted-offered-effort regime accounts for less than 20% of variability compared with 20.7% and 22.3% in the adjusted forced and non-adjusted forced fits respectively. Diagnostic plots (observed proportion non-zero on expected proportion non-zero) (Figures B1 to B3) indicate no major deviations in estimated values.

Table 4: Distribution of flights exclusive to the Bay of Plenty throughout the data period (1998–99 to 2007–08), by fishing year and month.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Totals	Means
1998–99	11	7		2				8	6	9	9	1	53	4
1999–00	2	3	7	12	13	18	2	2	4		8	8	79	7
2000–01	13	4	4	6	8					5	8	8	56	5
2001–02	7	3	6	7	1			1	2	4	5	5	41	3
2002–03	1	3		3	7					8	6	9	37	3
2003–04	6	2	7	5	2	1		6	3	2	1		35	3
2004–05	3	5		2	1	3		2	7	1	11	10	45	4
2005–06	7	3		4		1	3	5	6	7	9	2	47	4
2006–07			3		3	1		7	4	2		2	22	2
2007–08	3	12	2	10	16	1		4	11	5	3	9	76	6
Totals	53	42	29	51	51	25	5	35	43	43	60	54	491	
Means	5	4	3	5	5	2	< 1	4	4	4	6	5		

Table 5: Number of sightings of kahawai and trevally comprising the datasets used in the lognormal and binomial fits, by fishing year and month; highlighted cells indicate discrepancies in number of sightings between the two datasets for each species.

Species	Dataset	Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Kahawai	Lognormal	1998–99	16	14						11	4	14	12	3
		1999–00	5	12	8	13	2	5	1	4	12		24	18
		2000–01	42	8	7	8	12					7	15	33
		2001–02	30	8	13	7						7	18	18
		2002–03	4	7		3	13					2	11	18
		2003–04	22	6	25	9	4			7	7	3		
		2004–05	12	18		4					16	5	43	27
		2005–06	49	12		4			11	14	23	10	20	7
		2006–07			7					30	7	4		15
		2007–08	14	42	12	13	23			15	38	24	11	35
		Totals	194	127	72	61	54	5	12	81	107	76	154	174
		Grand total												1117
	Binomial	1998–99	16	14						11	4	14	12	3
		1999–00	5	12	8	13	2	5	1	4	12		24	18
		2000–01	42	10	7	8	12					7	15	33
		2001–02	31	8	13	7						7	18	18
		2002–03	4	7		3	14					2	11	18
		2003–04	22	6	26	9	4			7	7	3		
		2004–05	12	20		4					16	5	43	27
		2005–06	49	12		4			11	14	23	10	20	7
		2006–07			7					30	7	4		15
		2007–08	14	43	13	14	23			15	38	24	11	35
		Totals	195	132	74	62	55	5	12	81	107	76	154	174
		Grand total												1127
Trevally	Lognormal	1998–99	14	7						3	1	6	3	
		1999–00		3	2	7	5	2	1	1	3			3
		2000–01	12	1	4	3	2					1		5
		2001–02	16	2	3	3						1	1	1
		2002–03	2	6		2	5							
		2003–04	3		2	3	3			2	1			
		2004–05	4	5		2								2
		2005–06	2	2		2			3	1	3		2	
		2006–07			7									
		2007–08		5	1		1						1	
		Totals	53	31	19	22	16	2	4	7	8	8	7	11
		Grand total												188

Table 5: Continued

Binomial	1998–99	14	7						3	1	6	3	
	1999–00		3	2	7	5	2	1	1	3			3
	2000–01	12	2	4	3	2					1		5
	2001–02	17	2	3	3						1	1	1
	2002–03	2	6		2	5							
	2003–04	3		2	3	3			2	1			
	2004–05	4	7		2								2
	2005–06	1	2		2			3	1	3		2	
	2006–07			7									
	2007–08		6	1		1						1	
	1998–99	14	7						3	1	6	3	
	Totals	53	35	19	22	16	2	4	7	8	8	7	11
	Grand total												192

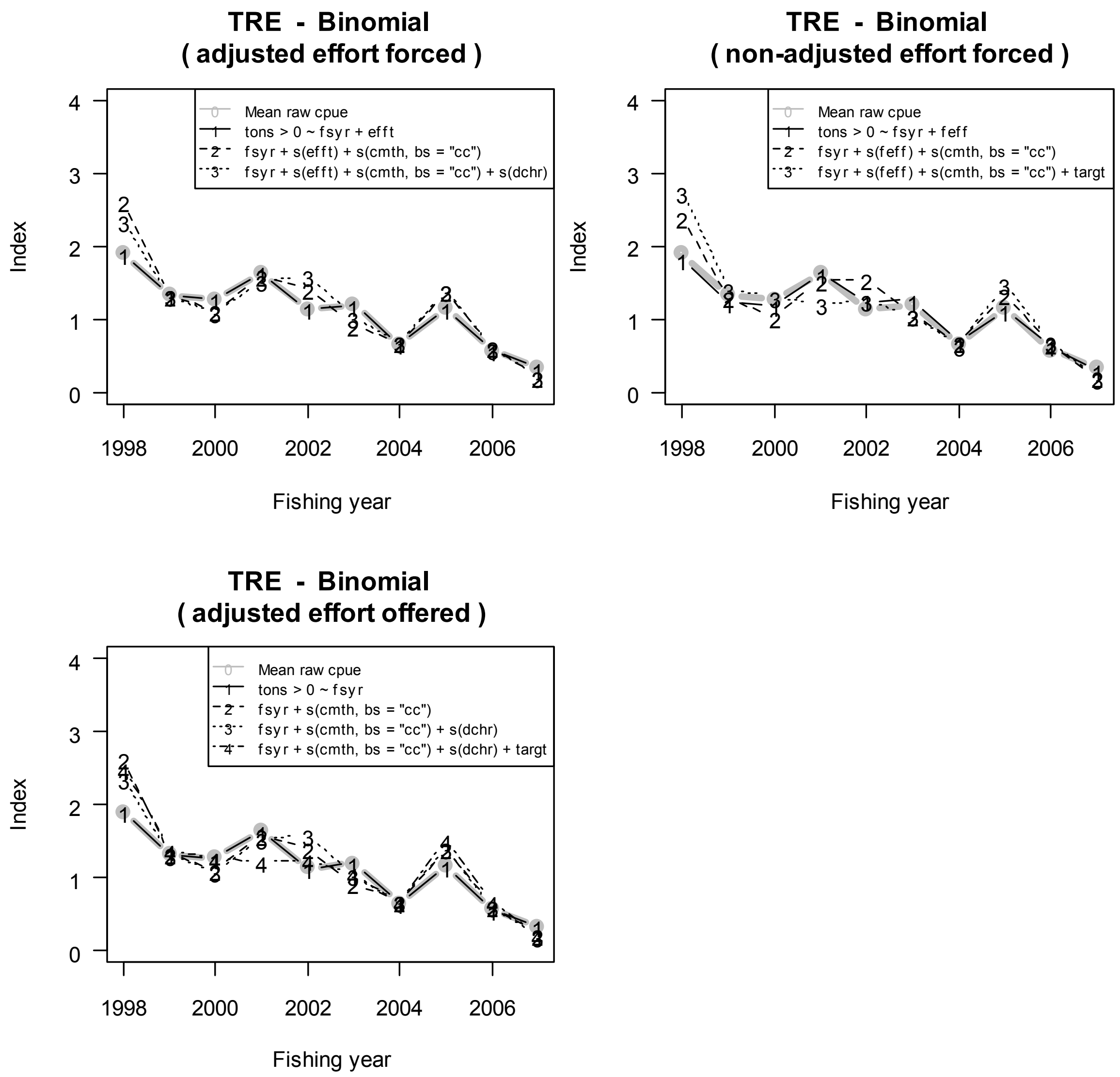

Figure 7: Stepwise standardised annual indices and mean raw (unstandardised) sightings (="CPUE") from the trevally (TRE) binomial regressions under three different effort regimes; fishing year labels show first year of the couple e.g., 1998 is 1998–99.

Table 6: Stepwise binomial model fits for trevally (with mixed schools) under three different effort regimes.

Effort type	change	df	Deviance	AIC	R^2
Adjusted forced	fsyr	10	534	554	6.2
	+efft	11.00	534	556	6.3
	+s(cmth, bs = "cc")	15.38	478	508	16.1
	+s(dchr)	**23.59**	**453**	**501**	**20.4**
	+s(sst)	24.82	444	494	22.1
	+s(moon)	26.83	434	487	23.9
	+targt	32.62	414	479	27.3
	+s(soi)	36.65	404	477	29.1
Selected model	tons>0 ~ fsyr + s(efft) + s(cmth, bs = “cc”) + s(dchr)				
Unadjusted forced	fsyr	10	534	554	6.2
	+feff	12.49	516	541	9.4
	+s(cmth, bs = "cc")	17.22	464	499	18.5
	+targt	**23.23**	**440**	**487**	**22.7**
	+s(sst)	26.49	428	481	24.9
	+s(soi)	27.67	424	480	25.5
	+s(moon)	29.67	418	477	26.7
	+s(dchr)	30.70	417	479	26.7
Selected model	tons>0 ~ fsyr + s(feff) + s(cmth, bs = “cc”) + s(targt)				
Adjusted offered	fsyr	10.00	534	554	6.2
	+s(cmth, bs = "cc")	14.38	478	507	16.1
	+s(dchr)	22.58	454	499	20.4
	+targt	**28.42**	**434**	**491**	**23.8**
	+s(sst)	32.52	418	483	26.6
	+s(soi)	33.78	414	481	27.3
	+s(moon)	36.01	404	476	29
	+s(efft)	36.65	404	477	29.1
Selected model	tons>0 ~ fsyr + s(cmth, bs = “cc”) + s(dchr) + s(targt)				

3.6.3 Trevally — lognormal fits and indices

The results of the trevally lognormal fits are shown in Table 7 and Figure 8. Target species is significant in each of the model fits and the amount of variability accounted for by the fit is relatively high at about 26% in all cases. The trend in the indices is flat with a peculiar peak in 2006. There is a hint of assumptions being violated in the diagnostic plots (Figures B4, B6, B8), i.e., assumption of constant variance, assumption of normally distributed residuals, which may be related to the small number of available tonnage data points. The normal Q-Q plot is discussed in Section 4.4 below. Plots of partial effects are shown in Figures B5, B7, and B9.

Table 7: Stepwise lognormal model fits for trevally (with mixed schools) under three different effort regimes.

Effort type	change	df	Deviance	AIC	R^2
Adjusted forced	fsyr	10	83	334	14.5
	+efft	11.83	80	333	17.4
	+s(cmth, bs = "cc")	17.28	55	296	37
	+s(moon)	21.94	50	292	42.8
	+s(sst)	24.04	45	283	48.5
	+targt	**28.65**	**43**	**284**	**51.6**
	+s(dchr)	30.93	41	283	53.5
	+s(soi)	31.85	41	284	53.8
Selected model	Adjusted forced: log(tons) ~ fsyr + s(efft) + s(cmth, bs = “cc”) + s(moon) + s(sst) + s(targt)				

Table 7: Continued

Unadjusted forced	fsyr	10	83	334	14.5
	+feff	11.28	82	335	15.5
	+s(cmth, bs = "cc")	16.51	58	300	34.3
	+s(moon)	21.46	52	296	40.8
	+s(sst)	23.11	47	286	46.5
	+targt	**27.80**	**43**	**284**	**50.9**
	+s(soi)	28.77	43	285	51.3
Selected model	Adjusted forced: log(tons) ~ fsyr + s(feff) + s(cmth, bs = “cc”) + s(moon) + s(sst) + s(targt)				
Adjusted offered	fsyr	10.00	83	334	14.5
	+s(cmth, bs = "cc")	15.46	58	298	34.1
	+s(moon)	20.39	52	294	40.5
	+s(sst)	22.24	47	285	46.2
	+targt	**26.97**	**44**	**284**	**50.2**
	+s(efft)	28.65	43	284	51.6
	+s(dchr)	30.93	41	283	53.5
	+s(soi)	31.85	41	284	53.8
Selected model	Adjusted forced: log(tons) ~ fsyr + s(cmth, bs = “cc”) + s(moon) + s(sst) + s(targt)				

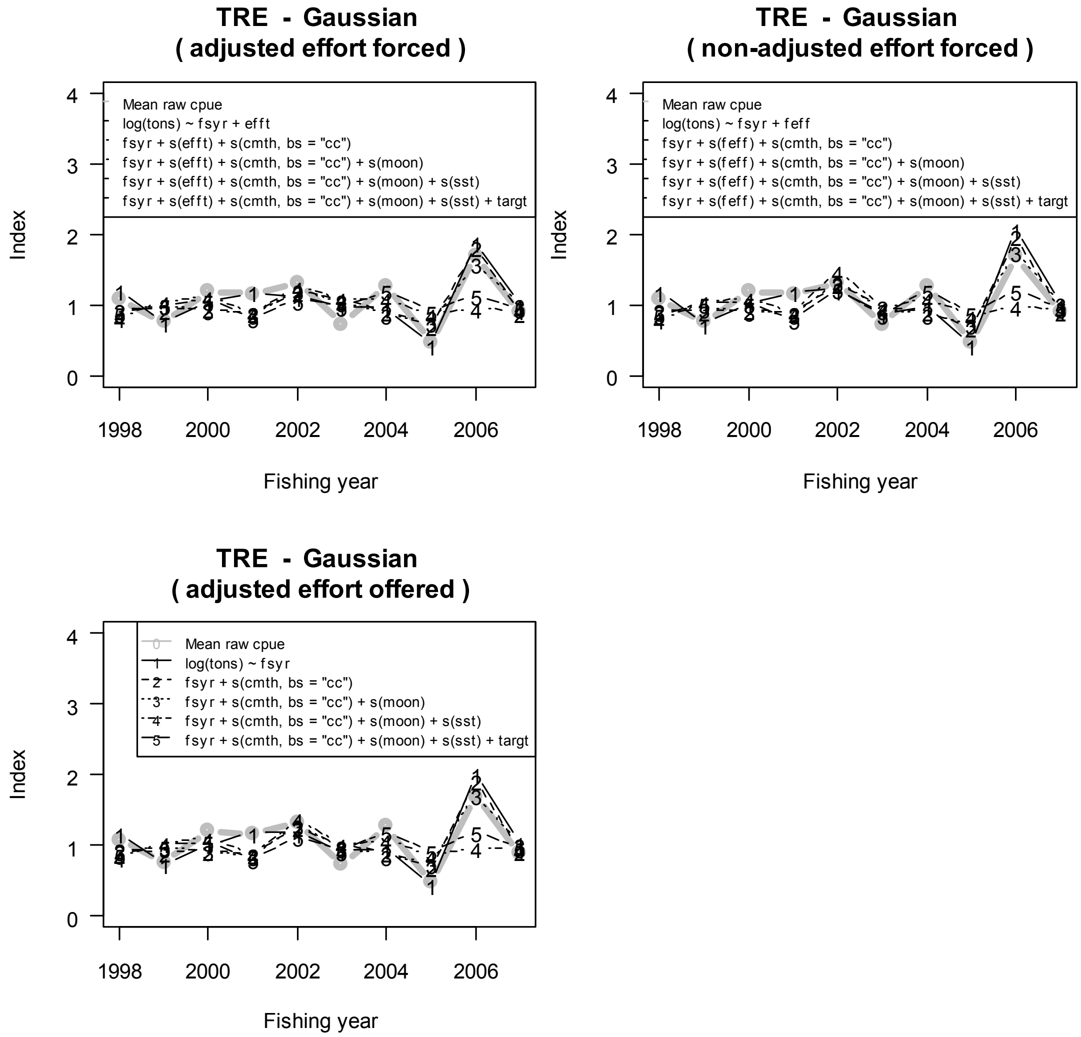

Figure 8: Standardised lognormal index curves for trevally from stepwise addition of covariates with mean raw (unstandardised) sightings; fishing year labels show first year of the couple e.g., 1998 is 1998–99.

3.6.4. Trevally — combined indices

The combined indices (Figure 9) are similar for each of the model series, indicating a steep decline between the first and second years and a continued but much flatter decline throughout the remainder of the period, with a minor increase in 2005–06 and 2006–07 before falling again in the final year.

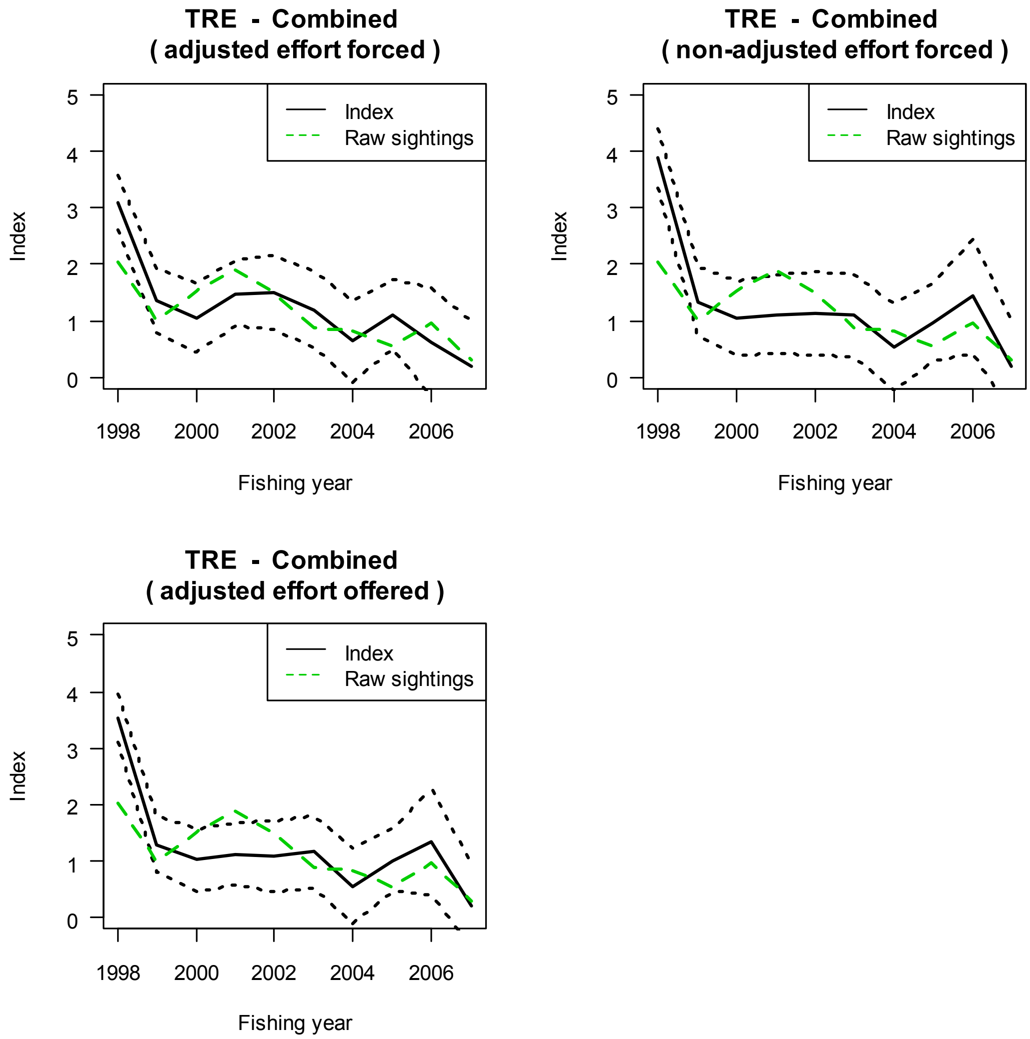

Figure 9: Trevally indices of relative abundance (with mixed schools), combined binomial and lognormal series; fishing year labels show first year of the couple e.g., 1998 is 1998–99.

3.6.5 Kahawai — binomial fits and indices

The results of the binomial model-fitting are shown in Figure 10 and Table 8. The indices are flat throughout the time series. The unadjusted-forced effort regime accounts for the highest amount of variability with an R^2 of 26.4%. Effort is not accepted by the model in the third regime. Target is not selected for any of the three models, and is just outside the selection criterion (accounting for an additional 3% of variability in the R^2). Diagnostic plots (observed proportion non-zero on expected proportion non-zero) (Figures B10 to B12) indicate no major deviations in estimated values. Plots of partial effects are included in these figures.

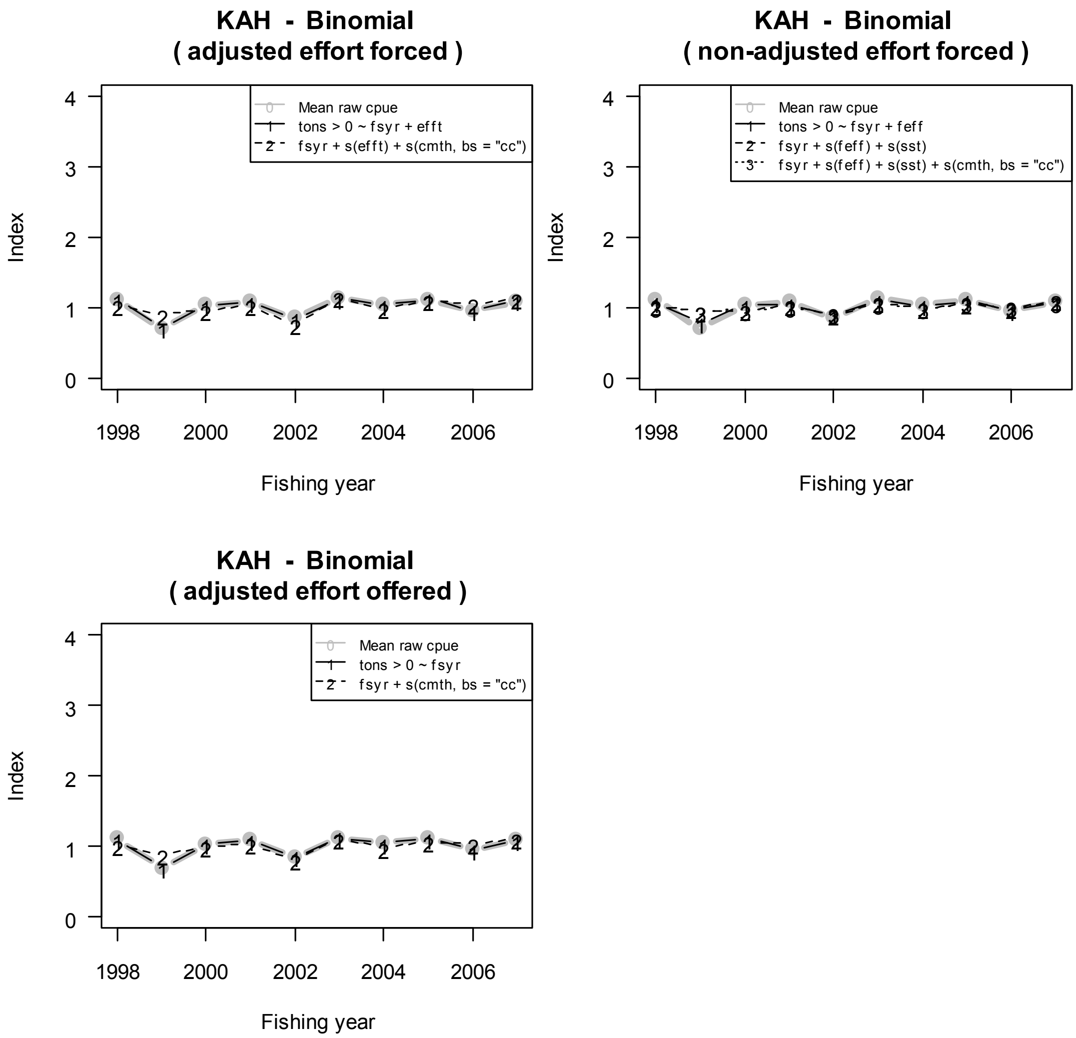

Figure 10: Stepwise standardised annual indices and mean raw (unstandardised) sightings (="CPUE") from the kahawai (KAH) binomial regressions under three different effort regimes; fishing year labels show first year of the couple e.g., 1998 is 1998–99.

Table 8: Stepwise binomial model fits for kahawai under three different effort regimes.

Effort type	change	df	Deviance	AIC	R^2
Adjusted forced	fsyr	10	506	526	6.1
	+efft	11.00	499	521	7.5
	+s(cmth, bs = "cc")	**19.21**	**423**	**462**	**21.5**
	+targt	25.90	409	461	24.1
	+s(sst)	28.00	402	458	25.5
	+s(soi)	32.16	390	454	27.7
	+s(moon)	32.75	390	455	27.8
Selected model	Adjusted forced: tons>0 ~ fsyr + s(efft) + s(cmth, bs = "cc")				
Unadjusted forced	fsyr	10	506	526	6.1
	+feff	13.68	492	520	8.7
	+s(sst)	19.17	418	456	22.5
	+s(cmth, bs = "cc")	**24.81**	**397**	**446**	**26.4**
	+s(dchr)	22.71	390	435	27.7
	+s(soi)	26.41	377	430	30.1
	+targt	32.47	367	432	31.9
	+s(moon)	33.27	367	433	32
Selected model	Unadjusted forced: : tons>0 ~ fsyr + feff + s(sst) + s(cmth, bs = "cc")				

Table 8: Continued

Adjusted offered	fsyr	10.00	506	526	6.1
	+s(cmth, bs = "cc")	**14.52**	**435**	**464**	**19.4**
	+targt	20.81	422	464	21.7
	+s(efft)	25.90	409	461	24.1
	+s(sst)	28.00	402	458	25.5
	+s(soi)	32.16	390	454	27.7
	+s(moon)	32.75	390	455	27.8
Selected model	Adjusted offered: : tons>0 ~ fsyr + s(cmth, bs = “cc”)				

3.6.6 Kahawai — lognormal fits and indices

The results of the lognormal model-fitting are shown in Figure 11 and Table 9. The indices are flat through the first years with an increase in 2003–04 and again in 2004–05, with a brief decline in 2006–07 before increasing again in the final year. Target species is significant in all of the fits. There is little difference between the effort regimes in the amount of variability accounted for which is high at about 47% in all cases. Effort has no appreciable effect on the fits. Diagnostic plots (Figures B13, B15, B17) indicate no violation of model assumption. They are discussed in detail in Section 4.4 below. Partial effects plots are shown in Figures B14, B16, and B18.

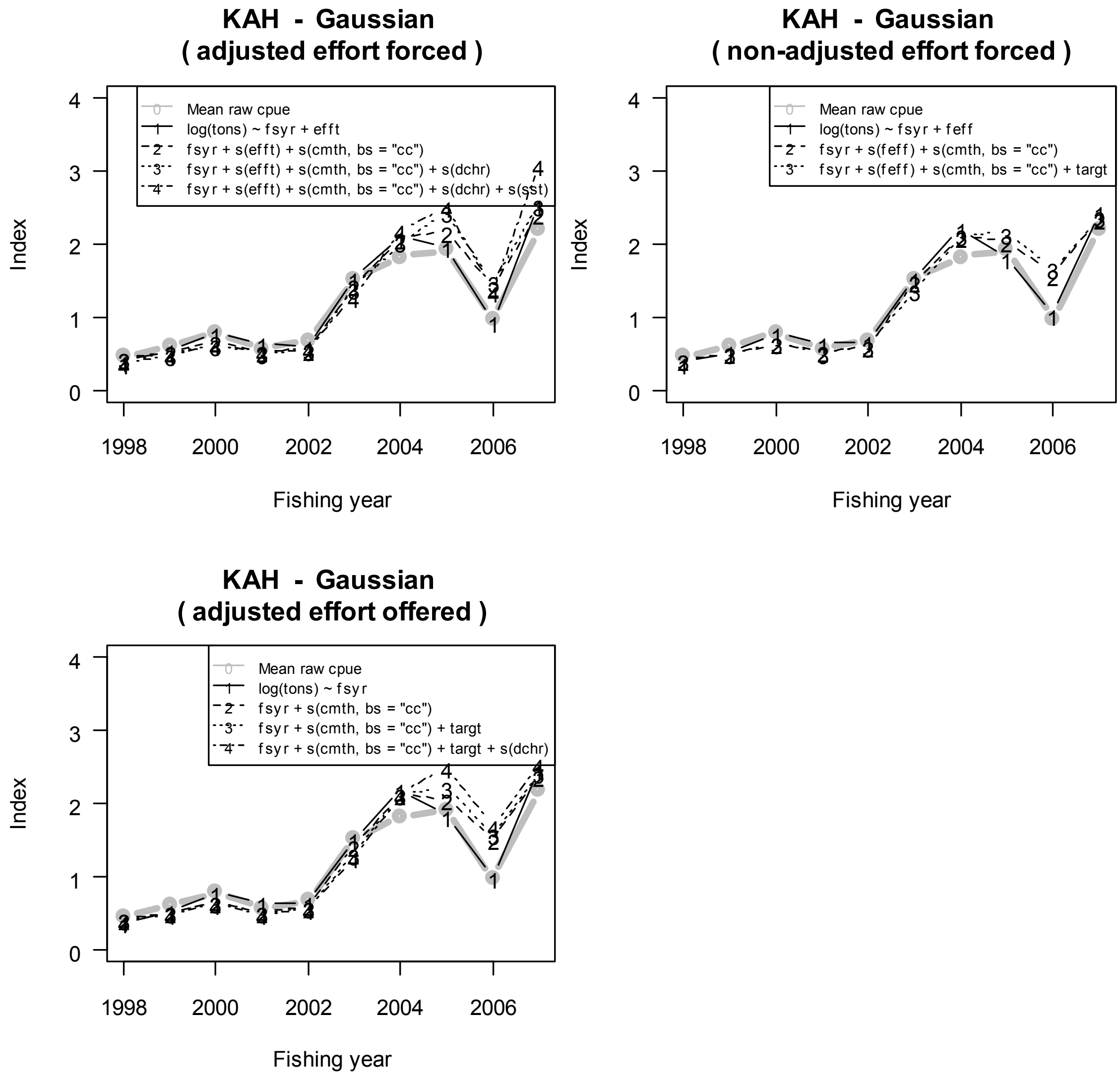

Figure 11: Stepwise standardised annual indices and mean raw (unstandardised) sightings (=”CPUE”) from the kahawai (KAH) lognormal regressions under three different effort regimes; fishing year labels show first year of the couple e.g., 1998 is 1998–99.

Table 9: Stepwise lognormal model fits for kahawai under three different effort regimes.

Effort type	change	df	Deviance	AIC	R^2
Adjusted forced	fsyr	10	501	1193	24.8
	+efft	11.36	483	1182	27.5
	+s(cmth, bs = "cc")	13.58	420	1134	36.9
	+s(dchr)	16.50	395	1117	40.7
	+s(sst)	**24.60**	**369**	**1108**	**44.6**
Selected model	Adjusted forced: log(tons) ~ fsyr + s(efft) + s(cmth, bs = “cc”) + s(dchr) + s(sst)				
Unadjusted forced	fsyr	10	501	1193	24.8
	+feff	11.29	499	1194	25.1
	+s(cmth, bs = "cc")	14.46	425	1140	36.1
	+targt	**20.23**	**403**	**1131**	**39.5**
	+s(dchr)	22.29	387	1120	41.9
	+s(sst)	23.88	381	1118	42.7
	+s(soi)	31.82	356	1108	46.6
Selected model	Unadjusted forced: log(tons) ~ fsyr + s(feff) + s(cmth, bs = “cc”) + targt				
Adjusted offered	fsyr	10.00	501	1193	24.8
	+s(cmth, bs = "cc")	12.65	430	1140	35.5
	+targt	18.48	408	1133	38.8
	+s(dchr)	**21.24**	**387**	**1119**	**41.8**
	+s(efft)	22.45	374	1108	43.8
	+s(sst)	23.65	372	1108	44.2
	+s(soi)	25.35	370	1110	44.5
	+s(moon)	26.50	368	1110	44.7
Selected model	Adjusted offered: log(tons) ~ fsyr + s(cmth, bs = “cc”) + targt + s(dchr)				

3.6.7. Kahawai — combined indices

The combined indices are similar to those from the lognormal fits, with little difference between the three effort regimes (Figure 12).

3.7 Resolving issues related to pilchard as the target for trevally

A pilchard target always resulted in zero sightings of trevally. Table 10a shows three flights each in May, July, and August, and two flights in October, when pilchard was the target species. Table 10b shows that there were no flights with a pilchard target when trevally was sighted. Note also that trevally was sighted on only two flights during March.

For the binomial fit of trevally (Table 11, see Table 6), removing records with a target of pilchard resulted in minor changes. For adjusted effort forced into the model there was a small decrease in the R^2 (from 20.4% to 20%); there is no change to the selected covariates. A similar result occurred for unadjusted effort forced into the model with a decrease from 22.7% to 21.8%. For adjusted effort offered to the model the decrease was largest (from 23.8% to 20%) and target failed selection in the revised case by falling 0.1% outside the selection criterion of 3%.

Figure 13 shows the relative effects for the various target species in the independent partial effects plot. The value for PIL is very close to zero, which is to be expected given that no trevally is sighted when the target species is PIL.

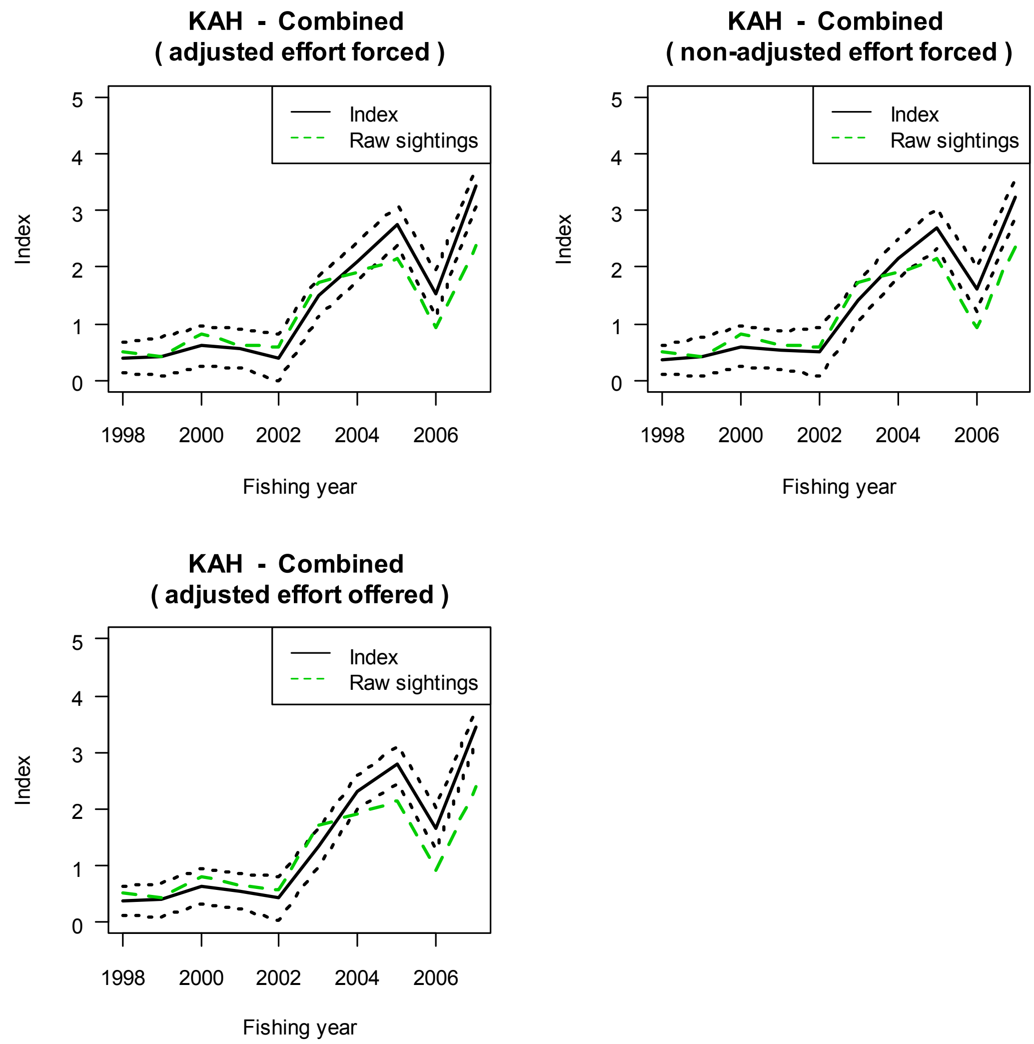

Figure 12: Combined indices for kahawai (KAH) under three different effort regimes; black broken line is a 95% CI; fishing year labels show first year of the couple e.g., 1998 is 1998–99.

Table 10a: Number of flights by target species and calendar month.

	Target							Totals
Month	EMA	JMA	KAH	MIX	PIL	SKJ	TRE	all targets
1	8	2	0	3	0	38	0	51
2	0	0	0	1	0	50	0	51
3	2	0	0	1	0	21	1	25
4	0	3	0	0	0	2	0	5
5	0	22	1	2	3	7	0	35
6	2	35	2	3	0	1	0	43
7	4	25	6	5	3	0	0	43
8	2	28	17	9	3	0	1	60
9	2	32	11	7	0	0	2	54
10	10	19	9	6	2	0	7	53
11	15	19	0	1	0	3	4	42
12	6	15	0	3	0	5	0	29

Table 10b: Number of flights sighting more than zero tonnes of trevally, by target species and calendar month.

	Target							Totals
Month	EMA	JMA	KAH	MIX	PIL	SKJ	TRE	all targets
1	2	0	0	1	0	15	0	18
2	0	0	0	1	0	13	0	14
3	0	0	0	0	0	2	0	2
4	0	3	0	0	0	1	0	4
5	0	2	0	1	0	4	0	7
6	0	6	0	0	0	1	0	7
7	0	2	2	1	0	0	0	5
8	0	4	2	0	0	0	1	7
9	0	4	0	1	0	0	0	5
10	5	10	3	4	0	0	6	28
11	7	6	0	1	0	3	4	21
12	2	6	0	2	0	2	0	12

Table 11: Stepwise binomial model fits for trevally (records with targt = pilchard omitted), under three different effort regimes.

Effort type	change	df	Deviance	AIC	R^2
Adjusted forced	fsyr	10	528	548	6.1
	+efft	11.00	528	550	6.2
	+s(cmth, bs = "cc")	15.44	473	504	15.9
	+s(dchr)	**23.48**	**450**	**497**	**20**
	+s(sst)	24.54	441	490	21.6
	+targt	31.88	418	482	25.7
	+s(moon)	31.52	414	477	26.4
	+s(soi)	35.59	404	475	28.2
Selected model	tons>0 ~ fsyr + s(efft) + s(cmth, bs = “cc”) + s(dchr)				
Unadjusted forced	fsyr	10	528	548	6.1
	+feff	12.62	511	536	9.3
	+s(cmth, bs = "cc")	17.39	460	494	18.3
	+targt	**22.24**	**440**	**485**	**21.8**
	+s(sst)	25.51	428	479	24
	+s(soi)	26.70	424	478	24.6
	+s(moon)	28.72	418	475	25.8
	+s(dchr)	29.75	417	477	25.8
Selected model	tons>0 ~ fsyr + s(feff) + s(cmth, bs = “cc”) + s(targt)				
Adjusted offered	fsyr	10.00	528	548	6.1
	+s(cmth, bs = "cc")	14.45	473	502	15.9
	+s(dchr)	**22.46**	**450**	**495**	**20**
	+targt	27.42	434	489	22.9
	+s(sst)	31.18	419	481	25.6
	+s(soi)	32.56	414	480	26.4
	+s(moon)	34.99	405	475	28.1
	+s(efft)	35.59	404	475	28.2
Selected model	tons>0 ~ fsyr + s(cmth, bs = “cc”) + s(dchr)				

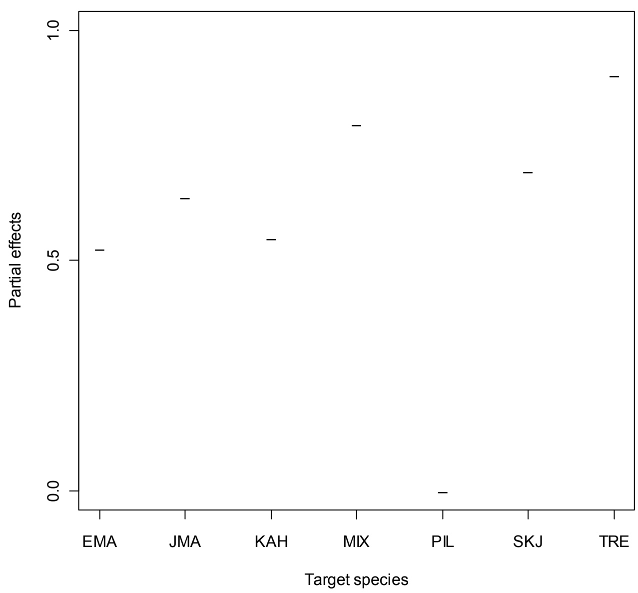

Figure 13: Partial effect plot for target species produced using the *predict* function in *R*.

3.8 Examining catch as a proxy for target

Catch data were used for this analysis. Middleton et al. (2010) identified 517 flights[4] being exclusive to the BoP during the third period and having catch data available on the day they were flown that could be used as a proxy for target. Of these, 4 were subsequently identified as having spurious catches recorded (i.e., barracouta, garfish, paddle crabs, octopus) and 1 was identified as being flown outside the BoP. With the restriction of the dataset to full fishing years (see Section 3.5) a further 38 flights were removed. The total number of flights remaining in the dataset was: 517 – 4 – 1 – 38 = 474 (Table 12).

The temporal distribution of flights is similar to the distribution in the target data. The distribution of sightings is also similar (Table 13), with a total of 1084 and 186 sightings for the binomial datasets of kahawai and trevally respectively. As was shown for the target data, and for the same reason (see Section 3.6.1), there were discrepancies between the number of sightings for the binomial and lognormal datasets for both species: the kahawai lognormal dataset contained 10 less sightings than the binomial and the trevally lognormal dataset contained 4 less sightings than the binomial dataset.

Table 12: Distribution of flights exclusive to the Bay of Plenty throughout the third period (1998–99 to 2007–08) for which catch data were available to provide a proxy for target, by fishing year and month.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Totals
1998– 99	10	7		1				8	6	9	8	1	50
1999–00	2	3	7	12	13	18	2	2	4	0	7	8	78
2000–01	13	4	4	6	7					5	8	8	55
2001–02	5	2	6	7	1			1	2	4	5	4	37
2002–03	1	1		3	7					8	6	9	35
2003–04	6	2	7	5	2	1		6	3	2	1		35
2004–05	3	5		2		3		2	7		10	10	42
2005–06	7	3		4		1	3	5	6	6	9	2	46
2006–07			3		3	1		6	4	2		2	21
2007–08	3	12	2	10	15	1		4	11	5	3	9	75
Totals	50	39	29	50	48	25	5	34	43	41	57	53	474

[4] The number of flights and some other details of this dataset differ from the modal target dataset summarised in Section 3.6.1.

Table 13: Number of sightings of kahawai and trevally comprising the datasets used in the binomial fits for model runs in which catch was used as a proxy for target, by fishing year and month.

Species	Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Kahawai	1998–99	12	14						11	4	14	11	3
	1999–00	5	12	8	13	2	5	1	4	12		24	18
	2000–01	42	10	7	8	12					7	15	33
	2001–02	20	7	13	7						7	18	17
	2002–03	4	2		3	14					2	11	18
	2003–04	22	6	26	9	4			7	7	3		
	2004–05	12	20		4					16		38	27
	2005–06	49	12		4			11	14	23	9	20	7
	2006–07			7					24	7	4	0	15
	2007–08	14	43	13	14	20			15	38	24	11	35
	Totals	180	126	74	62	52	5	12	75	107	70	148	173
	Grand total												1084
Trevally	1998–99	13	7						3	1	6	3	
	1999–00		3	2	7	5	2	1	1	3			3
	2000–01	12	2	4	3	2					1		5
	2001–02	15	1	3	3	0					1	1	1
	2002–03	2	4	0	2	5							
	2003–04	3	0	2	3	3			2	1			
	2004–05	4	7	0	2								2
	2005–06	1	2	0	2			3	1	3		2	
	2006–07			7									
	2007–08		6	1		1						1	
	Totals	50	32	19	22	16	2	4	7	8	8	7	11
	Grand total												186

From the results in Table 14, it can be seen that in many cases there is a similar result in the models using catch as a proxy for target when compared with those where target was used. There are a number of instances where target is the next covariate for selection into a particular model but falls marginally outside the 3% criterion. In these cases target is included in the lists in Table 14 in parentheses. The greatest difference occurred in model runs for kahawai lognormal — the covariate *targt* is selected for the unadjusted-effort-forced and adjusted-effort offered fits with the modal target data, but remains unselected for all the fits using catch as a proxy for target.

Table 14: Selected covariates with their associated R^2 values from binomial and lognormal model fits for trevally and kahawai using modal target data (= target) and catch as proxy for target (= catch), each for the following three different effort regimes — 1 = adjusted forced; 2 = unadjusted forced; 3 = adjusted offered.

		Trevally				Kahawai			
	Effort	Target		Catch		Target		Catch	
Model	Type	Covariate	R^2	Covariate	R^2	Covariate	R^2	Covariate	R^2
Binomial	1	cmth	16.1	cmth	15	**cmth**	**21.5**	cmth	**21.1**
		dchr	**20.4**	**dchr**	**19.7**	(targt)	24.1	(targt)	23.7
				(targt)	22.3				
	2	cmth	18.5	cmth	17.2	sst	22.5	sst	21.9
		targt	**22.7**	**targt**	**20.4**	**cmth**	**26.4**	**cmth**	**25.9**
	3	cmth	16.1	cmth	15	**cmth**	**19.4**	**cmth**	**18.9**
		dchr	20.4	**dchr**	**19.7**	(targt)	21.7	(targt)	21.1
		targt	**23.8**	(targt)	22.3				

Table 14: continued

Lognormal	1	cmth	37	cmth	36.2	cmth	36.9	cmth	37.5
		moon	42.8	moon	43.4	dchr	40.7	dchr	41.1
		sst	48.5	**sst**	**49.4**	**sst**	**44.6**	**sst**	**45.1**
		targt	**51.6**	(targt)	52.1				
	2	cmth	34.3	cmth	33.1	cmth	36.1	cmth	37.1
		moon	40.8	moon	41.1	**targt**	**39.5**	sst	41.3
		sst	46.5	sst	46.9			**dchr**	**44.6**
		targt	**50.9**	**targt**	**51.4**				
	3	cmth	34.1	cmth	32.9	cmth	35.5	**cmth**	**36.3**
		moon	40.5	moon	40.7	targt	38.8		
		sst	46.2	sst	46.6	**dchr**	**41.8**		
		targt	**50.2**	**targt**	**50.6**				

Note 1: only those covariates additional to the forced variables (i.e., fishing year and relevant effort) are listed here.
Note 2: bold indicates final covariate selected; brackets indicate cases where *targt* was the next covariate for selection, but 3% criterion prevented selection from occurring; this criterion requires that for selection, a covariate must account for an additional 3% of variability (i.e., total model R^2 increases by 3%).

Plots of relative indices for the binomial model, the lognormal model, and the combined binomial-lognormal are shown for kahawai in Figure 14a and for trevally in Figure 14b. All plots are based on model runs with effort included as adjusted-forced. Comparisons of 14a with the corresponding plots in Figures 10, 11, and 12, and of 14b with plots in Figures 7, 8, and 9, suggest very little difference between the results using the modal target data and the results using the catch data as a proxy for target.

4. DISCUSSION

4.1 Finalising the data

Possibly the most influential decision here was to limit the data to flights made by pilot #2 only. Two pilots (#2 and #50) had contributed most to the data collection during the third period, but only Pilot #2 had filled out Panel 5a according to the instructions. Results from examining the proportion of flights leaving the BoP provided useful information for discussion, but this result became redundant once the decision had been made to limit flights to those occurring on days when the flightpath data indicated that pilots had not flown outside the BoP.

Discussion at Northern Inshore Working Group meetings also focused on the issue of multiple counting, with Pilot #2 attempting to avoid this by not recording sightings he had seen on earlier flights on the same day. Consequently, records from the first flight of the day were the only ones that could be assumed to contain data for all sightings observed. The dataset was initially restricted to the first flight of the day and this was subsequently revised when it was discovered that some of the first flights of the day (i.e., approximately 20) were of short duration (i.e., 15 min or less), carried no sightings information, proceeded from the pilot's home airstrip to Tauranga Airport, and could be assumed to be repositioning flights to refuel. In these cases the second flight of the day was considered the first search flight of the day and was substituted for the first flight. According to Red Barker (Pilot 2) feedback from vessels/company suggests that pilot estimates of species composition in schools are generally accurate. Inaccurate estimates result in serious marketing and ACE issues.

As was stated in the Methods section, the SQL for data selection from the *aer_sight* database made initial access through table *t_flight*, thus constraining selection to those days on which effort was restricted to the BoP. In addition to avoiding several types of error in the *t_school_sight* table, this

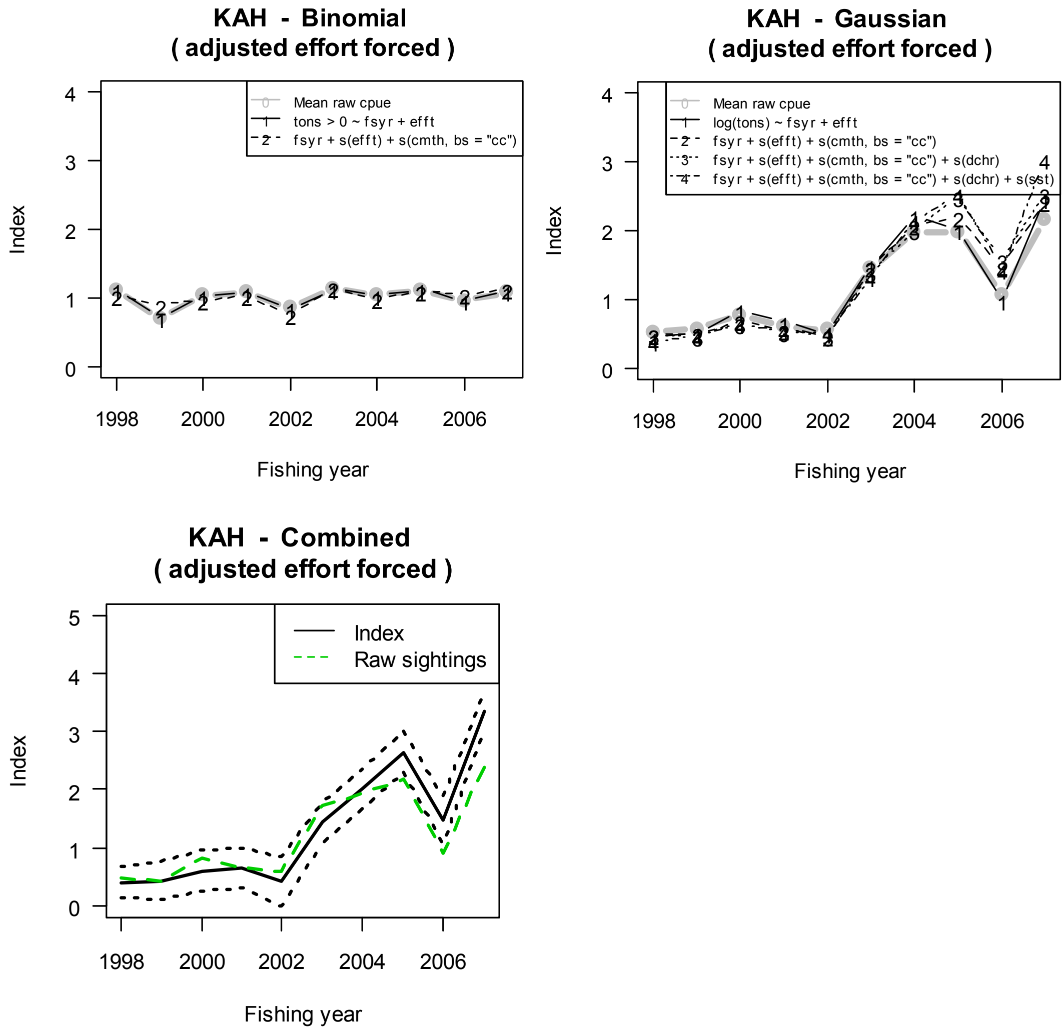

Figure 14a: Indices from the binomial and lognormal fits using adjusted-effort-forced, for kahawai (KAH); black broken line is a 95% CI; fishing year labels show first year of the couple e.g., 1998 is 1998–99.

approach was characterised by two important features. Firstly, it eliminated the uncertainty associated with the extent of geographical area visited and secondly, it included those flights during which no sightings were made, thus contributing important information by adding to the category of zero flights.

4.2 Investigating the effect of adjusting effort

It is clear from the results that there are some differences in the relative performance of fits using the three effort regimes for each model format (lognormal/binomial). The largest R^2 value for the binomial fits was provided by the unadjusted-effort-forced fits for both trevally and kahawai (see summary, Table 15), whereas the largest R^2 value from the lognormal fits for both species was produced by the adjusted-effort-forced fit. However, the margins are small and indicate no clear advantage of using one approach over another.

It is also clear that effort is only included in the model when it is forced i.e., effort is never accepted when offered to the model.

Table 15: Summary of R^2 values for adjusted-forced and unadjusted-forced fits.

	Trevally		Kahawai	
Effort "type"	Lognormal	Binomial	Lognormal	Binomial
Adjusted-forced	51.6	20.0	44.6	21.5
Unadjusted-forced	50.9	21.8	39.5	26.4
Adjusted-offered	50.2	20.0	41.8	19.4

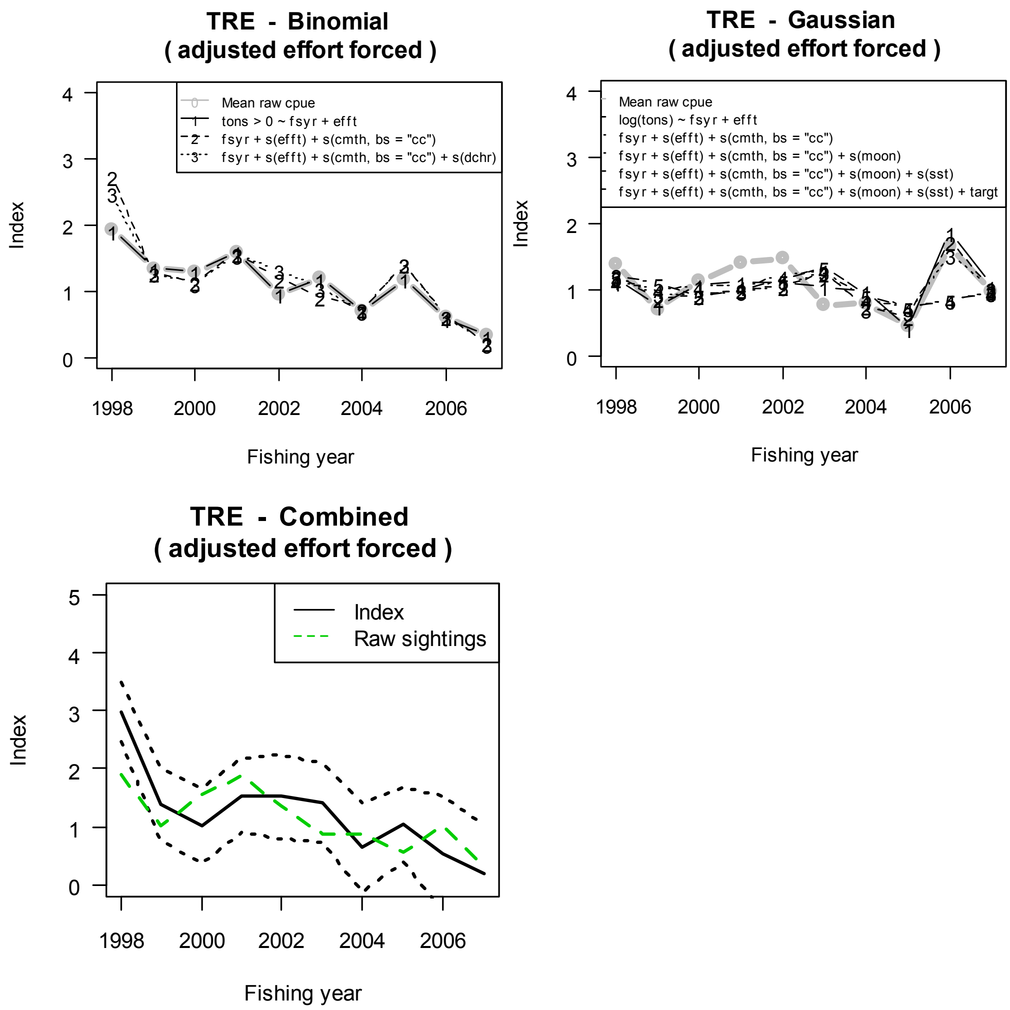

Figure 14b: Indices from the binomial and lognormal fits using adjusted-effort-forced, for trevally (TRE); black broken line is a 95% CI; fishing year labels show first year of the couple e.g., 1998 is 1998–99.

4.3 Examining the influence of target species on the spatial distribution of flying effort

For most target species, the spatial distribution of flying effort followed a somewhat similar pattern, with proportions in squares 147 and 164 dominating the plots. However, the plots also showed that there were key differences.

A target of skipjack tuna produced the greatest variation of the "common" pattern with its effort being dispersed over a wider area than was evident for the other species. Other effects were less obvious. The overall pattern for trevally was similar to the "common" pattern, but the added effort in square 129 seemed to suggest that generally effort is focused on shallow water inshore or around islands (e.g., the Mercury Islands) which are a feature of this square. Similarly for a target of pilchard which has associated with it a distribution that stretches from Great Barrier Island in the north to Whakatane in the south.

The distributions for blue mackerel, jack mackerel, kahawai, and the "mix" category are similar, and provide the "common" pattern referred to above. There are, however, certain subtle differences. For blue mackerel, the proportion of effort expended in square 147 is almost 50%, whereas it is less than 40% for the other species. The distribution for kahawai is characterised by the largest proportion (25%) of all targets in square 165 and less than 10% in square 130, which reflects the distribution known for this species in the south and centre of the BoP (Red Barker, spotter pilot, pers. comm.). The distributions for jack mackerel and "mix" are almost identical, except that the latter extends further west, into square 167, but only for a very small proportion of effort.

The fact that the "common" pattern dominates the distributions in a gross sense may explain why target is so often low in the list of covariates included in the models or is left out altogether.

4.4 The relative abundance indices

The final time series of annual relative abundance indices are a combination of the indices from the binomial and lognormal fits. The same flights are used for both the kahawai and trevally analyses, but the ratio of positive to zero sightings is markedly different between the two species. The lognormal model is based purely on tonnage, while the binomial model is a two-score dataset —there is either a sighting or there is not — so all the data points contribute to the binomial model.

Because the number of trevally sightings is very low (192 on 491 flights = 0.4 sighting/flight), there are few tonnage data points. Consequently, there is more information for the trevally binomial model than there is for the trevally lognormal model. For the kahawai case the number of sightings is much higher (1127 on 491 flights = 2.3 sightings/flight). Therefore there are many more tonnage data points and a greater contribution to the lognormal fit. Because the dataset is so small, the trevally lognormal fit is the least robust of the four fits.

Diagnostic plots for the lognormal fits indicate that, generally the assumptions of the GAM fitting methodology are met. For the kahawai fits, the normal Q-Q plots are all close to a straight line, suggesting that the distributional assumption is reasonable in each case. The residuals on linear predictor plots indicate that the assumption of constant variance is not violated and the histograms of residuals appear approximately consistent with normality, although the graph for the adjusted-effort-forced residuals is skewed a little to the left. The response on fitted value plots show a reasonable degree of scatter and a positive linear relationship with little indication of the assumption of constant variance being violated.

For trevally there are many fewer data points and this makes interpretation of the results a little less clear. There is a hint in the residuals on linear predictor plot and response on fitted values plot of variance increasing with fitted values, but this could be a result of the small dataset. The histograms of residuals are not so clearly normally distributed, but they are reasonable for the size of the dataset. The normal Q-Q plot seems problematic, but inference is not immediately clear regarding the reference line. The plotted residuals form a reasonably straight line, indicating that they are normally distributed. However, their variance is smaller than the model expects, which results in the oblique angle to the 1:1 line. Therefore, one model assumption is not met (i.e., residuals should be on the 1:1 line), but the effect is probably slight, especially since there are few trevally positive sightings.

In most cases the plots of observed proportion non-zero on expected proportion non-zero for the binomial fits for both trevally and kahawai cluster closely around the 1:1 line, indicating no major error in estimations from the fitting process.

4.5 Resolving issues for pilchard as a target for trevally

This analysis showed that no trevally were sighted when the target species was pilchard. Given that more information is contained within the dataset that includes the pilchard-based records and that associated R^2 values are higher, it was concluded that the full dataset including pilchard should be retained for these analyses.

4.6 Examining catch as a proxy for target

This analysis was performed to inform discussion on whether the research should be extended into stages 2 and 3 (see Section 1.2 above, Aims of the study). This was necessary because modal target is not available for the first and second periods. The results of this analysis showed little difference from those produced using the modal target data. It is concluded that catch will provide an acceptable proxy for target in analyses of data from the first two periods.

5. IMPLICATIONS FOR STOCK ASSESSMENTS

The primary aim of this work is to produce annual indices of relative abundance for inshore schooling pelagic finfish. Because jack mackerel cannot be separated into their three component species, and because high levels of variation were evident in preliminary estimates for blue mackerel, these data cannot provide satisfactory indices for these species. The results documented here show that reasonable indices can be expected for trevally and kahawai and, in light of these results, recommendations have been made to extend the work into stages 2 and 3 with the aim of producing annual indices of relative abundance for these two species within QMA 1 over the longest possible period. The ultimate aim is to use these series as stock indices in stock assessment models for trevally and kahawai in QMA 1.

6. ACKNOWLEDGMENTS

- Thanks to the fish-spotter pilots for continuing to supply data over the years, particularly Red Barker for his ongoing discussion on many issues related to the data collection and behaviour of the fish, and Brian Decke for other useful dialogue.
- Thanks to Ian Doonan for developing the rationale presented in Section 2.3 and the results, including plots, in Section 3.3; also to Ian for comments on an earlier version of the manuscript.
- Thanks to David Middleton and other members of the Northern Inshore Technical Group for identifying the approach used for selecting data exclusive to the BoP, and for providing flight group information used as a basis for the data extract; also to David for determining the best set of target-species data and supplying it for the analyses.
- This work was some 8 years in its development and completion. It was funded under a number of MFish projects including PEL2003-02, JMA2004/02, EMA2005/01, TRE2004/01, JMA2004/01, and SAP2006/10.
- This report was reviewed by Ian Doonan.

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8. APPENDICES

Appendix A: An explanation of components of the aerial sightings data collection form

The aerial sightings data reside in an EMPRESS 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 2). 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 during the group of flights.
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*.

Appendix B: Diagnostic plots for the standardised indices

1. Trevally — binomial fits

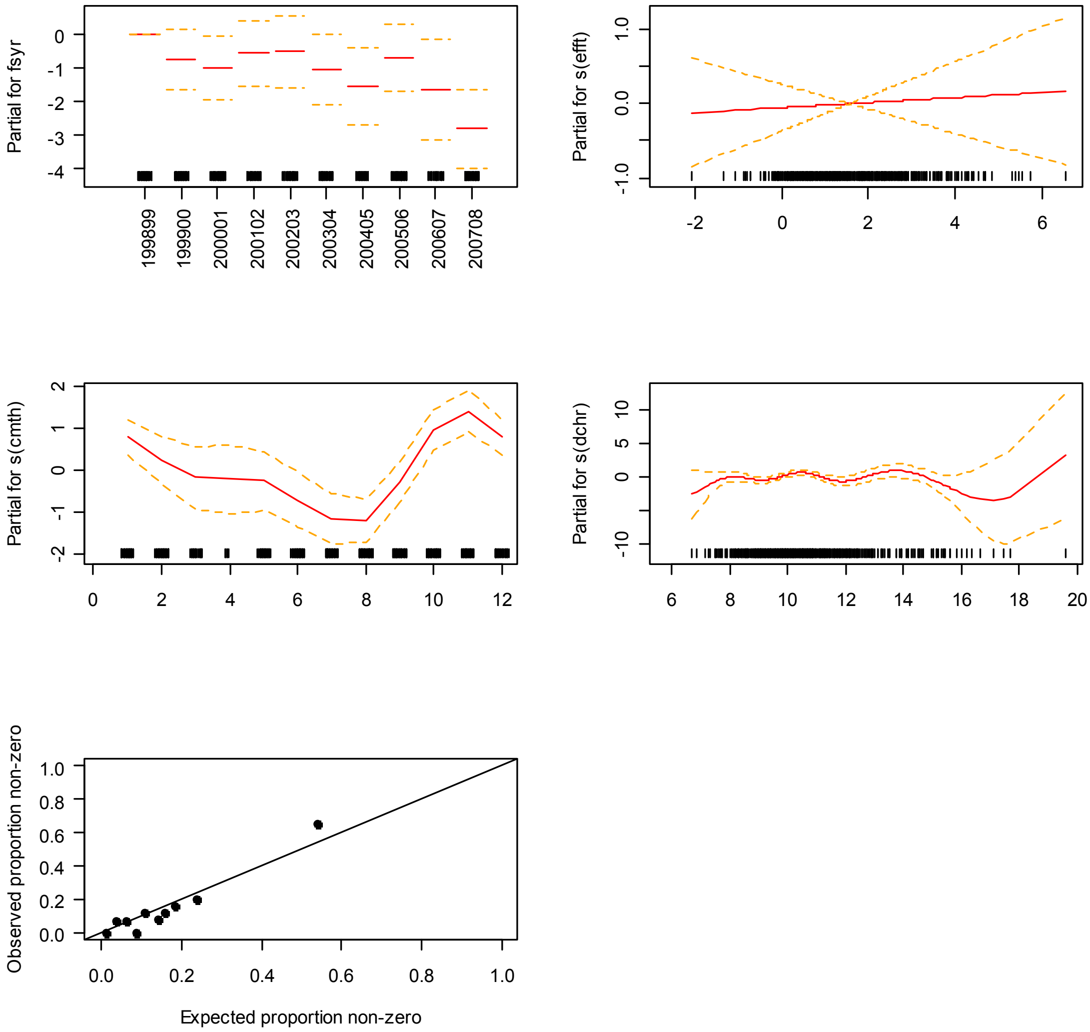

Figure B1: Partial effect plots and observed proportion non-zero on expected proportion non-zero, for trevally binomial fit including adjusted effort forced; note varying y-scale between plots.

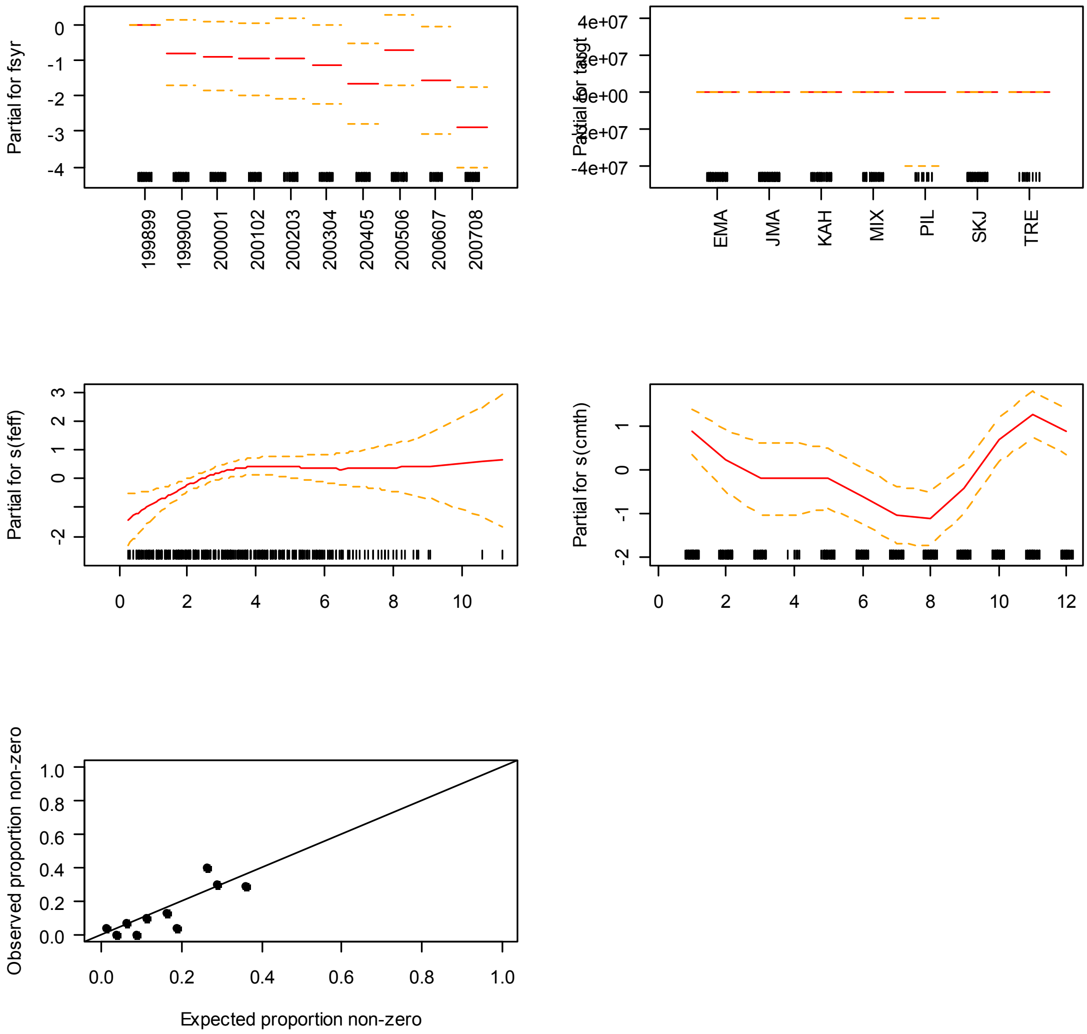

Figure B2a: Partial effect plots and observed proportion non-zero on expected proportion non-zero, for trevally binomial fit including unadjusted effort forced; note varying y-scale between plots.

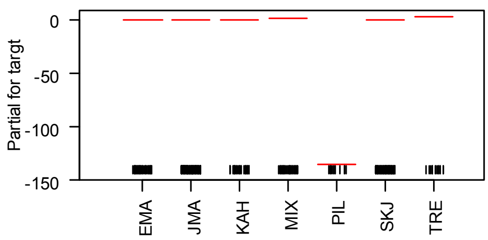

Figure B2b: Partial effect for target species from the trevally binomial fit including unadjusted effort forced; Figure B2a re-plotted without confidence intervals to clarify scale in the partial effect for "targt"; note varying y-scale between plots.

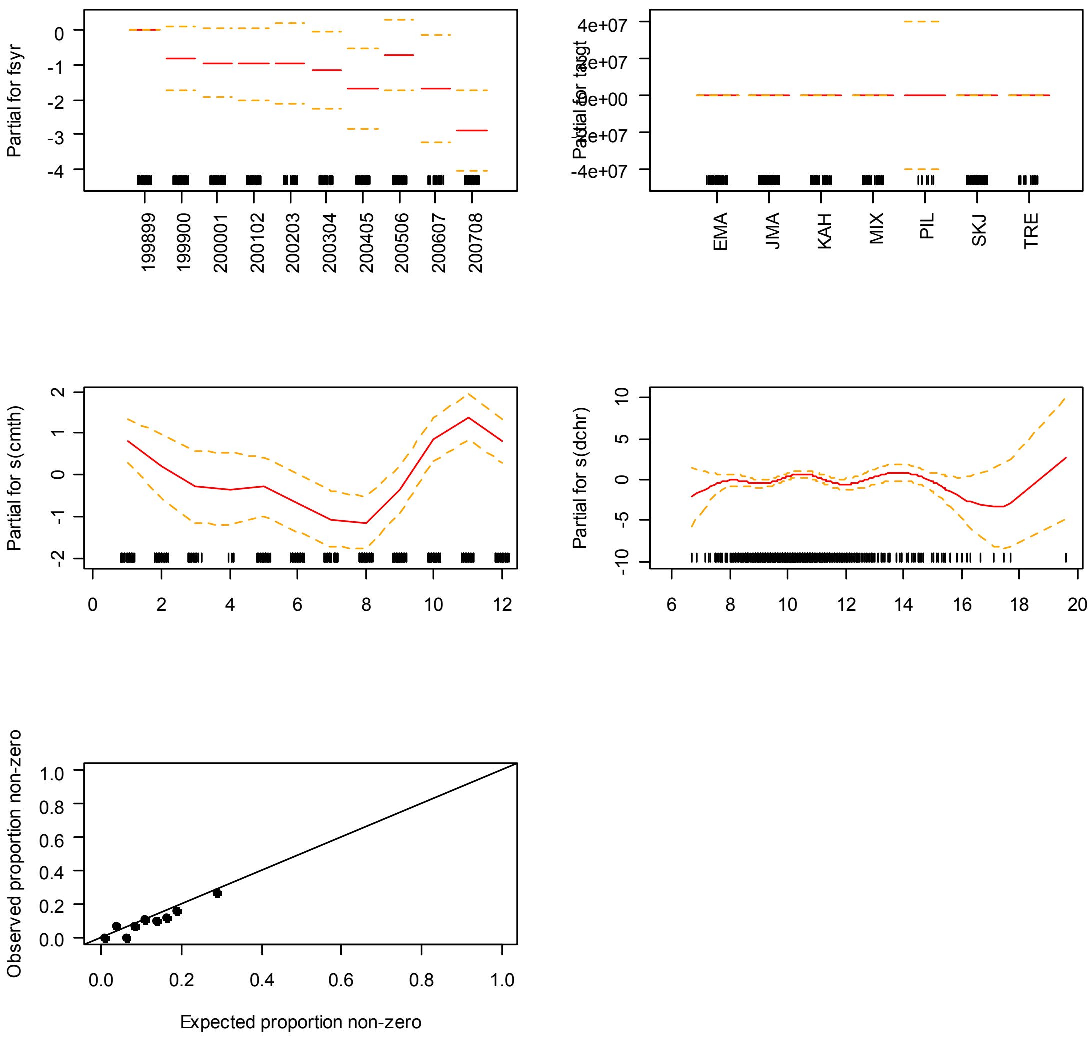

Figure B3: Partial effect plots and observed proportion non-zero on expected proportion non-zero, for trevally binomial fit including adjusted effort offered; note varying y-scale between plots.

2. Trevally — lognormal fits

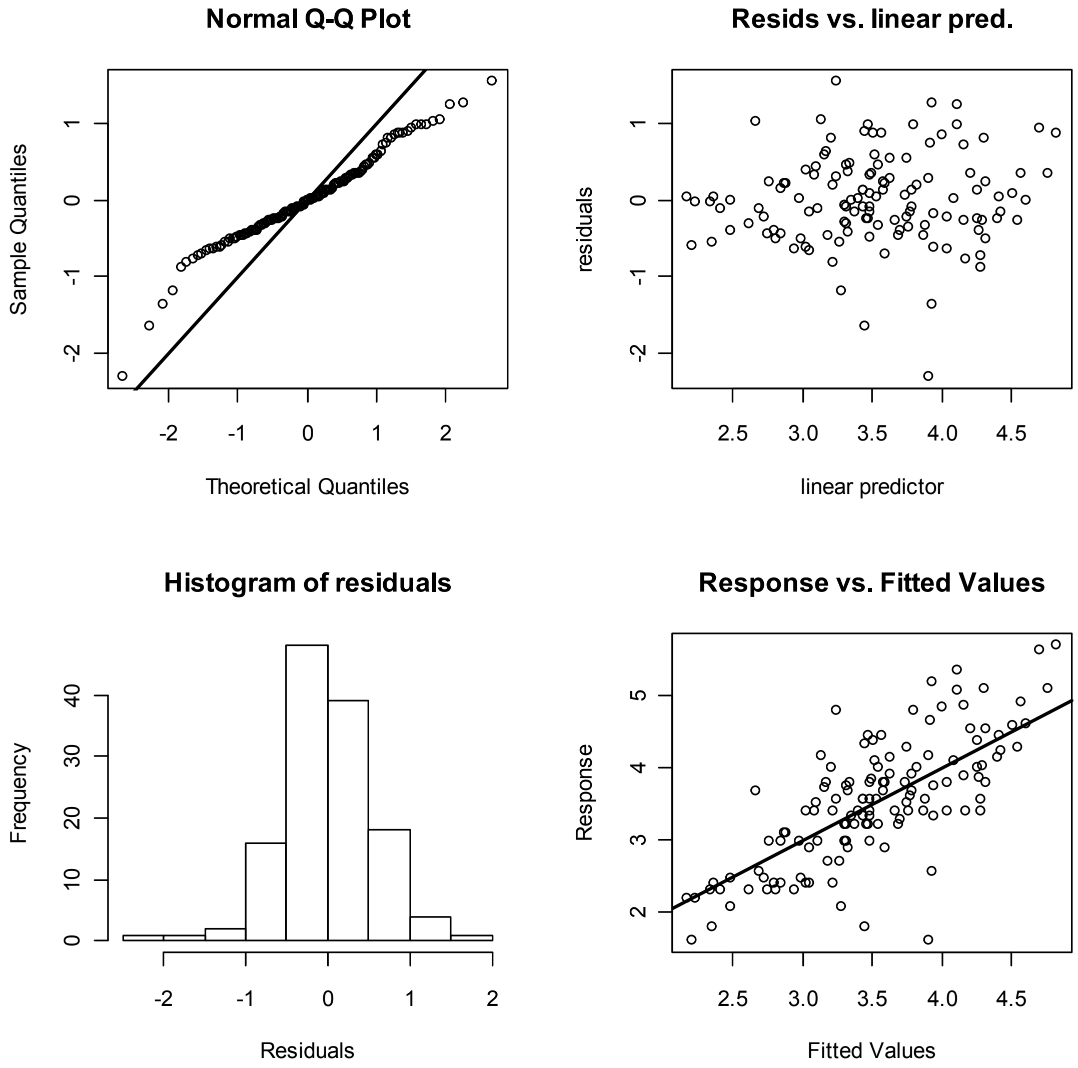

Figure B4: Diagnostic plots from trevally lognormal fit, including adjusted effort forced.

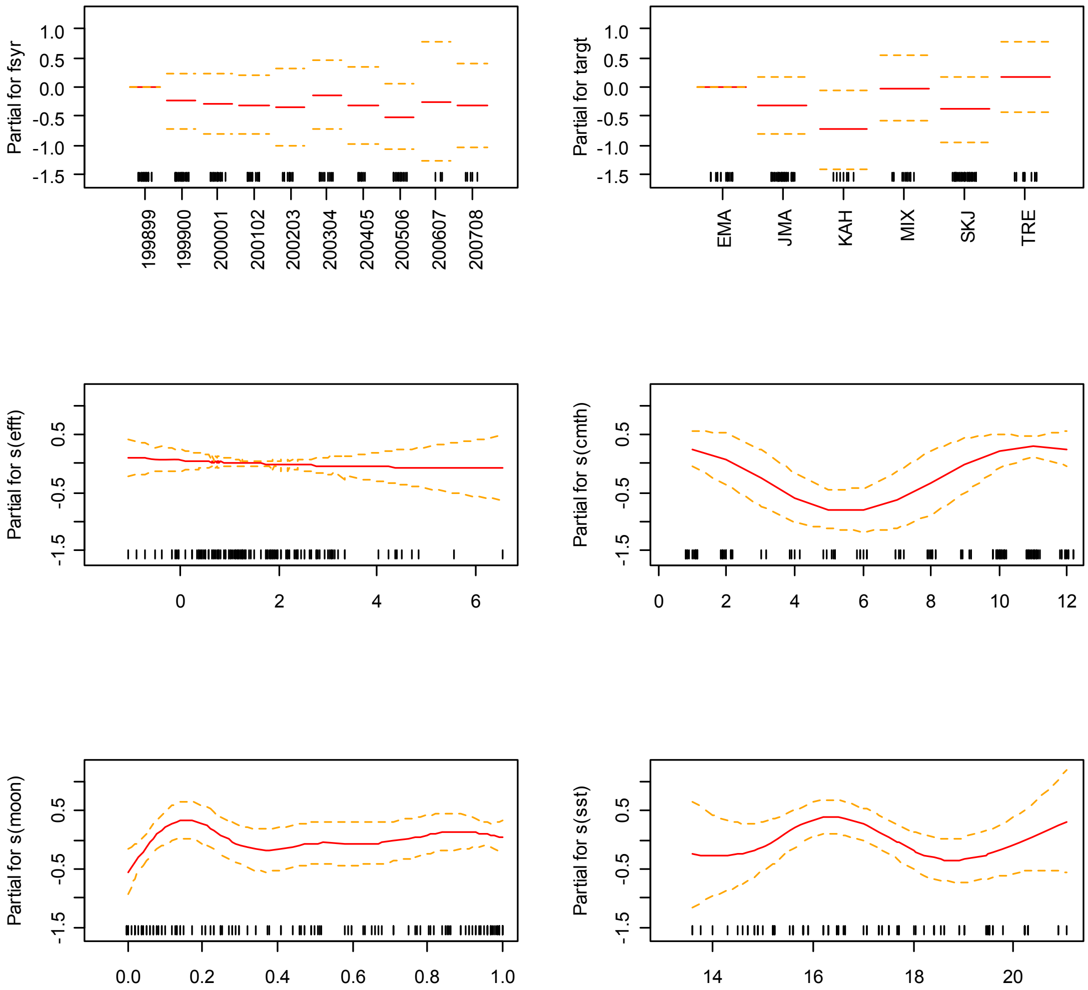

Figure B5: Partial effect plots for trevally lognormal fit with adjusted effort forced.

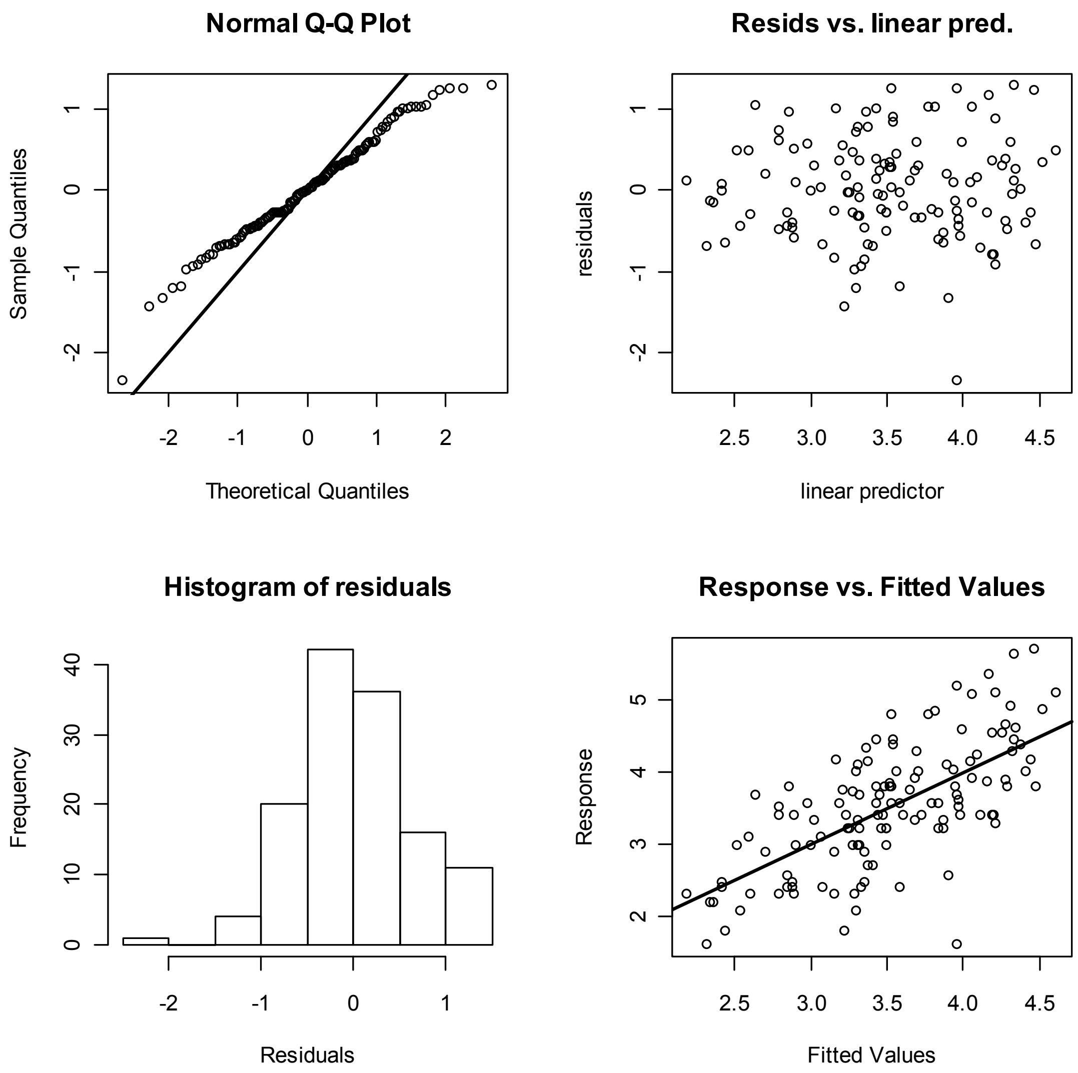

Figure B6: Diagnostic plots from the trevally lognormal fit with unadjusted effort forced.

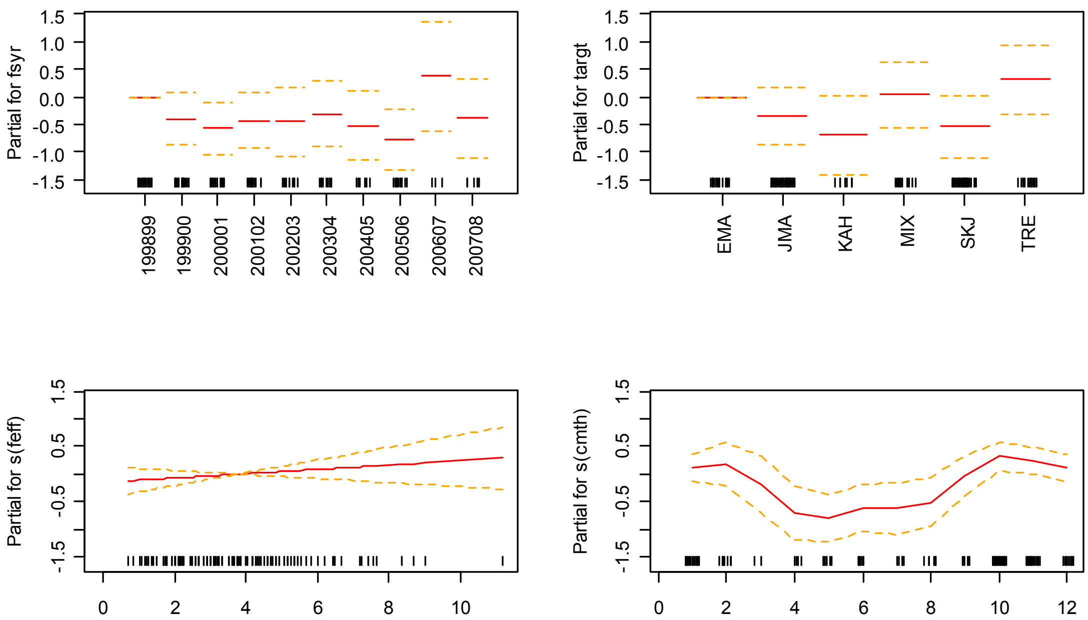

Figure B7: Partial effect plots for the trevally lognormal fit with unadjusted effort forced.

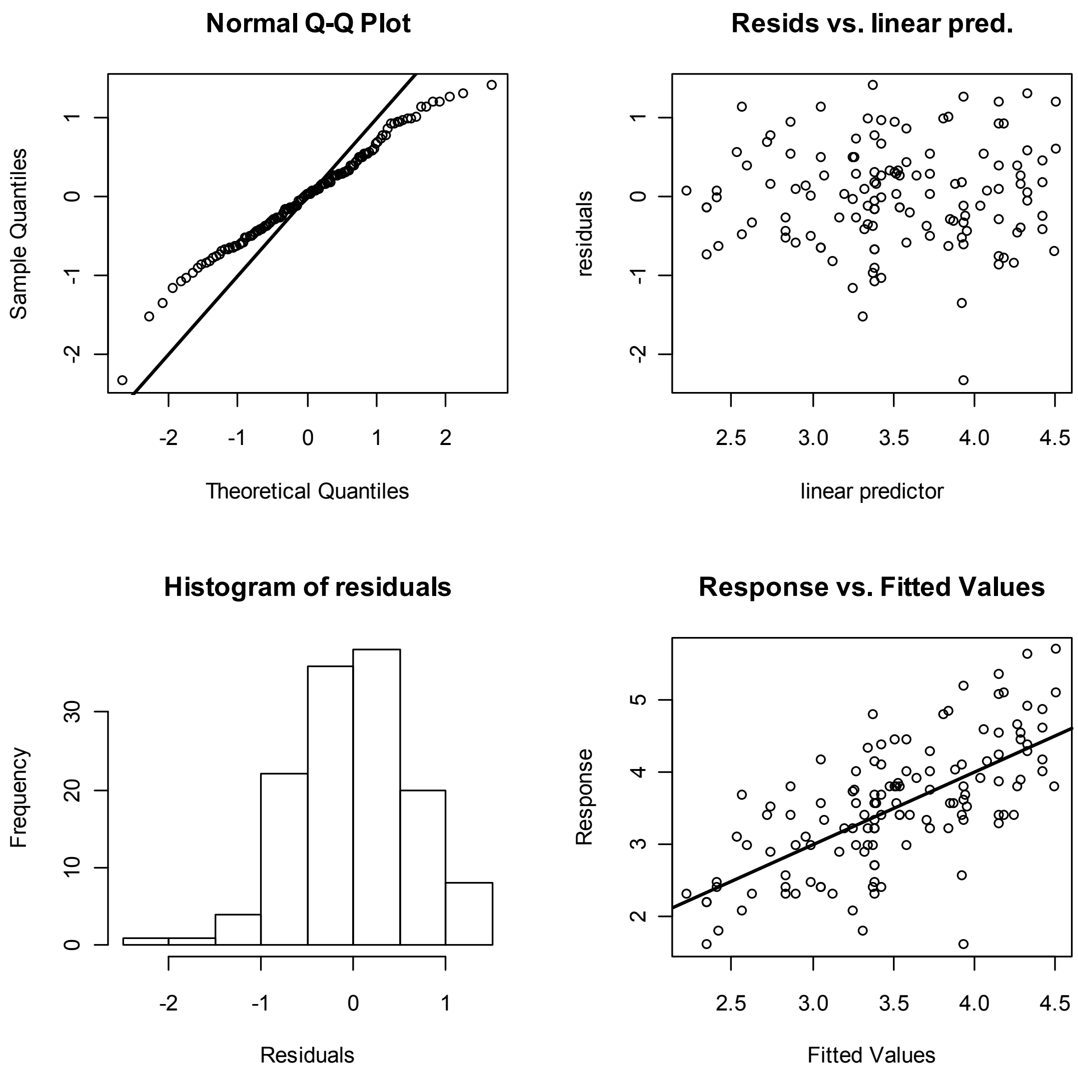

Figure B8: Diagnostic plots from the trevally lognormal fit with adjusted effort offered.

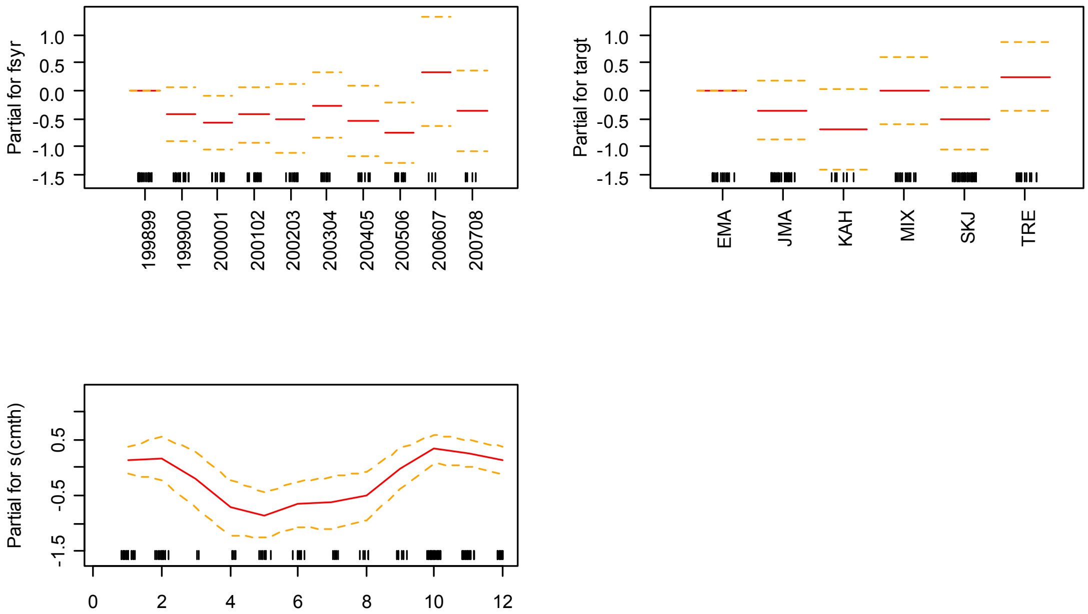

Figure B9: Partial effect plots for the trevally lognormal fit with adjusted effort offered.

3. Kahawai — binomial fits

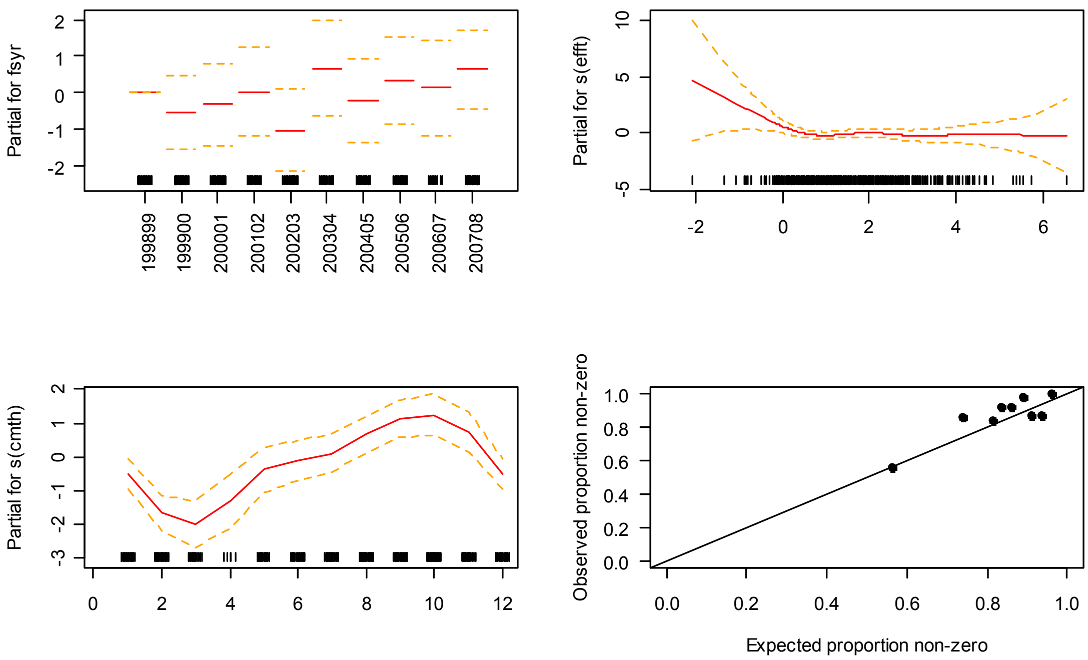

Figure B10: Partial effect plots and observed proportion non-zero on expected proportion non-zero, for the kahawai binomial fit with adjusted effort forced.

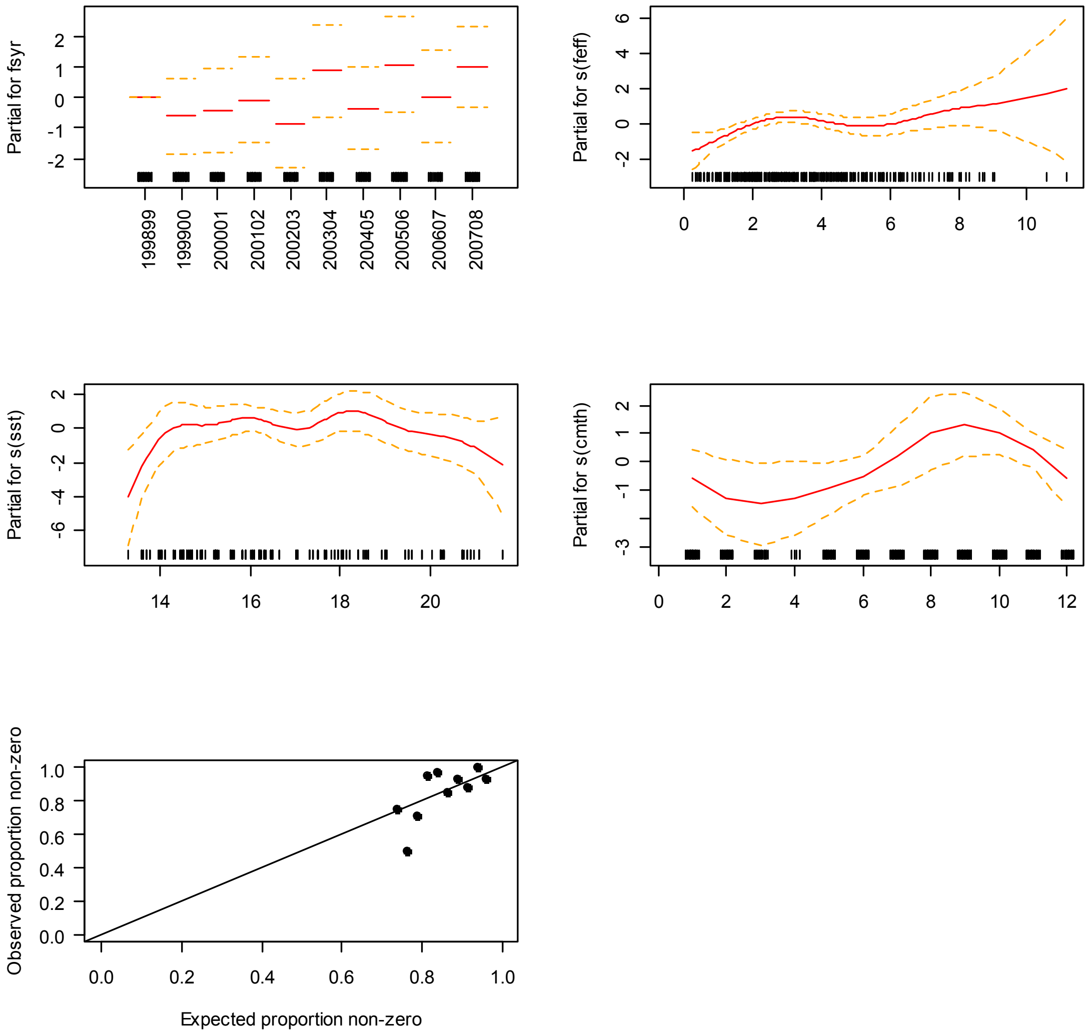

Figure B11: Partial effect plots and observed proportion non-zero on expected proportion non-zero, for the kahawai binomial fit with unadjusted effort forced.

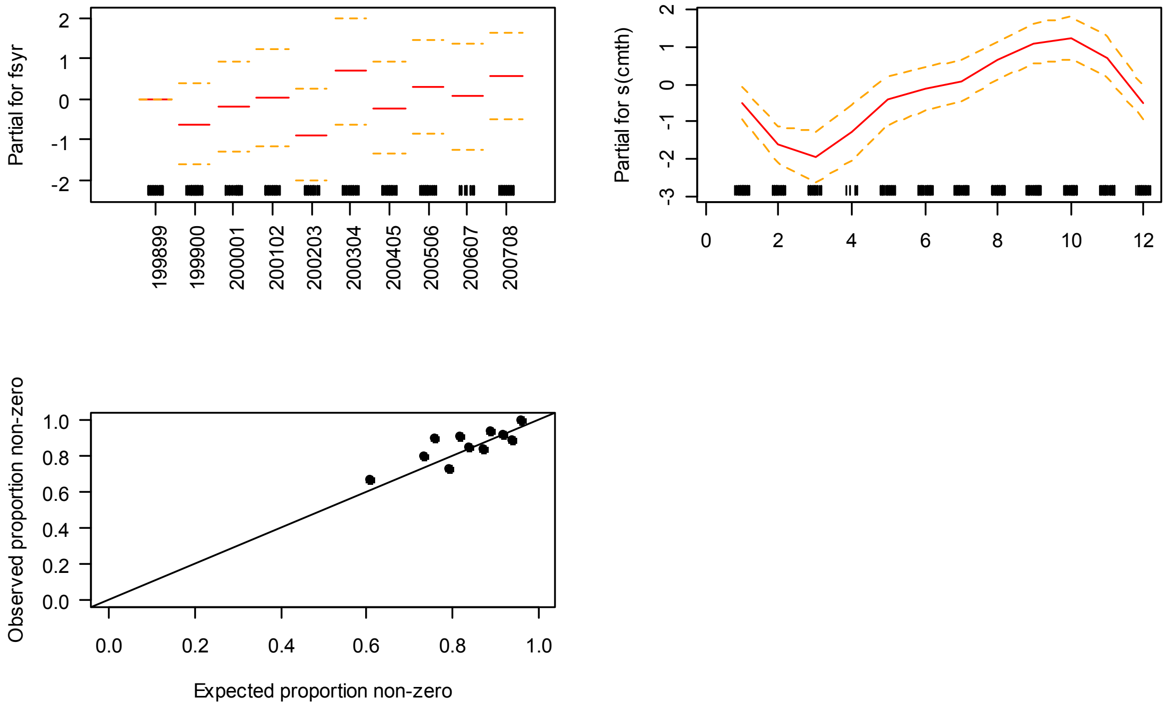

Figure B12: Partial effect plots and observed proportion non-zero on expected proportion non-zero, for the kahawai binomial fit with adjusted effort offered.

5. Kahawai — lognormal fits

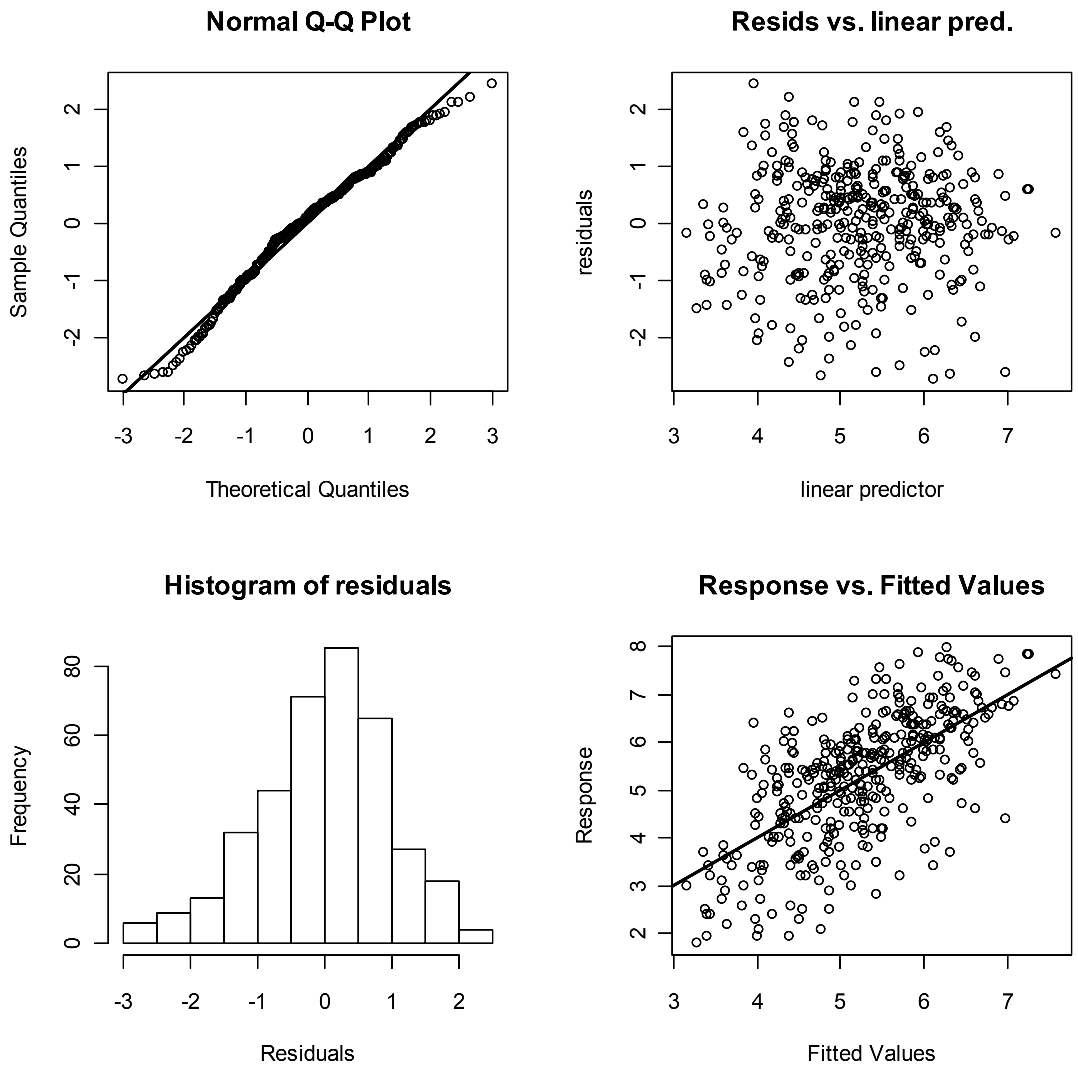

Figure B13: Diagnostic plots for the kahawai lognormal fit with adjusted effort forced.

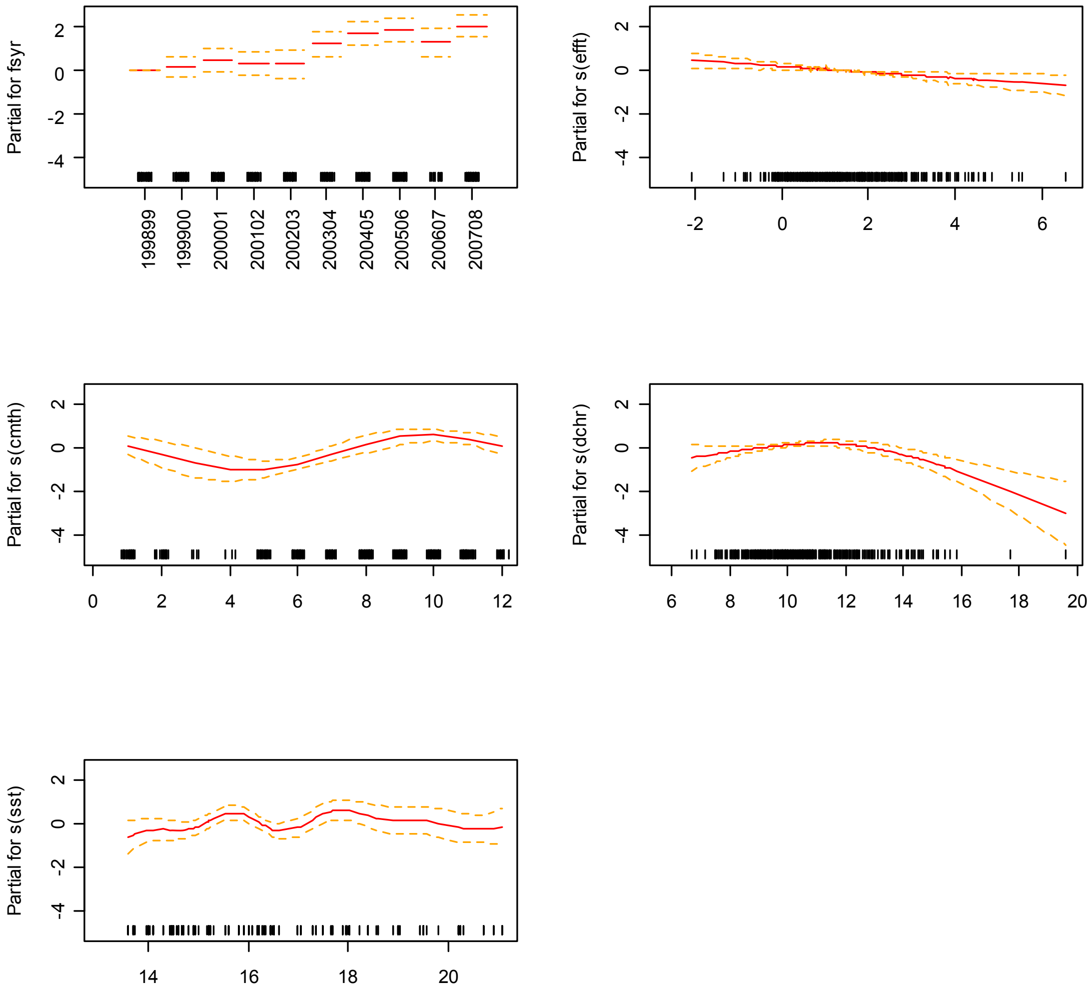

Figure B14: Partial effect plots for the kahawai lognormal fit with adjusted effort forced.

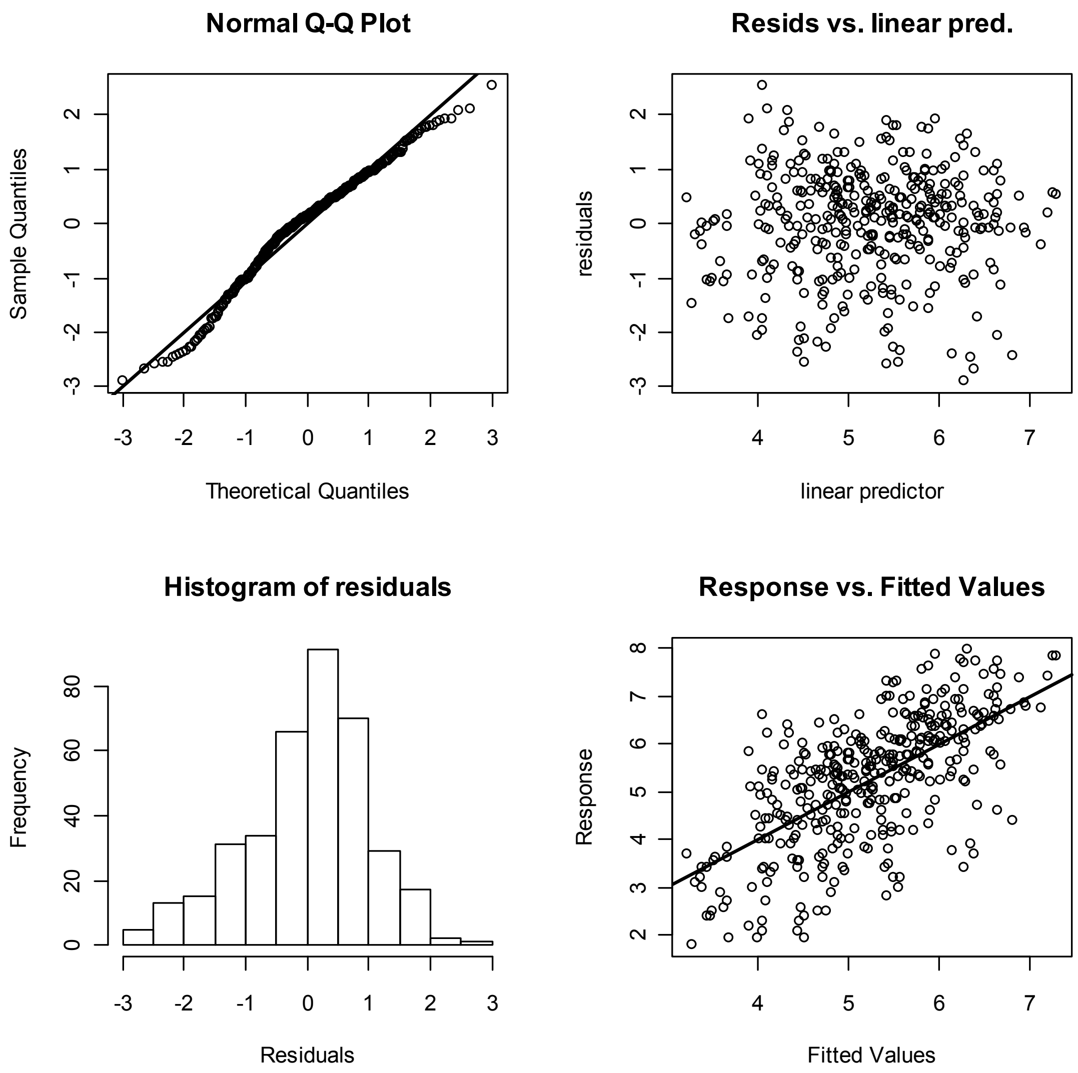

Figure B15: Diagnostic plots for the kahawai lognormal fit with unadjusted effort forced.

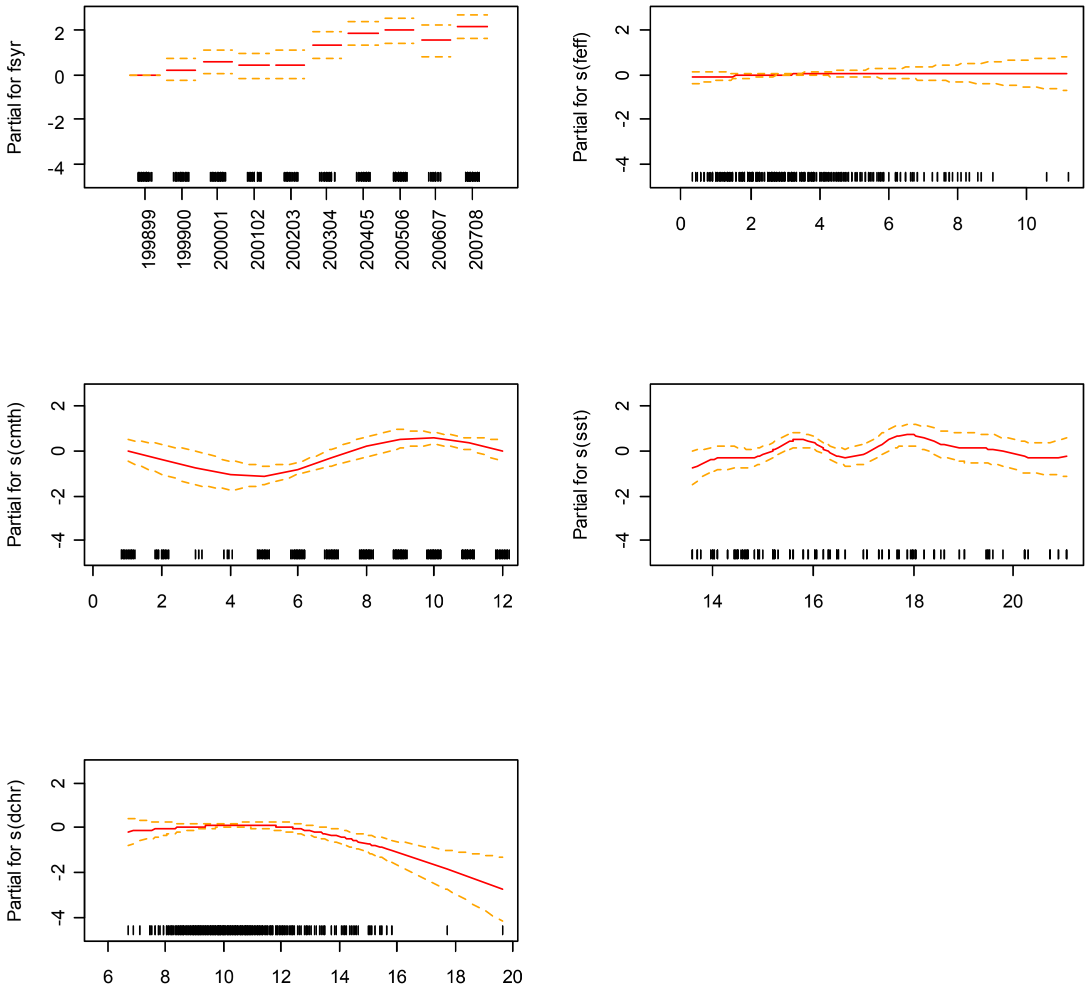

Figure B16: Partial effect plots for the kahawai lognormal fit with unadjusted effort forced.

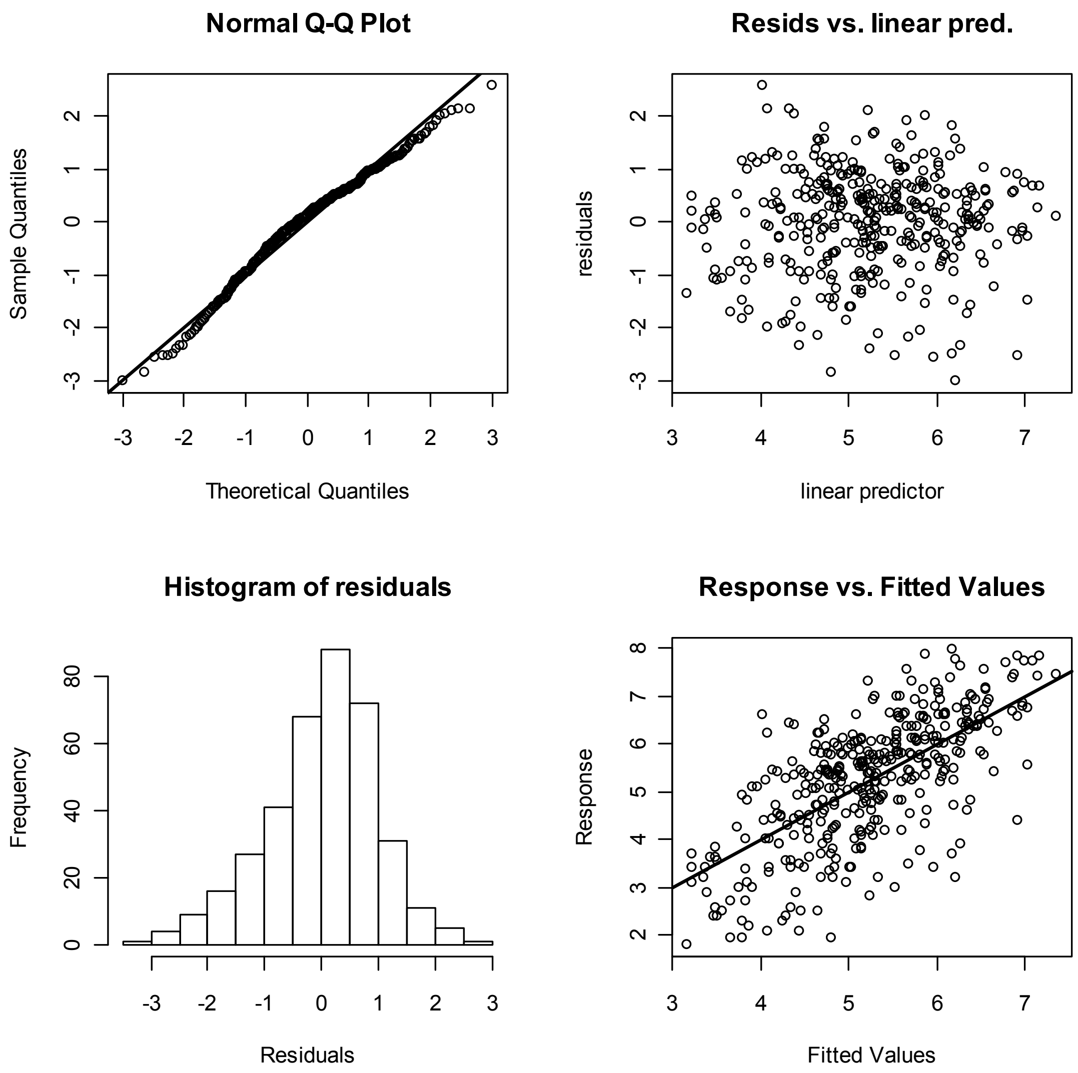

Figure B17: Diagnostic plots for the kahawai lognormal fit with non-adjusted effort offered.

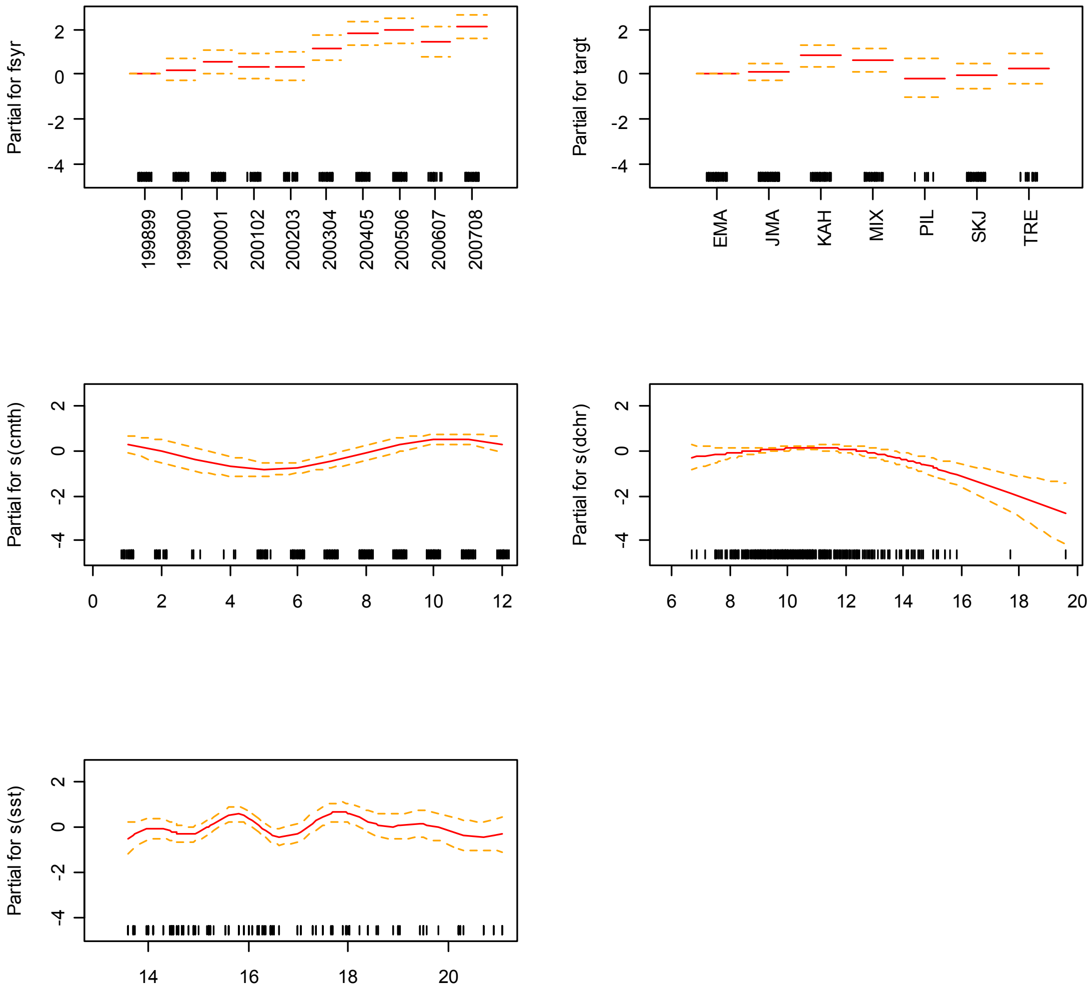

Figure B18: Partial effect plots for the kahawai lognormal fit with adjusted effort offered.

Appendix C: Model outputs for investigating pilot error

Table C1: Results of linear model fit — pilot’s tonnage estimate of school size, pilot, and species as predictors of the vessel’s tonnage estimate of school size.

> summary(lmreg1)

```
Call:
lm(formula = vestn ~ piltn + pilot + fpspp, data = compdatplay)

Residuals:
     Min       1Q   Median       3Q      Max
-234.017  -11.686   -2.893   10.093  176.233

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  8.97588    0.90174   9.954  < 2e-16 ***
piltn        0.47149    0.01232  38.261  < 2e-16 ***
pilot3      32.44946   24.77132   1.310   0.1903
pilot9       6.10798    5.74453   1.063   0.2877
pilot50      5.35241    0.92153   5.808 6.97e-09 ***
pilot87     -7.85459    3.29647  -2.383   0.0172 *
pilot96     15.91786    6.92628   2.298   0.0216 *
pilot97     12.12593   17.53425   0.692   0.4893
fpspp2       2.93033    4.90742   0.597   0.5505
fpspp3      12.69992    1.30561   9.727  < 2e-16 ***
fpspp4      17.00393    1.21745  13.967  < 2e-16 ***
fpspp5       7.42193    1.52610   4.863 1.21e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 24.76 on 3047 degrees of freedom
Multiple R-squared: 0.4694,     Adjusted R-squared: 0.4675
F-statistic: 245.1 on 11 and 3047 DF,  p-value: < 2.2e-16
```

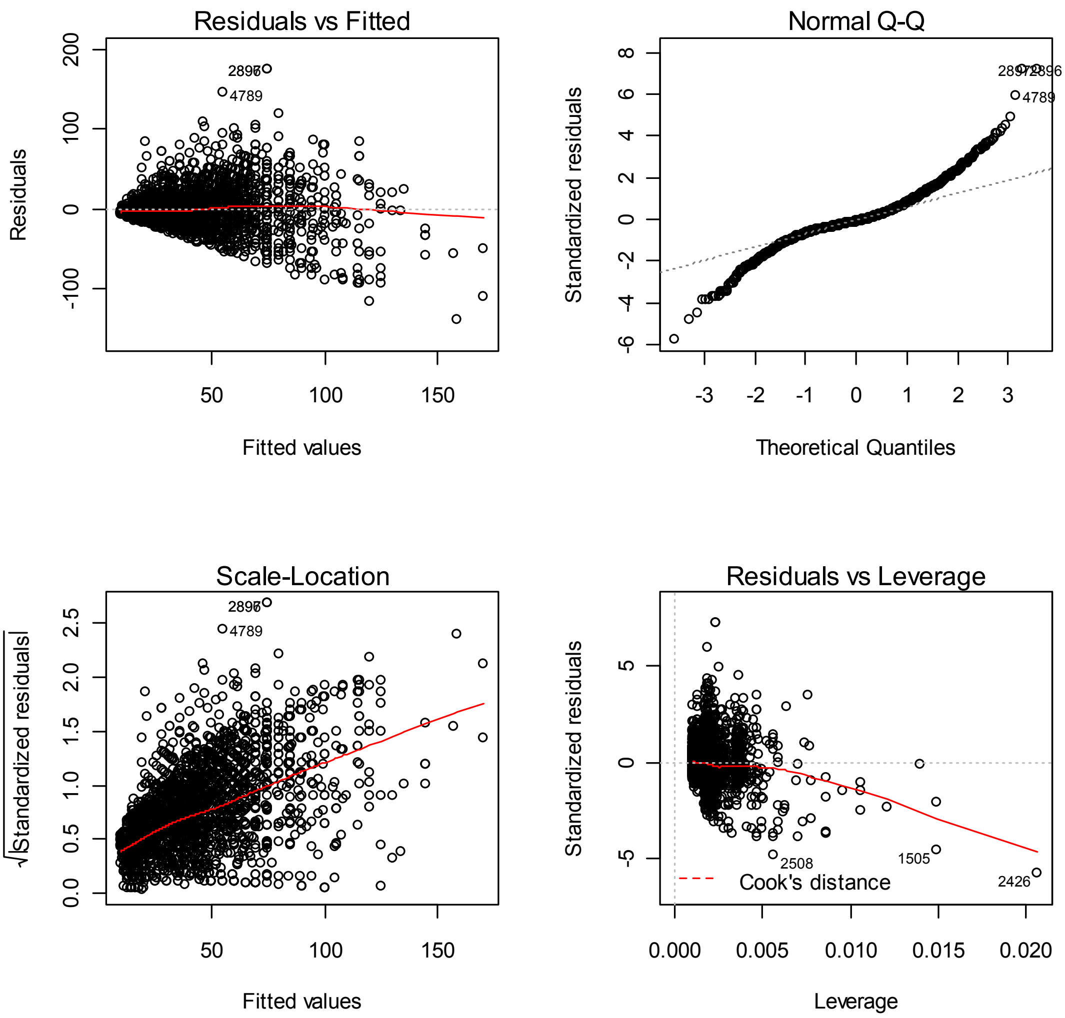

Figure C1: Diagnostic plots of linear model fit — pilot's tonnage estimate of school size, pilot, and species as predictors of the vessel's tonnage estimate of school size; note increasing variance with fitted value in top left plot.

Table C2: Results of linear model fit — pilot's tonnage estimate of school size, pilot, and species as predictors of the vessel's tonnage estimate of school size; with log transformed vessel tonnage and pilot tonnage.

> summary(lmreglog1)

```
Call:
lm(formula = log(vestn) ~ log(piltn) + pilot + fpspp, data = compdatplay)

Residuals:
     Min       1Q   Median       3Q      Max
-3.70774 -0.21724  0.09184  0.34024  2.40485

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  0.52122    0.05030  10.362  < 2e-16 ***
log(piltn)   0.76018    0.01475  51.546  < 2e-16 ***
pilot3       0.67935    0.58997   1.151 0.249619
pilot9       0.11297    0.13680   0.826 0.408989
```

```
pilot50       0.13703    0.02201   6.227 5.42e-10 ***
pilot87      -0.20090    0.07845  -2.561 0.010492 *
pilot96       0.26483    0.16493   1.606 0.108442
pilot97       0.21549    0.41772   0.516 0.605976
fpspp2       -0.07787    0.11688  -0.666 0.505322
fpspp3        0.06284    0.03244   1.937 0.052808 .
fpspp4        0.27618    0.03053   9.047  < 2e-16 ***
fpspp5        0.14025    0.03666   3.825 0.000133 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.5896 on 3047 degrees of freedom
Multiple R-squared: 0.5871,     Adjusted R-squared: 0.5856
F-statistic: 393.9 on 11 and 3047 DF,  p-value: < 2.2e-16
```

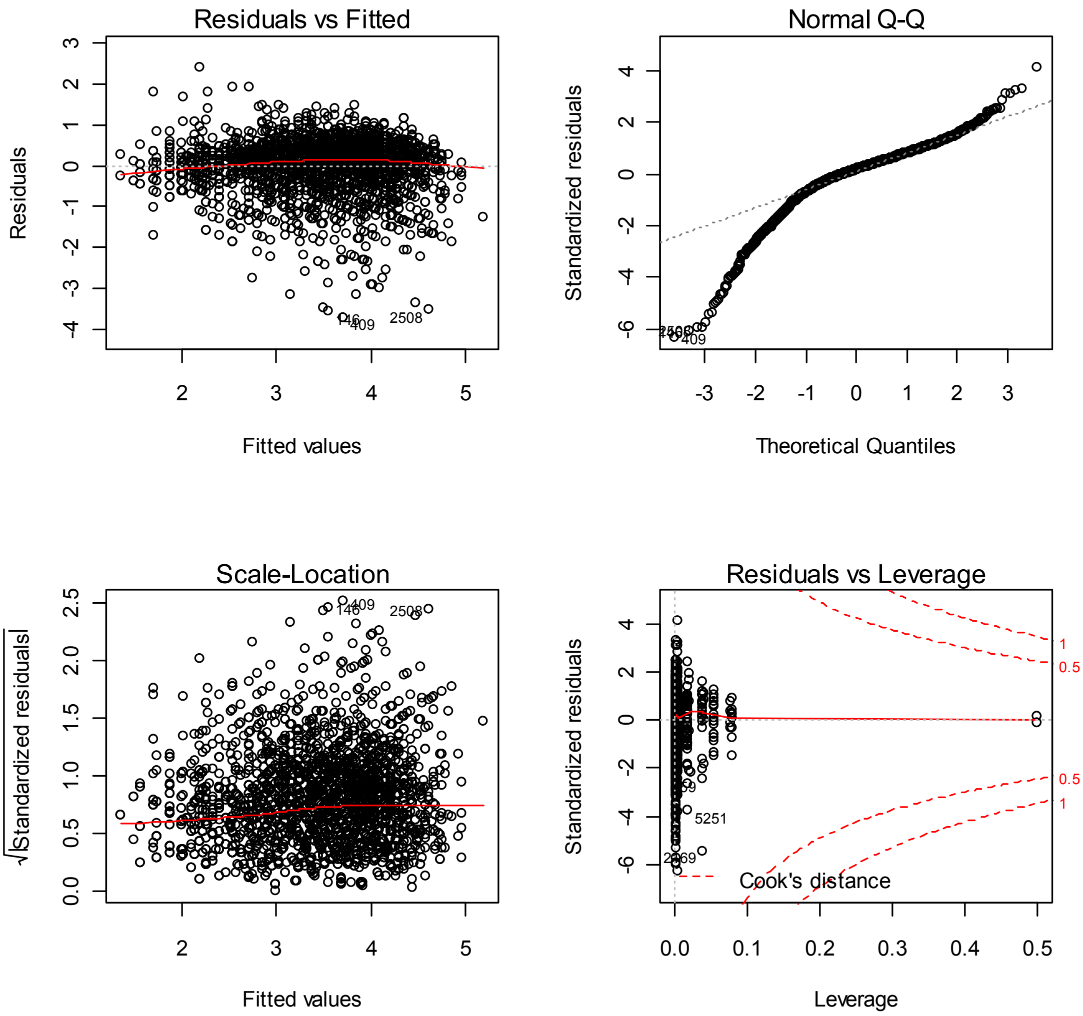

Figure C2: Diagnostic plots of linear model fit — pilot's tonnage estimate of school size, pilot, and species as predictors of the vessel's tonnage estimate of school size; with log transformed vessel tonnage and pilot tonnage; note increasing variance with fitted value in top left plot.

Table C3: Results of linear model fit — pilot's tonnage estimate of school size, pilot, and species as predictors of the vessel's tonnage estimate of school size; with log transformed vessel tonnage and pilot tonnage, and interaction between pilot's estimate and pilot.

> summary(lmreglog2)

```
Call:
lm(formula = log(vestn) ~ log(piltn) + pilot + fpspp + log(piltn):pilot,
    data = compdatplay)

Residuals:
     Min       1Q   Median       3Q      Max
-3.69912 -0.20317  0.09066  0.33606  2.47846

Coefficients: (1 not defined because of singularities)
                   Estimate Std. Error t value Pr(>|t|)
(Intercept)         0.63939    0.06709   9.530  < 2e-16 ***
log(piltn)          0.72896    0.01901  38.346  < 2e-16 ***
pilot3              0.68329    0.58933   1.159 0.246368
pilot9             -0.19614    1.01158  -0.194 0.846269
pilot50            -0.12726    0.09180  -1.386 0.165757
pilot87             0.29578    0.38268   0.773 0.439641
pilot96             0.06512    1.06557   0.061 0.951272
pilot97            -8.70694   60.61769  -0.144 0.885797
fpspp2             -0.09200    0.11684  -0.787 0.431119
fpspp3              0.05185    0.03262   1.590 0.112032
fpspp4              0.26731    0.03061   8.733  < 2e-16 ***
fpspp5              0.13855    0.03672   3.773 0.000164 ***
log(piltn):pilot3        NA         NA      NA       NA
log(piltn):pilot9   0.08208    0.25918   0.317 0.751487
log(piltn):pilot50  0.07412    0.02495   2.971 0.002992 **
log(piltn):pilot87 -0.13500    0.10192  -1.325 0.185419
log(piltn):pilot96  0.05275    0.26258   0.201 0.840783
log(piltn):pilot97  2.02659   13.73790   0.148 0.882733
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.5889 on 3042 degrees of freedom
Multiple R-squared: 0.5887,     Adjusted R-squared: 0.5865
F-statistic: 272.1 on 16 and 3042 DF,  p-value: < 2.2e-16
```

Table C4: Results of anova comparing linear model fit with and without interaction between pilot's estimate and pilot; note increase in sum of squares estimate.

```
> anova(lmreglog1,lmreglog2)
Analysis of Variance Table

Model 1: log(vestn) ~ log(piltn) + pilot + fpspp
Model 2: log(vestn) ~ log(piltn) + pilot + fpspp + log(piltn):pilot
  Res.Df     RSS   Df Sum of Sq      F  Pr(>F)
1   3047 1059.09
2   3042 1055.04    5      4.06 2.3396 0.03942 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
>
```

Table C5: Results of boosted regression tree fit — pilot's tonnage estimate of school size, pilot, and species as predictors of the vessel's tonnage estimate of school size; with log transformed vessel tonnage and pilot tonnage, and interaction between pilot's estimate and pilot; see summary (at bottom) for relative contribution of variables to the reduction of the loss function.

```
GBM STEP - version 2.8

Performing cross-validation optimisation of a boosted regression tree model
for LogVesTn with dataframe compdatplay and using a family of gaussian

Using 3056 observations and 3 predictors

creating 10 initial models of 50 trees

 folds are unstratified

total mean deviance =  0.838826

tolerance is fixed at  0.000839

ntrees resid. dev.
50    0.601381

now adding trees...
100   0.489049
150   0.430171
200   0.399092
250   0.381526
300   0.370577
350   0.363585
400   0.358872
450   0.355489
500   0.352782
550   0.350603
600   0.349158
650   0.347869
700   0.346901
750   0.346047
800   0.345384
850   0.344902
900   0.344621
950   0.344409
1000   0.344241
1050   0.344074
1100   0.343929
1150   0.343857
1200   0.343941
1250   0.343936
1300   0.343925
1350   0.343923
1400   0.343961
1450   0.343948
1500   0.344023
1550   0.344121
1600   0.344104
1650   0.344088
fitting final gbm model with a fixed number of  1150  trees for  LogVesTn

mean total deviance = 0.83883
mean residual deviance = 0.33566
```

```
estimated cv deviance = 0.343857 ; se = 0.018297

training data correlation = 0.775
cv correlation =  0.769 ; se = 0.014

elapsed time -  0.44 minutes

> summary(tonnage.gbm)

       var   rel.inf
1 LogPilTn 95.586437
2    fpspp  3.165157
3    pilot  1.248407
```

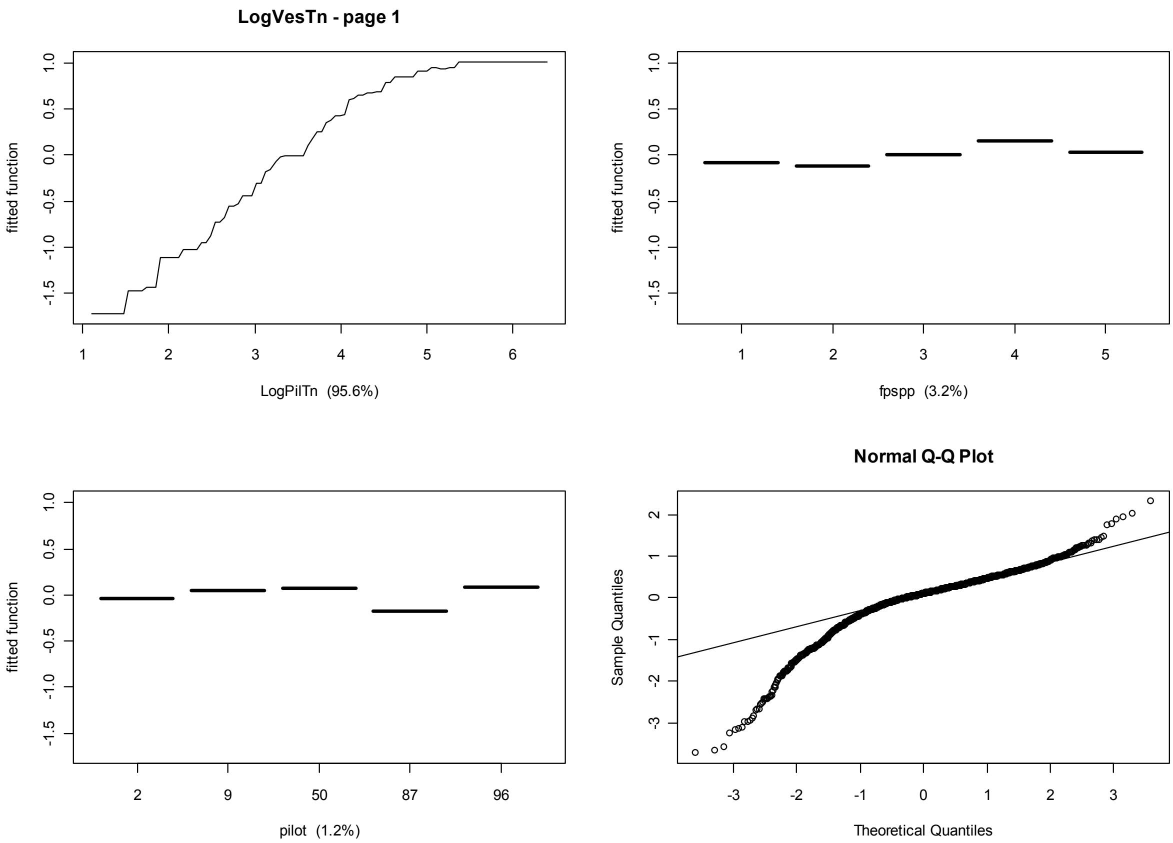

Figure C3: Comparative plots and diagnostic plot of the GBM fit; top left indicates 95.6% accuracy in pilots' tonnages; top right and bottom left indicate fine scale breakdown of individual pilot and species contribution to reducing the loss function; means are shown in GBM summary above.

Table C6: Results of GLM fit — pilot's tonnage estimate of school size, pilot, and species as predictors of the vessel's tonnage estimate of school size; with log transformed vessel tonnage and pilot tonnage.

```
> summary(glmreglog1)

Call:
glm(formula = log(vestn) ~ log(piltn) + pilot + fpspp, family = gaussian,
    data = compdatplay)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
```

```
-3.70774  -0.21834   0.09186   0.34024   2.40484

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  0.52122    0.05031  10.361  < 2e-16 ***
log(piltn)   0.76017    0.01475  51.537  < 2e-16 ***
pilot9       0.11297    0.13682   0.826 0.409064    
pilot50      0.13703    0.02201   6.226 5.46e-10 ***
pilot87     -0.20090    0.07846  -2.560 0.010505 *  
pilot96      0.26483    0.16496   1.605 0.108498    
fpspp2      -0.07787    0.11690  -0.666 0.505393    
fpspp3       0.06284    0.03244   1.937 0.052836 .  
fpspp4       0.27618    0.03053   9.046  < 2e-16 ***
fpspp5       0.14025    0.03667   3.825 0.000134 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.3476973)

    Null deviance: 2563.5  on 3055  degrees of freedom
Residual deviance: 1059.1  on 3046  degrees of freedom
AIC: 5456.1

Number of Fisher Scoring iterations: 2
```

Appendix D: Preliminary annual relative abundance indices for blue mackerel

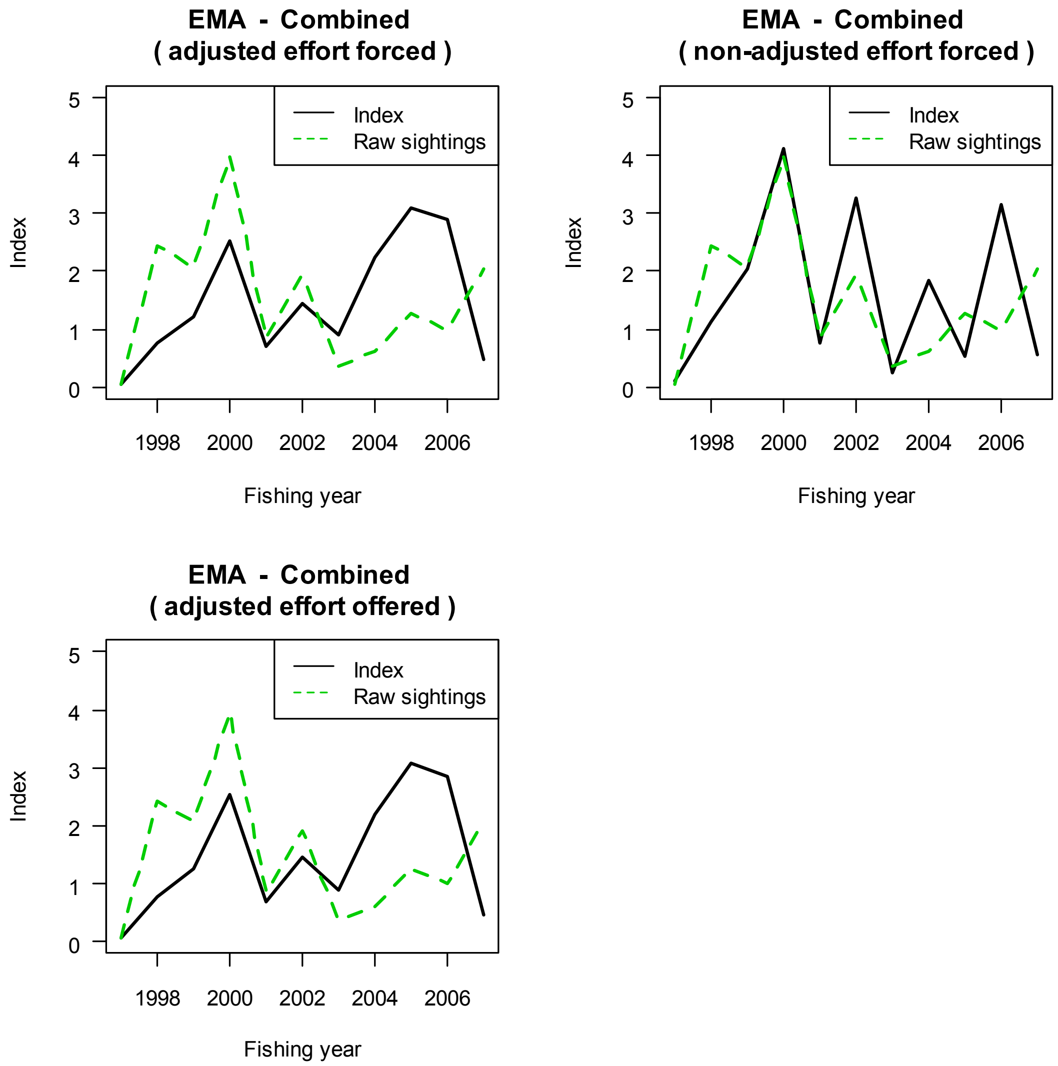

Figure D1: Preliminary annual relative abundance series for blue mackerel under three effort regimes, illustrating the extreme interannual variation in the estimates that resulted in blue mackerel being dropped from the analysis.