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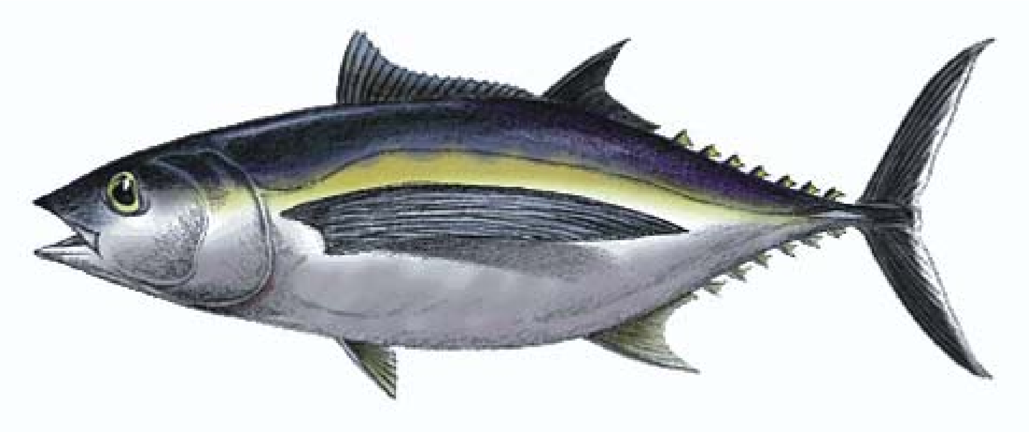
Industry based size-monitoring and data collection program for albacore tuna in the ETBF



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FRDC Tactical Research Fund Project 2008/075

June 2009

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Fisheries Research and Development Corporation

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Author: Farley, Jessica, 1968-

Title: Industry based size-monitoring and data collection program for albacore tuna in the ETBF / Jessica Farley, Natalie Dowling.

ISBN: 9781921605123 (pbk.)

Subjects: Albacore--Australia.
Albacore--Australia--Management.
Albacore fisheries--Australia.
Albacore fisheries--Australia--Management.
Fish stock assessment--Australia--Management.

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Dewey Number: 597.7830994

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Objectives:

1. Design and implement, in consultation with industry, a practical, cost-effective industry-based monitoring program for obtaining representative sized data for albacore in the ETBF.
2. In collaboration with SPC, develop a biological sampling program to ensure that unbiased estimates of biological parameters for albacore are also obtained for the southwest Pacific region.
3. Collect biological samples (otoliths, spines, gonads & muscle tissue) from at least 500 albacore caught in the ETBF in 2008/09.

Outcomes achieved to date:

- The most significant outcome of the project was the development and implementation of an industry-based size monitoring program for albacore in the ETBF. A comprehensive design study was undertaken, in consultation with industry, to determine the minimum sampling intensity required to ensure that unbiased estimates of size parameters are obtained. The sampling regime has been implemented by the five main ETBF tuna processors on the east coast (in addition to the three already collecting size data for all landed catches of albacore) and should provide robust estimates of the size composition of the albacore catch.
- The project has also produced estimates of the minimum number of biological samples required to estimate reproductive (maturity) and growth parameters for albacore with appropriate confidence intervals. These estimates were required for the development of a biological sampling plan for the ETBF and wider southwest Pacific that was developed and implemented during the project.
- A collection of biological samples (otoliths, spines, gonads, & muscle tissue) has been obtained from the full size range of albacore caught in the ETBF for use in the related project (FRDC 2009/012). This material will be used to estimate biological parameters for implementation of the harvest strategy for albacore in the ETBF and WTBF.
- The project has lead to the development of strong collaboration with SPC scientists studying albacore in their SCIFISH project.
- The procedures developed for the ETBF should be directly transferable to the WTBF with minor revision.

Non Technical Summary:

This report presents the results of an 8 month study on albacore tuna, *Thunnus alalunga*, with the aims of (i) developing an industry-based size monitoring program for the Eastern Tuna and Billfish Fishery (ETBF), (ii) designing a biological sampling program for the south-west Pacific in collaboration with SPC scientists, and (iii) collecting biological samples along the east coast of Australia.

An immediate priority for the ETBF was to establish sampling protocols to provide unbiased estimates of the size composition of the catch of albacore, which are required inputs for the ETBF harvest strategy. The need for this data has increased since the catch of albacore grown from a few hundred tonnes prior to 2004 to a peak of 2,591 tonnes in 2006 and 1,916 tonnes in 2007. Much of the individual size data currently collected by industry is biased towards larger export fish (Farley and Clear, 2008). Simulation modelling was used to assess whether individual size data that is already being collected as part of the current size monitoring program (Williams, 2008) is representative and, if not, determine the subsampling regime required at the key ports to provide representative samples of the size composition of the catches. The results indicate that provided an adequate sampling strategy is followed (~15 randomly selected fish per trip for 90 % of trips) robust estimates of size composition and harvest strategy indicators can be obtained. The sampling regime has been implemented by the five main ETBF tuna processors on the east coast (in addition to the three already collecting size data for all landed catches of albacore) and should provide robust estimates of the size composition of the albacore catch.

The second objective of the project was to develop, in collaboration with scientists at the Secretariat of the Pacific Community (SPC) in New Caledonia, a biological sampling program to provide unbiased estimates of biological parameters from albacore caught in the southwest Pacific region. To estimate the minimum sample size required for growth and maturity studies in the region, existing biological data for albacore were obtained from a pilot project in the ETBF (Farley and Clear, 2008). Von Bertalanffy growth curves were estimated from these data and bootstrapping was used to explore the characteristics of parameter estimates (CV) under different sampling levels. Bayesian bootstrap was undertaken to explore the CV of size at maturity (L_{50}). The results indicated that size at age data from direct age estimation of 100 individuals should provide acceptable CVs (i.e. CV< 0.2) for growth parameters, provided the samples cover the same size/age ranges used in the pilot sample (~7 fish per age class for ages 1+ to 14+ years). This is consistent with a previous study which recommended a general rule of 7–10 fish per age class (Kritzer et al., 2001). Given this is the first study of this nature for albacore in the South Pacific and that the maximum age of albacore could be older than 14 years, we suggest that at least 200 age estimates are obtained by year, sex and region in the first instance, and that this estimate is updated as additional otoliths are read. To estimate size at 50 % maturity, around 100 individuals are sufficient (by year, sex and region); however, it is recommended that the analysis is updated as more data becomes available. It is also recommended that sampling sites and sampling times are specifically selected to ensure that the program samples across the appropriate size range that includes immature to fully mature females (~70–100+ cm), at the time of year when it is possible to distinguish between the two reproductive states. The sampling programme developed in collaboration with SPC aims to sample up to 500 albacore from the ETBF, 160 from New Zealand and 1680 from across the Pacific Island Countries and Territories each year for two years.

The final objective of the project was to continue to collect biological samples (gonads, otoliths, dorsal spines, muscle tissue) and associated data (length and weight) from 500 albacore caught in the ETBF in 2008/09. The biological samples are required to provide the material for a related project "Population biology of albacore tuna in the Australian region" (FRDC 2009/012) and a complementary biological study at SPC (SCIFISH). These studies aim to provide estimates of key biological parameters central to implementation of harvest strategies for the ETBF, and improving the regional stock assessment for albacore in the South Pacific. Sampling was conducted at ports in all four eastern Australian states in the ETBF. A total of 382 fish were sampled, bringing the total number of albacore sampled in the ETBF to 857 since early 2006. Total sampling for the current project was slightly less than anticipated due to a shortening of the project schedule (from 12 to 8 months). This will not compromise the future biological work as the planned monthly sampling is likely to provide in excess of the minimum samples required for estimating the biological parameters. It is anticipated that the current sampling program will be extended to other ports in the ETBF as fish become available, and sampling will continue for the next 12–18 months.

KEYWORDS: South Pacific Albacore tuna, size monitoring, minimum sample size, biological sampling.

1. Acknowledgements

There are many people we would like to acknowledge for support during this project. We are especially grateful to industry members for their time, insights and willingness to ensure the implementation of a robust and practical sampling regime, and for their assistance with biological sampling in their factories; these include Gary Heilmann, Brett Taylor, Grant Taylor, Rod Fitzgerald, Charlie Krause, and Cathal Farrell. We are also grateful to those who collected, or coordinated the collection, of biological samples in Australia and New Zealand. These include: Steve Hall (AFMA observer), Tanya Birtenshaw (DeBretts Seafood), Kevin Williams and Deidre Waddington (WWfisheries), Geoff McPherson (Marine Acoustic Biodiversity Solutions), Mitchell Zischke and Matt Lansdell (CSIRO), Graeme Cottier (Vic DPI), Glen Cuthbert (Coffs Harbour), Shelton Harley (NZ MFish) , Lynda Griggs (NIWA) and the New Zealand Observer Program. Particular thanks also to the recreational fishers John and Ann Brooker (The Southern Game Fish Club), Justin Drysdale (Tuna Club of Tasmania) and Michael Maher (Game Fishing Club of Northern Tasmania) who helped collected small albacore for the project. Thanks also to Marinelle Basson, Campbell Davies and Paige Eveson for useful discussions throughout the project. We are also grateful to Rob Campbell and Scott Cooper for assisting in providing AFMA's logbooks and observer data, and data from the ETBF size monitoring program (WWFisheries). Finally, we especially thank Campbell Davies for thoroughly reviewing the report. The project was funded by FRDC Tactical Research Fund grant 2008/075.

2. Background and Need

Albacore tuna are found in waters between approximately 10–50°N and 5–45°S globally. Separate northern and southern stocks are assumed to exist in the Pacific Ocean based on their spatial distribution and different spawning times/locations. In the South Pacific, albacore have been targeted by longline fleets since the early 1950s, and recent catches have increased from 20,000–30,000 t per annum in the mid-1980s to 60,000–70,000 t per annum in the mid 2000s (Hoyle et al., 2008). The increase in catch has been largely due to an increase in the catch by small longline fisheries in Pacific Island Countries and Territories (PICTs).

The catch of albacore in Australia's Eastern tuna and Billfish Fishery (ETBF) has also grown substantially from a few hundred tonnes prior to 2004 to 2,591 tonnes in 2006 and 1,916 tonnes in 2007. The increase in 2006 was largely the results of domestic longliners based in Mooloolaba switching from targeting broadbill swordfish (shallow night sets) to albacore (deep daytime sets) as the catch rates and cannery price for albacore were both high. Industry has been actively developing markets for fresh product in the United States, Japan and Europe, and has stated that albacore will be an important component of the future economic viability of the Mooloolaba fleet. These increased catches have raised concerns about whether these catch levels can be maintained long term, the potential risk to the stock(s) and the potential reduction in the economic return from the fisheries.

To determine target reference levels for the ETBF harvest strategy for albacore (consistent with the Commonwealth Harvest Strategy Policy), data are required on the size composition of the catch, size and/or age-at-maturity, growth rates, fecundity and mortality (Campbell et al., 2007; Davies et al., 2008). The harvest strategy framework currently use biological parameters obtained from the SPC stock assessments to estimate reference points for the decision rules, and CPUE and size structure data from the domestic fishery to monitor and respond to changes in the ETBF. Many of the parameters used in the stock assessment (e.g. growth, maturity, fecundity, sex ratio, spawning fraction, and natural mortality) are either uncertain or assumed (Hoyle, 2008), reflecting the lack of focussed biological research on the species.

In 2006, a pilot project was undertaken in the ETBF to provide preliminary descriptions of a number of these biological parameters for albacore (Farley and Clear, 2008) for the ETBF, some of which were examined in the 2008 stock assessment and sensitivity analysis (Hoyle et al., 2008). However, one of the recommendations of the pilot project was that substantially more biological samples from a more spatially comprehensive sampling program were required to provide age-based estimates of population parameters to address the biological uncertainties in the current stock assessments for albacore in the South Pacific (Farley and Clear, 2008; Hoyle et al. 2008; Hoyle 2008).

It is also acknowledged that the individual size (weight) data collected for albacore landed in Mooloolaba through the size-monitoring project (Williams, 2008) may not be representative of the catch due to differences in processing based on fish size (Campbell, 2007; Farley and Clear, 2008). Given that the way albacore are processed may continue to change, and vary between operators, it is unlikely that representative size data can be obtained routinely through the current size-monitoring project. The ETBFRAG meeting in November 2007 also noted the importance of individual size data in terms of the harvest strategy, and agreed that CSIRO should be asked to design a sub sampling regime for albacore (Anon, 2007). It should be noted, however that three processors in the ETBF already collect individual weight data for albacore. These are in Cairns, Brisbane and one processor in Mooloolaba. In addition, the AFMA Observer Program collects individual length data for albacore.

Acknowledging all of the above, the ETMAC explicitly identified the determination of life-history parameters and improved stock assessments for albacore tuna as a High Priority project. The current project addresses both these high priority research areas. The Western and Central Pacific Fisheries Commission (WCPFC) endorsed the work and provided US$25,000 towards the project.

3. Objectives

1. Design and implement, in consultation with industry, a practical, cost-effective industry-based monitoring program for obtaining representative sized data for albacore in the ETBF.

2. In collaboration with SPC, develop a biological sampling program to ensure that unbiased estimates of biological parameters for albacore are also obtained for the southwest Pacific region.

3. Collect biological samples (otoliths, spines, gonads & muscle tissue) from at least 500 albacore caught in the ETBF in 2008/09.

These three research components are examined independently in the report.

4. Industry-based size monitoring

The aim of this component of the project was to develop, in consultation with industry, a statistically sound and practical port-based sampling protocol for collecting size data for albacore to provide representative estimates of the size composition of the catch for the fishery. This is necessary from both a population dynamics viewpoint (understanding the size distribution within the fishery and how this changes with fishing) and to provide inputs for the ETBF harvest strategy. The harvest strategy for the ETBF uses size-based indicators from the catch in the decision rule (Davies et al., 2008; Kolody et al., 2009; Preece et al 2009). Full details of the methods and results from the sample size simulations are provided in Appendix C and are summarised below.

4.1 Approach

Simulation modelling using existing size data for albacore was undertaken to determine the sampling regime required to achieve target levels of precision for specific size-based indicators and the size distribution of the catch.

The modelling was undertaken in two phases:

(i) A simulation approach using a formal experimental design in which the available size data from the fishery were stratified by season, location and depth of capture to account for the variability in size distribution within the catch. Within each stratum, a matrix of sampling regimes combinations, in terms of number of trips x number fish measured per trip was applied.

(ii) A simulation to determine the minimum number of fish to measure per trip if all (or most) trips were sampled each year.

Data used

Size data for albacore were obtained from two sources: (i) AFMA logbook and (ii) AFMA observer databases for 2005 and 2006. These years were chosen as encapsulating the periods of the fishery both prior to (2005) and during (2006) the active targeting of albacore, and also having a comprehensive set of accompanying observer data.

The logbook data included catch location, date, hooks-per-basket (as a proxy for fishing depth) and number of albacore caught by trip. These data were used to form a sample pool from which trips were sampled. It is important to note that it is not possible to distinguish fish by individual set when landed in port, so the primary sampling unit was defined as a boat trip.

Observer data comprising individual fish lengths was used to characterise the size structure of the catch, and was linked to the logbook data by a unique identifier. The observer data was edited to remove all reported lengths greater than 120 cm and less than 50 cm. Only logbook sets that caught at least one albacore were used in the sampling set. Table 1a (Appendix C) shows a summary of the logbook and observer data by stratum (see below) for 2005 and 2006.

Size was defined by length rather than weight, as this was the metric in which size information was reported within the observer data set that informed the simulation. However, it is acknowledged that most industry members would prefer to provide size information in terms of individual weights. The strongly significant length-weight power relationship from Farley and Clear (2008) ($r^2 = 0.9938$) indicated that length and weight can be used almost interchangeably as a metric of size. As such, the results given below can be considered to be applicable also to minimum sampling requirements based on weight measurements.

Stratification

According to industry, the size of albacore caught on a longline set varies according to location, time of year and set depth. As such, the data were stratified according to these factors in the size-sampling simulation. Strata comprised combinations of:

1. Fishing depth, defined in terms of hooks per basket (HPB):
   - Shallow 1–20 HPB
   - Deep > 20 HPB

2. Region, defined as three latitude bands according to historical fish catch rates and spatial size distributions from observer data:
   - North 10–23S
   - Mid 23–30S
   - South 30–40S

3. Season: four assigned according to historical temporal availability of fish:
   - Dec-Feb
   - Mar-May
   - Jun-Aug
   - Sep-Nov

Model

Knowing i) the total number of albacore per trip by strata and ii) observer-based subsets of individual size data, the aim of the simulation was to generate a length-frequency distribution for the catch, unique to each stratum, following the approach of Knuckey and Gason (2001).

Simulations were run using both a) separate strata and b) the combined dataset. For both approaches, the minimum sample size required to provide a representative length-frequency distribution of the catch was determined. We calculated three indicators of overall size composition:

- sums of squares between observed and sampled proportions in each length category (this is a good indicator of overall fit, does not take into account the number of fish in each length class)
- maximum absolute difference between observed and sampled cumulative length distribution functions (Gomez-Buckley et al., 1999) (an alternative measure but one that does not necessarily detect differences due to skew)
- mean weighted coefficient of variation (MWCV) (Gerritsen and McGrath 2007; Knuckey and Gason 2001). If the precision in each length class is expressed in terms of a CV, an overall measure of precision can be obtained by weighting each CV by the number of fish in each length class. This mean weighted coefficient of variation (MWCV) provides a description of the precision over the entire range of size classes in a length-frequency distribution (Gerritsen and McGrath 2007).

In addition, we calculated the three harvest strategy (HS) inputs (Davies et al., 2008), in order to confirm that the minimum sample size required to provide a representative length-frequency distribution of the catch also yielded robust estimates of these values . The size category thresholds were defined from consultation with industry stakeholders as follows:

- proportion “recruits” (< 83 cm)
- proportion “prime sized” (93–94 cm)
- proportion “old” (> 94 cm)

Simulations were run repeatedly for 100 realisations for each matrix combination (number of trips) x (number fish measured per trip), within each stratum, and the mean and coefficient of variation (CV) for each HS and overall size composition indicator was obtained. An overall mean and standard deviation for each indicator across all strata was also obtained by weighting the strata-specific values according to the historical catch in that stratum for that year.

The main criterion we used for selecting a sampling protocol (i.e. the minimum sampling regime) was:

i) that the value of the coefficient of variation (CV) for each indicator is < 20 %

Additional criteria we considered were:

ii) that the value of the coefficient of variation (CV) shows a minimal reduction in magnitude with increased sampling (i.e. choose the minimum number of trips and numbers of fish to measure per trip, above which the CV for each indicator is < 20 % and shows a minimal reduction in magnitude with increased sampling)

iii) that the change in the mean weighted coefficient of variation (MWCV) is < 1 % for an increase of 20 in the number of fish in the sample for a given number of trips sampled (the criterion by which Knuckey and Gason (2001) define the optimal sample size)

iv) that the indicators of overall size composition (i.e. the sums of squared differences, the maximum cumulative distance and the MWCV) are minimized

v) That the values of the harvest strategy indicators are stable above any minimum sampling regime

4.2 Results

As expected, the results showed that as more trips are sampled, less numbers of fish per trip are required to be measured. However, the minimum sampling regime required varied according to the indicator, the year, between strata, and with the approach used (combined data versus strata-specific). Overall, the mean value of each indicator showed little variation across the combinations of number of trips and number of fish measured per trip (with the exception of the MWCV, which decreased with increased sampling). Standard deviations were higher as the number of fish measured per trip, and, to a greater extent, the number of trips covered, reduced. Standard deviations were generally minimized at sampling levels of at least 50 trips and at 9 fish per trip. CV's for the indicators were generally below 20 % when at least 25 trips and 6 fish per trip were sampled.

It was a consistent feature across all indicators and simulation types that CV values and variation about indicator values was minimized when sampling a low number of fish across more trips, than when sampling a high number of fish across fewer trips.

The approach using the combined data showed that a higher level of sampling was required to obtain robust estimates of the overall size composition of the catch, than was required to obtain robust estimates of the harvest strategy indicators. However, the absolute values for the indicators of overall size composition were consistently low irrespective of sampling regime, which suggests a robust sample can be readily obtained.

When using the strata-specific approach to obtain overall indicators weighted by catch, different values for the harvest strategy indicators were obtained than when using the combined data approach, but similar values for the overall goodness of fit to observed size distributions were obtained across both approaches. The absolute mean values of all indicators showed little variability with sampling regime.

In practical terms, it is clear that there is a trade-off between number of trips and numbers of fish measured per trip in order to fulfil the minimum sampling requirement of a CV value < 20 %. That is, various combinations of these above the specified minimum will yield acceptably low CV values. This would grant some flexibility for individual operators to determine their preferred approach, especially given that absolute values of indicators do not appear to show much variation in mean value between sampling regimes. Moreover, the results consistently showed that, in order to obtain a representative size distribution and robust, reliable harvest strategy indicators, it is clearly preferable (in terms of minimizing the CV values, the indicators of overall size composition and the change in MWCV) to sample a low number of fish across more trips, than to sample a high number of fish across fewer trips.

Strata-specific recommendations are appropriate for determining minimum required levels from each. However, this minimum level may change depending on the level of effort within any stratum. This approach is appropriate to determine the minimum sampling requirement acknowledging the size variability by location, season and setting depth (i.e. strata), but if stakeholders are prepared to sample fish across all or almost all trips, then the question about the minimum level of sampling in each strata becomes less important, provided all strata are covered. The question simplifies to that of the minimum number of fish to be measured per trip, given that all trips are sampled.

As would be expected, sampling all trips in each year results in samples with extremely low CV values (approaching zero in most cases) for all size based HS indicators, irrespective of the number of fish sampled per trip .The simulation modelling ultimately showed that reliable estimates of size composition may be obtained by measuring 15 fish per trip for at least 90 % of trips where albacore were caught. It is emphasized that the robustness of samples taken by measuring some fish on all trips far exceeds that of the minimum sampling regimes required. By sampling all trips, measuring as few as 3–6 fish per trip will yield CVs approaching zero for each of the indicators. However, by measuring 15 fish per trip, there is greater likelihood that the absolute value of the indicators will be stable, and that the MWCV criteria (< 1 % change in MWCV for an increase of 20 in the number of fish sampled per trip) will also be satisfied.

4.3 Consultation

Following consultation with the main industry members in Mooloolaba and Coffs Harbour, where the results from the above simulations were presented, by unanimous consensus the operators indicated that they would prefer to measure a fixed, smaller number of fish from every trip as opposed to a set, possibly larger, number of fish from a subset of trips within each strata (where the number of trips and fish to be measured within each stratum may also vary between strata). This was an ideal outcome, since the results from the (number of trips) x (number of fish measured per trip) matrix approach suggested that coverage of every trip would require a low number of fish to be measured per trip for statistical robustness to be ensured. In addition, it is practically easier to implement a standard protocol for all trips, than a more complex protocol that requires keeping track of which trips have been sampled from each stratum.

Industry members also indicated that they would prefer to provide a single estimate of average weight of albacore in the catch from each trip (as opposed to measuring a sample of individual fish) since the sense was that the size of fish is tightly consistent within any given trip. After running an additional simulation where only the average length, as calculated across the entire catch, we found that this scenario resulted in an underestimates of the proportion of “recruits” and overestimates of the proportion of prime sized fish in the catch for 2006. This shows that overall size composition estimates are more robust when individual fish measurements are used as opposed to trip-specific means (see Appendix C).

4.4 Implementation

Practically, it is acknowledged that measuring more than 20 fish per trip across every trip is too demanding and time consuming to form an ongoing sustainable sampling regime. The suggested level of 15 fish per trip represents a practically achievable value while delivering representative estimates of the size composition of the catch. It is important to ensure that the individual fish are a random sample of the albacore catch taken from the trip, which can be achieved by spacing the selection of individuals so that this spans the entire offloading process. Both the sample size and offloading fish selection protocols should be reviewed 12 month following full implementation to assess whether the size samples are unbiased and whether the number of fish measured per trip is appropriate.

Three processors in the ETBF have been identified as currently measuring (weighting) a high proportion of albacore (~100 %) from every trip. These are located in Cairns, Brisbane and Mooloolaba and their data are collected through the existing size monitoring program (Williams, 2008). An additional five processors located in Mooloolaba (x3), Coffs Harbour and Ulladulla have agreed to collect individual size data based on our simulation results (15 fish per trip). It should be noted that some of these operators collect fish unloaded at other ports along the coast increasing the total coverage of trips. Provided all eight continue to measure a proportion of albacore from every trip, then simulation results would suggest that robust sampling is ensured. It will be important, however, to continue to monitor the program to ensure that the individual fish are a random sample of the albacore catch taken from the trip.

The only port where there is a potential for significant numbers of albacore to be landed, which is not currently monitored Sydney. In 2006 and 2007, 3.1 % and 6.7 % of trips with albacore landed at this port respectively. Although this does not appear to be particularly high, Sydney had the second highest number of albacore landed in 2007, after Mooloolaba. Collecting size data for albacore unloaded in Sydney is difficult because there are several ‘markets’ (Sydney Fish Market, wholesalers, smaller shops etc) rather than large processors which can easily collect size data related to a vessel. It may be possible to obtain size data direct from vessels landing in Sydney and this will be perused if substantial numbers of albacore are landed in Sydney in the future.

5. Design and implementation of a biological sampling program

5.1 Sampling requirements

The second component of the project was to develop, in collaboration with the Secretariat of the Pacific Community (SPC), a biological sampling program to provide unbiased estimates of biological parameters for albacore are obtained for the southwest Pacific region. The sampling program is required to provide the biological material for a subsequent project “Population biology of albacore tuna in the Australian region” (FRDC 2009/012) and complementary biological work at SPC (SCIFISH project). These studies are focussed on providing estimates of age-based population parameters to improve regional stock assessments and to further evaluate and implement the formal harvest strategy in the ETBF. The aims are to obtain:

- age-based estimate of growth;
- representative distribution(s) of catch-at-age
- quantitative estimates of reproductive potential, via size and/or age-based estimates of specific reproductive parameters (maturity, spawning fraction, batch fecundity, and possibly total annual fecundity etc)
- length-weight relationships
- sex ratio statistics

To fulfil the objectives of the biological projects, the following biological material and data are required:

- sagittal otoliths (direct age estimation)
- gonads (maturity, batch fecundity, spawning frequency)
- first dorsal fin spine (compare/verify age with otoliths)
- fork length to the nearest cm
- weight to the nearest 0.1 kg (whole and dressed for conversion factors)
- capture date, location and time (if possible)
- fishing method

It is anticipated that otoliths collected during the project may also be used in other research areas such as otolith chemistry research to infer stock structure.

5.2 Minimum sample size

When designing a biological study, it is important to determine the sample size required to estimate the reproductive (maturity) and growth parameters with appropriate confidence intervals. Analyses were conducted on existing biological data for 83 albacore obtained from a 2007 pilot (Farley and Clear, 2008) in the ETBF to determine the minimum sample size required.

Growth

Von Bertalanffy growth curves were estimated and bootstrapping (200 replicates of four types of bootstrap) was used to explore the characteristics of parameter estimates (uncertainty, CV in particular) under different sampling levels. The full analyses are provided in Appendix F and summarised below.

Although the existing length-age data set for albacore caught in the ETBF is small (n=83; size range 48–108 cm FL; age range 1–14+ years), initial examination showed that these provided low CVs for growth parameters (CVs of 1.2 % for L_∞, 6.9 % for K and ~ 12.7 % for t_0) (Table 1). CVs on the parameter estimates decreased when the sample size was increased to 150 and 200.

Table 1. %CVs for 200 bootstraps for all, males and females. Note that n=10 were of unknown sex. The %CVs for other sample sizes (150 and 200) was inferred.

%CV	L_∞	k	t_0
All (n=83)	1.19	6.9	12.70
By individual n=83	1.28	7.46	10.76
By age n=83	1.19	8.89	24.34
Males (n=45)	1.53	10.56	24.11
Females (n=28)	1.85	11.98	28.69
n=150 sample size	0.90	5.30	7.70
n=200 sample size	0.80	4.60	6.70

The effect of dropping out individual age classes was also examined. This confirmed the importance of the first age class (age 1) as CVs for growth parameters were the highest when this age class was dropped (%CVs: 1.8 % for L_∞, 13.2% for k and ~ 28.1 % for t_0) (see Appendix F). The analysis also confirmed the importance of the third age class (age 3) which is the age at which growth is estimated to decelerate considerably.

Examining the sex specific data indicated higher CVs for the growth parameters () and show that sample sizes as low as 28 or 45 are not adequate for estimating separate growth curves by sex. Given that there appears to be significant differences in growth rate (and/or mortality) and L_∞ (male 104.5; female 98.4), it was recommended that sufficient samples be collected to be able to estimate separate growth curves by sex.

Overall, the results suggest that 100 individuals should give acceptable CVs for growth parameters for each sex, provided the samples cover the size/age ranges as in the pilot sample. It was recommended that:

- A minimum of one hundred albacore be aged for both males and females, and that there is good coverage of ages 1 to 5 and old fish. If area specific growth curves are the aim, then > 100 individuals applies to each area and gender.

- Otoliths for ageing are stratified by length class, and that it may be necessary to sample additional large individuals to provide sufficient samples sizes.

The above analyses were based on age estimates ranging from 1 –14+ years (48–108 cm). A minimum of 100 age estimates suggests that ~7 fish per age class are required to calculate a growth curve. This estimate is consistent with a simulation study by Kritzer et al. (2001) which recommended a general rule of 7–10 fish per age class. Given that the maximum age of albacore could be older than 14 years (since albacore larger than 108 cm have been landed) we suggest that at least 200 age estimates are obtained by strata. The analysis should then be updated to re-assess the distribution of sizes at age and avoid reading more otoliths than necessary.

Several factors need to be taken into account in attempting to obtain unbiased estimates of growth parameters for each sex/year/area strata. For example, Farley and Clear (2008) showed that ~70 % of albacore caught by longliners in the Coral Sea are male, and that ~15 % of the otoliths sectioned for ageing were unreadable due to poor otolith clarity. In addition, it is likely that there will be fewer fish sampled from certain size/age classes (i.e. the very small and very large in each region – especially if random sampling is undertaken), and that some otoliths may be broken or found to be unsuitable for sectioning. Therefore, substantially more otoliths need to be collected to obtain 200 sizes at age estimates with a good spread across age classes. We suggest that at least 40 otoliths are sampled per month from eastern Australia, 20 per month from the PICT's, and 40 per month from New Zealand, so that there are sufficient otoliths to select from for ageing.

Maturity

Bayesian bootstrapping was undertaken to explore the CV of the predicted size at 50 % maturity (L_{50}) estimate based on a logistic regression fitted to the maturity data (from histology) to determine the minimum sample size required (see Appendix F). The existing data set for maturity estimates for the ETBF is small (n=61). However, the %CV from the L_{50} estimate (-apar/bpar) is 1.7 % and the direct CV of L_{50} is 1.5 %. Again, these CVs are very low suggesting that a sample size of ~100 individuals would be acceptable. However, it is recommended that the sample-size checks are updated as more data becomes available.

It is important to note that sampling for maturity depends on both immature and mature individuals having been sampled in an unbiased way. Thus, estimating the maturity schedule is difficult for any species where the mature fish migrate to discrete areas to spawn, or where there is any bias towards mature/immature fish in the sampling program. Although the migratory patterns of albacore are poorly understood, albacore are thought to be one of only four tuna species that are truly migratory and undertake seasonal migrations to specific feeding and spawning areas (Schaefer, 2001). Spawning is thought to occur predominantly between 10–25ºS in the western and central regions during summer, and juveniles quickly move south of 30°S. It has been suggested that juveniles and subadults do not return to the subtropics and tropics until they mature (Jones, 1991; Murray, 1994; Chen et al., 2005).

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It is important to note that robust estimates of maturity depends on both immature and mature individuals been sampled in an unbiased way. Thus, estimating the maturity schedule is difficult for any species where the mature fish migrate to discrete areas to spawn, or where there is any bias towards mature or immature fish in the sampling program. Although the migratory patterns of albacore are poorly understood, they are thought to be one of only four tuna species that are truly migratory and undertake seasonal migrations to specific feeding and spawning areas (Schaefer, 2001). Spawning is thought to occur predominantly between 10–25ºS in the western and central regions of the Pacific Ocean during summer, and juveniles quickly move south of

30°S. It has been suggested that juveniles and subadults do not return to the sub tropics and tropics until they mature (Jones, 1991; Murray, 1994; Chen et al., 2005).

To obtain an accurate maturity schedule for albacore, it is important that sampling sites and times are selected to sample across the size range that includes immature to fully mature females at the time of year when it is possible to distinguish between the two reproductive states. There are three main factors to consider:

1. **Size range**: Farley and Clear (2008) indicated that L_{50} could be around 82 cm in the ETBF, although this estimate could be biased because the sampling was targeted at the spawning latitudes in the northern ETBF where immature fish are potentially underrepresented. Thus it is recommended that sampling should include fish at least in the size range of 70–100+ cm FL, and ideally smaller.

2. **Sampling area**: The size frequency of albacore caught in the ETBF by latitude suggests that albacore caught in the south are smaller than those in the north. Thus, to sample the above size range (70–100 cm), sampling must include the latitudinal bands from at least 15–35ºS across the pacific, rather than simply concentrating on the northern latitudes where albacore landings are highest.

3. **Sampling time**: Farley and Clear (2008) found that there is a relatively long temporal window for sampling albacore (January to July at least) which will allow for a clear distinction between mature and immature females. For the months following the spawning season (April to the end of July), maturity is based on the presence of delta stage atresia in ovaries. These months will be particularly important for sampling.

5.3 Sampling strategy

To undertake a complete study on age, growth and reproduction, ideally the sampling should include the entire distribution of the species on a regular basis (monthly) over a year. To determine if there is variation in parameters such as growth and maturity over time, it is necessary to repeat the sampling over a second year at least and ideally three or more. However, a sampling program must also be cost effective and logistically feasible as complete time and space sampling is costly and requires extensive field work.

In the South Pacific, albacore is caught over a large area predominantly by longline fisheries west of 110ºE (Figure 1). The most cost effective way to obtain biological samples is from these fisheries via port sampling or regional observer programs in Australia (ETBF) and the Pacific Island country and territory (PICT) fisheries on a monthly-basis. Port sampling of the seasonal troll fishery in New Zealand and recreational fishery in south eastern Australia is also feasible.

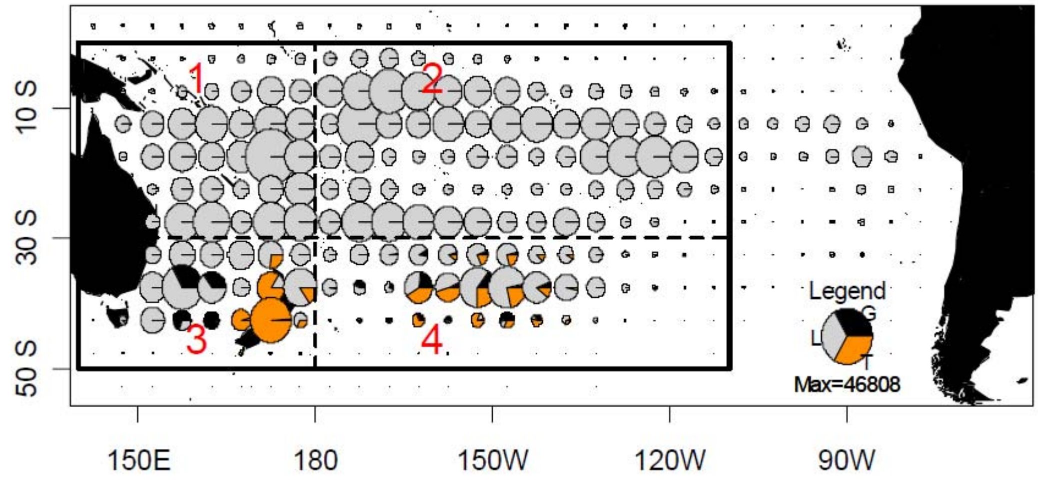

Figure 1. Total catch from 1960 to 2003 by 5 degree squares of latitude and longitude by fishing gear: longline (L), driftnet (G), and troll (T). The area of the pie chart is proportional to the total catch. The boundary of the stock assessment area is delineated by the grey lines. (Reproduced from Langley, 2006).

Australia

CSIRO is coordinating collection of biological samples from albacore caught in the ETBF and the local recreational fishery in south eastern Australia. The ETBF is particularly well positioned to obtain hard parts from albacore as the fishery covers almost the entire latitudinal (and thus size) range of the species. In addition, the recreational fishery in southern Australia predominantly catches juveniles ranging in size from 45-75 cm FL. Thus sampling along the length of Australia's east coast will allow for the full size/age range of the species to be sampled, which is not possible in many other fisheries. Port sampling is the most efficient method for the collection of biological material for albacore caught in the ETBF as the fish are landed whole and cannot be sampled at sea and there is a formal port sampling program in place.

Sampling method: Observers, contractors and CSIRO staff in ports.

Spatial coverage: The ETBF domestic longline fishery along Australia's east coast and recreational fisheries in southern Australia. The main sampling ports will be Cairns, Mooloolaba, Brisbane, Coffs Harbour, Portland, Ulladulla and Hobart. Other ports will be sampled if fish become available.

Temporal coverage: Sample on a monthly basis for 2 years. Start date: November 2008.

Biological samples: Sagittal otoliths, gonads, dorsal spine and muscle tissue (gonads stored frozen or fixed in formalin). Samplers of the longline fishery will record fork length, dressed/whole weight, landing date and vessel name. Capture details, fishing method and set information can be obtained from AFMA logbook records. Samplers of the recreational fishery will record fork length, weight if possible, catch date and location.

Sample size: Target of 40-50 fish per month from the landed catch. The expected total number of fish sampled could be 1200 (50 fish x 12 months x 2 years). A mixture of random and stratified sampling will be undertaken depending on the size of fish landed and logistics. Where possible, very small (< 50 cm FL) and very large (> 110 cm FL) fish will be selected so the maximum sample size of these rarer sized fish is obtained.

Fish size: It is anticipated that the full size range of albacore will be sampled. The recreational fisheries will be dominated by juveniles, while the longline fishery will comprise sub-adults and adults depending on the latitude caught.

Sample processing: All biological samples will be processed at CSIRO (Australia).

Pacific Island Countries and Territories (PICTs)

SPC is coordinating the collection of biological samples from albacore across the PICTs as part of their EU-funded SCIFISH project. Seven longline fisheries will be sampled from New Caledonia in the west to French Polynesia in the east. The latitudinal range of the fisheries is approximately 10-25ºS and it is expected that adults (> 80 cm) will dominate the samples from this source.

Sampling method: Observers on PICT domestic tuna longline fleets.

Spatial coverage: PICT nations of New Caledonia, Vanuatu, Fiji, Tonga, Samoa, Cook Island and French Polynesia.

Temporal coverage: Aim to sample on a monthly basis from each country for 2 years.

Biological samples: Sagittal otoliths and gonads (stored frozen). Fixing gonads in formalin is not possible at sea on commercial vessels. Observers will also record fork length, location and date/time of capture, fishing method and set information.

Sample size: Target of at least 20 fish per trip (month) across a broad size range of fish. The expected total number of fish sampled might be 3360 (20 fish x 7 countries x 24 months).

Fish size: The majority will be > 80 cm FL (adults).

Sample processing: All biological samples will be frozen and sent to CSIRO (Australia) for laboratory processing.

New Zealand

The New Zealand Ministry of Fisheries (MFish) and the National Institute of Water and Atmospheric Research (NIWI) are coordinating the collection of biological samples from troll caught albacore in New Zealand waters. In addition, SPC are sampling albacore caught during tagging operations within the New Zealand EEZ (Williams et al., 2009). It is anticipated that juveniles will dominate the troll caught fish, while juveniles and adults will be sampled during the tagging operations.

Sampling method: NZ MFish Observer Program in ports and SPC staff during tagging operations.

Spatial coverage: New Zealand's west coast domestic troll fishery and east coast troll/longline via SPC's tagging program.

Temporal coverage: Sample the troll fishery on a monthly basis during the 4 month season (Jan-Apr) for 2 years (2008 and 2010). Additional samples collected by SPC in summer 2009 via trolling and autumn 2010 via longlining.

Biological samples: Sagittal otoliths, gonads, dorsal spine and muscle tissue (stored frozen). Observers will also record fork length, location and time of capture, fishing method and set information.

Sample size: Target of 40 fish per month randomly selected from the landed troll catch. The expected total number of fish sampled is 320 (40 fish x 4 months x 2 years). A total of 70 samples collected by SPC in 2009 and a target of 100 fish in 2010.

Fish size: Predominantly juveniles ranging in size from 45-70 cm. Some adults sampled by SPC via longlining.

Sample processing: The 2008 material has already been frozen and sent to CSIRO (Australia) for processing. The 2010 material will also be sent to CSIRO.

Laboratory processing

As already noted, the biological material sampled for CSIRO and SPC projects will be sent to CSIRO for archiving and laboratory processing:

1. **Ageing**: In the laboratory, all otoliths and spines will be cleaned, dried and archived into the 'Hard parts' collection. Otoliths/spines selected for annual ageing will be sent to 'Fish Ageing Services Pty Ltd' for sectioning following protocols developed in Farley and Clear (2008). Potential otoliths selected for daily ageing will be sections at SPC. Ageing protocols will be fully developed following the preliminary work by Farley and Clear (2008), including the development of a Reference set (otoliths of agreed interpretation). Age validation will be undertaken where possible including: direct, semi-direct, and indirect validation. Comparison of spines and otoliths will provide a method of age verification. Otoliths and spines will be read at CSIRO (annual age), with inter-agency comparisons undertaken to measure precision.

2. **Reproduction**: If gonads were frozen after collection, a sub-sample will be taken from each ovary while frozen and fixed in 10 % buffered formalin. Histological methods will be used to determine the maturity and reproductive status of each female and a sub-sample of males based on the methods developed for yellowfin tuna (Schaefer, 1996; 1998) and southern bluefin tuna (Farley and Davis, 1998) and applied to albacore in the pilot project (Farley and Clear, 2008). Inter-agency comparisons of histological staging will be undertaken.

3. **Database**: All data collected from the ETBF and by New Zealand will be entered into existing CSIRO ORACLE/MS ACCESS databases (data custodian). SPC will be

responsible for data collected in the wider SW Pacific. Data will be shared with SPC–CSIRO for collaborative analysis.

6. Biological sample collection

The final objective of the project was to continue to collect biological samples (gonads, otoliths, dorsal spines, muscle tissue) and associated data (length and weight) from 500 albacore caught in the ETBF in 2008/09. As mentioned previously, biological samples are required to provide the material for a subsequent project "Population biology of albacore tuna in the Australian region" (FRDC 2009/012) and a complementary biological study at SPC. These studies are focussed on determine biological parameters central to the development and implementation of sustainable Harvest Strategies, and improving the regional stock assessment.

6.1 Methods

As mentioned previously, port sampling is the most efficient method for the collection of biological material for albacore caught in the ETBF as the fish are landed whole and cannot be sampled at sea. Gonads, sagittal otoliths, and fin spines were sampled from albacore landed at ports in the four eastern Australian states bordering the ETBF (Queensland, New South Wales, Victoria and Tasmania). For each fish sampled, the fork length (FL) was measured to the nearest cm and weight to the nearest 0.1 kg where possible (whole and or dressed). For commercially caught fish, the vessel name was recorded so that the fishing location and other data can be obtained from AFMA logbooks at a later stage. Full catch details were obtained for recreational caught fish. Muscle tissue samples were also collected for each fish for potential future genetic or stable isotope work aimed at stock structure and trophodynamics.

6.2 Results

Albacore sampling was conducted at five locations: Cairns, Mooloolaba, Coffs Harbour, Ulladulla, Portland and the east coast of Tasmania. A total of 384 fish were measured for length, and biological samples were obtained from most (Table 2). Details of the sampling by state are as follows:

Queensland

The majority of albacore caught in the ETBF are landed in Mooloolaba (89 % and 82 % of fish in 2006 and 2007 respectively). We initiated biological sampling in Mooloolaba at the start of the project in November 2008. Albacore that were landed over the summer months were caught in the northern ETBF where spawning occurs. Landings of albacore are expected in increase over winter from catches east of Mooloolaba. It is anticipated that sampling will be established in Cairns as landed started to increase.

New South Wales

Coffs Harbour and Ulladulla were identified as ports suitable to sample adults and/or juvenile albacore in NSW over winter. Sampling adults and juveniles together is especially important for estimating size at maturity (see section 5.3). Sampling was initiated in Coffs Harbour in May and it is anticipated that sampling in Ulladulla will start in June 2009 as the number of albacore landed increase.

Victoria

Biological samples were collected from recreational caught albacore landed in Portland (Vic) in May 2009, after it was learned that relatively large numbers were being caught. All fish sampled were greater than ~100 cm FL and one was 116.5 cm which is the largest sampled to date. These large fish will be important for estimating longevity.

Tasmania

In Tasmania, recreational caught albacore were sampled in St Helens, Coles Bay and Pirates Bay on the east coast between January and April. These fish were samples in cooperation with three local game fishing clubs. The fish were juveniles ranging in size from 48-70 cm FL.

Table 2. Number of biological samples obtained from albacore caught in the ETBF by month.

Month	Fork Length	Weight (whole)	Weight (dressed)	Gonad	Otolith	Fin spine	Muscle
Aug 08	2			2	2	2	2
Nov 08	29	29	-	29	28	29	28
Jan 09	33	33	-	32	33	33	26
Feb 09	54	54	-	56	57	57	57
Mar 09	87	86	28	86	85	87	87
Apr 09	21	21	1	21	21	21	21
May 09	36	35		35	35	36	35
Jun 09	122	115		115	101	121	119
Total	*384*	*373*	*29*	*376*	*362*	*386*	*375*

Overall, the number of albacore sampled was slightly less than anticipated due to a shortening of the project (from 12 to 8 months) but will not compromise the imminent biological work as the monthly sampling is above the minimum required for estimating the biological parameters (see section 5 above). It is anticipated that sampling will continue at these ports, and possibly others such as Sydney, over the next 12-18 months.

7. Benefits and Adoption

This study provides an improved way to collect and analyse size data for albacore to ensure that representative estimates of the size composition of the catch are obtained for the ETBF. Processors, not already collecting unbiased size data, have agreed to collect individual size data based on our simulation results. This industry-based size monitoring program will reduce monitoring costs to the fishery and build greater ownership and understanding of data inputs for the harvest strategy. Ultimately, it will provide a consistent data source to review the inputs and indicator values for the ETBF HS on a regular basis and provide improved size-based catch data for regional stock assessment.

The development of a biological sampling plan for albacore in the southwest Pacific (and the collection of biological material) will ultimately lead to of improved estimates of biological parameters for the region. This will, in turn, contribute to the regional stock assessment. It will allow managers to further assess the sustainability, and likely performance of current management strategies, for albacore in region.

In the long-term, commercial fishers in the ETBF will benefit from this research because it will provide a biological basis for assessing the status of the albacore resource in the future, and the involvement of industry in the monitoring and will build greater confidence in the outcomes and improve the cost-efficiency of monitoring programs.

The results of this study will be presented to the WCPFC SC in August 2009, and to the Tropical Tuna MAC in early 2010.

8. Further Development

The recommended sampling regime of 15 fish per trip to obtain representative estimates of the size composition of albacore in the catch is based on simulations undertaken on two years of relatively recent data. It is important to note that the fishery should continue to be monitored and the simulation exercise revisited over time. If fishing effort converges around certain strata, the sampling requirements may lower as the exploited size distributions become more consistent. However, if dedicated targeting for albacore ceases, or if albacore is fished more opportunistically than in 2005, sampling requirements may be higher in order to reflect the variability in the exploited size compositions.

The biological sampling program was designed to ensure that unbiased estimates of biological parameters for albacore are obtained and will form the basis of ongoing sampling in the southwest Pacific by CSIRO and SPC. The samples obtained will be used in subsequent project "Population biology of albacore tuna in the Australian region" (FRDC 2009/012).

9. Planned Outcomes

The most significant outcome of the project was the implementation of a formally designed, industry-based size monitoring program for albacore. This was achieved through the development of a simulation model to determine the sampling intensity required at the major ports in the ETBF (15 fish per trip for 90 % of trips), and the willingness of ETBF operators to implement this program in a consistent manner over time as part of their regular off-loading procedures.

The second planned outcome of the project was the development of a biological sampling regime for albacore in the ETBF and wider southwest Pacific. This was achieved through consultation with SPC during the project, and by determining the minimum sample size required to estimate reproductive (maturity) and growth parameters with appropriate confidence intervals. An archived collection of biological samples (otoliths/spines, gonads, & muscle) has also been obtained for use in a subsequent FRDC-funded project. The material will be used to estimate biological parameters required as inputs to the Harvest Strategies for albacore in the ETBF.

10. Conclusion

This project has successfully met all of its objectives. A practical and cost-effective industry-based size monitoring program was developed and implemented in the fishery to obtain representative sized data for albacore in the ETBF. The simulation modelling work showed that to obtain representative sized data for albacore either (1) a small number of fish would need to be measured from a large number of fishing trips, OR (2) a large number of fish would need to be measured from a small number of trips. For the second scenario, the operator would also need to keep track of where the boat had operated, the time of year, and depth of fishing so that there was an even spread of data from each area, depth and quarter. Not surprisingly, industry indicated that they would prefer to measure a fixed, smaller number of fish from every trip. Our analysis showed that a minimum of 15 fish per trip would need to be measured (weighed) individually for all trips processing fish in Cairns, Mooloolaba, Brisbane, Coffs Harbour and Ulladulla. It is important to note that three processors already measure ~100 % of albacore in their factories.

We also developed a biological sampling plan in collaboration with SPC for the ETBF and southwest Pacific. Analysis was undertaken to determine the minimum sample size required to estimate the growth and reproductive (maturity) parameters with appropriate confidence intervals. Overall, it was suggest that at least 500 otoliths are sampled per year from eastern Australia (from the full size rage caught) so that there are sufficient otoliths to select from for ageing. To estimate a maturity schedule, it was recommended that targeted sampling occurs around 25-34ºS in early winter, to sample across the size range that includes immature to fully mature females, at the time of year when it is possible to distinguish between the two.

An archived collection of biological samples (otoliths/spines, gonads, & muscle) was also obtained for use in a subsequent FRDC-funded project “Population biology of albacore tuna in the Australian region” (FRDC 2009/012).

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12. Appendix A: Intellectual Property

No commercial intellectual property arose from this work.

13. Appendix B: Staff

Jessica Farley - Pelagic Fisheries and Ecosystems, CSIRO Marine and Atmospheric Research

Natalie Dowling - Pelagic Fisheries and Ecosystems, CSIRO Marine and Atmospheric Research

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14. Appendix C: Simulation methods and results

Simulation modelling was undertaken to determine the sub-sampling regime required at the key ports and assess whether adequate individual size data is already being collected as part of the current size monitoring program (Williams, 2008). The sampling simulations accounted for differences in the size of fish caught between areas, months and depth of capture. It will be important to evaluation procedures to ensure that the data are representative of the catch and that target precisions (CVs) for the size compositions are met.

To provide a statistically sound basis to:

1) maintain a cost-effective sampling regime for estimating the length/age composition of the albacore component of the Eastern Tuna and Billfish Fishery

2) determine the minimum

- Number of trips
- Number of albacore to measure (weigh) per trip
- both i) overall and ii) by area x season x depth (HPB) strata

in order to obtain robust estimates of

a) the representativeness of the overall size composition of albacore in the catch, as evaluated by the following three indictors

- sums of squares of squares between observed and sampled proportions in each length category;
- maximum absolute difference between observed and sampled cumulative length distribution functions (Gomez-Buckley et al., 1999)
- mean weighted coefficient of variation (MWCV) (Gerritsen and McGrath 2007; Knuckey and Gason 2001) (see below for more detail);

and

b) of the harvest strategy required inputs:

- CPUE “prime sized” fish (inferred from the proportion of “prime sized” fish in the catch)
- CPUE “recruits” (inferred from the proportion of “recruit sized” fish in the catch)
- CPUE “large/old” fish (inferred from the proportion of “large sized” fish in the catch)
- Proportion “large/old” fish

It should be noted that both objectives relate to obtaining a robust sample of total catch, as opposed a robust sample of the population. The harvest strategy was predicated on the lack of understanding of population abundance and as such is based on indicators within the catch. As such, the issue is the minimum sampling required to obtain indicator values for the harvest strategy, and an overall size distribution that are representative of the entire catch.

Methods

The expected size data for the fishery was characterized using logbook and observer data from 2005 and 2006. These years were chosen as encapsulating the periods of the fishery both prior to (2005) and during (2006) the active targeting of albacore, and also having a comprehensive set of accompanying observer data. Separate sets of simulations were run for each of these years.

Logbook data was used to form a sample pool from which trips were sampled. Observer data comprising individual fish lengths was used to characterise the size structure and was linked to the logbook data by a unique identifier. The observer data was edited to remove all reported lengths greater than 120 cm and less than 50 cm. Only logbook sets that caught at least one albacore were used in the sampling set. Table C1a shows a summary of the logbook and observer data by stratum for 2005 and 2006.

The mean size of albacore caught on a longline set varies according to location, time of year and set depth. As such, the fishery was stratified according to these factors in the size-sampling simulation. Strata comprised combinations of

- fishing depth, defined in terms of hooks per basket (HPB): 2 categories, deep (> 20 HPB) and shallow (≤ 20 HPB)
- region, defined as three latitude bands (-10S ≥ x > -23S; -23S ≥ x > -30S; -30S ≥ x > -40S) defined according to historical fish catch rates and spatial size distributions from observer data
- season: 4 assigned (Dec-Feb, Mar-May, Jun-Aug, Sep-Nov) according to historical temporal availability of fish

It should be noted that, in a practical sense, trips often use various setting configurations so that it is impossible to assign individual fish from a trip as originating from a deep or a shallow set. However, given that set depth has an effect on the size structure of albacore caught (deep sets are used to actively target albacore), it is still of theoretical interest to stratify the fishery by fishing depth.

From the observer data, the proportion of fish in each 1 cm length class for each trip was calculated. Length frequency distributions were derived for each stratum from the observer data as the mean and standard deviation of the number of fish in each 1 cm length category across all sets in the stratum. Even when undertaking non-strata-specific sampling, strata-specific length-frequencies were still used to derive the sizes of fish in the sampled trip.

The size category thresholds for the proportion of “recruits”, “prime” and “old” sized fish were defined for albacore, from consultation with industry stakeholders, as follows:

“recruits”:	< 83 cm
“prime”:	83-94 cm
“old”:	> 94 cm

(noting that the terms “recruits”, “prime” and “old” in the context of these size classes do not necessarily correspond to a set age range or, in the case of the former, to the cohort recruiting into the fishery. Rather, they relate to how the size of a fish in perceived in the context of its market value).

Model structure

The model followed the approach used by Knuckey and Gason (2001) to develop an integrated scientific monitoring program for the South East Fishery.

Knowing i) the total number of ALB per trip by location, season and hooks per basket (depth of set), and ii) observer-based subsets of individual size data, the aim of the simulation was to generate a length-frequency distribution for the catch, unique to each stratum as defined by location, season and hooks per basket (depth of set) combination. Clearly, the accuracy of this will be dependent of how representative the size sampling is by location, season and hooks per basket. It should be noted that stratifying by port would be inappropriate since this is not specific to a given size distribution: vessels from different ports may visit the same region in the same season using the same gear.

Size was defined by length rather than weight, as this was the metric in which size information was reported within the observer data set that informed the simulation. However, it is acknowledged that most industry members would prefer to provide size information in terms of individual weights. The strongly significant length-weight power relationship from Farley and Clear (2008) ($r^2 = 0.9938$) indicated that length and weight can be used almost interchangeably as a metric of size. As such, the results from the length-based simulations can be considered to be applicable also to minimum sampling requirements based on weight measurements.

Simulations were run using both a) separate strata and b) the combined dataset. Some strata will clearly contribute far more than others to the overall data set, so an overall weighted mean value for each indicator was calculated by weighting the strata-specific values by the catch from that stratum. It is also of interest to consider the minimum number of trips and fish per trip to sample in order to yield a representative length-frequency distribution sample across each stratum. The combined dataset is already inherently weighted according to the most commonly occurring strata. The question is whether randomly sampling from the entire distribution of sets gives a similar output to the strata-specific sampling (in terms of the value of the indicators and the CV associated with a given sample size).

When the combined dataset was used, the fish sampled from each trip was assigned a length-frequency corresponding to that of a randomly selected strata sampled from within that trip. If the chosen trip did not have any observer length-frequency data for the stratum visited, then the overall observed length-frequency distribution was used. For the strata-specific simulations, only strata for which observer length-frequency data existed were sampled.

We randomly sampled from a) each strata and b) the entire dataset, for a matrix of the number of trips sampled and the number of fish measured within each set. The matrix used was as follows:

number of trips (1, 5, 10, 25, 50, 75, 100, 125, 150, 175)
x
number of fish measured per trip (1, 3, 6, 9, 12, 15, 20, 40, 60, 80)

A total of 100 realisations were run for each combination of number of trips and number of fish measured per trip. A single realisation of random sampling for a given matrix combination (i.e. x number of trips and y number of fish measured within a set) thus involved the following.

a) From the logbook data, trips were selected (without replacement) up to the required number of trips (x) (or actual number of trips if this was $< x$)

b) It was assumed that each trip caught fish from a given length-frequency distribution associated with the stratum fished. For each trip, a length-frequency distribution was generated from a multinomial distribution, where these distributions are determined by the observer data within that stratum and year. (Note: the mean and inter-trip variance within each length class for the observer data was compared to that obtained within each length class as sampled using a multinomial distribution. These variances were comparable in magnitude, such that the multinomial distribution sufficed, as opposed to a Dirichlet distribution)

c) For each set, we "measured" the required number of fish (y) (or actual number of fish if this was $< y$). To do this, we generated a vector of lengths for the total number of actual fish caught on the trip. We multiplied the actual number of fish caught by the proportion in each 1 cm length category for that trip, and then sampled lengths randomly from within that 1 cm length category. From the resulting vector, y fish were randomly sampled.

d) On the basis of the sampling regime (number of trips and number of fish measured per trip), using the combined measurements across all trips, indicator values were calculated.

The following indicators were used:

Harvest strategy required inputs (Davies et al., 2008):

i) Proportion "recruits"

ii) Proportion "prime sized"

iii) Proportion "old"

For thoroughness, we calculated three indicators of overall size composition:

iv) sums of squares between observed and sampled proportions in each length category (this is a good indicator of overall fit, does not take into account the number of fish in each length class)

v) maximum absolute difference between observed and sampled cumulative length distribution functions (Gomez-Buckley et al., 1999) (an alternative measure but one that does not necessarily detect differences due to skew)

vi) mean weighted coefficient of variation (MWCV) (Gerritsen and McGrath 2007; Knuckey and Gason 2001). If the precision in each length class is expressed in terms of a CV, an overall measure of precision can be obtained by weighting each CV by the number of fish in each length class. This mean weighted coefficient of variation (MWCV) provides a description of the precision over the entire range of size classes in a length-frequency distribution (Gerritsen and McGrath 2007).

Across the 100 realisations, a mean and CV for each HS indicator and overall size composition indicator for each matrix combination (number of trips) x (number fish measured per trip), for each stratum, was obtained. An overall mean and standard deviation for each indicator across all strata was also obtained by weighting the strata-specific values according to the historical catch in that stratum for that year.

For both the strata-specific and combined approaches, we determined the minimum number of trips (noting that it is not possible or practical to distinguish fish by set), and the minimum number of fish measured per trip, required to provide a representative length-frequency distribution of the catch, which could then be used to estimate the values of the required indicators for the harvest strategy. The main criterion we used for selecting a sampling protocol (i.e. the minimum sampling regime) was:

i) that the value of the coefficient of variation (CV) for each indicator is < 20 %.

Additional criteria we considered were:

ii) that the value of the coefficient of variation (CV) shows a minimal reduction in magnitude with increased sampling (i.e. choose the minimum number of trips and numbers of fish to measure per trip, above which the CV for each indicator is < 20 % and shows a minimal reduction in magnitude with increased sampling).

iii) that the change in the mean weighted coefficient of variation (MWCV) is < 1 % for an increase of 20 in the number of fish in the sample for a given number of trips sampled [the criterion by which Knuckey and Gason (2001) define the optimal sample size].

iv) that the indicators of overall size composition (i.e. the sums of squared differences, the maximum cumulative distance and the MWCV) are minimized.

v) That the values of the harvest strategy indicators are stable above any minimum sampling regime.

Plots of CVs (for the harvest strategy indicators) and mean indicator values (for the indicators of goodness of fit) versus number sets by numbers of fish measured, enabled determination of not only the minimum number of trips and number of fish to measure within each trip, but also the performance of individual strata as compared to treating the dataset as a combined entity.

Scenarios tested:

Initially, scenarios using the combined and strata-specific approaches, for both 2005 and 2006 were run for the sampling regimes described above.

Following consultation with the main industry members in Mooloolaba and Coffs Harbour, where the results from the above simulations were presented, by unanimous consensus the operators indicated that they would prefer to measure a fixed, smaller number of fish from every trip as opposed to a set, possibly larger, number of fish from a subset of trips within each strata (where the number of trips and fish to be measured within each stratum may also vary between strata). This was an ideal outcome, since the results from the (number of trips) x (number of fish measured per trip) matrix approach suggested that coverage of every trip would require a low number of fish to be measured per trip for statistical robustness to be ensured.

Strata-specific recommendations are theoretically sound for determining minimum required levels from each. However, this minimum level may change depending on the level of effort within any stratum. This approach is appropriate to determine the minimum sampling requirement acknowledging the size variability by location, season and setting depth (i.e. strata), but if stakeholders are prepared to sample fish across all or almost all trips, then the question about the minimum level of sampling in each strata becomes moot since all strata are covered. The question simplifies to that of the minimum required fish to be measured per trip, given that all trips are sampled. Note, however, that the original strata-specific, (number of trips) x (number of fish per trip) sampling matrix regime simulations are retained as an informative academic/theoretical exercise.

Industry members in Mooloolaba also unanimously indicated that they would prefer to provide a single estimate of average weight of albacore in the catch from each trip (as opposed to measuring a sample of individual fish) since the sense was that the size of fish is tightly consistent within any given trip. Although it was explained that the cumulative influence of tails across sets of size distributions is not insignificant, it was nonetheless agreed to run a simulation where only the average length, as calculated across the entire catch, was obtained.

Scenarios investigated assuming all trips were sampled used the vector of number of fish measured per trip = (1,3,6,9,12,15,20,40,60,80) and were as follows:

- 100 % all trips sampled: 2005 and 2006
- 90 % all trips sampled: 2006 only (since this was shown to be the more variable year)
- 100 % trips sampled, using average weight across the whole of the catch per trip rather than individual weights: 2006 only
- 100 % trips sampled, but using logbook and observer data only for vessels that also operated in 2007. This was done to evaluate the robustness of sampling among the subset vessels that are still currently operating.

Results

Academic exercise of number of trips and number of fish per trip

The minimum sampling regime in terms of number of trips and number of fish to measure (weigh) per trip varied according to the indicator, the year, between strata, and with the approach used (combined data versus strata-specific). These results are summarized in Table C2 and Figures D1-D38 in Appendix D. These plots are broken down as follows:

- There are 6 indicators: the 3 HS inputs (proportion of "recruits", "prime" and "old" - sized fish, and 3 indictors of representativeness of the length-frequency distribution (the sum of squared differences across the 1 cm length categories, the maximum distance between the observed and modelled cumulative l/f distributions, and the MWCV).
- For each of the three HS inputs, we are more interested in the behaviour of the coefficient of variation as opposed to the magnitude of the indicator. There are 6 plots presented for each indicator: 3 each for 2005 and 2006. Each set of 6 plots is as follows:
  - the coefficient of variation of the indicator for each number fish measured per trip/number of trips combination, for the combined dataset
  - the coefficient of variation of the weighted mean indicator for each number of fish measured per trip/number of trips combination, using the strata-specific simulation
  - the coefficient of variation of the mean indicator for each number fish measured per trip/number of trips combination for each stratum.

However, as per criterion v) above, the mean values of the indicators themselves were also considered when evaluating the minimum required sampling regime (Table C2), since it is possible that, as sampling level increases, the coefficient of variation could be approximately constant (and below 20 %) while the magnitude of the indicator is yet to stabilise. As an example, these are presented for the "Proportion Old" indicator for the 2005 and 2006 "combined" simulations (Figures D1 and D5 in Appendix D).

- For each of the three indictors of representativeness of the length-frequency distribution, we consider the values of these by sampling regime. There are 6 plots presented for each indicator: 3 each for 2005 and 2006. Each set of 6 plots is as follows:

  - the mean value of the indicator versus number of fish measured per trip, for each number of trips considered, for the combined dataset (i.e. strata not considered), plus and minus 1 standard deviation
  - the overall (catch) weighted mean value of the indicator versus number of fish measured per trip, for each number of trips considered, using the strata-specific simulation, plus and minus 1 standard deviation
  - the mean value of the indicator versus number of fish measured per trip, for each number of trips considered, for each strata, plus and minus 1 standard deviation

  Note that the coefficients of variation of these indicators were also considered in Tables C2 and C3.

Overall and in general, the mean value of each indicator showed little variation across the combinations of number of trips and number of fish measured per trip (with the obvious exception of the MWCV, which decreased with increased sampling). Standard deviations were higher as the number of fish measured per trip, and, to a greater extent, the number of trips covered, reduced. Standard deviations were generally minimized at sampling levels of at least 50 trips and at 9 fish per trip. Coefficients of variation for the indicators were generally below 20 % when at least 25 trips and 6 fish per trip were sampled. It was a consistent feature across all indicators and simulation types that CV values and variation about indicator values was minimized when sampling a low number of fish across more trips, than when sampling a high number of fish across fewer trips.

The approach using the combined data showed that a higher level of sampling was required to obtain robust estimates of the overall size composition of the catch, than was required to obtain robust estimates of the harvest strategy indicators. However, the absolute values for the indicators of overall size composition were consistently low irrespective of sampling regime, which suggests a robust sample can be readily obtained. The 2006 combined data estimates of harvest strategy indicators show more variability in their values (in the range of 5–10 %) over the sampling regime than do those in 2005. The proportions of fish in each size class also show differences between the two years. Although the minimum sampling regime varies between indicators and years, in general, across both years, the results suggest a minimum sampling regime of 25 trips and 6 fish per trip would yield a robust size sample and harvest strategy indicators. However, it is only above a sample size of ~20 fish per trip that the change in MWCV is < 1 % for an increase of 20 in the number of fish in the sample (the criterion by which Knuckey and Gason (2001) define the optimal sample size).

When using the strata-specific approach to obtain overall indicators weighted by catch, different values for the harvest strategy indicators were obtained than when using the combined data approach, but similar values for the overall goodness of fit to observed size distributions were obtained across both approaches. The absolute mean values of all indicators showed little variability with sampling regime. However, as would expected, weighting the indicators by catch when these are derived for each strata results in more variability and hence higher overall CVs on indicators, particularly on those of overall size composition.

For a given sampling level, some strata will yield a more variable sample than others, which in turn results in high variability when values are combined across strata to give weighted overall CVs. It follows that the minimum robust sampling level is different for each strata (Table C2 and Table C3 and discussion below). This brings into question the diagnostic merit of considering catch-weighted indicators and CVs that are obtained by combining values across all strata for a fixed level of sampling (number fish measured per trip/number of trips combination). The point is more that different sampling levels would be required in different strata depending on the level of variability within each. As such, it would be more worthwhile to use the strata-specific results to identify the minimum sampling level required within each stratum, and then calculate an overall catch-weighted value of the indicator based on the results from each sampling regime within each stratum.

Within any strata, the absolute mean values of indicators were almost constant, with low variability, irrespective of the sampling regime (with the obvious exception of the MWCV, which decreased with increased sampling). Mean absolute indicator values were highly variable between strata, reflecting the size segregation evident by location, season and setting depth and highlighting the need to sample across all fished strata in order to obtain a representative size sample. The minimum sampling requirement varied between individual strata, for indicators within each stratum, and with year (Table C3). In general, for most strata across for both years, CVs were less than 20 % when at least 25 trips and 6 fish per trip were sampled within each stratum, although the minimum sampling requirement sometimes as high as 50 trips or 60 fish per trip per stratum, particularly for the proportion recruits, sums of squares and the maximum cumulative distance indicators (Table C3). However, again, for the ranges of numbers of trips considered, it is generally only above a sample size of ~20-40 fish per trip that the change in MWCV is < 1 % for an increase of 20 in the number of fish in the sample

In terms of practical recommendations from this strata-specific, (number of trips) x (number of fish measured per trip) matrix simulation approach, it is clear that there is a trade-off between number of trips and numbers of fish measured per trip in order to fulfil the minimum sampling requirement of a CV value < 20 % (and ideally, a < 1 % change in MWCV for an increase in 20 in the number of fish in the sample). That is, various combinations of these above the specified minimum will yield acceptably low CV values. This would grant some flexibility for individual operators to determine their preferred approach, especially given that absolute values of indicators do not appear to show much variation in mean value between sampling regimes. Moreover, the results consistently showed that, in order to obtain a representative size distribution and robust, reliable harvest strategy indicators, it is clearly preferable (in terms of minimizing the CV values, the indicators of overall size composition and the change in MWCV) to sample a low number of fish across more trips, than to sample a high number of fish across fewer trips.

Table C1(a). Summary of the logbook and observer data by stratum, giving the number of trips each year in each stratum, the mean number of albacore caught per trip and stratum, and the total number of fish measured by observers in each year, and in each stratum across all years. See Table C1(b) for the strata definitions.

No. Trips	**STRATUM**																									**mean fish/**	**# fish**
YEAR	**all**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**trip & strata**	**(obs)**
2003	3492								1					112	341	371	105	435	431	94	564	379	106	433	417	11.25	2344
2004	3071	1							1	1				80	273	315	80	324	520	70	404	498	59	342	387	16.65	3211
2005	2455	4			1				10		4	13		46	271	323	57	314	370	68	355	202	58	284	262	132.84	3033
2006	1852	33	6		41	24	3	56	87	1	64	41	5	52	172	180	47	223	255	50	194	140	48	138	168	123.52	7272
2007	1589	39	13	22	26	33	11	9	122	15	18	56	39	49	151	135	43	206	197	46	165	93	40	155	182	125.22	2918
# fish	**(observer)***	42			1230	371		1048	897	30	1498	200		60	226	216	53	798	565	302	1837	5074	56	421	1485		

* sums of numbers of fish measured by observers in each stratum over all years includes incomplete data for 2007 (i.e. does not include all of the 2918 fish observed across all strata)

Table C1(b). Definition of each stratum in terms of the unique combination of hooks per basket, season and location. Italicised strata are those for which there was no simulated sampling in either 2005 or 2006.

STRATUM	HPB	SEASON	LOCATION
1	1	1	1
2	*1*	*1*	*2*
3	*1*	*1*	*3*
4	1	2	1
5	1	2	2
6	*1*	*2*	*3*
7	1	3	1
8	1	3	2
9	1	3	3
10	1	4	1
11	1	4	2
12	*1*	*4*	*3*
13	2	1	1
14	2	1	2
15	2	1	3
16	2	2	1
17	2	2	2
18	2	2	3
19	2	3	1
20	2	3	2
21	2	3	3
22	2	4	1
23	2	4	2
24	2	4	3

Table C2. A summary of the results of the combined and strata-specific, (number of trips) x (number of fish per trip) matrix sampling simulations, based on Figures D1 to D38.

		PropOld	PropPrime	PropRecruits	SSQ	Max Cum Dist	MVCV
2005 combined	Absolute value	stable at ~33%	Increasing with number of fish measured per trip, range~17%-22%	Stable at ~47%	→0 above minimal sampling levels	<0.2 above minimum sampling levels	Decreasing with number of trips sampled and number of fish measured per trip, stabilizing at <0.2 when >10 trips and >20 fish per trip sampled
	Lowest variability	> 10 trips, > 6 fish per trip	>25 trips, at least 6 fish per trip	>25 trips, at least 6 fish per trip	>1 trip, at least 3 fish per trip	>1 trip, at least 3 fish per trip	>1 trip, at least 3 fish per trip
	CV <20%	at least 10 trips, 6 fish per trip	At least 10 trips, 20 fish per trip, OR at least 6 fish per trip if at least 25 trips sampled	At least 5 trips, 9 fish per trip, OR at least 6 fish per trip if at least 10 trips sampled	At least 25 trips, any number of fish per trip	At least 25 trips, 3 fish per trip	>5 trips
2006 combined	Absolute value	increasing with number of fish measured per trip, stabilizing at ~55% (from ~45%) above 40 fish per trip	increasing with number of fish measured per trip, stabilizing at ~20% (from ~15%) above 9 fish per trip	Decreasing with number of fish measured per trip, stabilizing at ~25% (from ~35%) above 20 fish per trip	→0 above minimal sampling levels	→0.2 above minimal sampling levels	Decreasing with number of trips sampled and number of fish measured per trip, stabilizing at <0.2 when >10 trips and >20 fish per trip sampled
	Lowest variability	>10 trips, > 6 fish per trip	>10 trips, > 6 fish per trip	>10 trips, > 6 fish per trip	>1 trip, at least 3 fish per trip	>1 trip, at least 3 fish per trip	>1 trip, at least 3 fish per trip
	CV <20%	at least 10 trips, 6 fish per trip	At least 10 trips, 20 fish per trip, OR at least 6 fish per trip if at least 25 trips sampled	At least 10 trips, 20 fish per trip, OR at least 3 fish per trip if at least 25 trips sampled	At least 25 trips, any number of fish per trip	At least 25 trips, 6 fish per trip	>1 trip
2005 weighted	Absolute values	stable (~33%) across sampling levels but	Stable (~37%) across sampling levels but	Stable (~30%) across sampling levels but	→0 above minimal	<0.2 above minimum	Decreasing with number of trips

across strata		high variability	high variability	high variability	sampling levels	sampling levels	sampled and number of fish measured per trip, stabilizing at <0.2 when >10 trips and >20 fish per trip sampled
	CV of overall weighted value	never <20% (<30% at highest sampling regime)	Never <20% (<30% at highest sampling regimes)	Never <20% (<30% at highest sampling regimes)	Generally >100%	Generally >80%	<20% when >100 trips, at least 20 fish per trip sampled
2006 weighted across strata	Absolute values	stable (~60%) across sampling levels but high variability	stable (~35%) across sampling levels but high variability	stable (~5.5%) across sampling levels but high variability	→0 above minimal sampling levels	→0.2 above minimal sampling levels	Decreasing with number of trips sampled and number of fish measured per trip, stabilizing at <0.2 when >10 trips and >20 fish per trip sampled
	CV of overall weighted value <20%	at least 150 trips and 20 fish per trip sampled per strata	Never <20% (<30% at highest sampling regimes)	Never <20% and always >80%	Generally >60%	Generally >60%	When >1 trip sampled, CV between 20 and 40%
2005 strata-specific values	Absolute values	mean values highly variable between strata (range ~20%-60%), but stable within each strata irrespective of sampling regime, when sampling > 1 trip and > 3 fish per trip	mean values highly variable between strata (range ~10%-100%), but stable within each strata irrespective of sampling regime, when sampling > 1 trip and > 3 fish per trip	mean values highly variable between strata (range ~0%-60%), but stable within each strata irrespective of sampling, when sampling > 1 trip and > 3 fish per trip	<0.5 except for one stratum which had SSQ ~2	<0.4 except for one stratum which had a max cumsum dist of >0.8	Values highly variable between strata, but all strata show decreasing MWCV values with increased sampling
	CV <20%	across most strata, when at least 25 trips and 6 fish per trip	across most strata, when at least 25 trips and 6 fish per trip	Many highly variable strata, but in general when at least 25 trips	Across most strata, when at least 25 trips	Across most strata, when at least 50 trips	Across almost all strata when number of trips >1

		sampled	sampled	and 6 fish per trip sampled	sampled	and 6 fish per trip sampled	
2006 strata-specific values	Absolute values	mean values highly variable between strata (range ~20%-100%), but stable within each strata irrespective of sampling regime	mean values highly variable between strata (range ~0%-80%), but stable within each strata irrespective of sampling regime	mean values highly variable between strata (range ~0%-50%), but stable within each strata irrespective of sampling regime	<0.25 except for two strata which had SSQ ~0.5 and 2.0 respectively	<0.4 except for two strata which had max cumsum dists of ~0.5 and 1.0 respectively	Values highly variable between strata, but all strata show decreasing MWCV values with increased sampling
	CV <20%	across most strata, when at least 25 trips and 6 fish per trip sampled	across most strata, when at least 25 trips and 6 fish per trip sampled	Many highly variable strata, but in general when at least 25 trips and 20 fish per trip sampled	Across most strata, when at least 25 trips sampled	Across most strata, when at least 25 trips and 20 fish per trip sampled	Across almost all strata when number of trips >1

Table C3. Sampling level at which the coefficient of variation for each indicators drops below 20% (given that absolute value of the indicator shows little variation in response to sampling regime) (NB ignoring 1 fish per trip) (NB a blank means no values)

	strata	PropOld	PropPrime	PropRecruits	Sum Squares	Max cumsum dist	MWCV
2005 combined		10 trips 6 fish OR 5 trips 20 fish	25 trips 6 fish OR 10 trips 20 fish	25 trips 3 fish OR 10 trips 6 fish OR 5 trips 9 fish	25 trips 3 fish	25 trips 9 fish	5 trips 3 fish
2005 strata-specific	10	5 trips 15 fish	5 trips 6 fish	none	5 trips 40 fish	25 trips 60 fish	1 trip 3 fish
	11	10 trips 15 fish	5 trips 3 fish	25 trips 40 fish OR 10 trips 60 fish	10 trips 20 fish	10 trips 20 fish	5 trips 3 fish
	13		5 trips 3 fish	25 trips 3 fish	1 trip 3 fish	1 trips 3 fish	25 trips 3 fish
	14	25 trips 6 fish	10 fish 3 trips OR 5 fish 12 trips	25 trips 6 fish	25 trips 3 fish OR 10 fish 12 trips	50 trips 6 fish OR 25 trips 20 fish	5 trips 3 fish
	15	25 trips 6 fish	25 trips 3 fish OR 10 trips 9 fish	25 trips 3 fish OR 10 trips 9 fish	50 trips 3 fish OR 25 trips 9 fish	75 trips 9 fish	10 trips 3 fish
	17	10 trips 6 fish OR 5 trips 12 fish	25 trips 3 fish OR 10 trips 6 fish	25 trips 6 fish OR 10 trips 20 fish	25 trips 3 fish	100 trips 3 fish OR 50 trips 9 fish OR 25 trips 60 fish	5 trips 3 fish
	18	25 trips 3 fish	25 trips 3 fish OR 10 trips 9 fish	25 trips 3 fish OR 10 trips 6 fish OR 5 trips 20 fish	25 trips 3 fish	50 trips 3 fish OR 25 trips 60 fish	5 trips 3 fish
	19	5 trips 3 fish	10 trips 6 fish OR 5 trips 12 fish		25 trips 6 fish OR 10 trips 9 fish	50 trips 6 fish OR 25 trips 12 fish OR 10 trips 60 fish	5 trips 3 fish
	20	25 trips 3 fish OR 10 trips 9 fish OR 5 trips 12 fish	25 trips 3 fish OR 10 trips 9 fish OR 5 trips 40 fish	25 trips 3 fish OR 10 trips 6 fish OR 5 trips 9 fish	10 trips 6 fish	150 trips 3 fish OR 75 trips 9 fish OR 50 trips 12 fish OR 25 trips 20 fish	5 trips 3 fish
	21	10 trips 9 fish OR 25 trips 3 fish	50 trips 3 fish OR 25 trips 12 fish OR 10 trips 40 fish	10 trips 3 fish OR 5 trips 6 fish	25 trips 6 fish	50 trips 3 fish OR 25 trips 6 fish	5 trips 3 fish
	22	25 trips 6 fish	10 trips 3 fish OR 5 trips 6 fish	25 trips 3 fish	10 trips 3 fish OR 5 trips 6 fish	25 trips 3 fish OR 10 trips 6 fish	5 trips 3 fish
	23	25 trips 1 fish OR 10 trips 6 fish OR 5 trips 9 fish	10 trips 3 fish OR 5 trips 6 fish	175 trips 6 fish OR 125 trips 12 fish OR 100 trips 15 fish OR 75 trips 20 fish OR 50 trips 40 fish	50 trips 3 fish OR 25 trips 9 fish	75 trips 3 fish OR 50 trips 6 fish OR 25 trips 12 fish	5 trips 3 fish
	24	25 trips 3 fish OR 10 trips 12 fish	50 trips 3 fish OR 25 trips 9 fish OR	10 trips 3 fish OR 5 trips 12 fish	25 trips 3 fish	75 trips 3 fish OR 50 trips 6 fish	5 trips 3 fish

			10 fish 20 trips				
2006 combined		10 trips 3 fish OR 5 trips 6 fish	50 trips 3 fish OR 25 trips 6 fish OR 10 trips 20 fish	25 trips 3 fish	25 trips 3 fish	50 trips 3 fish	5 trips 3 fish
2006 strata-specific	1	5 trips any fish OR 1 trip 6 fish	25 trips 9 fish OR 10 trips 20 fish		25 trips 3 fish OR 10 trips 9 fish OR 5 trips 15 fish	25 trips 6 fish OR 10 trips 40 fish	1 trip 3 fish
	4	1 trip 12 fish OR 5 trips 3 fish	25 trips 3 fish OR 10 trips 12 fish OR 5 trips 40 fish	50 trips 40 fish	50 trips 15 fish	25 trips 20 fish	1 trip 3 fish
	5	10 trips 3 fish OR 5 trips 6 fish	25 trips 3 fish OR 10 trips 6 fish OR 5 trips 9 fish	50 trips 20 fish	25 trips 20 fish	25 trips 20 fish	5 trips 3 fish
	7	5 trips 3 fish OR 1 trip 6 fish	50 trips 3 fish OR 25 trips 9 fish OR 10 trips 15 fish OR 5 trips 40 fish	none	50 trips 6 fish OR 25 trips 12 fish OR 10 trips 40 fish	50 trips 15 fish OR 25 trips 60 fish	1 trip 3 fish
	8	10 trips 6 fish OR 5 trips 20 fish	5 trips 3 fish	50 trips 6 fish OR 25 trips 15 fish OR 10 trips 40 fish	75 trips 12 fish OR 50 trips 20 fish OR 25 trips 60 fish	75 trips 6 fish OR 50 trips 15 fish OR 25 trips 40 fish	1 trip 3 fish
	9						
	10	5 trips 3 fish OR 1 trip 12 fish	25 trips 3 fish OR 10 trips 9 fish OR 5 trips 20 fish	75 trips 60 fish	25 trips 3 fish OR 10 trips 15 fish OR 5 trips 60 fish	50 trips 6 fish OR 25 trips 15 fish	5 trips 3 fish
	11	25 trips 6 fish OR 10 trips 12 fish OR 5 trips 20 fish	5 trips 3 fish OR 1 trip 9 fish		25 trips 3 fish OR 10 trips 9 fish OR 5 trips 12 fish	50 trips 6 fish OR 25 trips 9 fish OR 10 trips 15 fish	5 trips 3 fish
	13	5 trips 3 fish	25 trips 9 fish		25 trips 3 fish OR 10 trips 6 fish	25 trips 3 fish	5 trips 3 fish
	14	50 trips 3 fish OR 25 trips 6 fish	10 trips 3 fish OR 5 trips 6 fish	25 trips 3 fish OR 10 trips 20 fish	50 trips 3 fish OR 25 trips 12 fish	75 trips 3 fish OR 50 trips 6 fish OR 25 trips 15 fish	5 trips 3 fish
	15		5 trips 3 fish	50 trips 3 fish OR 25 trips 9 fish	50 trips 6 fish OR 25 trips 12 fish	50 trips 3 fish OR 25 trips 12 fish	5 trips 3 fish
	16	5 trips 3 fish		none	1 trip 3 fish	1 trip 3 fish	
	17	10 trips 6 fish OR 5 trips 9 fish	25 trips 3 fish OR 10 trips 6 fish	50 trips 6 fish OR 25 trips 9 fish OR 10 trips 40 fish	50 trips 3 fish OR 25 trips 6 fish	75 trips 3 fish OR 50 trips 6 fish OR 25 trips 9 fish	5 trips 3 fish

	18	25 trips 3 fish OR 10 trips 9 fish OR 5 trips 20 fish	5 trips 3 fish		25 trips 3 fish OR 10 trips 6 fish OR 5 trips 9 fish	10 trips 3 fish OR 5 trips 6 fish	5 trips 3 fish
	19	5 trips 3 fish OR 1 trip 12 fish	50 trips 3 fish OR 25 trips 6 fish OR 10 trips 40 fish	50 trips 15 fish OR 25 trips 40 fish	25 trips 3 fish OR 10 trips 12 fish OR 5 trips 40 fish	50 trips 9 fish OR 25 trips 60 fish	5 trips 3 fish
	20	10 trips 3 fish OR 5 trips 6 fish	10 trips 3 fish OR 5 trips 6 fish OR 5 trips 12 fish	50 trips 6 fish OR 25 trips 9 fish OR 10 trips 60 fish	50 trips 3 fish OR 25 trips 6 fish OR 10 trips 20 fish	75 trips 6 fish OR 50 trips 12 fish OR 25 trips 20 fish	5 trips 3 fish
	21	25 trips 3 fish OR 10 trips 9 fish OR 5 trips 15 fish	25 trips 6 fish OR 10 trips 20 fish	10 trips 3 fish OR 5 trips 6 fish	25 trips 3 fish	50 trips 3 fish OR 25 trips 9 fish	5 trips 3 fish
	22	5 trips 3 fish	50 trips 6 fish OR 25 trips 9 fish		25 trips 6 fish	25 trips 12 fish	5 trips 3 fish
	23	25 trips 3 fish OR 10 trips 6 fish OR 5 trips 12 fish	10 trips 6 fish OR 25 trips 9 fish	175 trips 3 fish OR 50 trips 9 fish OR 25 trips 20 fish	25 trips 3 fish OR 10 trips 6 fish OR 5 trips 20 fish	75 trips 3 fish OR 50 trips 9 fish OR 25 trips 15 fish	5 trips 3 fish
	24	50 trips 3 fish OR 25 trips 6 fish	25 trips 6 fish	10 trips 3 fish OR 5 trips 12 fish	25 trips 6 fish	75 trips 6 fish OR 50 trips 9 fish	5 trips 3 fish

All trips covered – how many fish per trip?

As would be expected, sampling all trips in each year results in samples with extremely low CV values (approaching zero in most cases) for all indicators, irrespective of the number of fish sampled per trip (Table C4, Figures E1-E25 in Appendix E). The values of the sums of squares and MWCV indicators for each year stabilize when 15 or more fish are sampled per trip. The absolute value of the size-based harvest strategy indicators is constant irrespective of number of fish sampled per trip for 2005. The proportion of "recruits" and proportion of "old" fish decrease (17 % to 10 %) and increase (42 % to 50 %) respectively with number of fish sampled per trip in 2006, but these values begin to stabilize above a sample size of approximately 15 fish per trip. Values for the overall size composition indicators are very low when all trips are covered, even when lower numbers of fish per trip are measured. The results for 2006 show slightly more variability between sampling level than 2005, but overall the results show that robust estimates of size composition and robust harvest strategy indicators may be obtained when at least 3 fish per trip are measured across all trips. In order to fulfill the criterion of < 1 % change in MWCV for an increase of 20 in the number of fish sampled per trip, the 2005 and 2006 results suggest that at least 15 fish per trip should be measured.

It is emphasized that the robustness of samples taken by measuring some fish on all trips far exceeds that of the minimum sampling regimes suggested by the (number of trips) x (number of fish per trip) matrix approach above. By sampling all trips, measuring as few as 3–6 fish per trip will yield CVs approaching zero for each of the indicators. However, by measuring 15 fish per trip, there is greater likelihood (based on the two years used in the simulation) that the absolute value of the indicators will be stable, and that the MWCV criteria (< 1 % change in MWCV for an increase of 20 in the number of fish sampled per trip) will also be satisfied.

When substituting 100 % sampling of trips for 90 % sampling in 2006, the only observed difference was slight increases in the CV value for proportion recruits and maximum cumulative distance indicators. Otherwise, the outcomes were indiscernible, suggesting that it is not critical to sample absolutely every trip. However, it should be noted that this simulation assumed random sampling of trips from the entire pool for 2006. If 90 % of trips were chosen in a temporal-, gear-, or location-biased manner, the samples may not be as robust or representative.

Sampling all trips, but having only an estimate of the mean length in the catch on each trip, resulted in underestimates of the proportion of "recruits" and overestimates of the proportion of prime sized fish in the catch for 2006. The "recruits" size class had the lowest proportion of fish in the catch in 2006, so it follows that trip-specific mean size estimates will result in a lower frequency of reported catch in this size category; there is not the frequency of smaller sized fish to lower the overall mean length to a value low enough for it to correspond to this size category. It is also worth noting that all of the indicators of overall size composition have far higher values(~ 10x for sums of squares, ~2x for maximum cumulative distance, and ~5x for MWCV) when the size samples are determined using mean length caught per trip, than when fish are individually measured. This shows that overall size composition estimates are more robust when individual fish measurements are used as opposed to trip-specific means..

When the 2006 simulations were repeated using data obtained only from vessels that also fished in 2007, the mean values of the harvest strategy indicators was more stable/showed less change with number of fish per trip sampled than when data from all vessels was used (although the variation about each mean value was higher when using this subset of data). This was possibly because the vessels that were not relinquished as part of the 2006 buy-back scheme form the core component of the fishery and are thus more effective with regard to active targeting. Hence the albacore catch may comprise less of a range of sizes because the peripheral fishing activities are removed. The CVs about all indicators were higher when using this subset of data: although these were < 20 % when at least 3 fish per trip were sampled, for most indicators they did not approach zero until a higher number of fish per trip were measured. However, again, sampling 15 fish per trip for this scenario fulfilled both the < 20 % CV criteria for all indicators, and the < 1 % change in MWCV criterion.

The willingness of many ETBF processors to measure (weigh) a sample of fish from every trip, together with the existing size monitoring data (Williams, 2008), greatly simplifies the issue of obtaining representative estimates of the size composition of the catch. The results from the (number of trips) x (number of fish per trip) matrix simulations showed that it is clearly preferable (in terms of minimizing the CV values, the indicators of overall size composition and the change in MWCV) to sample a low number of fish across more trips, than to sample a high number of fish across fewer trips.

Reasonably reliable estimates of size composition (as defined by < 20% CV values) may be obtained by sampling very few fish (3-6) fish per trip. However, in order to obtain a highly robust size sample of the catch, and robust and reliable values for the harvest strategy indicators, it is recommended that 15 randomly selected fish per trip be sampled across at least 90% of randomly chosen trips, in order to obtain reliable HS indicator values and highly robust estimates of overall size composition.

Table C4. A summary of the results of the simulations sampling 90-100% of trips, testing a range of numbers of fish per trip, based on Figures E1 to E25 in Appendix E.

		PropOld	PropPrime	PropRecruits	SSQ	Max Cum Dist	MVCV
2005 all trips sampled	value	~0.33 at all sampling levels; minimal variability within each sampling level	~0.33 at all sampling levels; minimal variability within each sampling level	~0.32 at all sampling levels; minimal variability within each sampling level	Stabilises at ~ 0.008 when number of fish per trip >12; minimal variability within each sampling level	Stabilises at ~ 0.2 when number of fish per trip >9; minimal variability within each sampling level	Stabilises at ~ 0.025 when number of fish per trip >15; minimal variability within each sampling level
	CV	→ 0 when number of fish per trip >6	→ 0 when number of fish per trip >6	→ 0 when number of fish per trip >6	→ 0 when number of fish per trip >6	→ 0 when number of fish per trip >6	→ 0
2006 all trips sampled	value	Increases with number of fish per trip from ~0.42 to ~0.5; minimal variability within each sampling level	~0.4 at all sampling levels; minimal variability within each sampling level	Decreases with number of fish per trip from ~0.17 to ~0.10; minimal variability within each sampling level	Stabilises at ~ 0.006 when number of fish per trip >20; minimal variability within each sampling level	Decreases with number of fish per trip from ~0.17 to ~0.10; minimal variability within each sampling level	Stabilises at ~ 0.025 when number of fish per trip >20; minimal variability within each sampling level
	CV	→ 0 when number of fish per trip >3	→ 0 when number of fish per trip >3	→ 0 when number of fish per trip >6	→ ~2% when number of fish per trip >12	→ ~2% when number of fish per trip >6	→ 0
2006 90% trips sampled	value	As per 100% sampling	As per 100% sampling	As per 100% sampling	As per 100% sampling	As per 100% sampling	As per 100% sampling
	CV	As per 100% sampling	As per 100% sampling	→ 2% when number of fish per trip >6	As per 100% sampling	→ ~5% when number of fish per trip >3	As per 100% sampling
2006 all trips sampled but only	value	~0.33	~0.6	~0.1	~0.055	~0.3	~0.11

mean length provided across all fish caught on each trip (i.e. no range of samples of number of fish per trip)							
2006 all trips sampled but only using trips from vessels that also fished in 2007	value	~0.21; variability high at low numbers of fish per trip, stabilizing at ≥20 fish per trip	~0.57; variability high at low numbers of fish per trip, stabilizing at ≥15 fish per trip	~0.22; variability high at low numbers of fish per trip, stabilizing at ≥15 fish per trip	Stabilises at ~ 0.006 when number of fish per trip >6; variability higher at lower numbers of fish per trip	~0.68; minimal variability within each sampling level	Stabilises at <0.2 when number of fish per trip >20; minimal variability within each sampling level
	CV	<20% if at least 3 fish per trip sampled; <10% if >9 fish per trip sampled	<10% if at least 3 fish sampled per trip	<20% if at least 6 fish per trip sampled; <10% if >12 fish per trip sampled	<10% if at least 6 fish sampled per trip	→ 0	→ 0 when number of fish per trip >15

Discussion

The strata-specific, (number of trips) x (number of fish per trip) matrix sampling approach provided a comprehensive theoretical evaluation of the minimum level of sampling required to obtain representative, robust estimates of the size composition of the catch and of the harvest strategy indicators. The high variability in the minimum sampling level between indicators, years, strata, and with the approach used (combined data versus strata-specific), renders it difficult to prescribe a fixed level of required sampling in each stratum. A constant sampling regime across strata may be obtained by prescribing that the largest of the minimum required samples be applied to all strata. However, the temporally dynamic nature of the fishery would require that the minimum sampling levels be re-evaluated when the strata utilised show significant change between years. Moreover, even with a constant sampling regime within each stratum, it would be difficult in a logistical/practical sense to monitor and ensure the minimum samples are obtained from each strata, especially since strata are location and season-specific (and set depths may vary within a trip making it impossible to distinguish the set depth at which a fish was caught), and fished by different vessels possibly operating out of different ports. Strata showing similar absolute indicator values and mean sampling requirements may be combined to reduce the required sampling effort, but this does not diminish the practical issue of monitoring the cumulative level of sampling from each.

Provided that adequate observer data are obtained from each stratum, the "combined" approach of randomly sampling from all trips within a year provides reasonably robust estimates of size composition and harvest strategy indicators. However, this requires that the trips sampled are randomly chosen across all trips taken within a year, so that the sample of trips is inherently weighted according to the most frequently visited strata. In practice and when sampling in real time, this may be difficult to implement without bias. If, however, operators are not willing to cover close to 100 % of their trips into the future, the combined or strata-specific, (number of trips) x (number of fish per trip) matrix approaches provide a comprehensive means to evaluate the minimum level of sampling required to ensure robust ongoing sampling.

Moreover, the above approaches illustrate the nature of the trade-offs between number of trips and numbers of fish measured per trip in order to fulfil the minimum sampling requirement of a CV value < 20 % (and ideally, a < 1 % change in MWCV for an increase in 20 in the number of fish in the sample). That is, various sampling combinations above the specified minimum will yield acceptably low CV values and thus confer flexibility in terms of how the minimum sampling requirement is achieved. However, the results consistently showed that, in order to obtain a the most representative size distribution and robust, reliable harvest strategy indicators, it is clearly preferable (in terms of minimizing the CV values, the indicators of overall size composition and the change in MWCV) to sample a low number of fish across more trips, than to sample a high number of fish across fewer trips.

The simulation results based on 2005 and 2006 data indicate that the most reliable and robust harvest strategy indicator values and size composition estimates are obtained when at least 15 randomly selected albacore per trip are individually measured for at least 90 % of trips. The results also showed that it was important to measure individual fish as opposed to taking a mean weight for the catch on every trip, and that sampling trips only from vessels still fishing in 2007 yielded more consistent absolute mean indicator values across different sampling levels.

Practically, it is acknowledged that measuring more than 20 fish per trip across every trip is too demanding and time consuming to form an ongoing sustainable sampling regime. The suggested level of 15 fish per trip hopefully represents a practically achievable value while delivering highly robust information. It is important to ensure that the individual fish are a random sample of the albacore catch taken from the trip,

15. Appendix D: Results of the academic simulation exercise to determine the minimum sampling regime in terms of number of trips and number of fish to measure per trip.

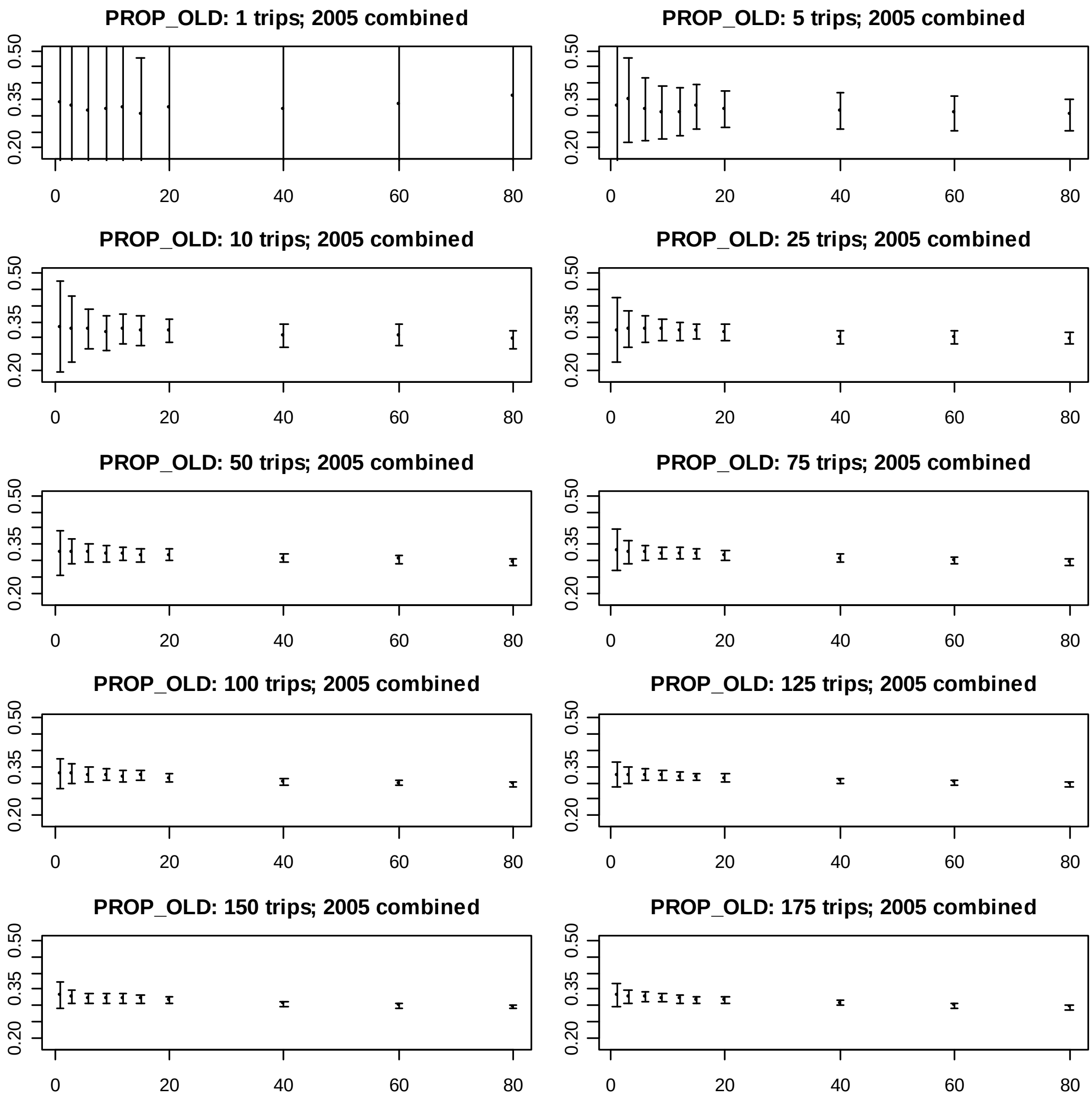

Figure D1: Mean proportion of "old" albacore (± 1 standard deviation) versus number of fish measured per trip, for each number of trips considered, across the 100 realisations for the 2005 "combined" (i.e. strata not considered) simulations.

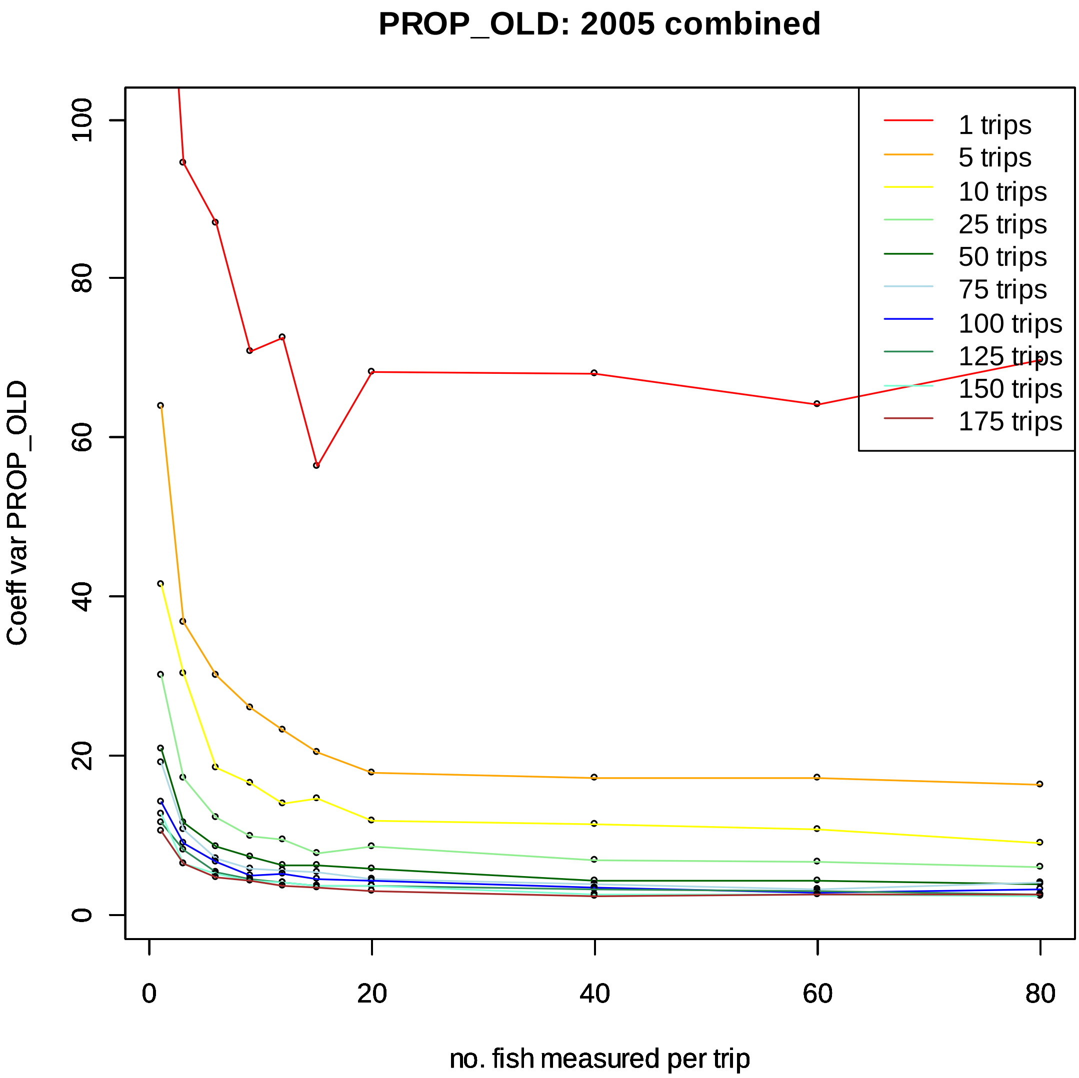

Figure D2: The coefficient of variation about the mean proportion of "old" albacore, for each number of fish measured per trip/number of trips combination, for the 2005 "combined" (i.e. strata not considered) simulations.

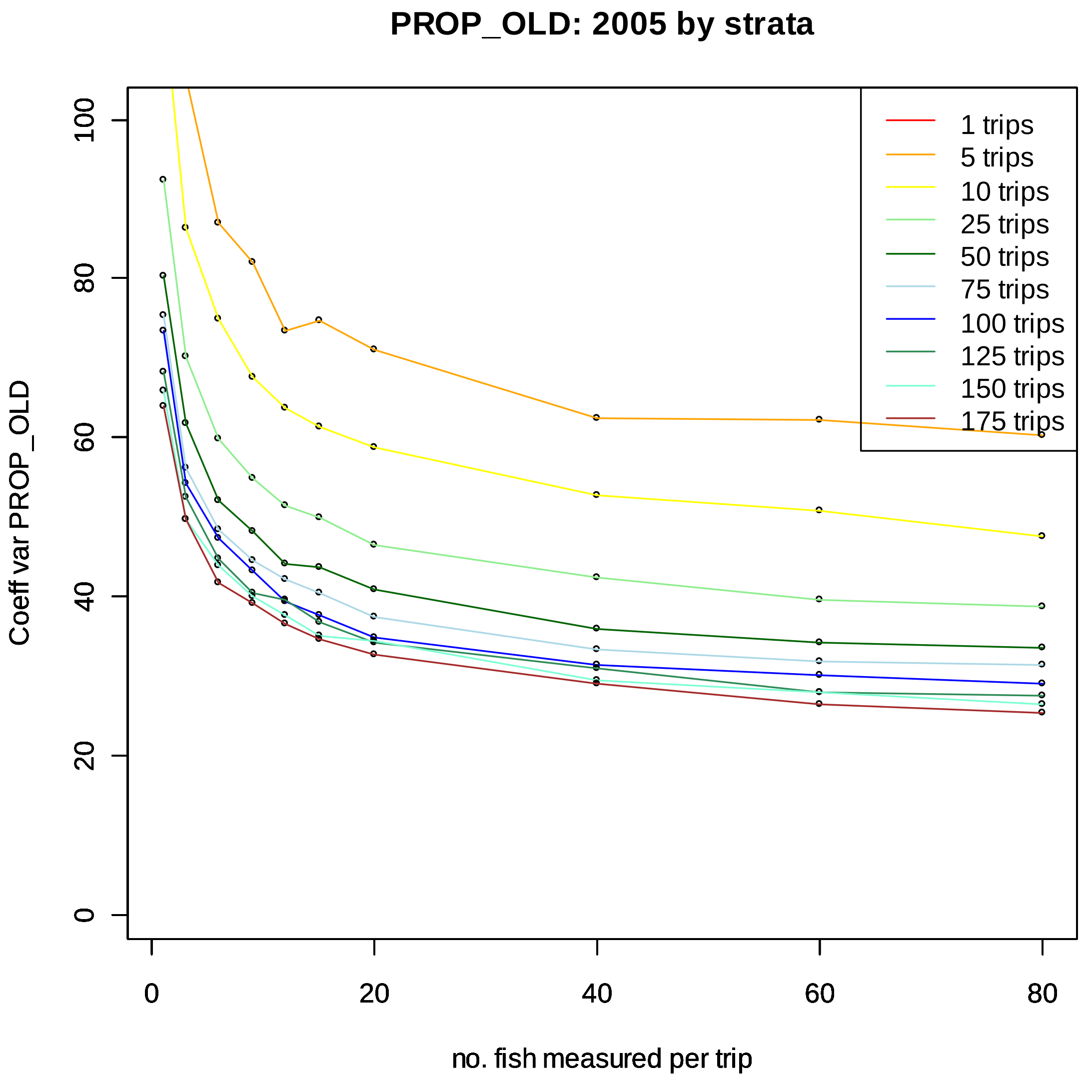

Figure D3: The coefficient of variation about the mean proportion of "old" albacore, for each number of fish measured per trip/number of trips combination, for the 2005 strata-specific simulations.

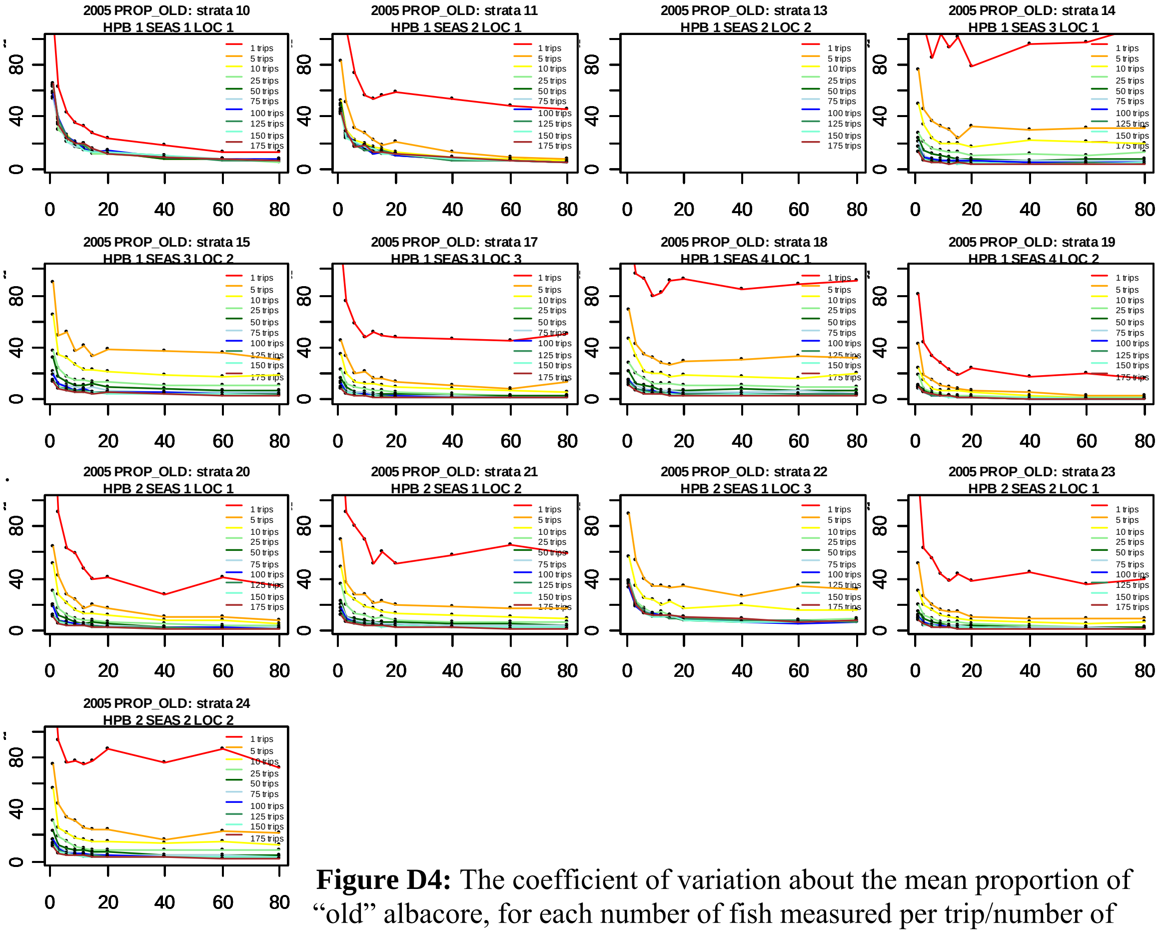

Figure D4: The coefficient of variation about the mean proportion of "old" albacore, for each number of fish measured per trip/number of trips combination, for each stratum, for the 2005 strata-specific simulations.

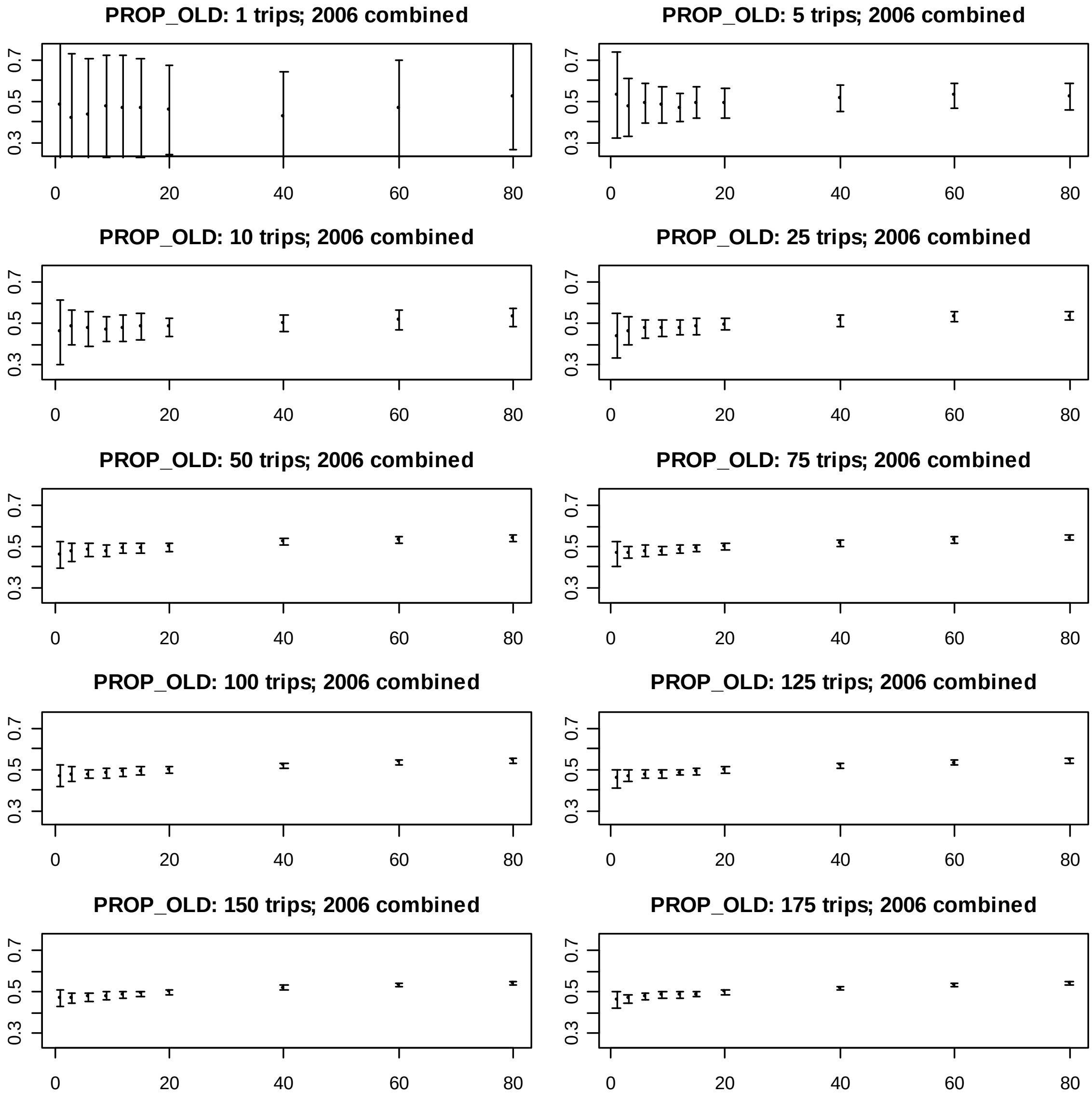

Figure D5: Mean proportion of "old" albacore (± 1 standard deviation) versus number of fish measured per trip, for each number of trips considered, across the 100 realisations for the 2006 "combined" (i.e. strata not considered) simulations.

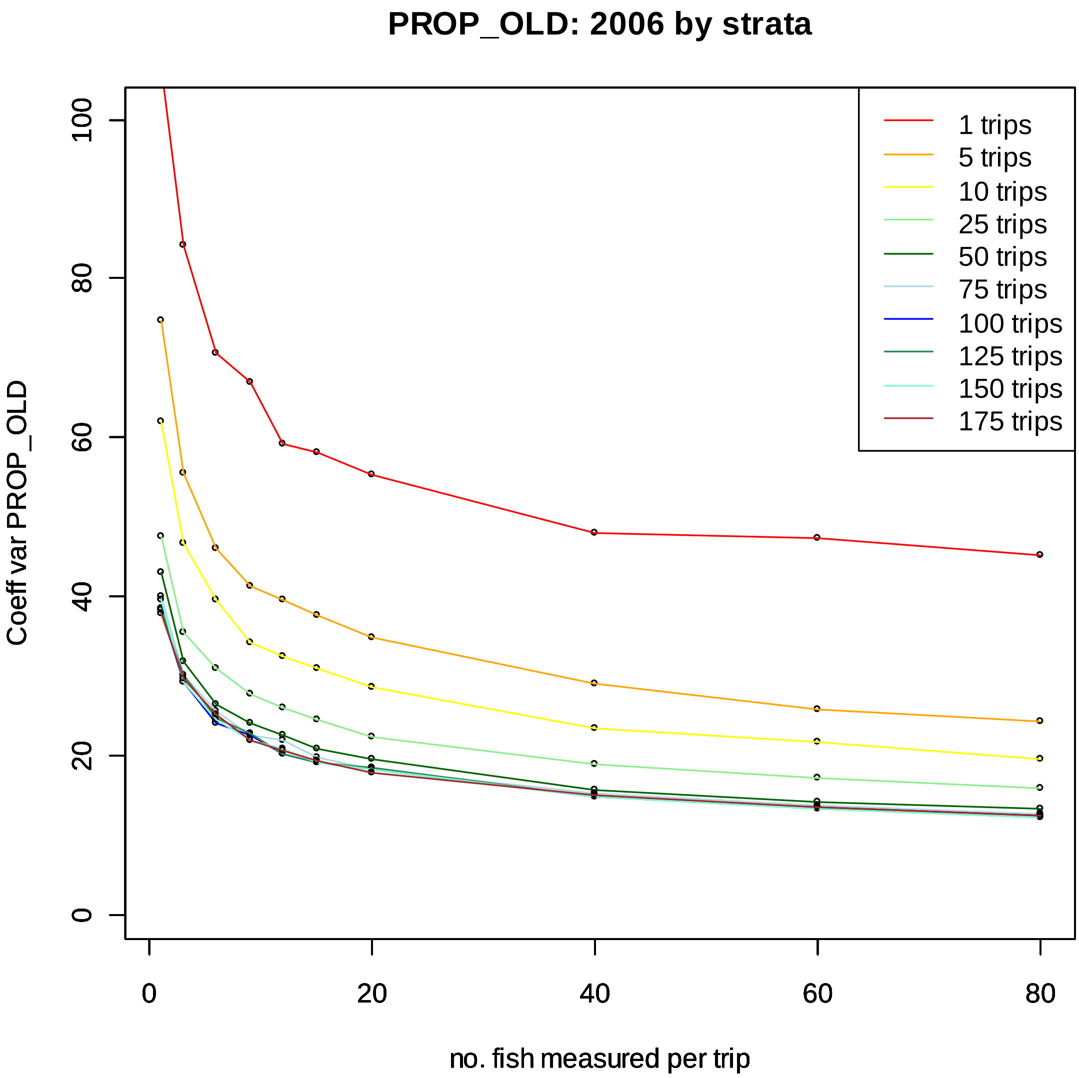

Figure D6: The coefficient of variation about the mean proportion of "old" albacore, for each number of fish measured per trip/number of trips combination, for the 2006 "combined" (i.e. strata not considered) simulations.

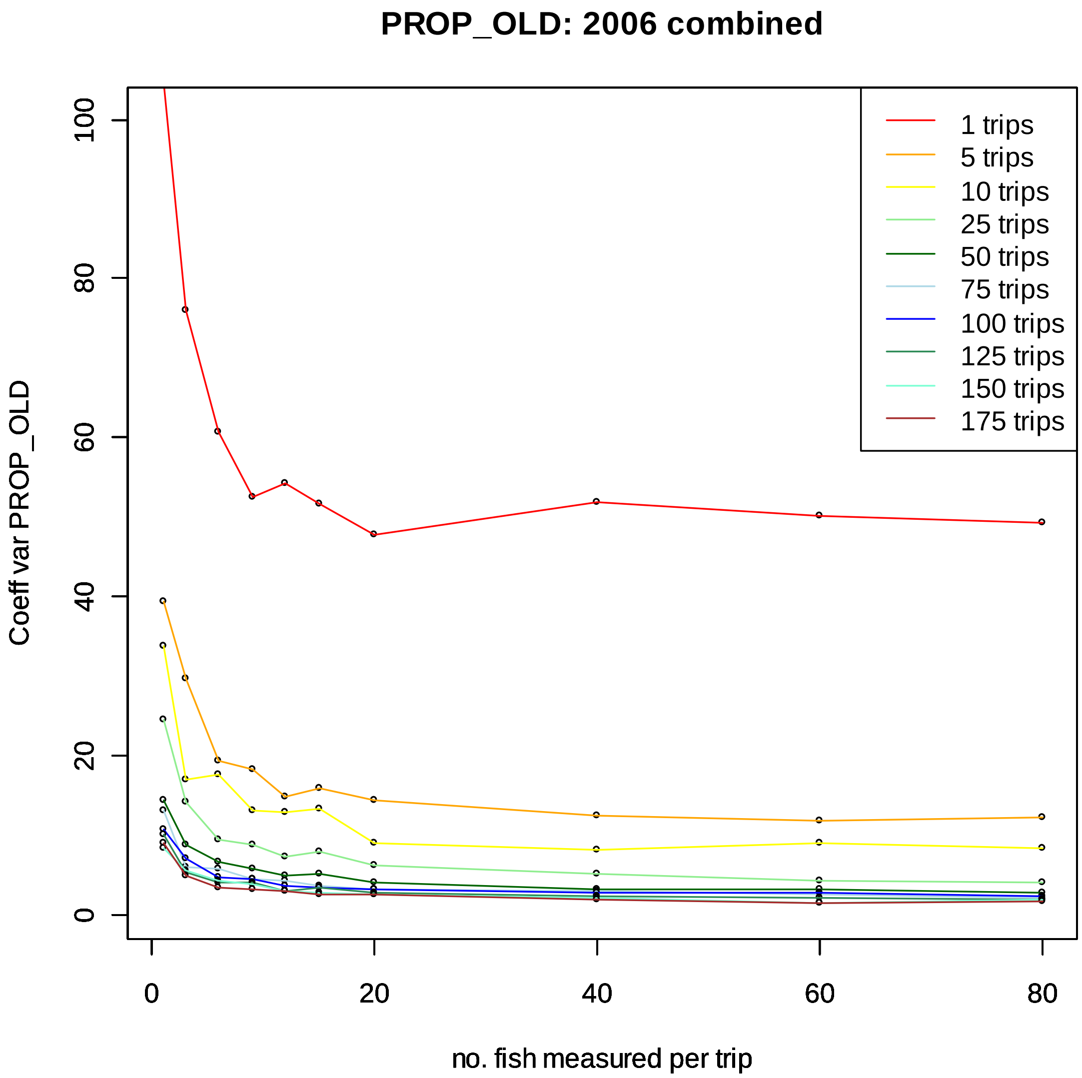

Figure D7: The coefficient of variation about the mean proportion of "old" albacore, for each number of fish measured per trip/number of trips combination, for the 2006 strata-specific simulations.

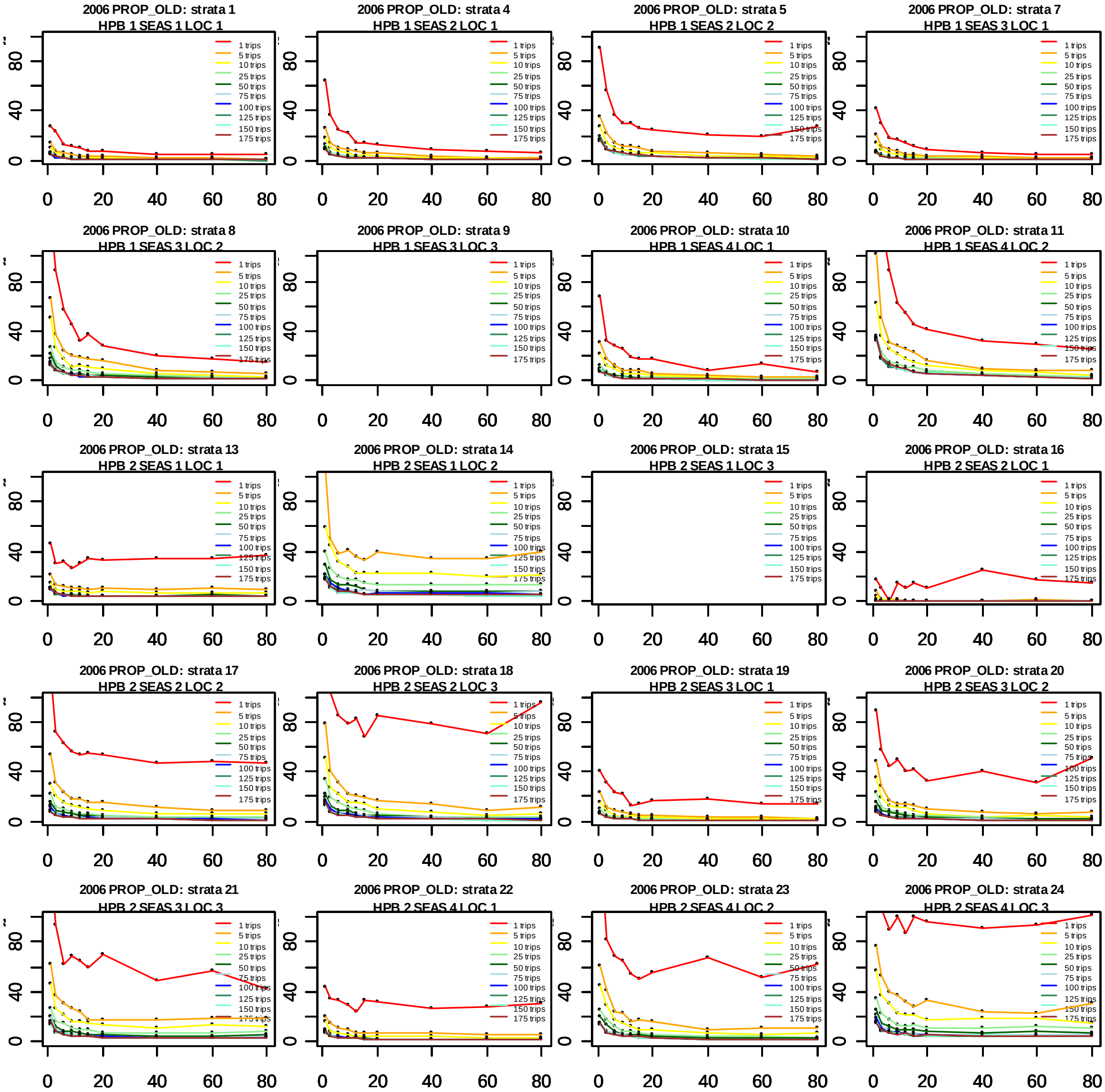

Figure D8: The coefficient of variation about the mean proportion of "old" albacore, for each number of fish measured per trip/number of trips combination, for each stratum, for the 2006 strata-specific simulations

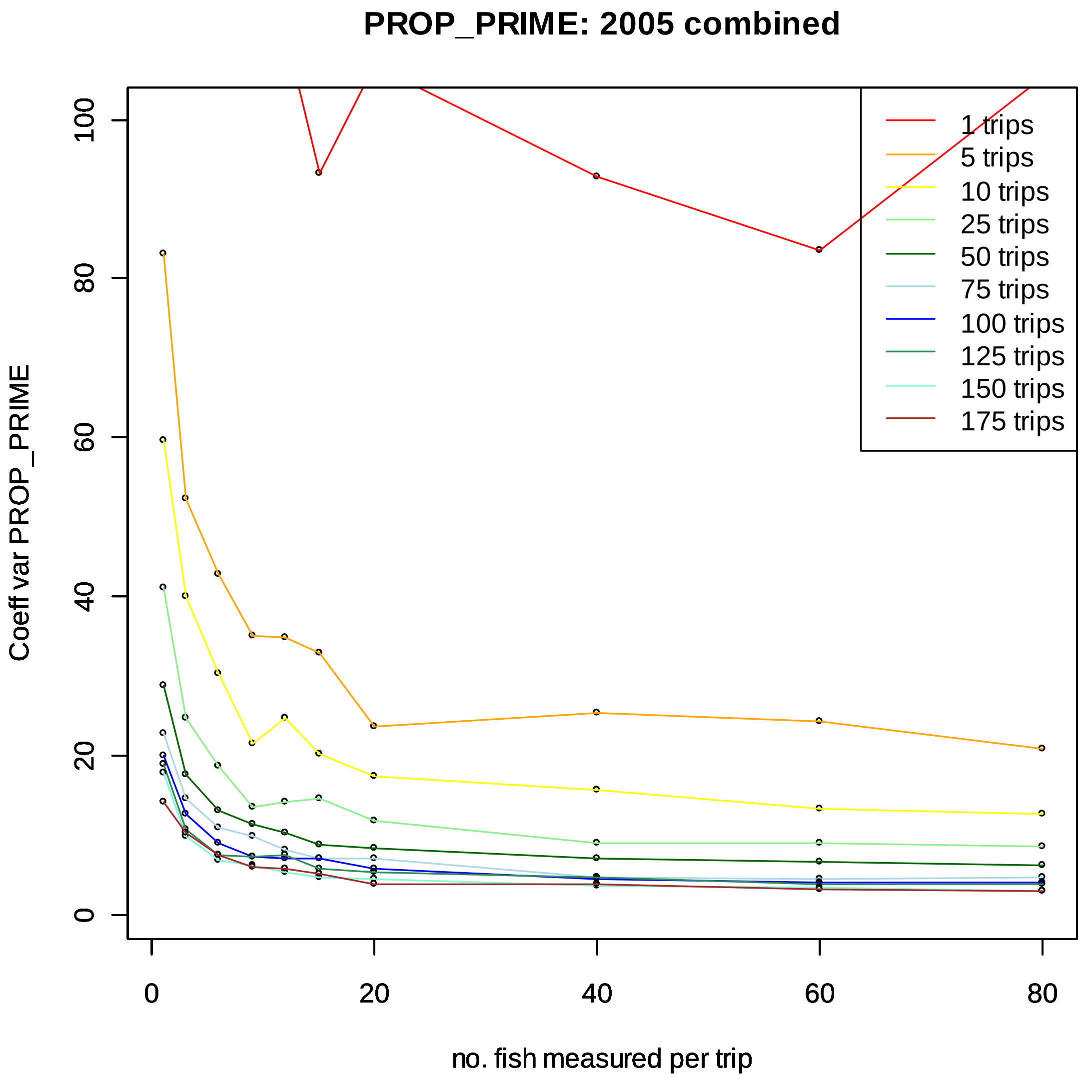

Figure D9: The coefficient of variation about the mean proportion of "prime sized" albacore, for each number of fish measured per trip/number of trips combination, for the 2005 "combined" (i.e. strata not considered) simulations.

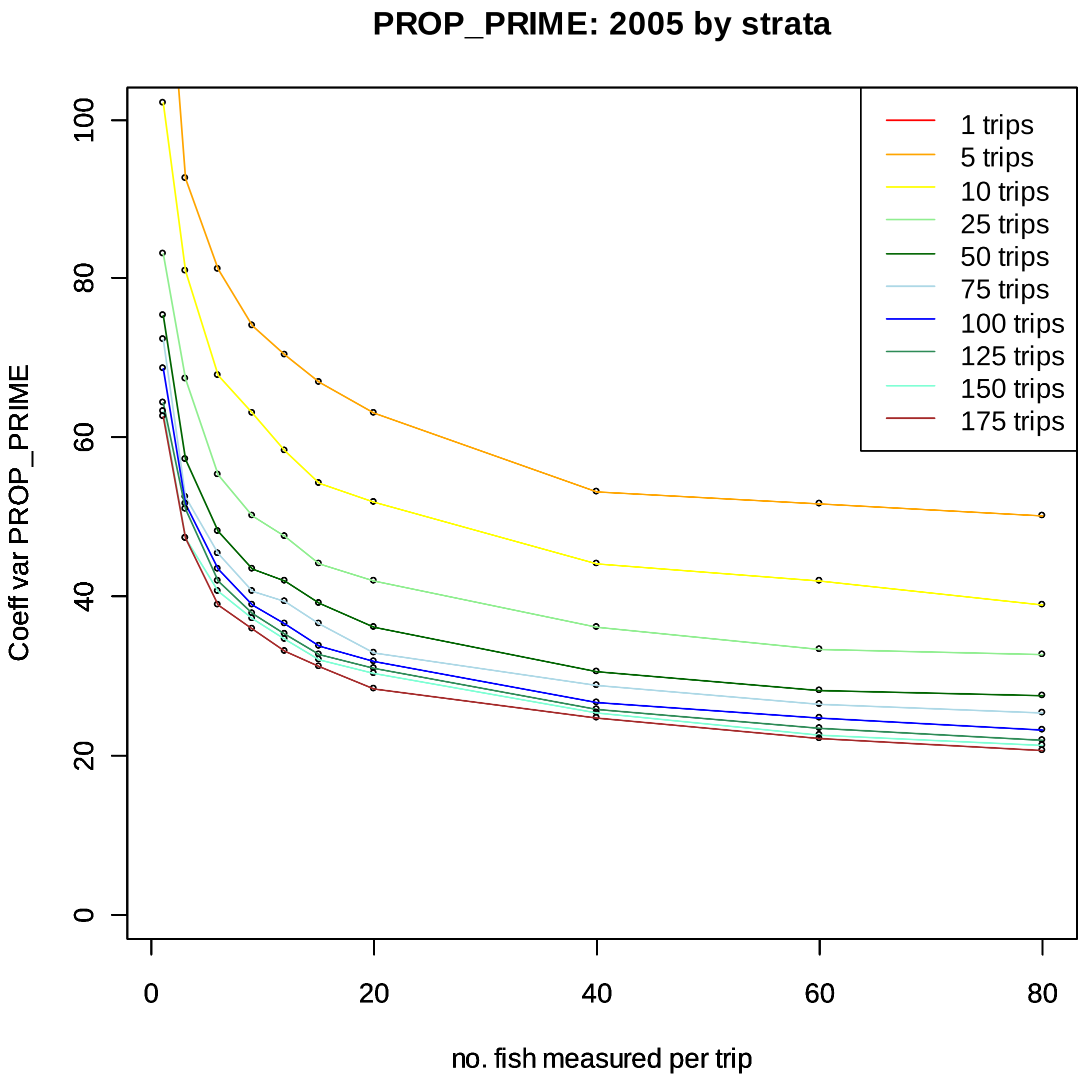

Figure D10: The coefficient of variation about the mean proportion of “prime sized” albacore, for each number of fish measured per trip/number of trips combination, for the 2005 strata-specific simulations.

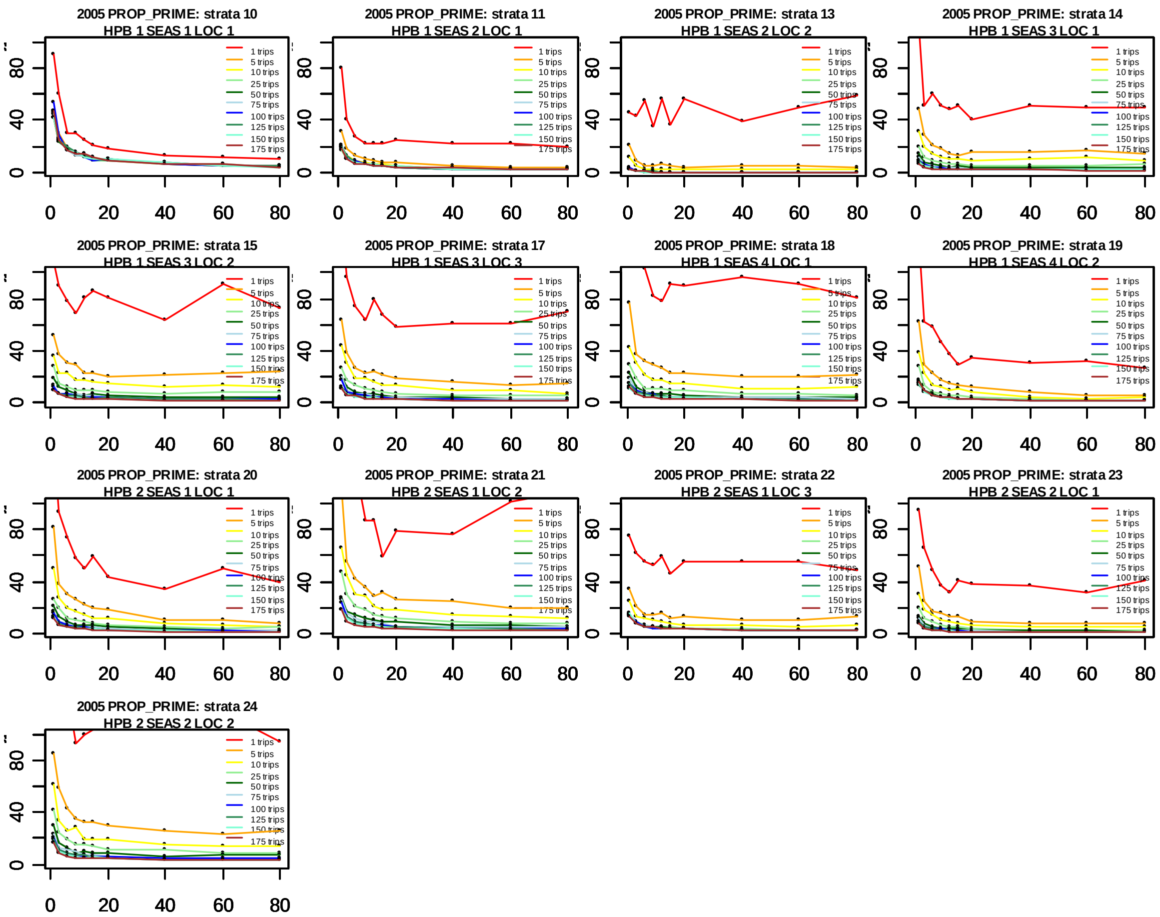

Figure D11: The coefficient of variation about the mean proportion of "prime sized" albacore, for each number of fish measured per trip/number of trips combination, for each stratum, for the 2005 strata-specific simulations

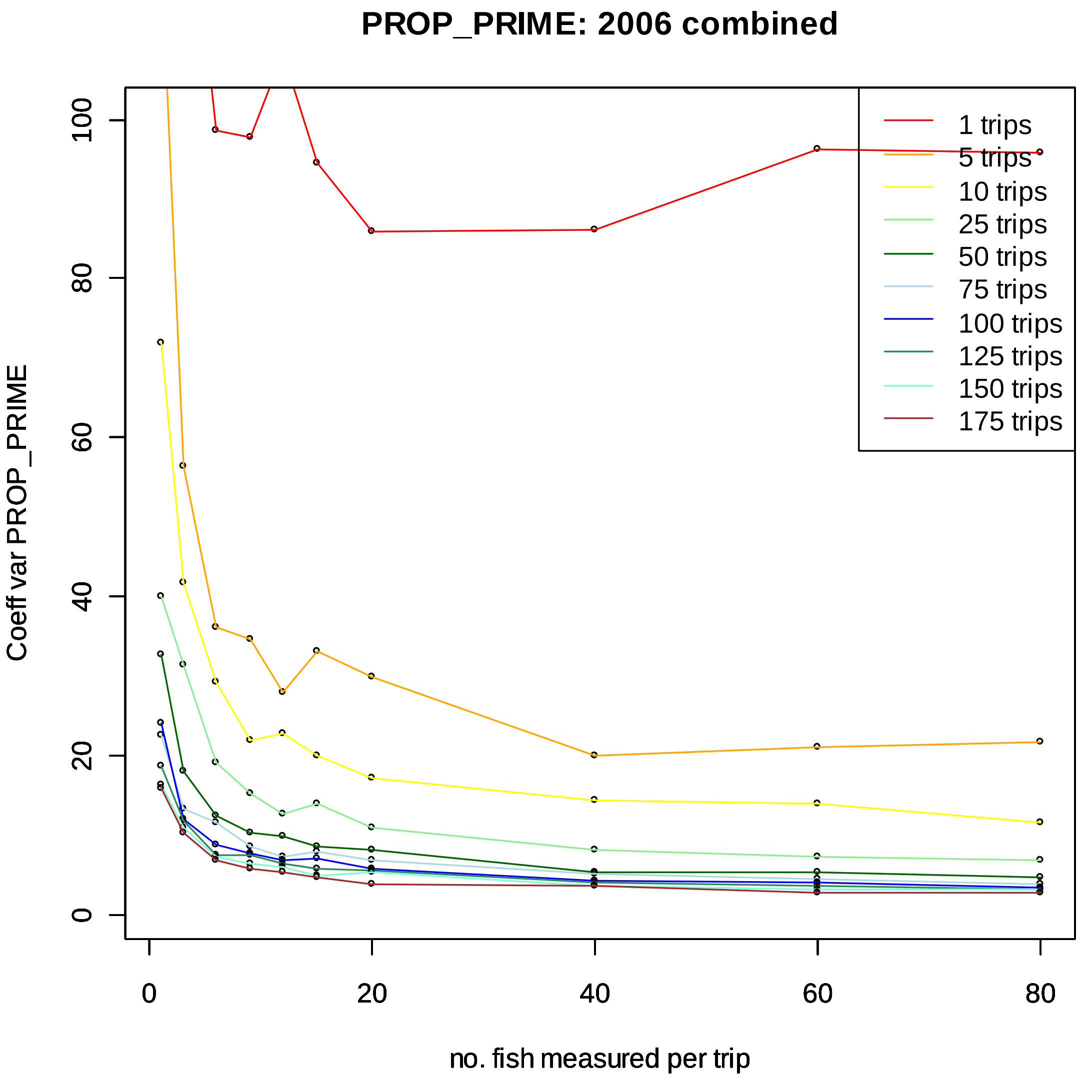

Figure D12: The coefficient of variation about the mean proportion of “prime sized” albacore, for each number of fish measured per trip/number of trips combination, for the 2006 “combined” (i.e. strata not considered) simulations.

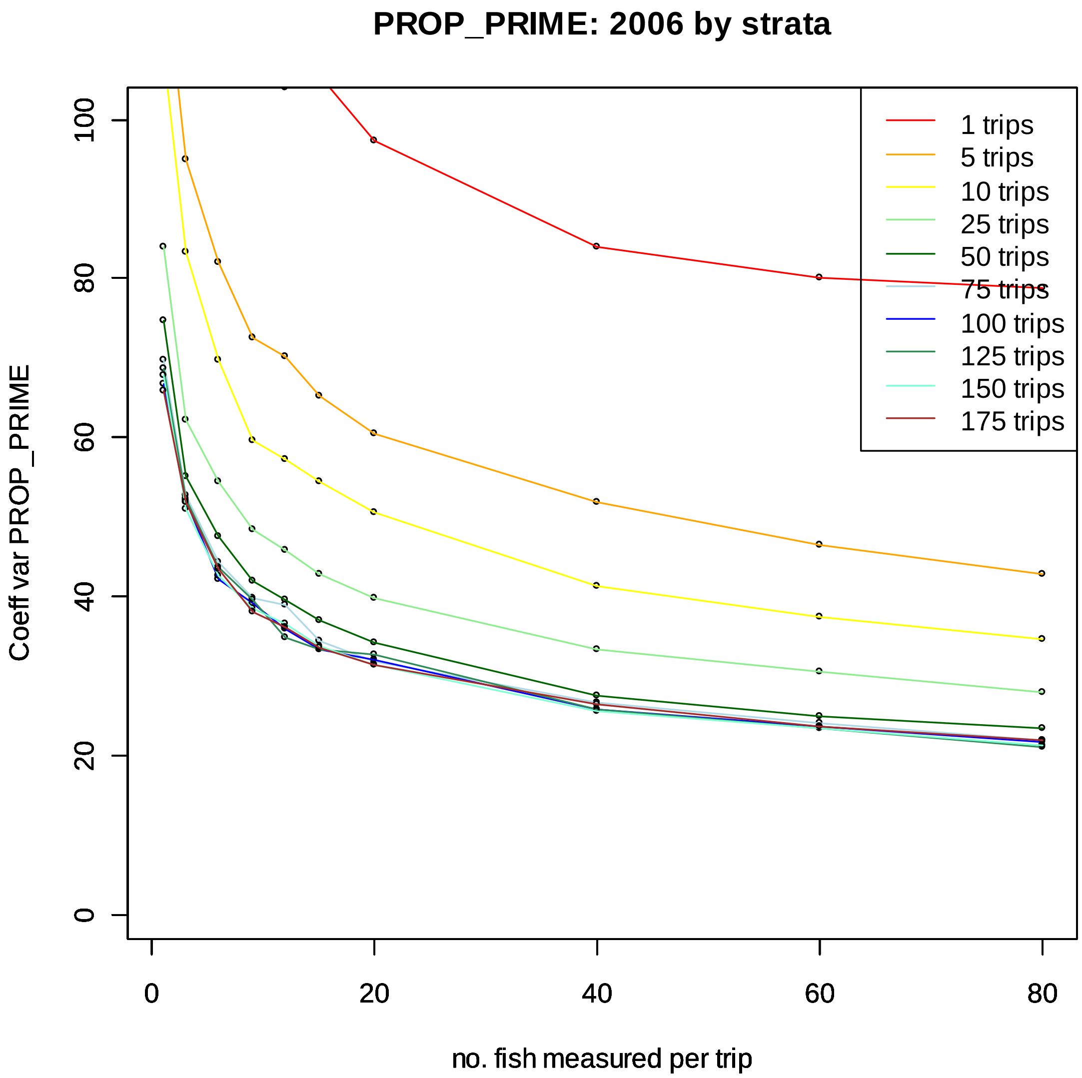

Figure D13: The coefficient of variation about the mean proportion of "prime sized" albacore, for each number of fish measured per trip/number of trips combination, for the 2006 strata-specific simulations.

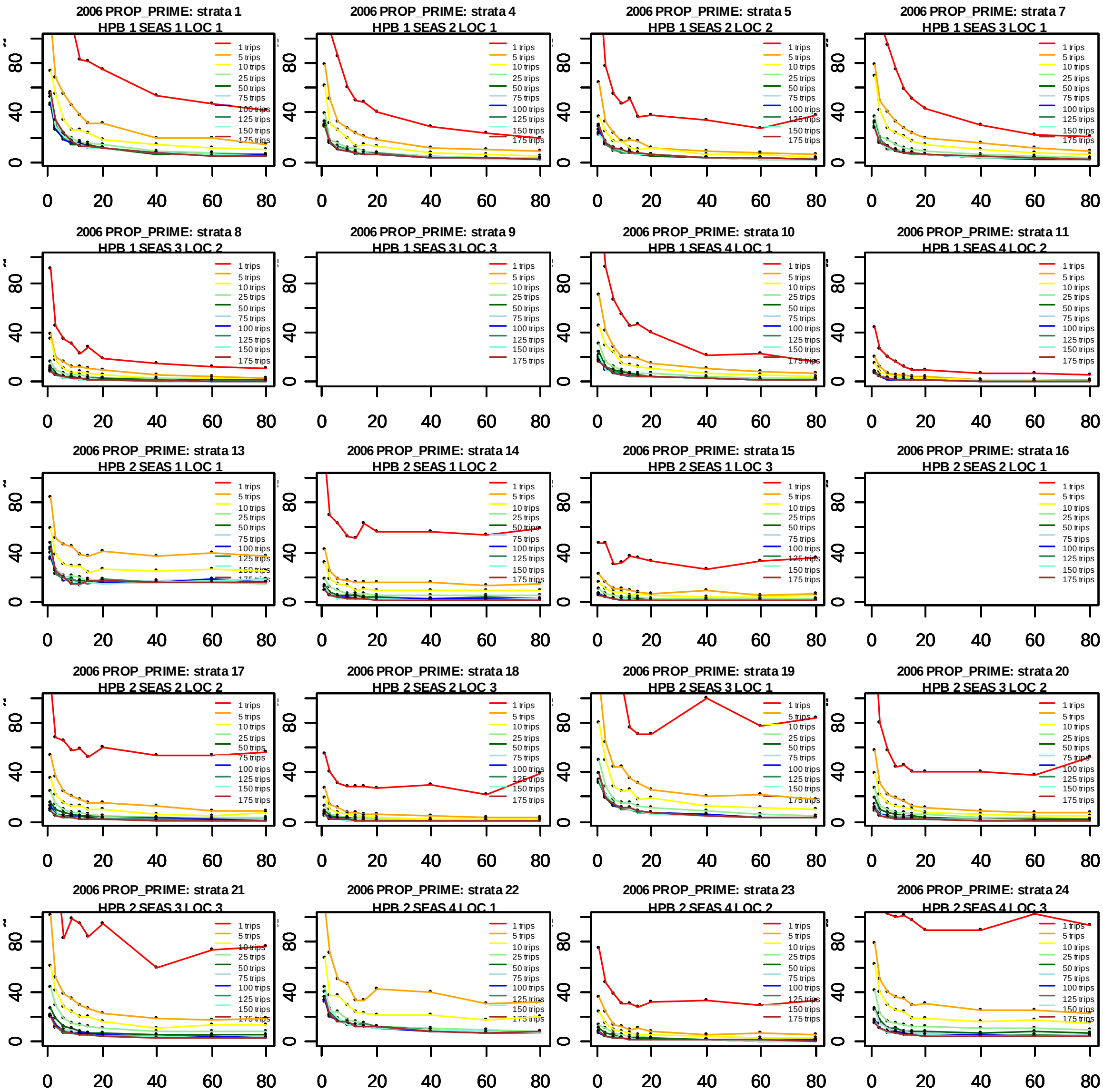

Figure D14: The coefficient of variation about the mean proportion of "prime sized" albacore, for each number of fish measured per trip/number of trips combination, for each stratum, for the 2006 strata-specific simulations

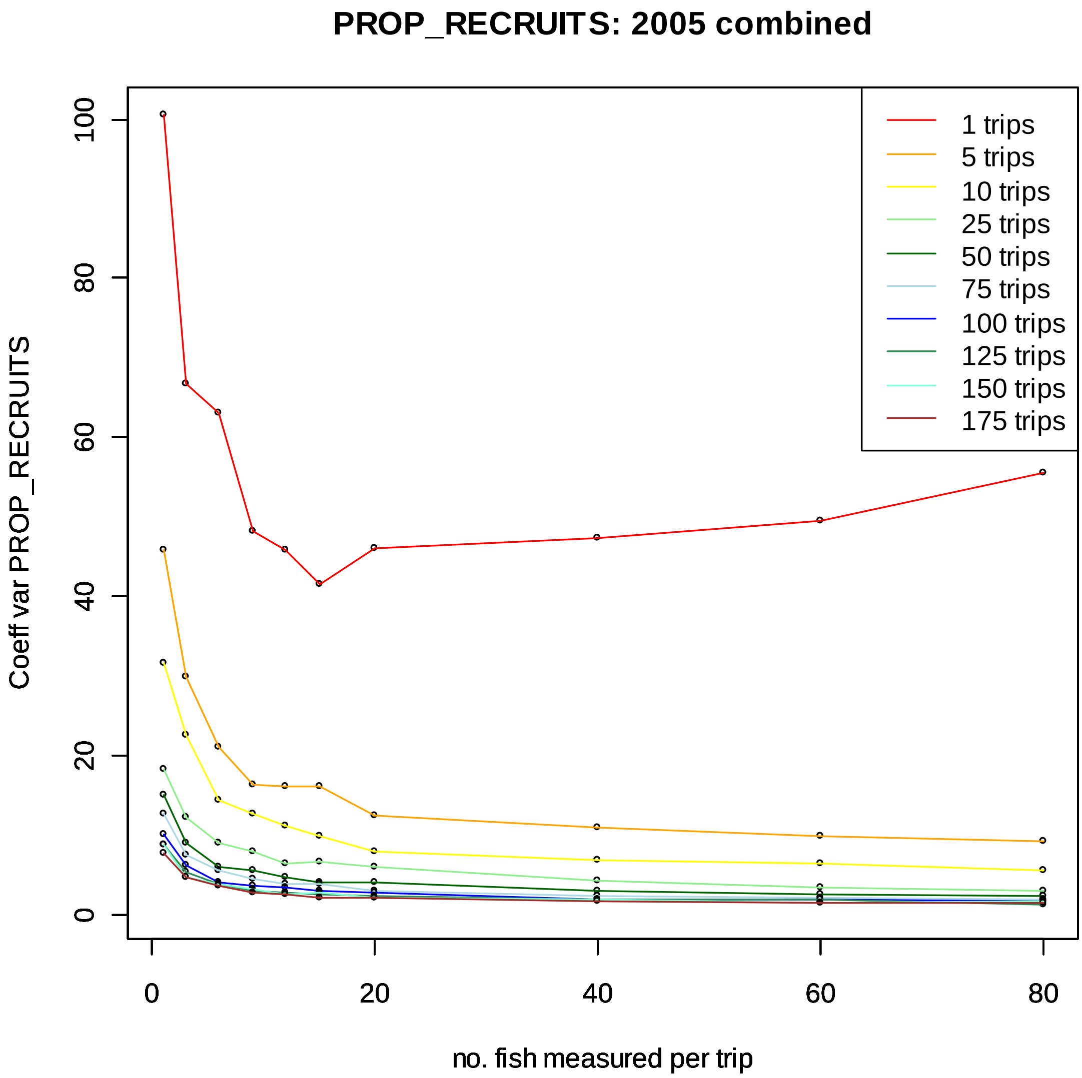

Figure D15: The coefficient of variation about the mean proportion of "recruit sized" albacore, for each number of fish measured per trip/number of trips combination, for the 2005 "combined" (i.e. strata not considered) simulations.

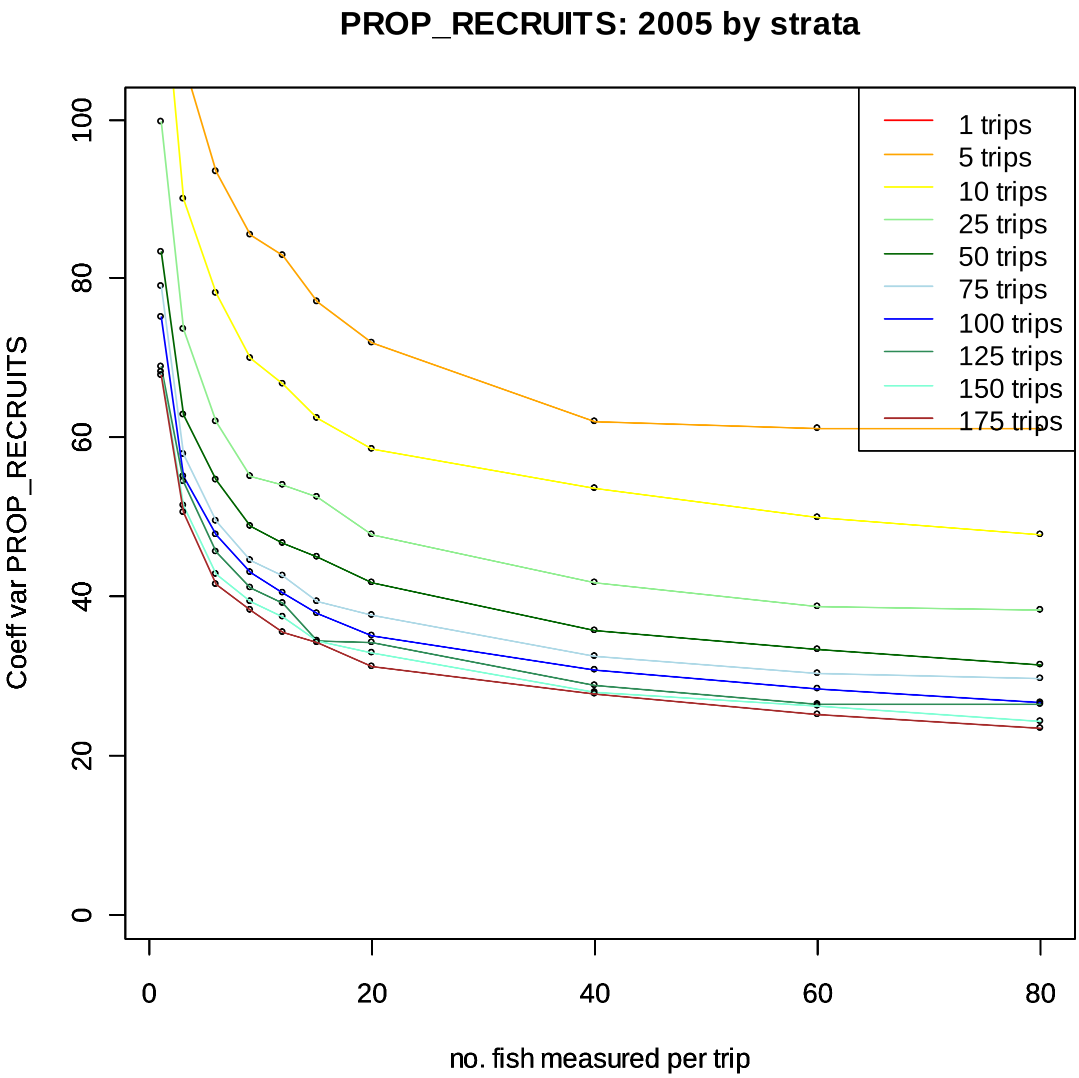

Figure D16: The coefficient of variation about the mean proportion of "recruit sized" albacore, for each number of fish measured per trip/number of trips combination, for the 2005 strata-specific simulations.

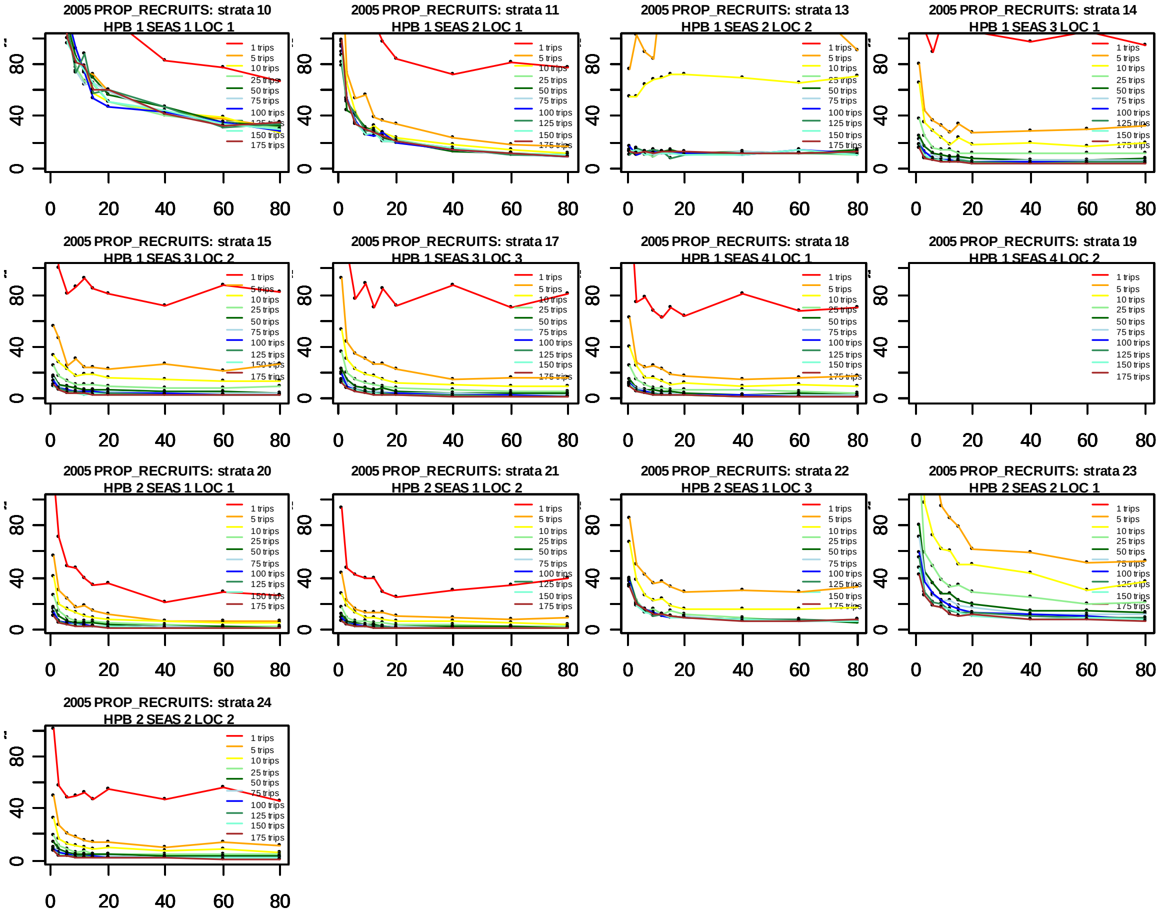

Figure D17: The coefficient of variation about the mean proportion of "recruit sized" albacore, for each number of fish measured per trip/number of trips combination, for each stratum, for the 2005 strata-specific simulations

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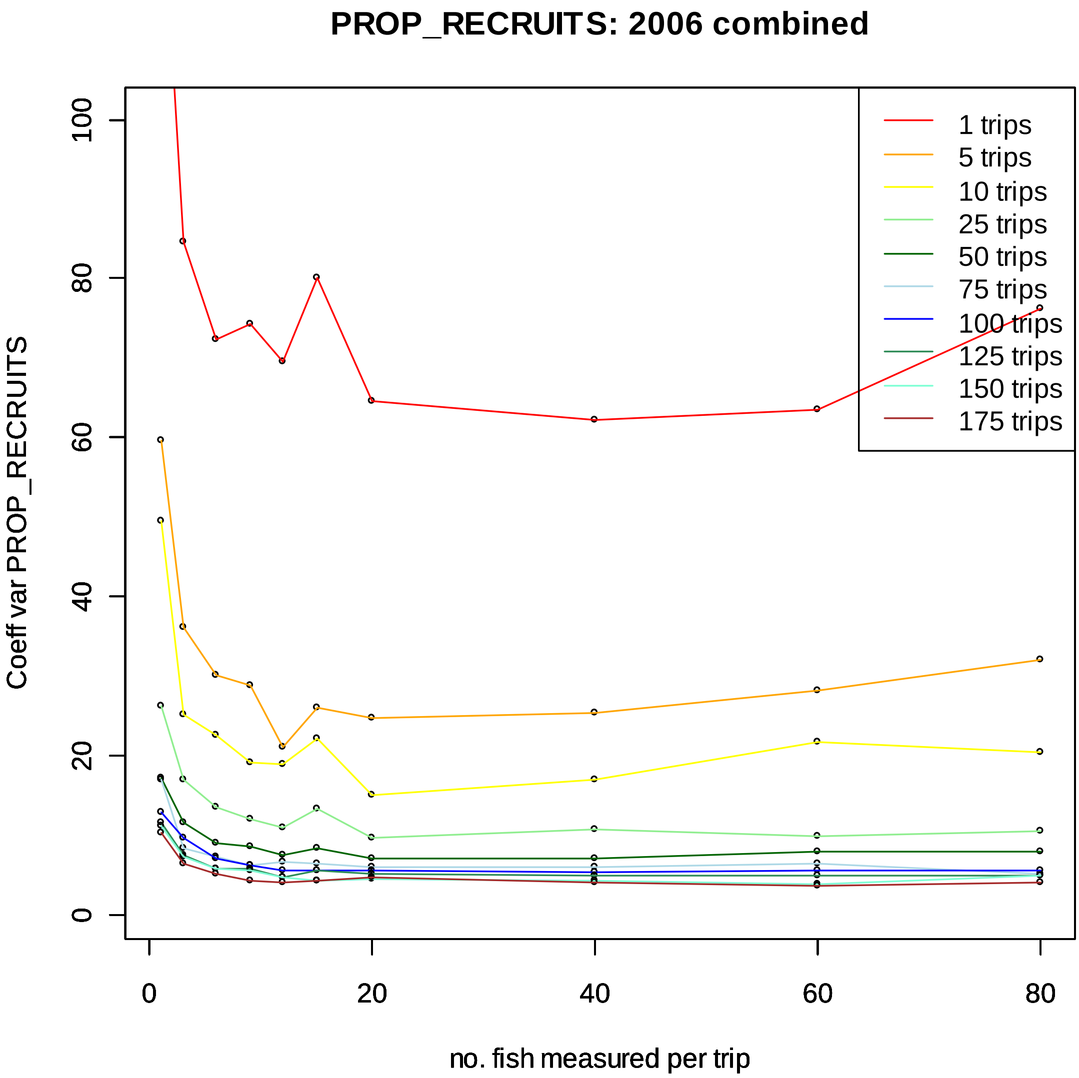

Figure D18: The coefficient of variation about the mean proportion of "recruit sized" albacore, for each number of fish measured per trip/number of trips combination, for the 2006 "combined" (i.e. strata not considered) simulations.

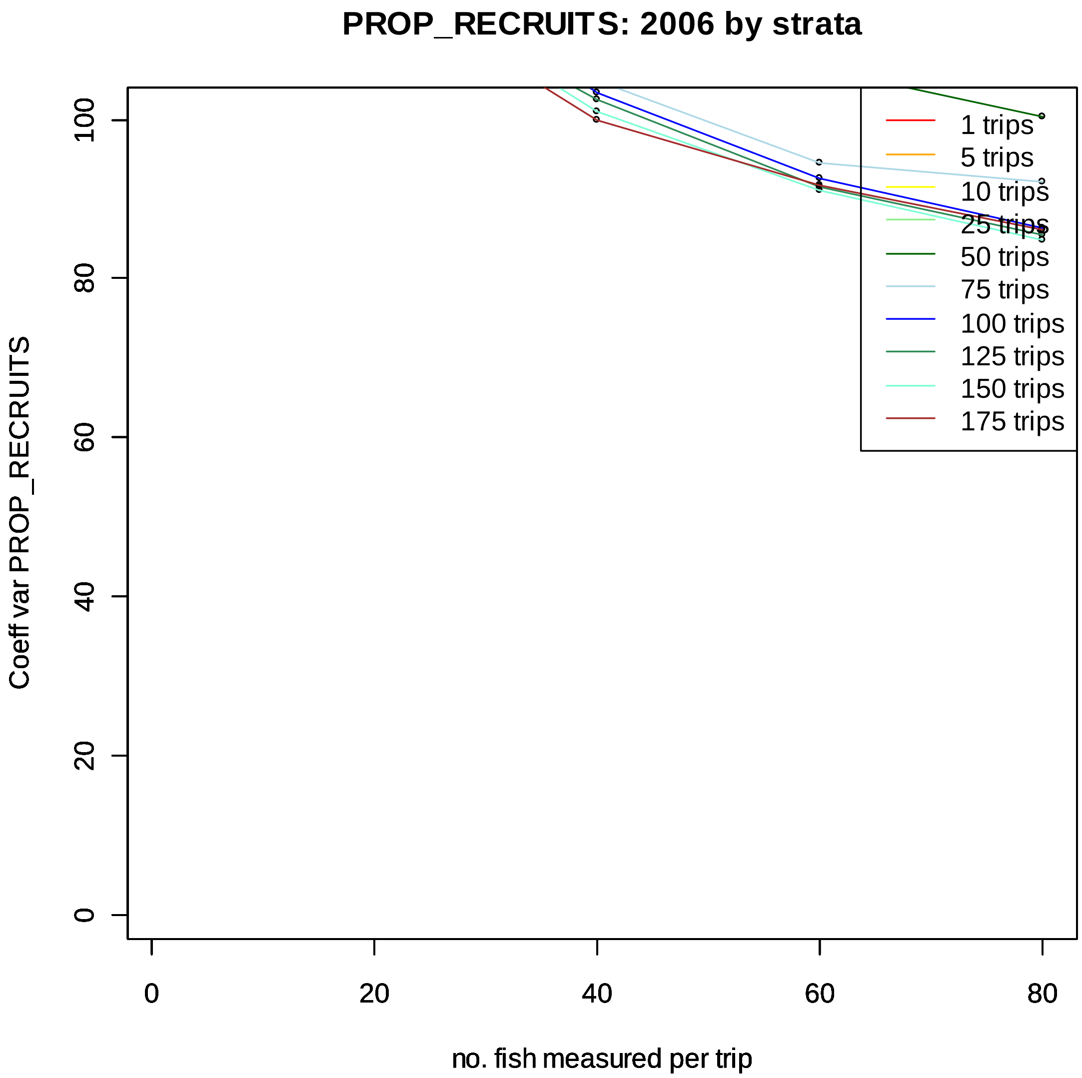

Figure D19: The coefficient of variation about the mean proportion of "recruit sized" albacore, for each number of fish measured per trip/number of trips combination, for the 2006 strata-specific simulations.

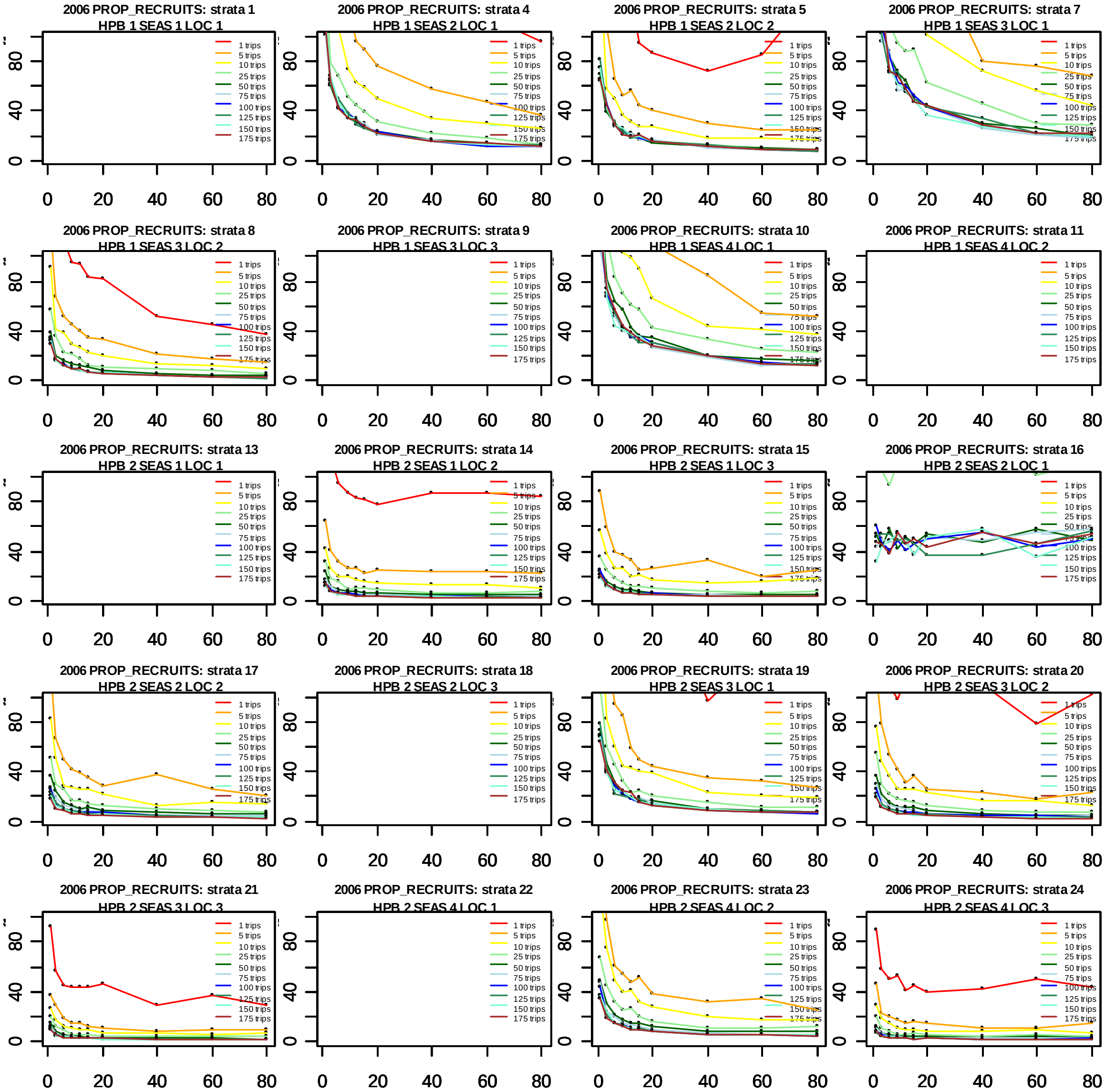

Figure D20: The coefficient of variation about the mean proportion of "recruit sized" albacore, for each number of fish measured per trip/number of trips combination, for each stratum, for the 2006 strata-specific simulations

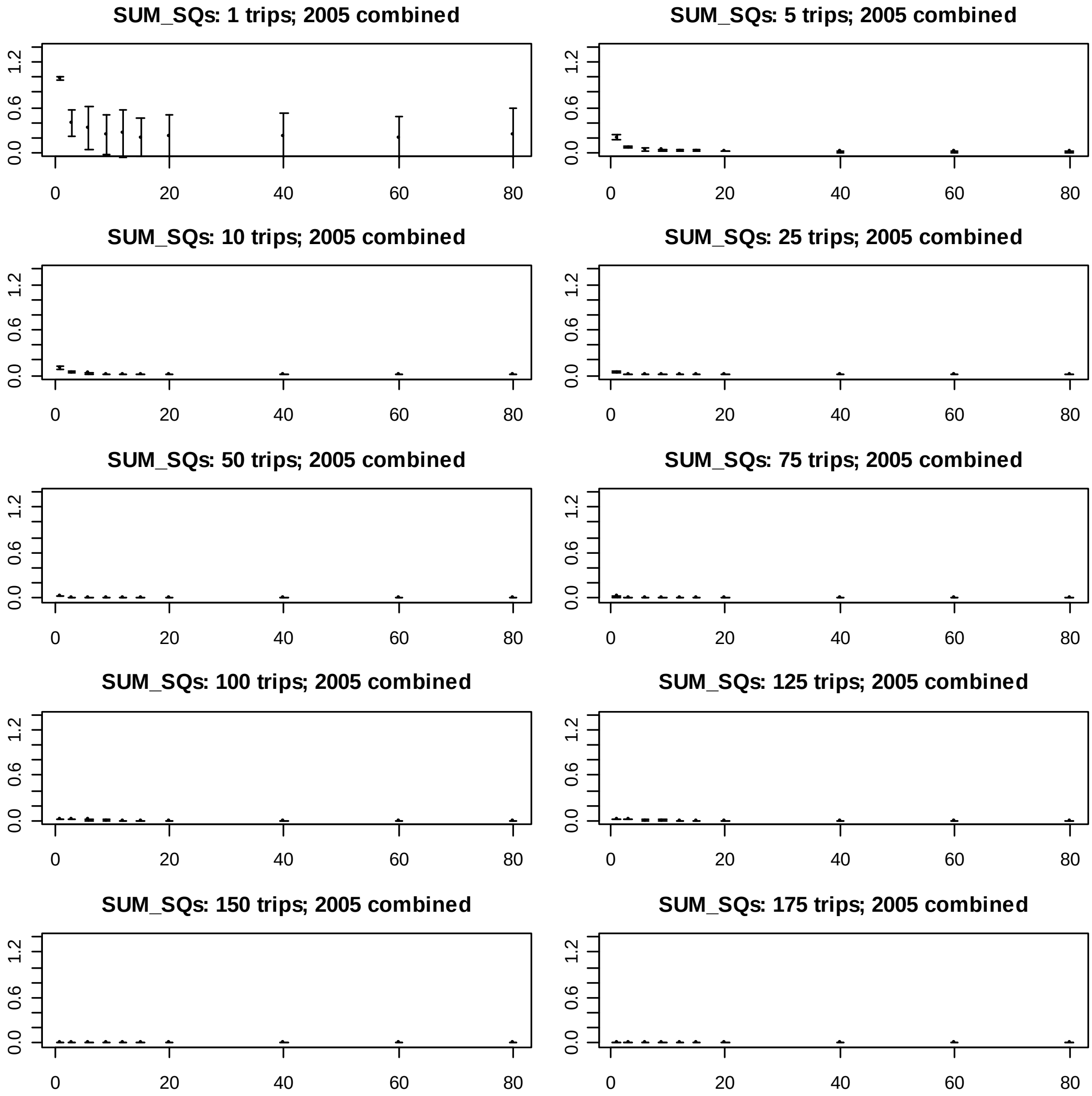

Figure D21: Mean sums of squared differences for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, for each number of trips considered, across the 100 realisations for the 2005 "combined" (i.e. strata not considered) simulations.

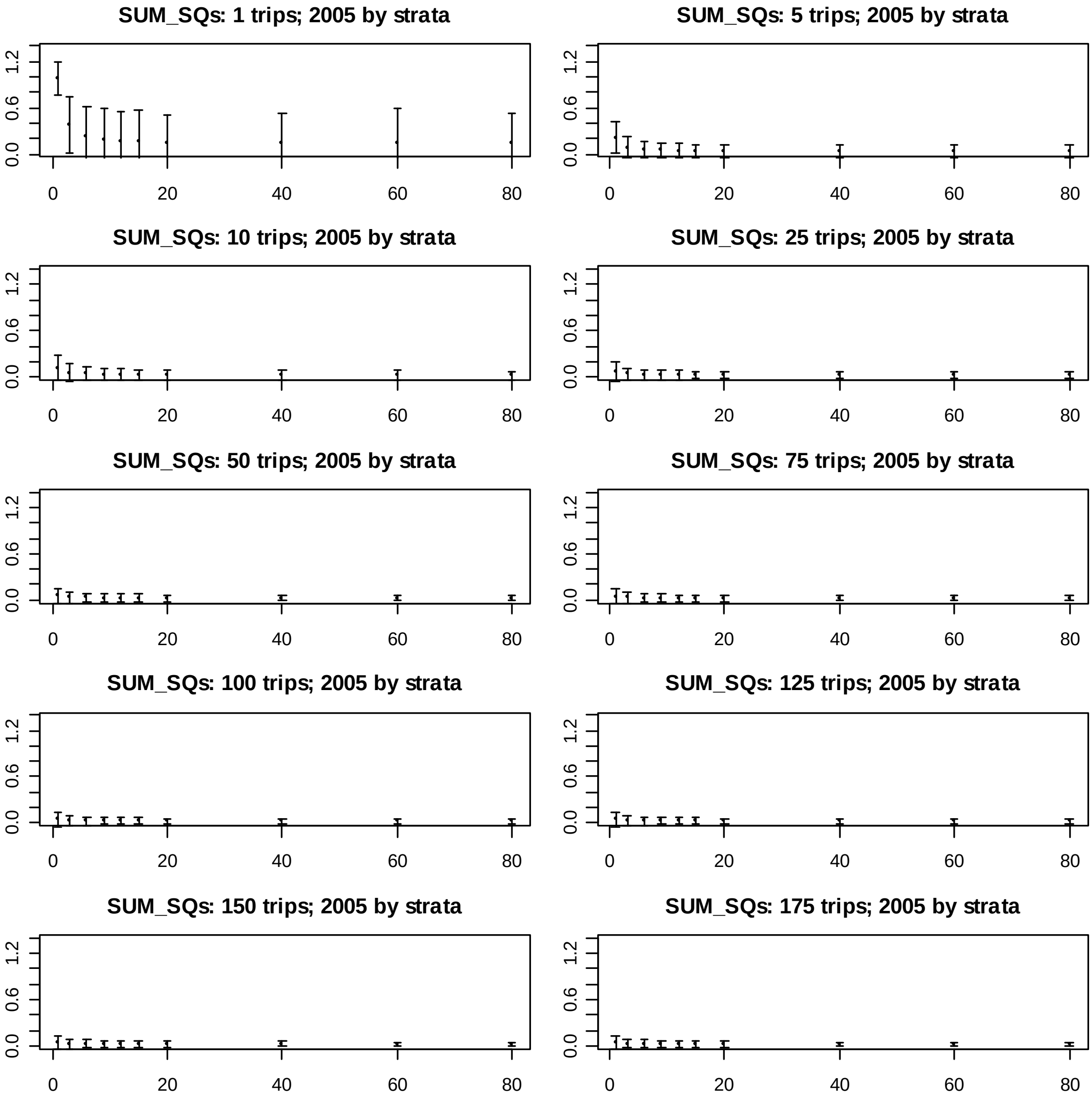

Figure D22: Overall (catch) weighted mean sums of squared differences for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, for each number of trips considered, across the 100 realisations for the 2005 strata-specific simulations.

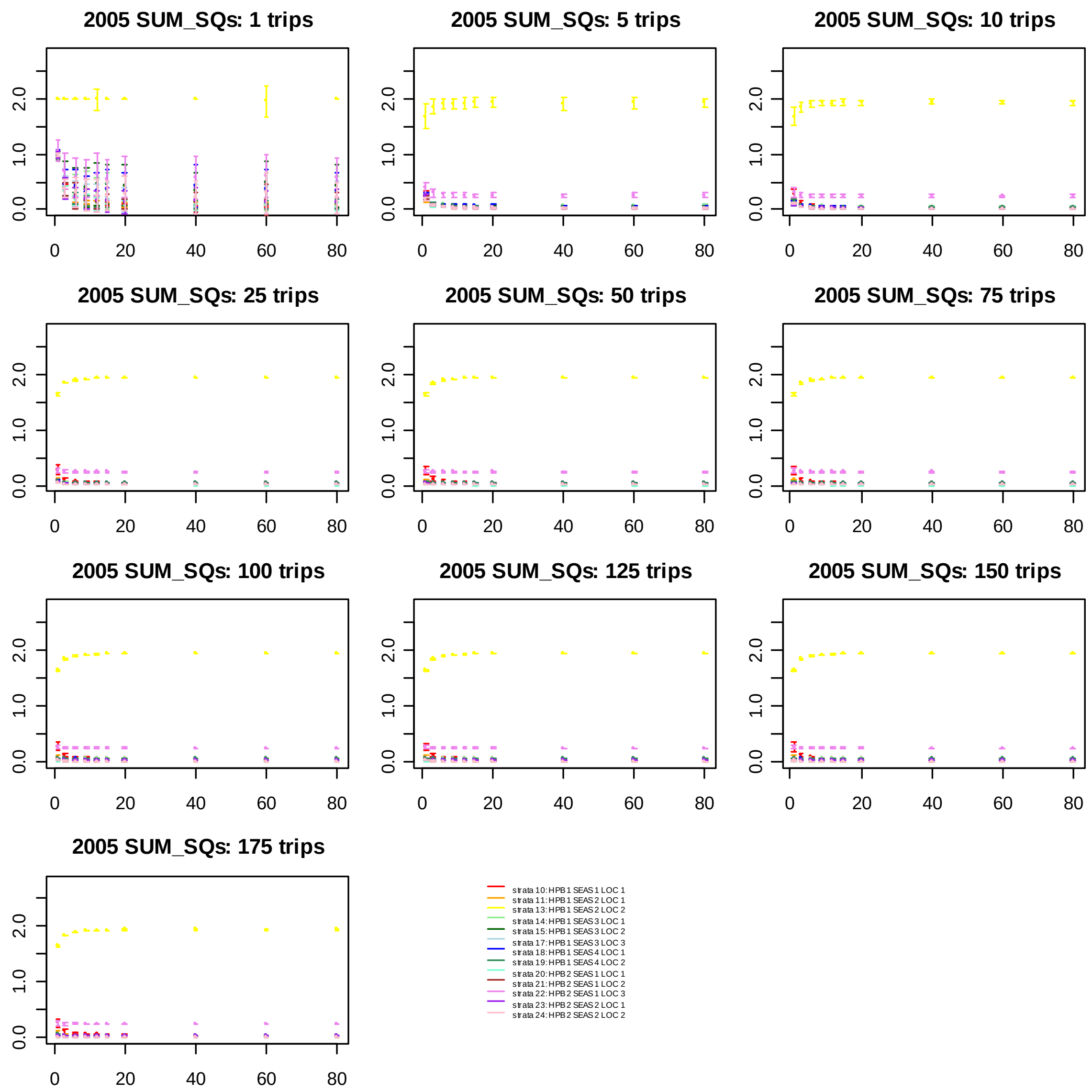

Figure D23: Mean sums of squared differences for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, for each number of trips considered, for each stratum, across the 100 realisations for the 2005 strata-specific simulations.

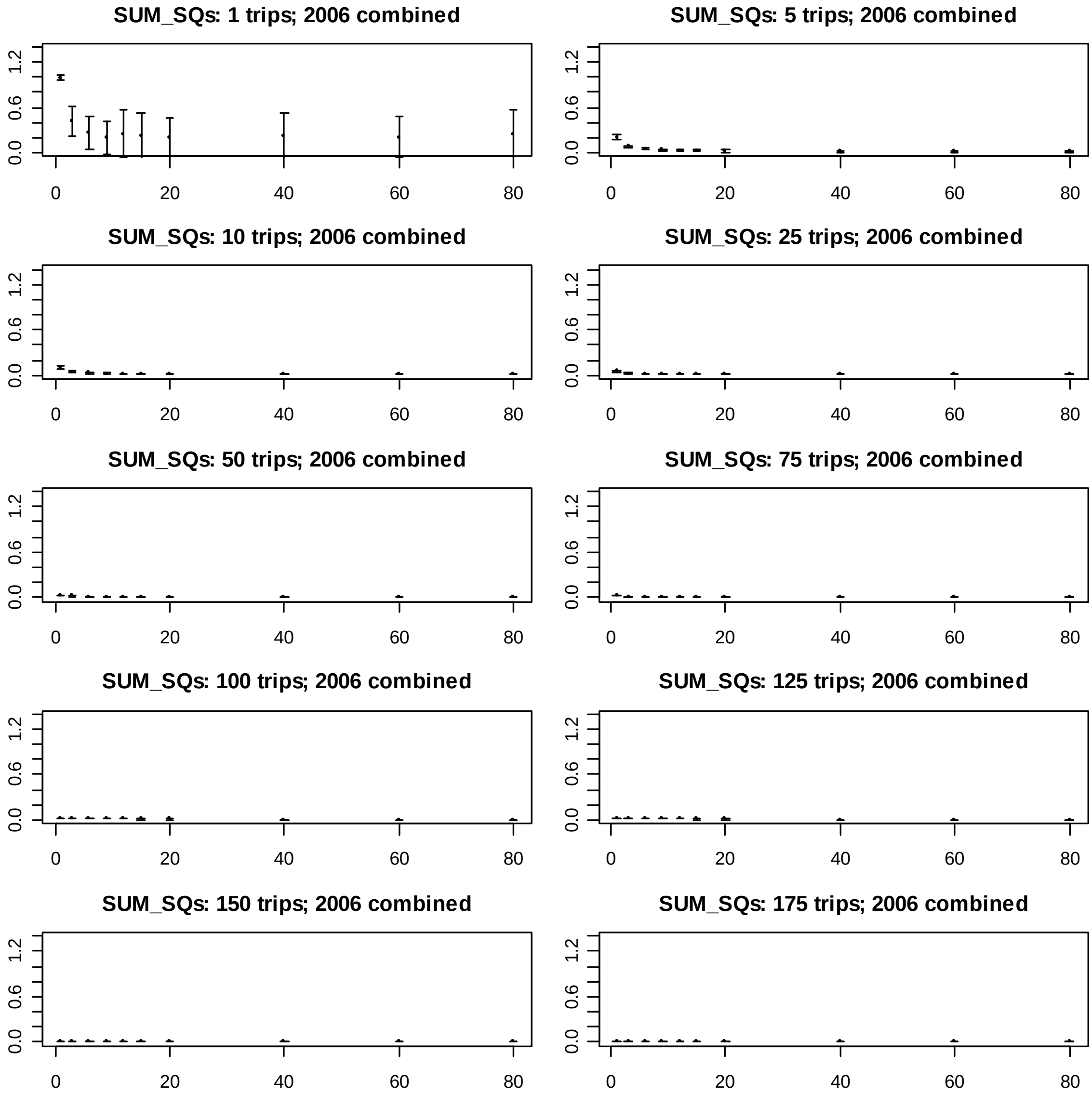

Figure D24: Mean sums of squared differences for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, for each number of trips considered, across the 100 realisations for the 2006 “combined” (i.e. strata not considered) simulations.

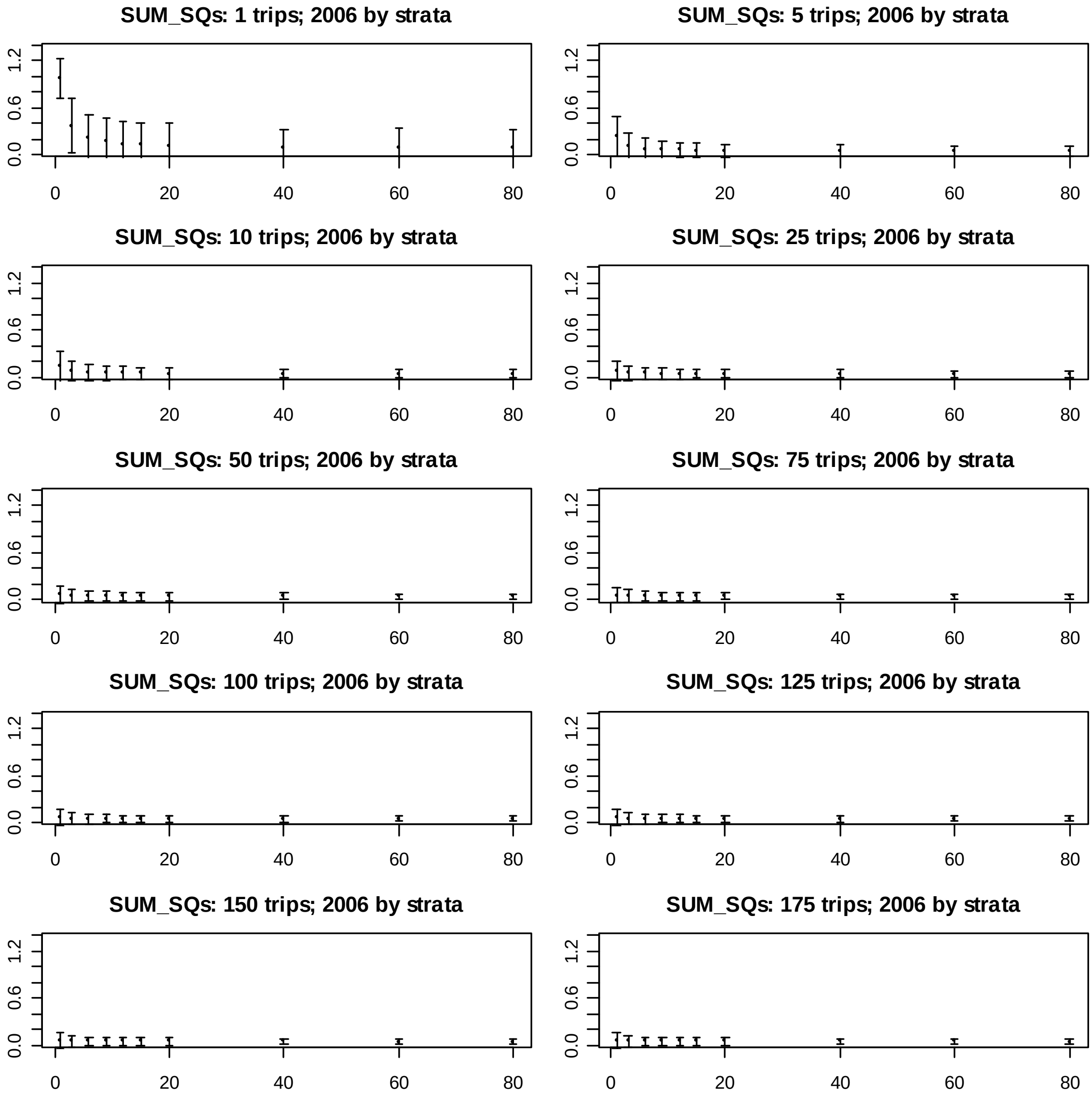

Figure D25: Overall (catch) weighted mean sums of squared differences for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, for each number of trips considered, across the 100 realisations for the 2006 strata-specific simulations

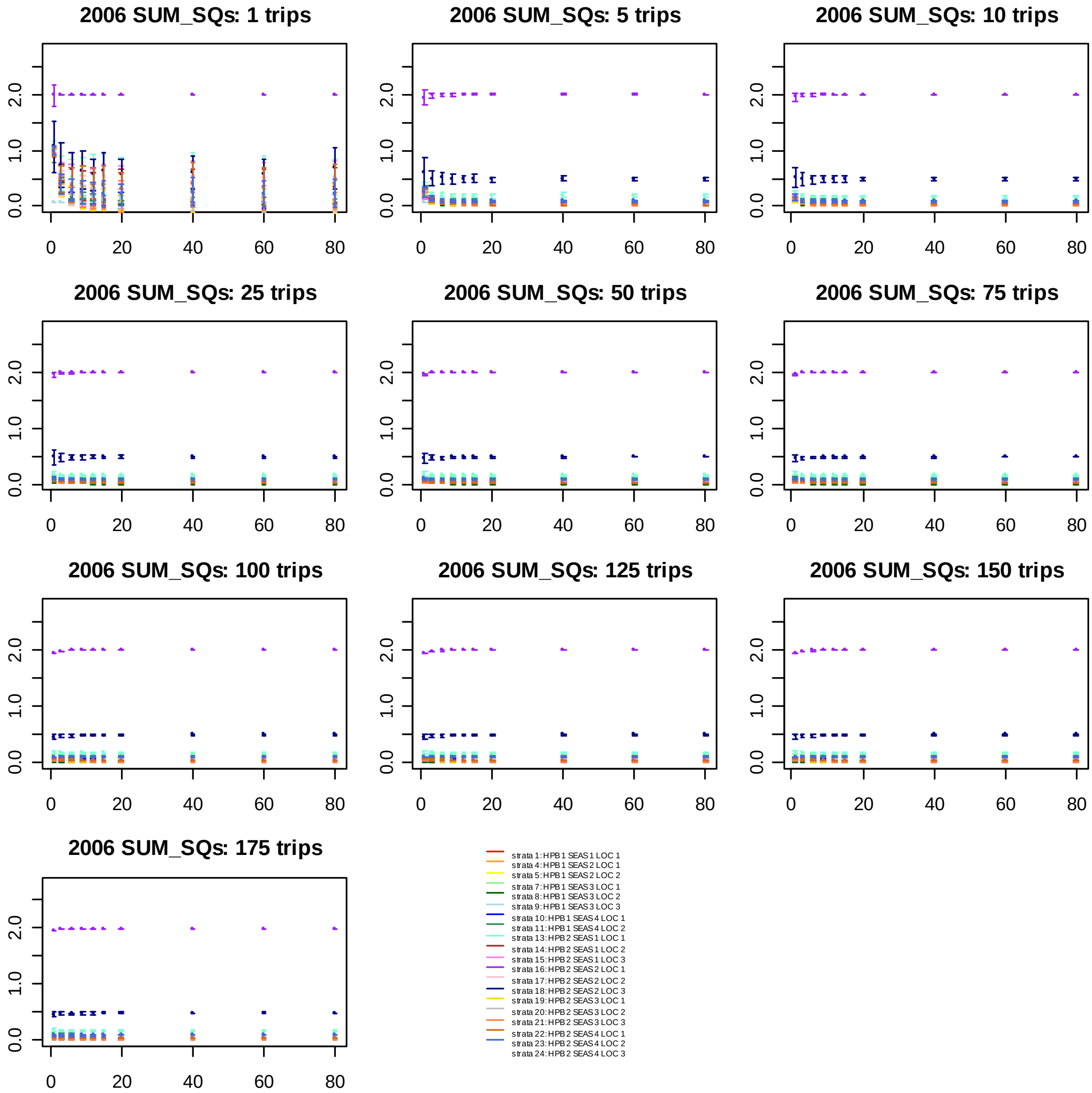

Figure D26: Mean sums of squared differences for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, for each number of trips considered, for each stratum, across the 100 realisations for the 2006 strata-specific simulations.

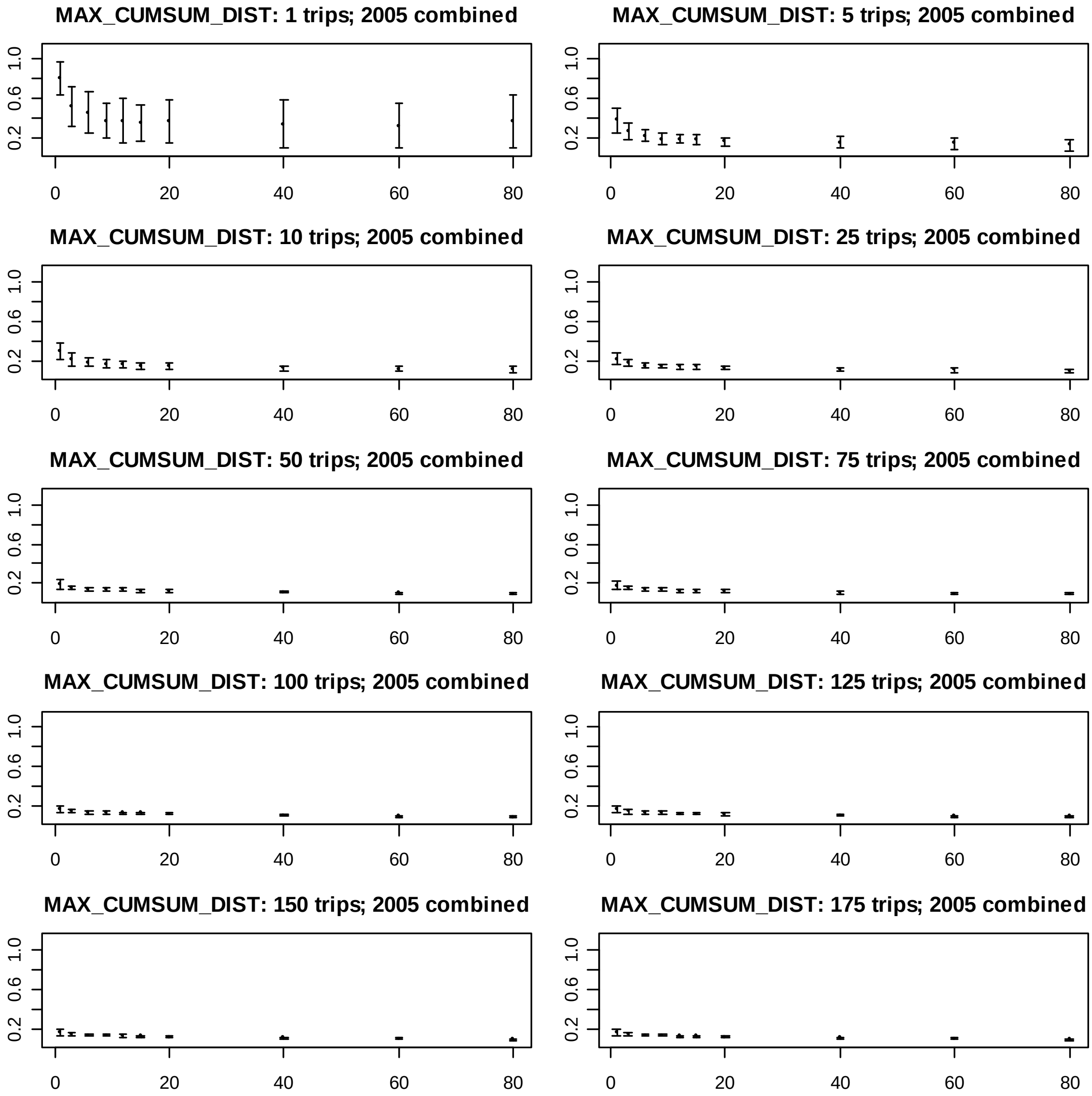

Figure D27: Mean maximum absolute difference between observed and sampled cumulative length distribution functions for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, for each number of trips considered, across the 100 realisations for the 2005 "combined" (i.e. strata not considered) simulations.

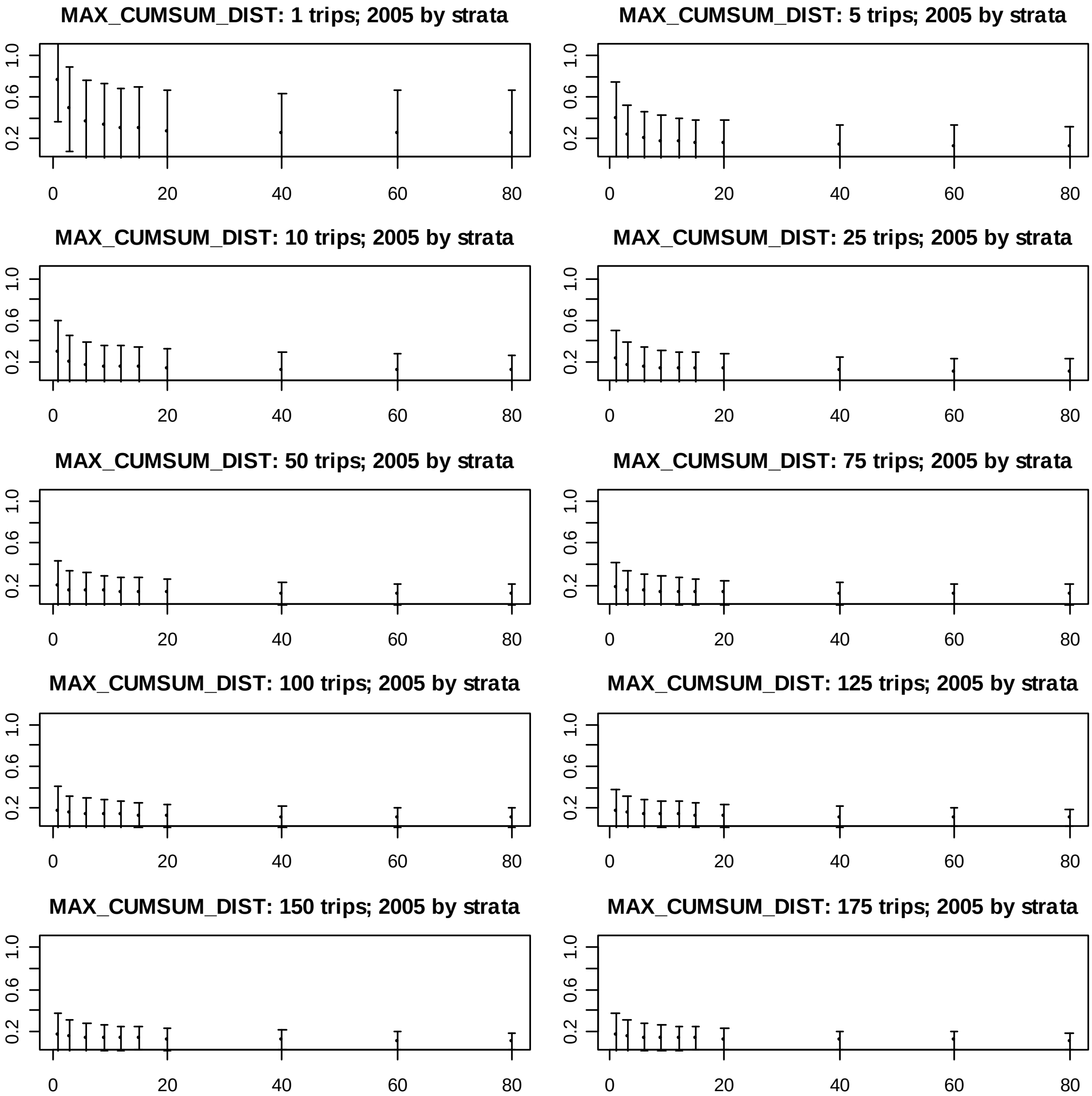

Figure D28: Overall (catch) weighted mean maximum absolute difference between observed and sampled cumulative length distribution functions for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, for each number of trips considered, across the 100 realisations for the 2005 strata-specific simulations

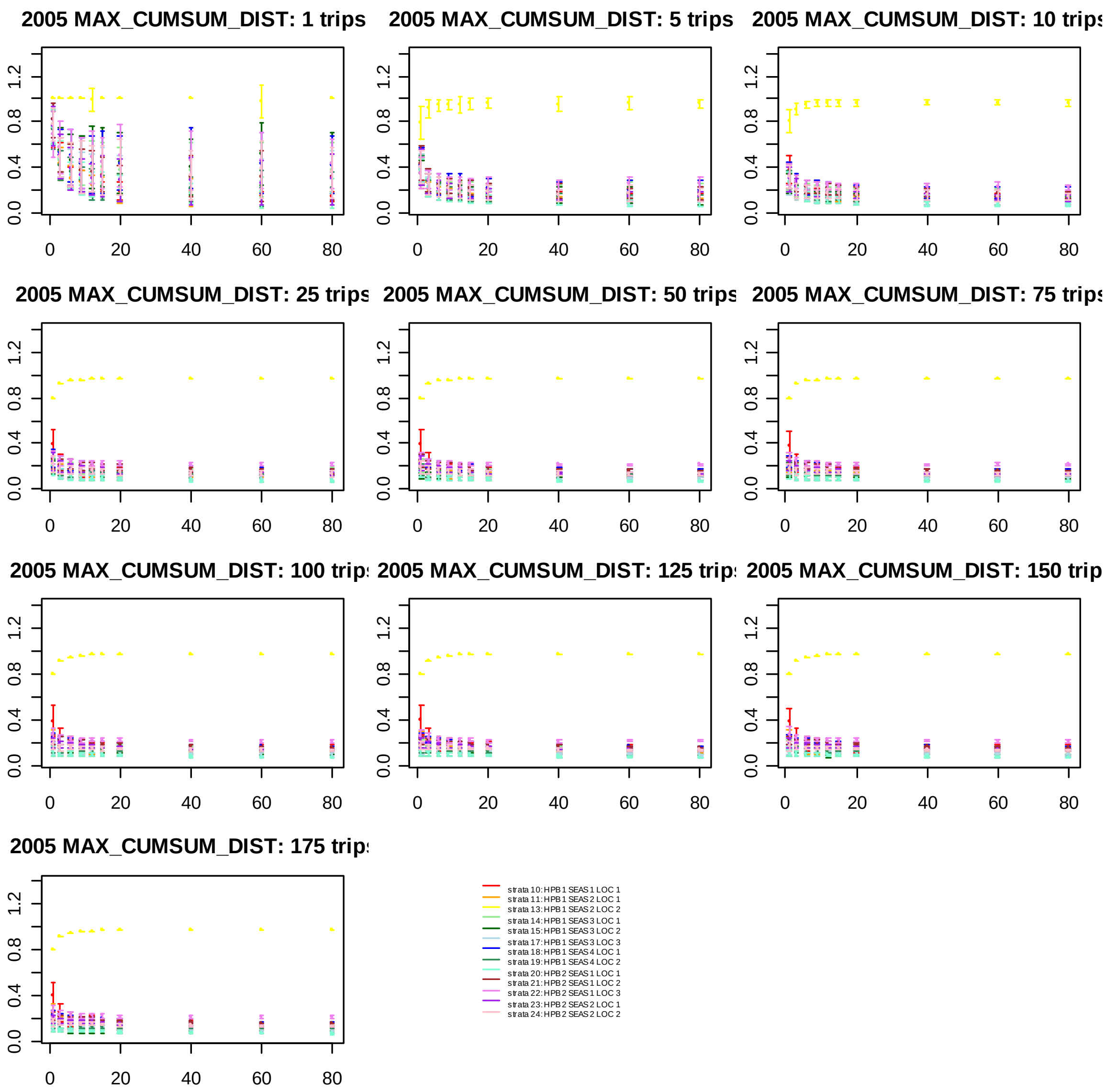

Figure D29: Mean maximum absolute difference between observed and sampled cumulative length distribution functions for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, for each number of trips considered, for each stratum, across the 100 realisations for the 2005 strata-specific simulations.

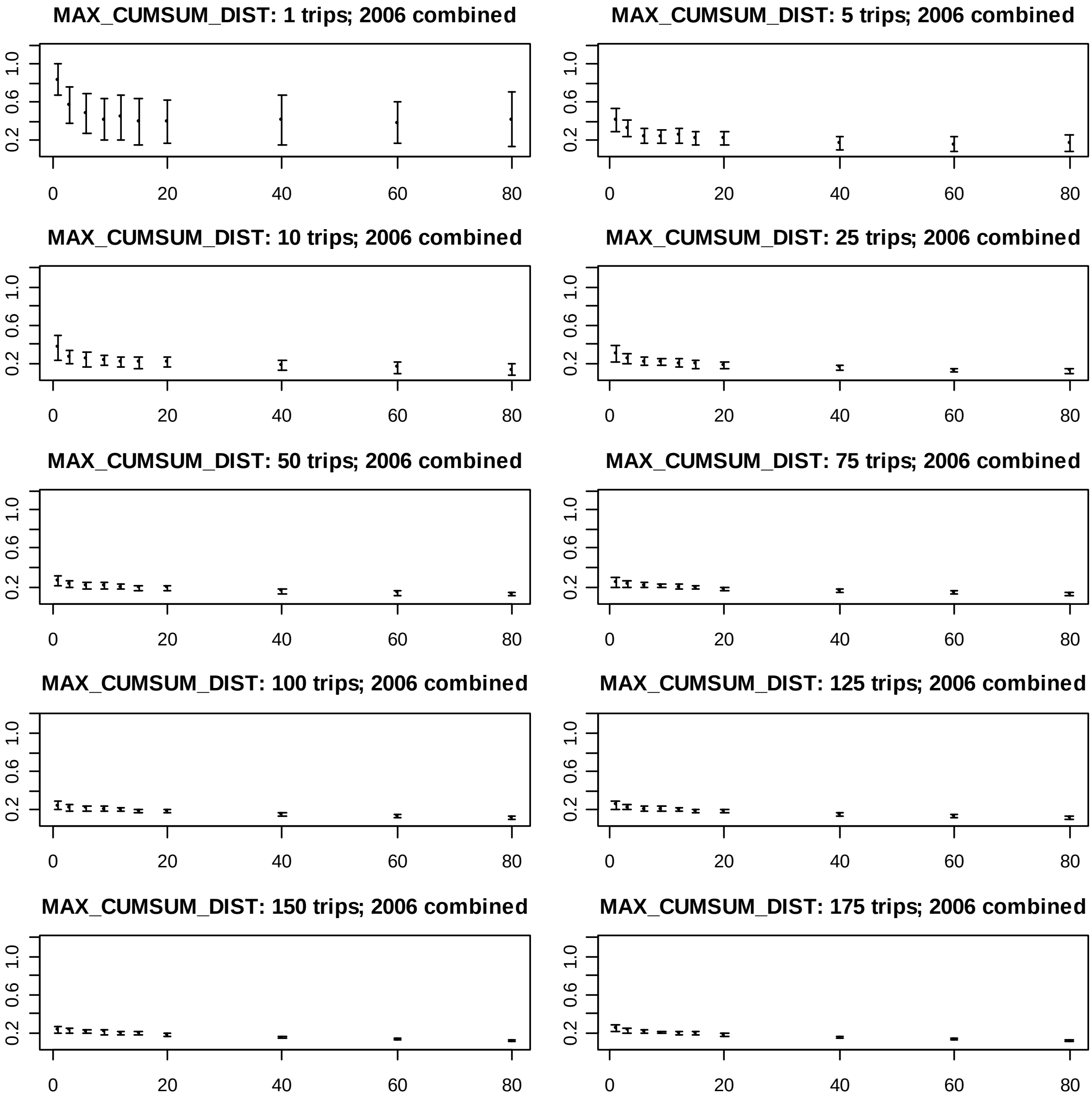

Figure D30: Mean maximum absolute difference between observed and sampled cumulative length distribution functions for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, for each number of trips considered, across the 100 realisations for the 2006 "combined" (i.e. strata not considered) simulations.

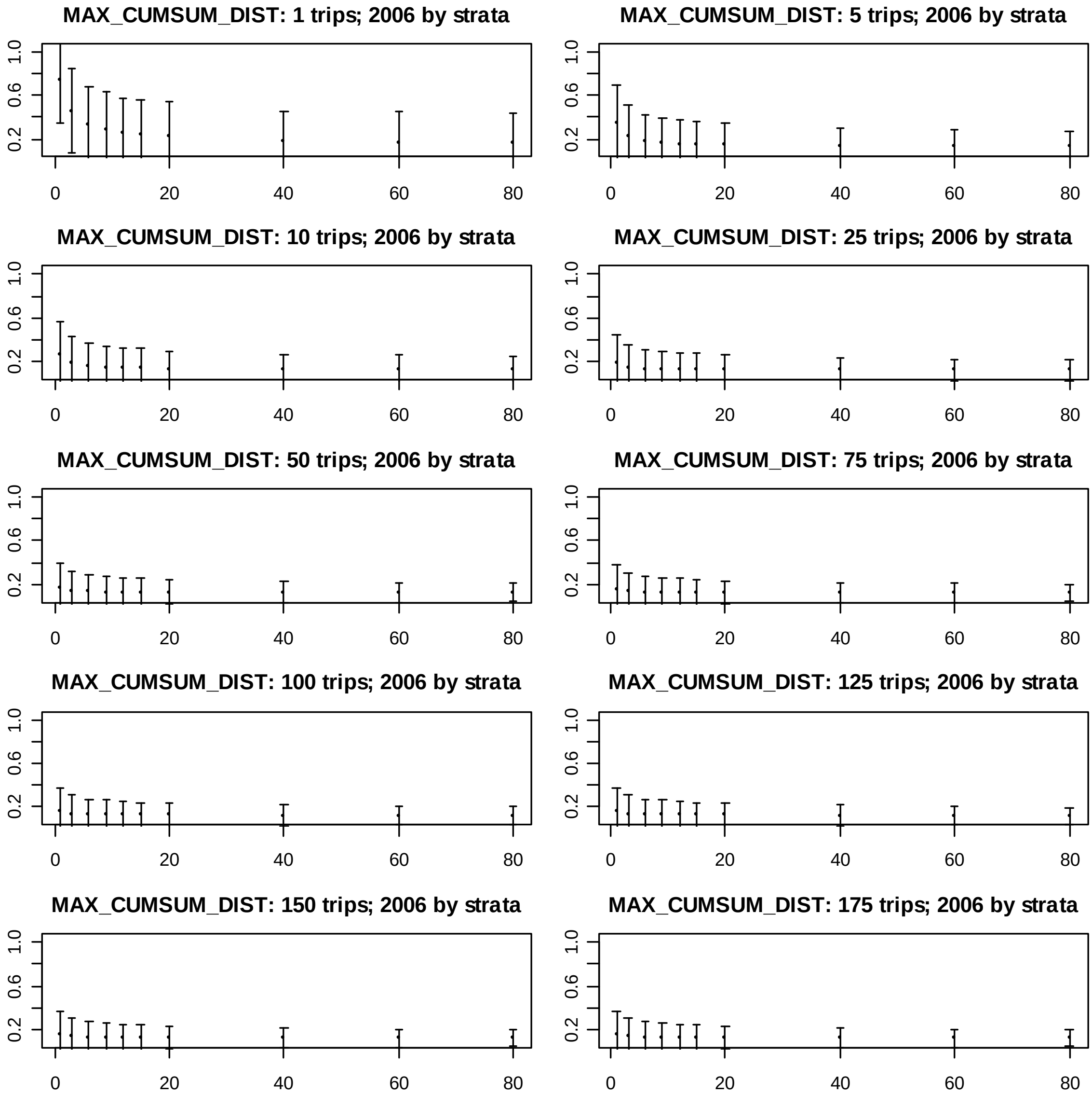

Figure D31: Overall (catch) weighted mean maximum absolute difference between observed and sampled cumulative length distribution functions for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, for each number of trips considered, across the 100 realisations for the 2006 strata-specific simulations

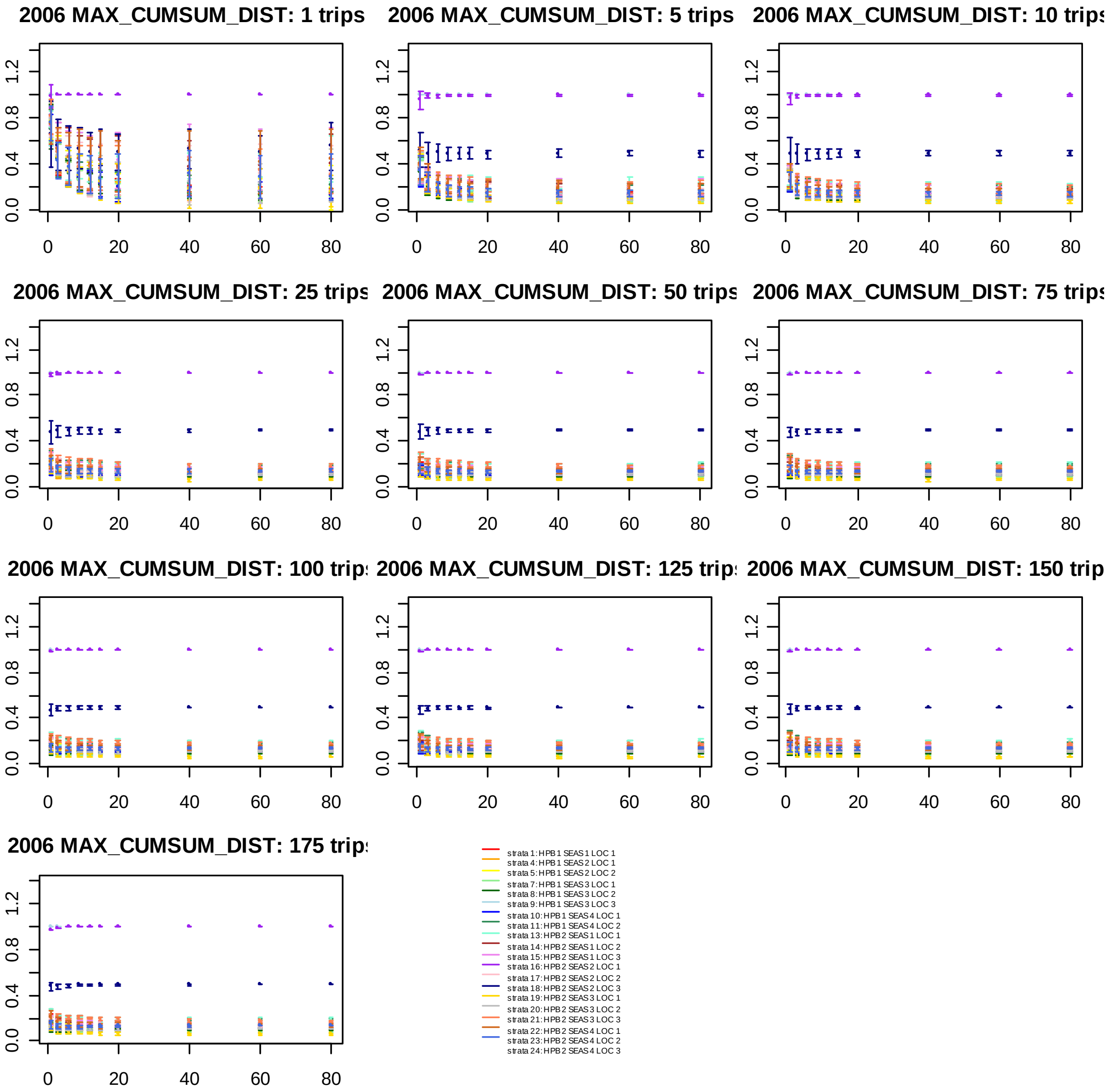

Figure D32: Mean maximum absolute difference between observed and sampled cumulative length distribution functions for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, for each number of trips considered, for each stratum, across the 100 realisations for the 2006 strata-specific simulations.

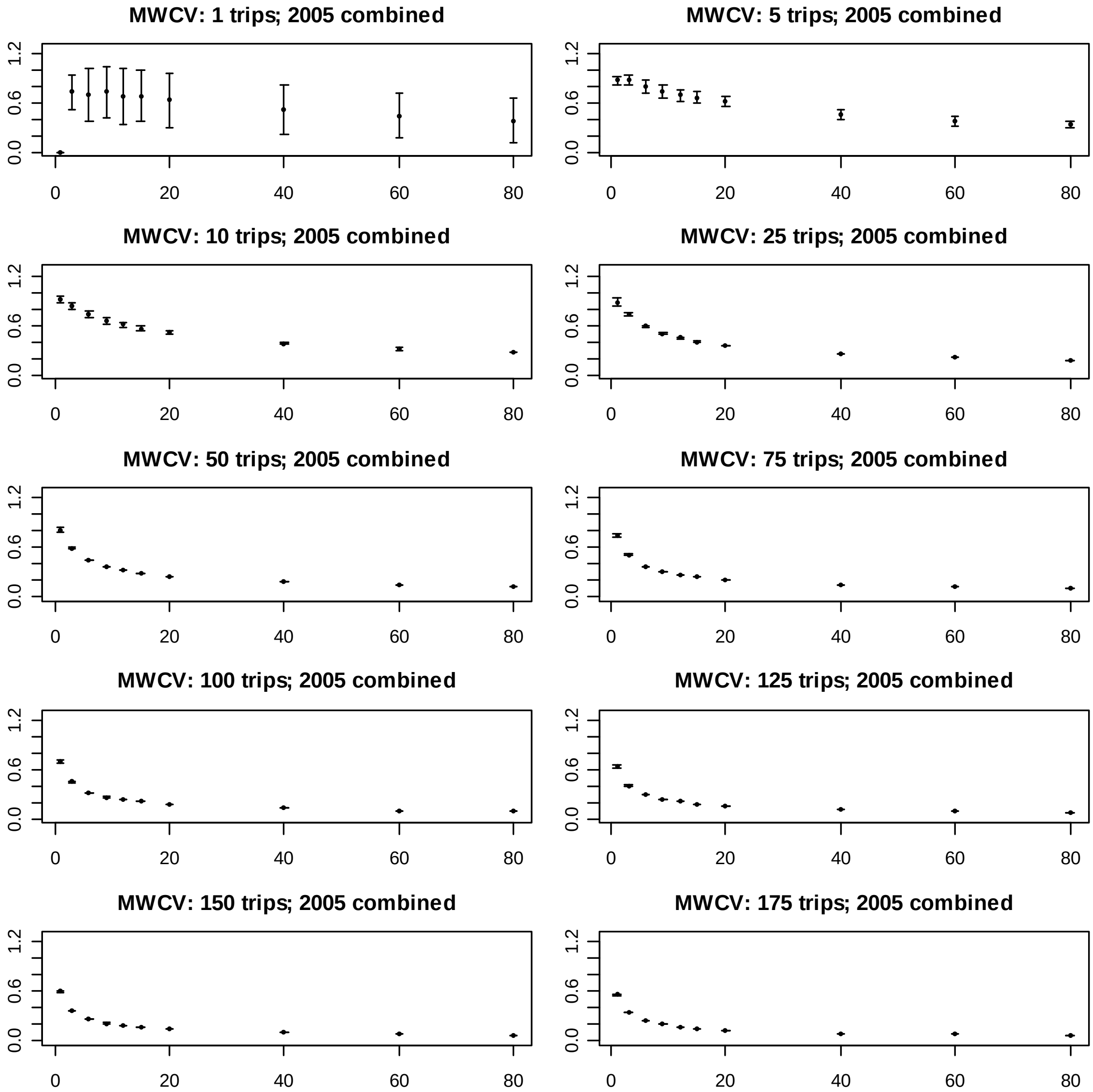

Figure D33: Mean of the mean weighted coefficients of variation for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, for each number of trips considered, across the 100 realisations for the 2005 "combined" (i.e. strata not considered) simulations.

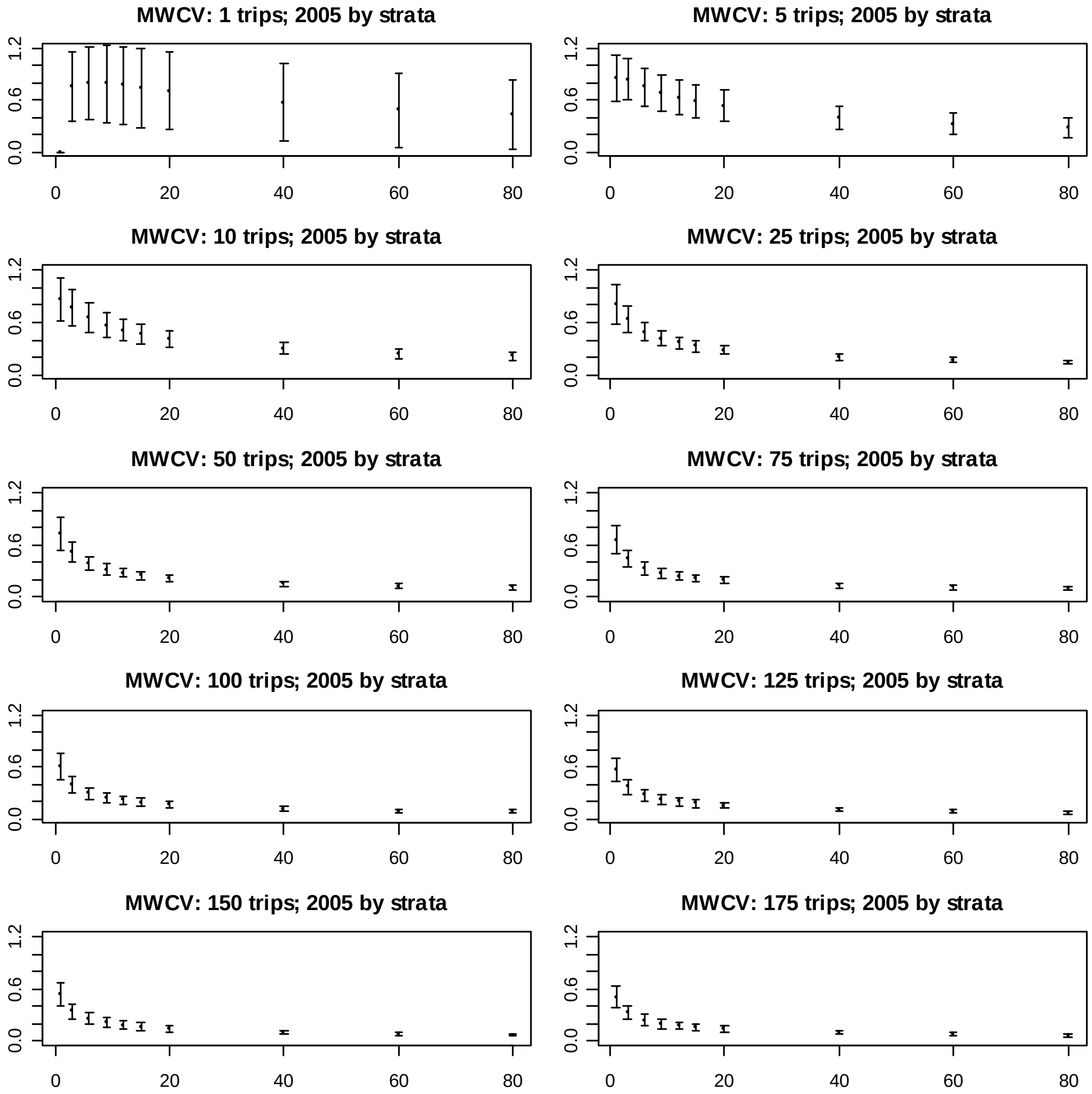

Figure D34: Overall (catch) weighted mean of the mean weighted coefficients of variation for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, for each number of trips considered, across the 100 realisations for the 2005 strata-specific simulations

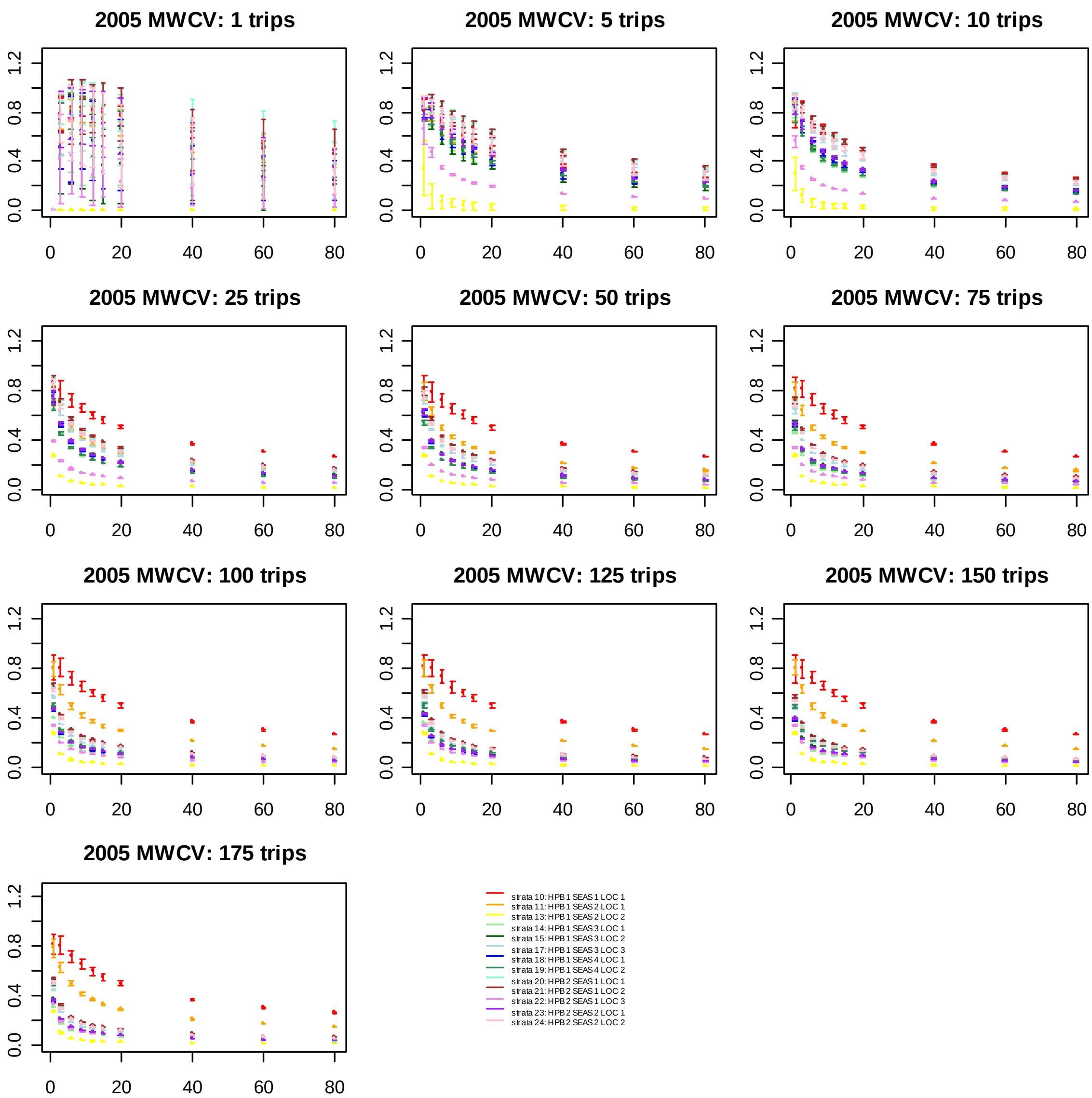

Figure D35: Mean of the mean weighted coefficients of variation for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, for each number of trips considered, for each stratum, across the 100 realisations for the 2005 strata-specific simulations.

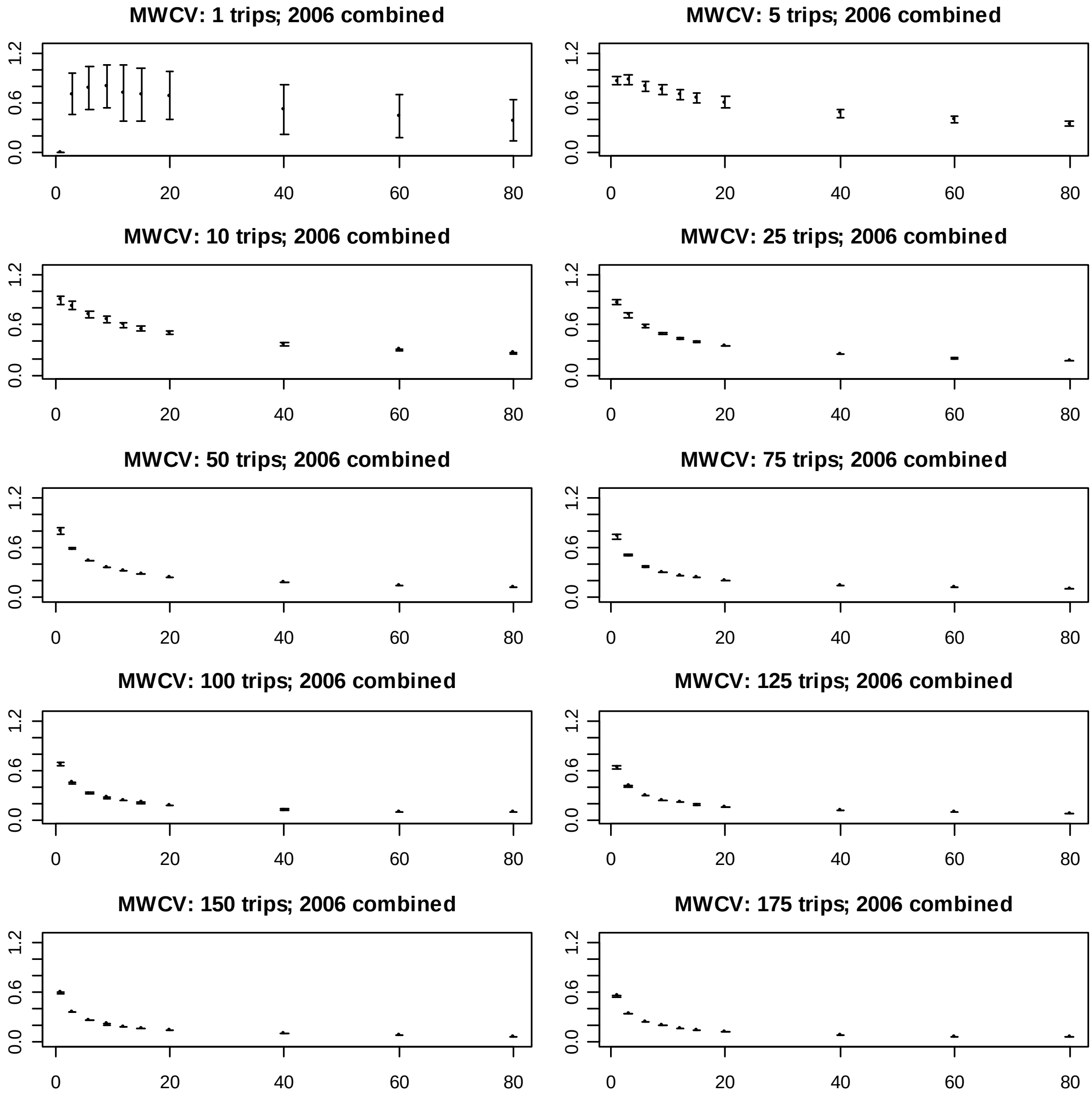

Figure D36: Mean of the mean weighted coefficients of variation for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, for each number of trips considered, across the 100 realisations for the 2006 "combined" (i.e. strata not considered) simulations.

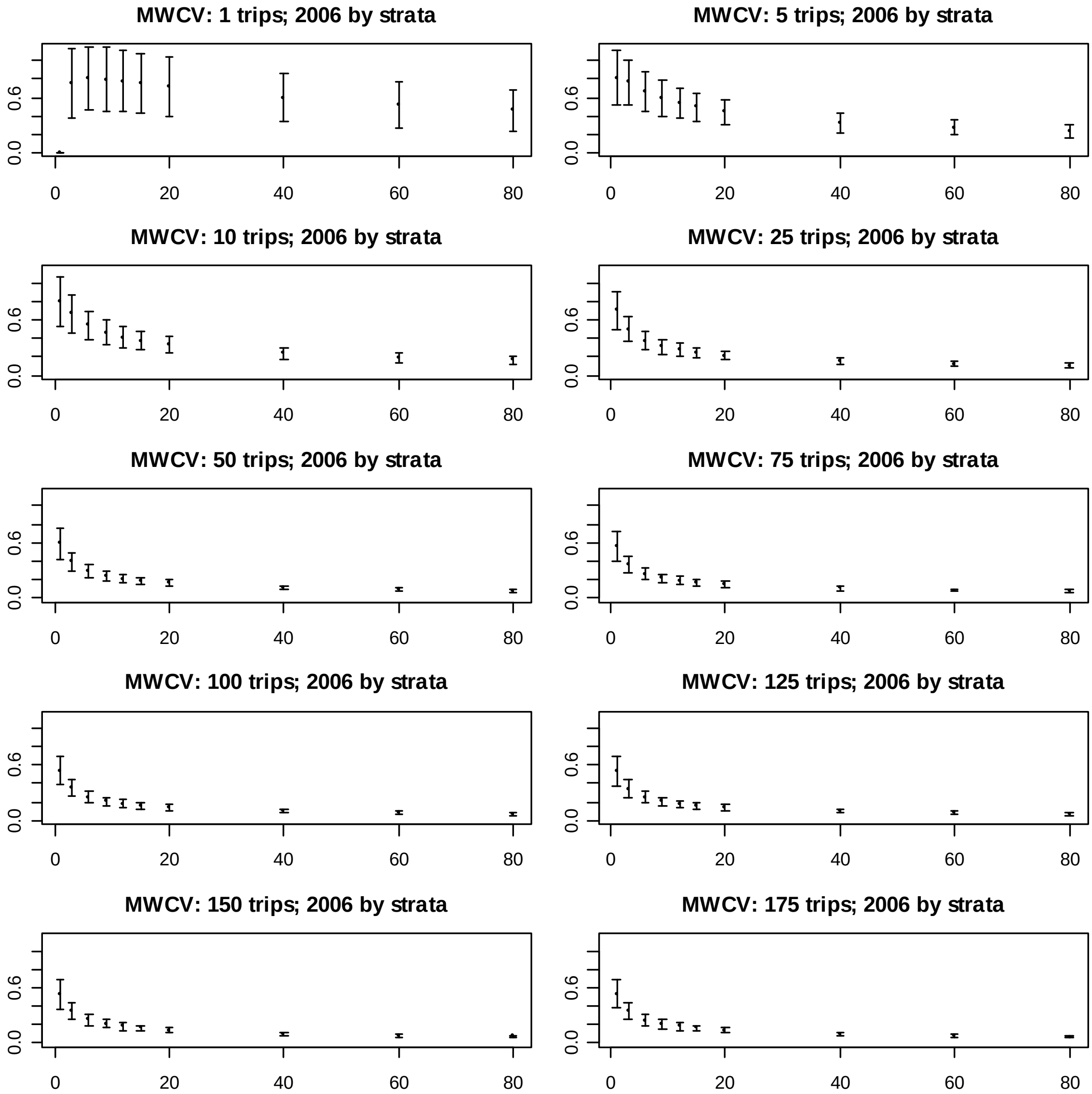

Figure D37: Overall (catch) weighted mean of the mean weighted coefficients of variation for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, for each number of trips considered, across the 100 realisations for the 2006 strata-specific simulations

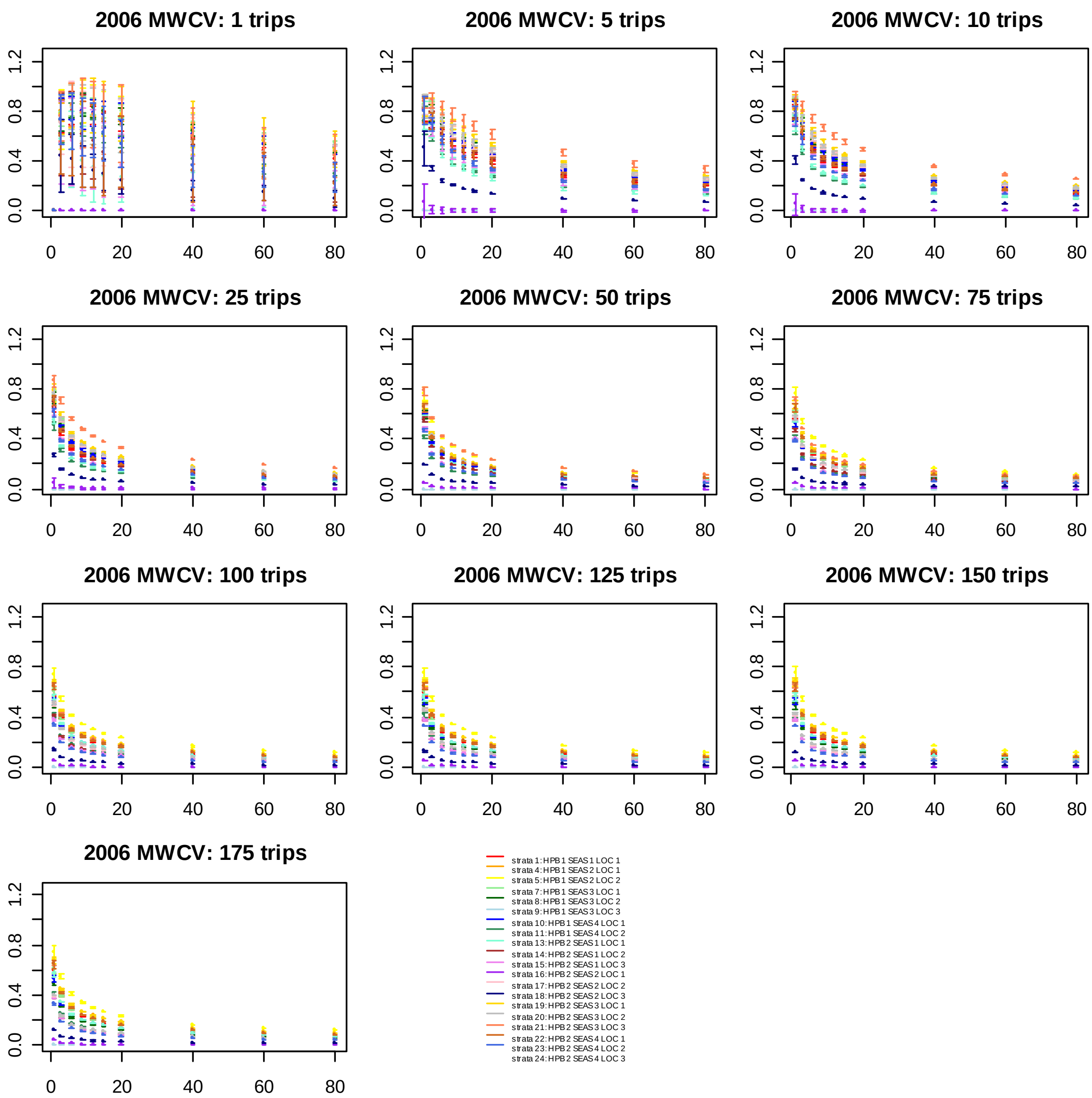

Figure D38: Mean of the mean weighted coefficients of variation for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, for each number of trips considered, for each stratum, across the 100 realisations for the 2006 strata-specific simulations.

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16. Appendix E: Results of the simulation exercise to determine the minimum number of fish to measure if 100% of trips are sampled.

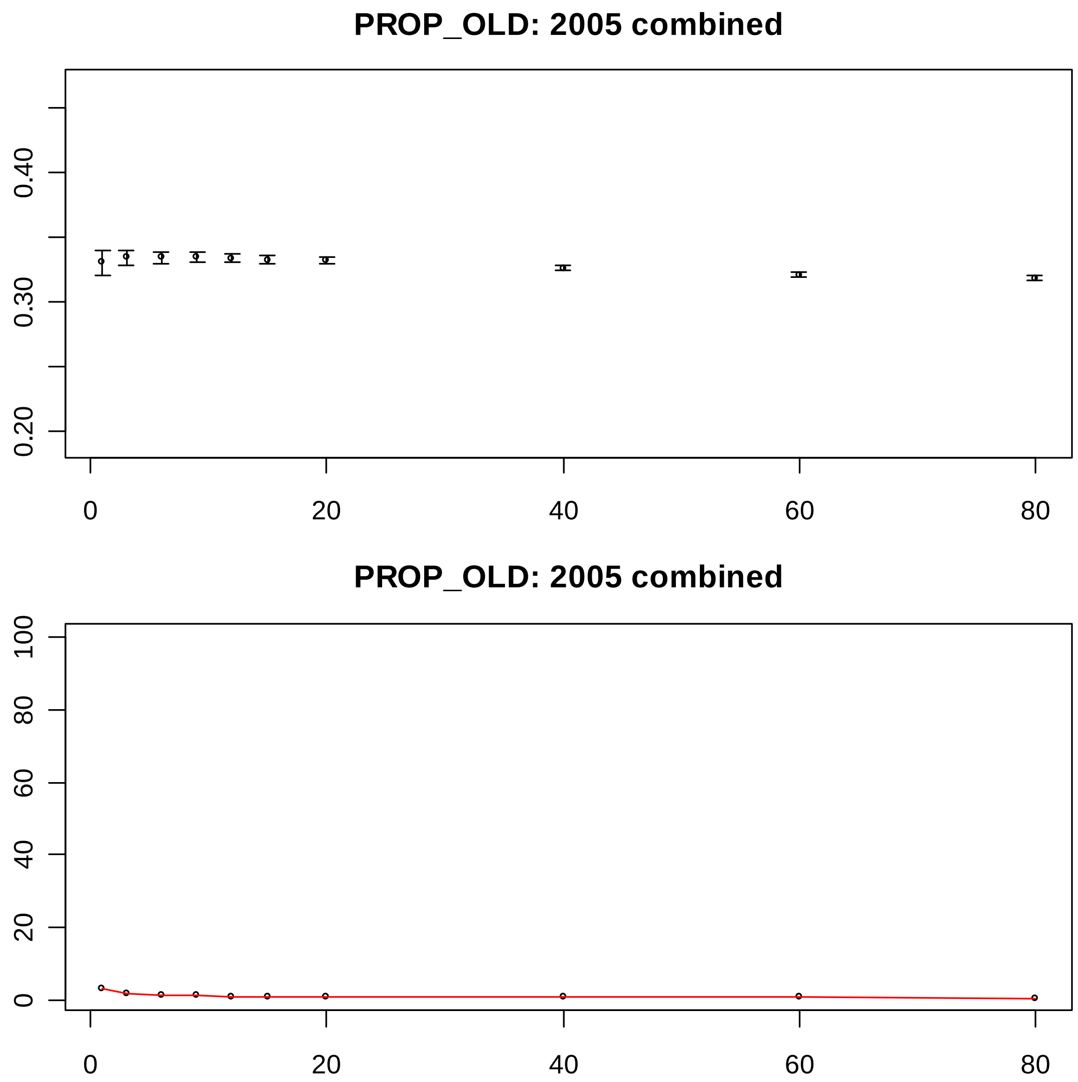


Figure E1: Mean proportion of "old" albacore (± 1 standard deviation) versus number of fish measured per trip, with 100 % of trips sampled, across 100 realisations (top panel), and the coefficient of variation about the mean proportion of "old" albacore, for each number of fish measured per trip that was tested (with 100 % of trips sampled) (lower panel), for the 2005 "combined" (i.e. strata not considered) simulations

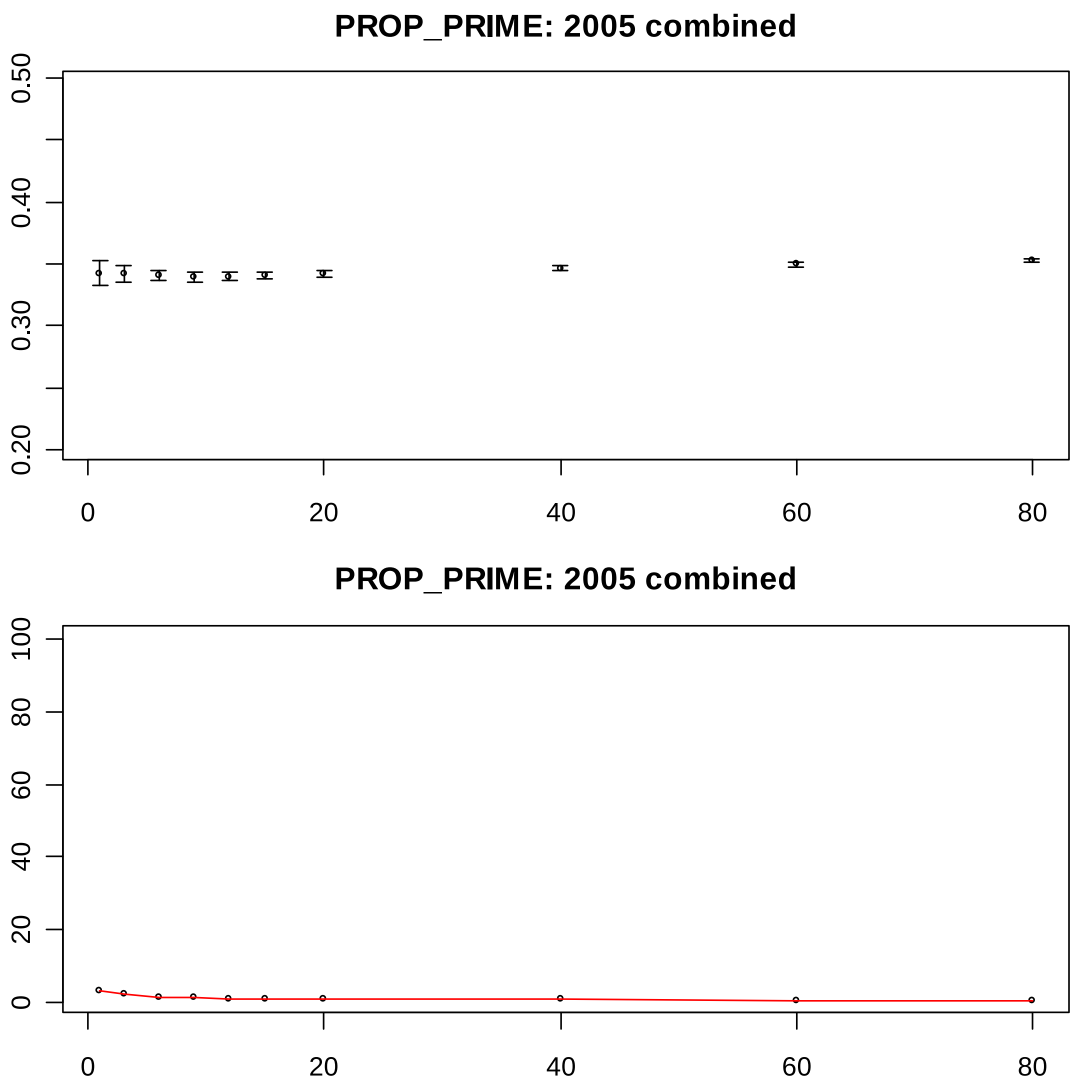


Figure E2: Mean proportion of "prime sized" albacore (± 1 standard deviation) versus number of fish measured per trip, with 100 % of trips sampled, across 100 realisations (top panel), and the coefficient of variation about the mean proportion of "prime sized" albacore, for each number of fish measured per trip that was tested (with 100 % of trips sampled) (lower panel), for the 2005 "combined" (i.e. strata not considered) simulations

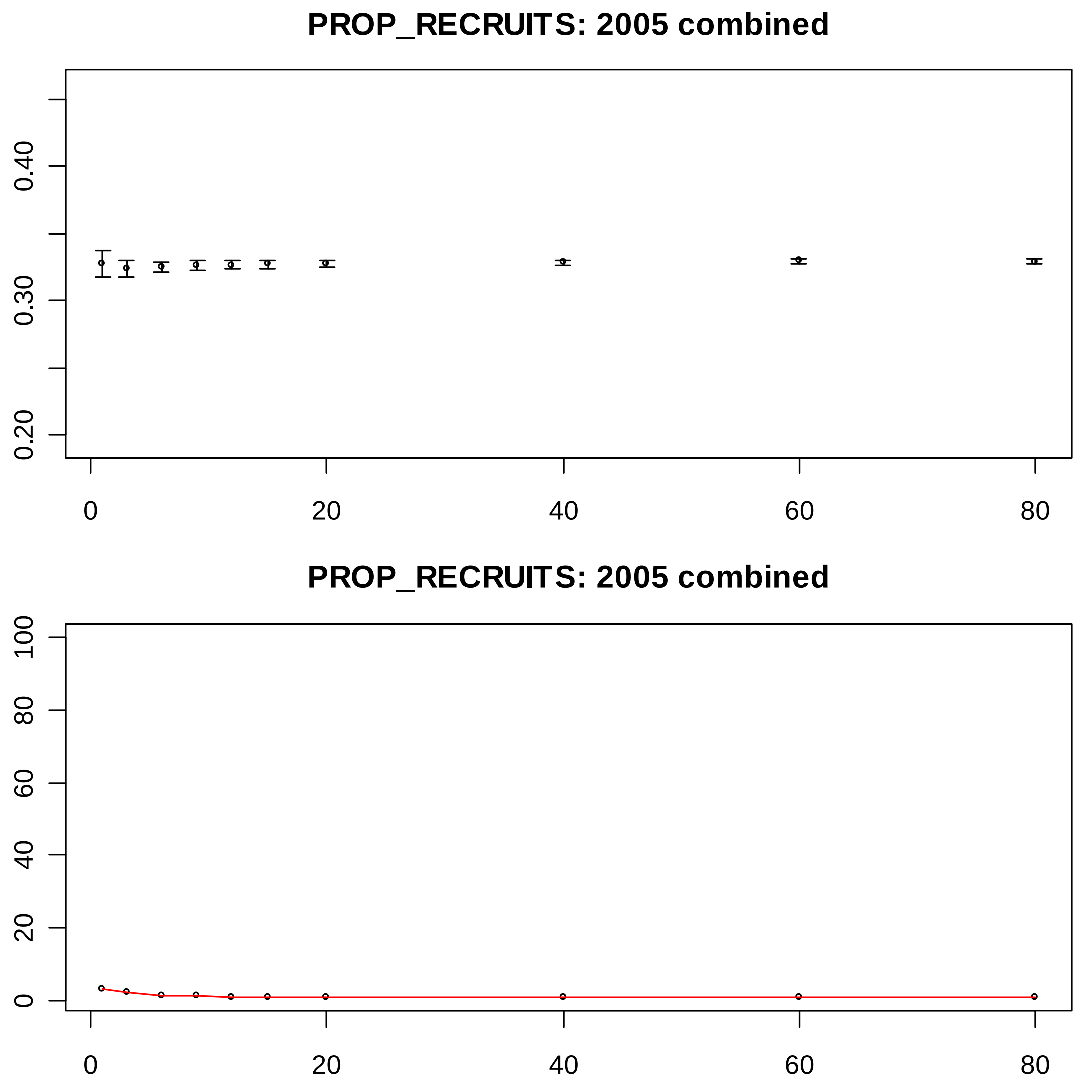


Figure E3: Mean proportion of “recruit sized” albacore (± 1 standard deviation) versus number of fish measured per trip, with 100 % of trips sampled, across 100 realisations (top panel), and the coefficient of variation about the mean proportion of “recruit sized” albacore, for each number of fish measured per trip that was tested (with 100 % of trips sampled) (lower panel), for the 2005 “combined” (i.e. strata not considered) simulations

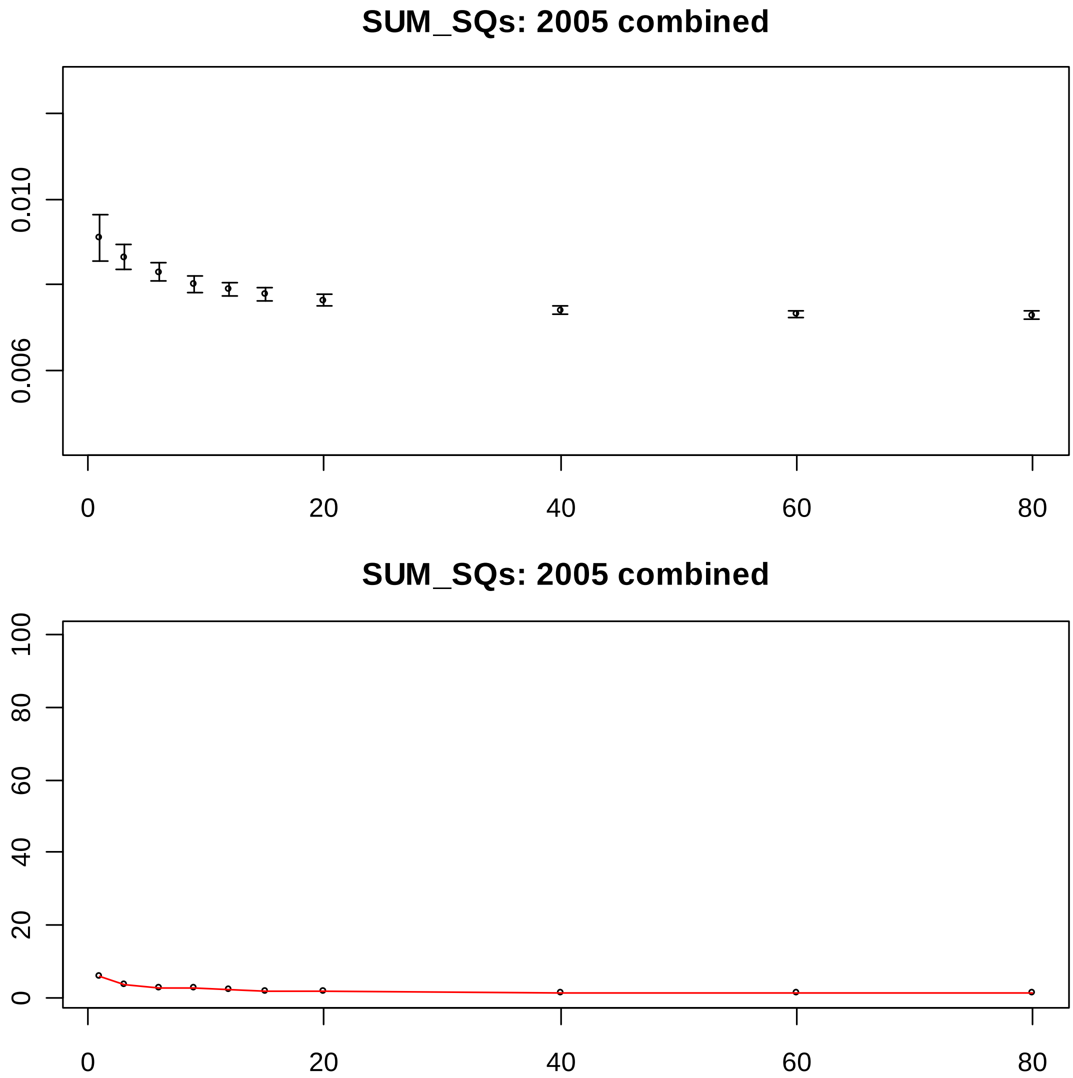


Figure E4: Mean sums of squared differences for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, with 100 % of trips sampled, across 100 realisations (top panel), and the coefficient of variation about the mean sums of squared differences for the overall albacore size distribution, for each number of fish measured per trip that was tested (with 100 % of trips sampled) (lower panel), for the 2005 "combined" (i.e. strata not considered) simulations

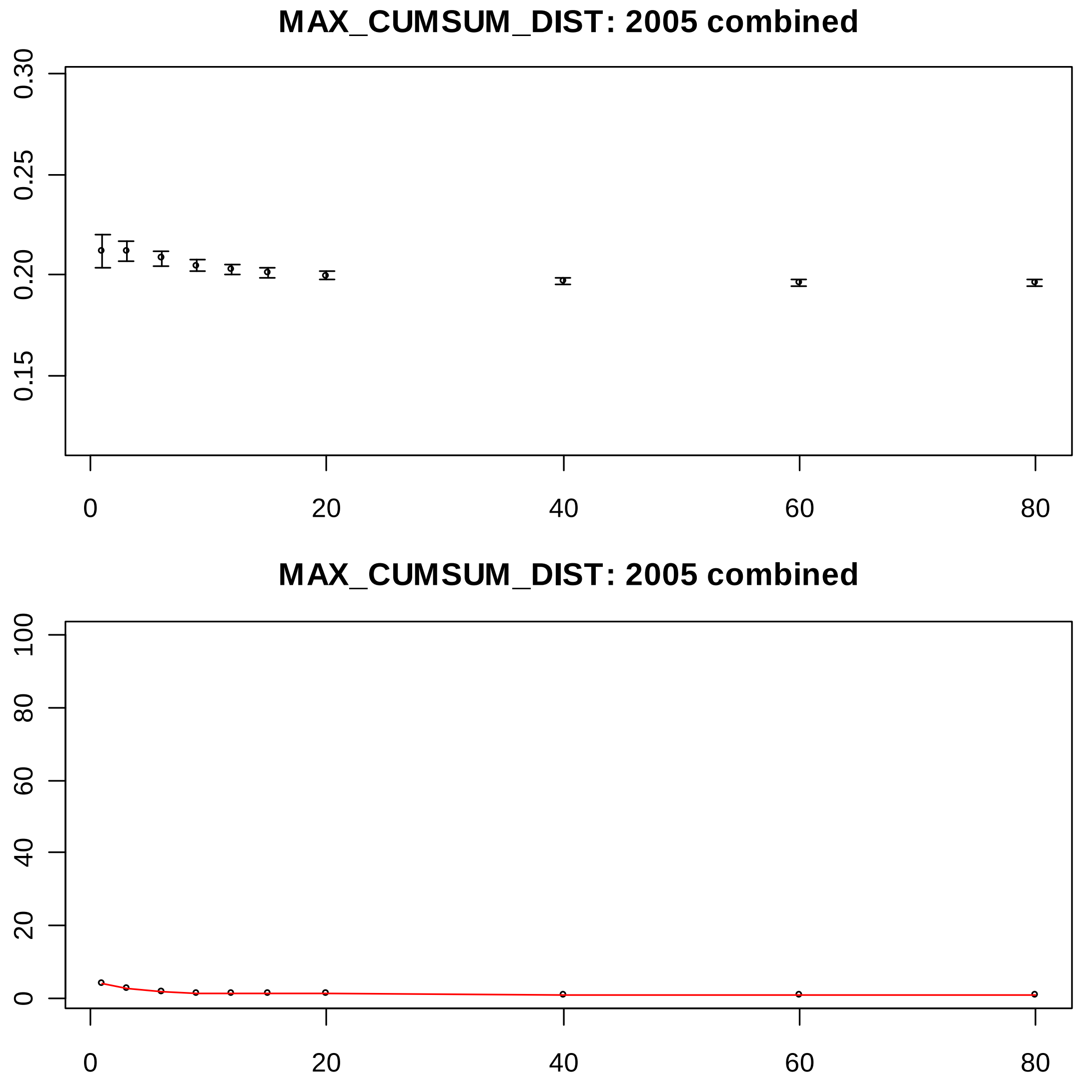


Figure E5: Mean maximum absolute difference between observed and sampled cumulative length distribution functions for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, with 100 % of trips sampled, across 100 realisations (top panel), and the coefficient of variation about the mean maximum absolute difference between observed and sampled cumulative length distribution functions for the overall albacore size distribution, for each number of fish measured per trip that was tested (with 100 % of trips sampled) (lower panel), for the 2005 "combined" (i.e. strata not considered) simulations

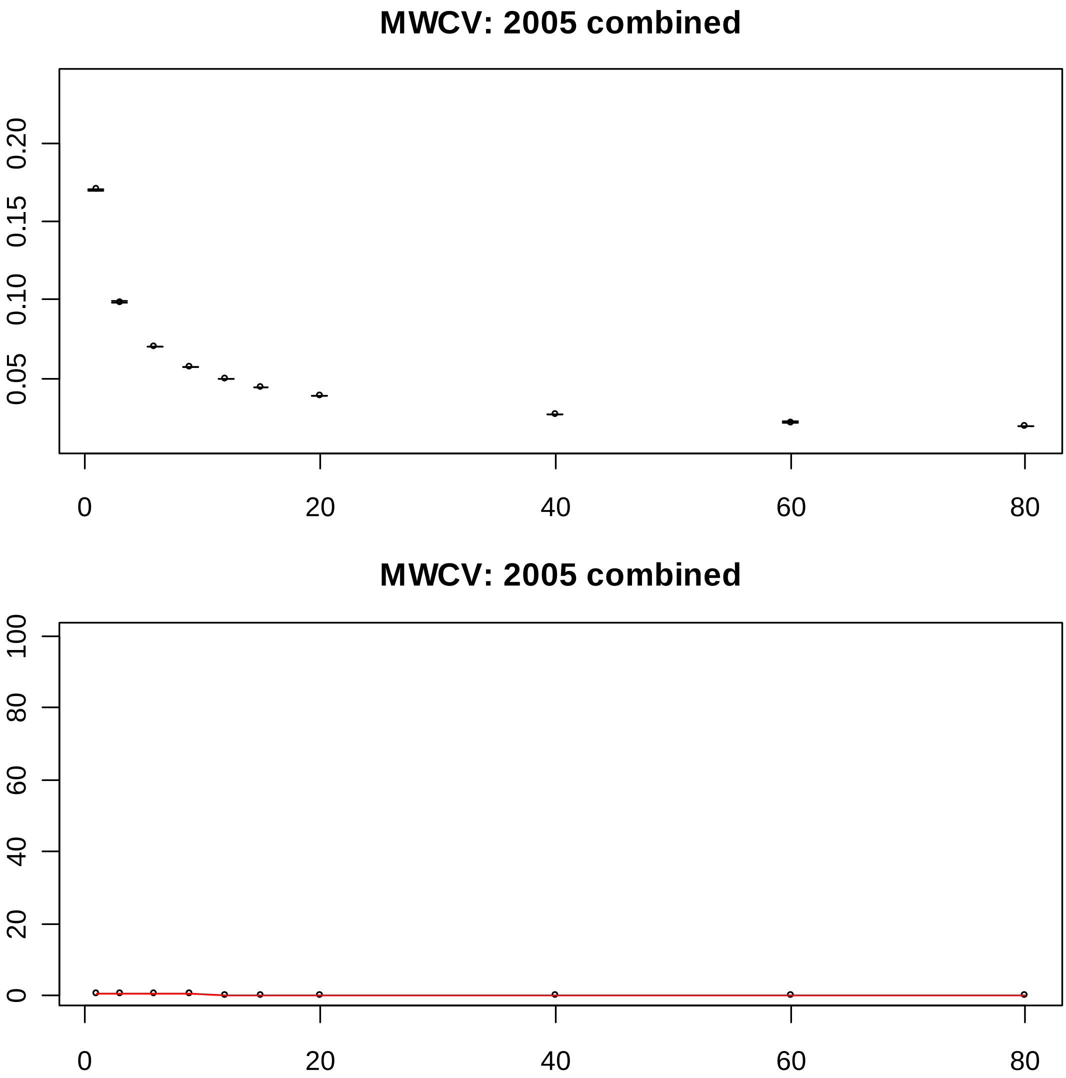


Figure E6: Mean of the mean weighted coefficients of variation for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, with 100 % of trips sampled, across 100 realisations (top panel), and the coefficient of variation about the mean of the mean weighted coefficients of variation for the overall albacore size distribution, for each number of fish measured per trip that was tested (with 100 % of trips sampled) (lower panel), for the 2005 "combined" (i.e. strata not considered) simulations

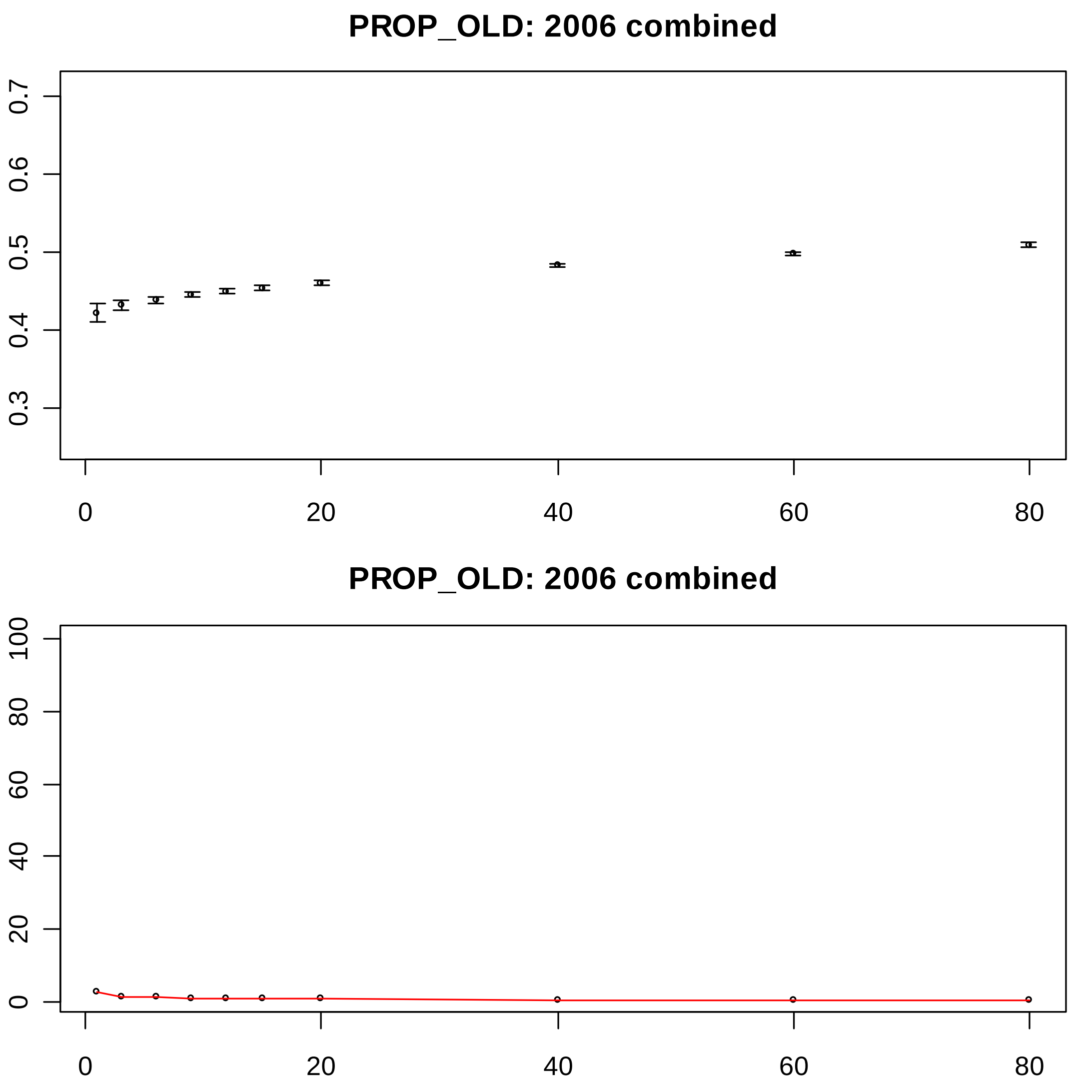


Figure E7: Mean proportion of “old” albacore (± 1 standard deviation) versus number of fish measured per trip, with 100 % of trips sampled, across 100 realisations (top panel), and the coefficient of variation about the mean proportion of “old” albacore, for each number of fish measured per trip that was tested (with 100 % of trips sampled) (lower panel), for the 2006 “combined” (i.e. strata not considered) simulations

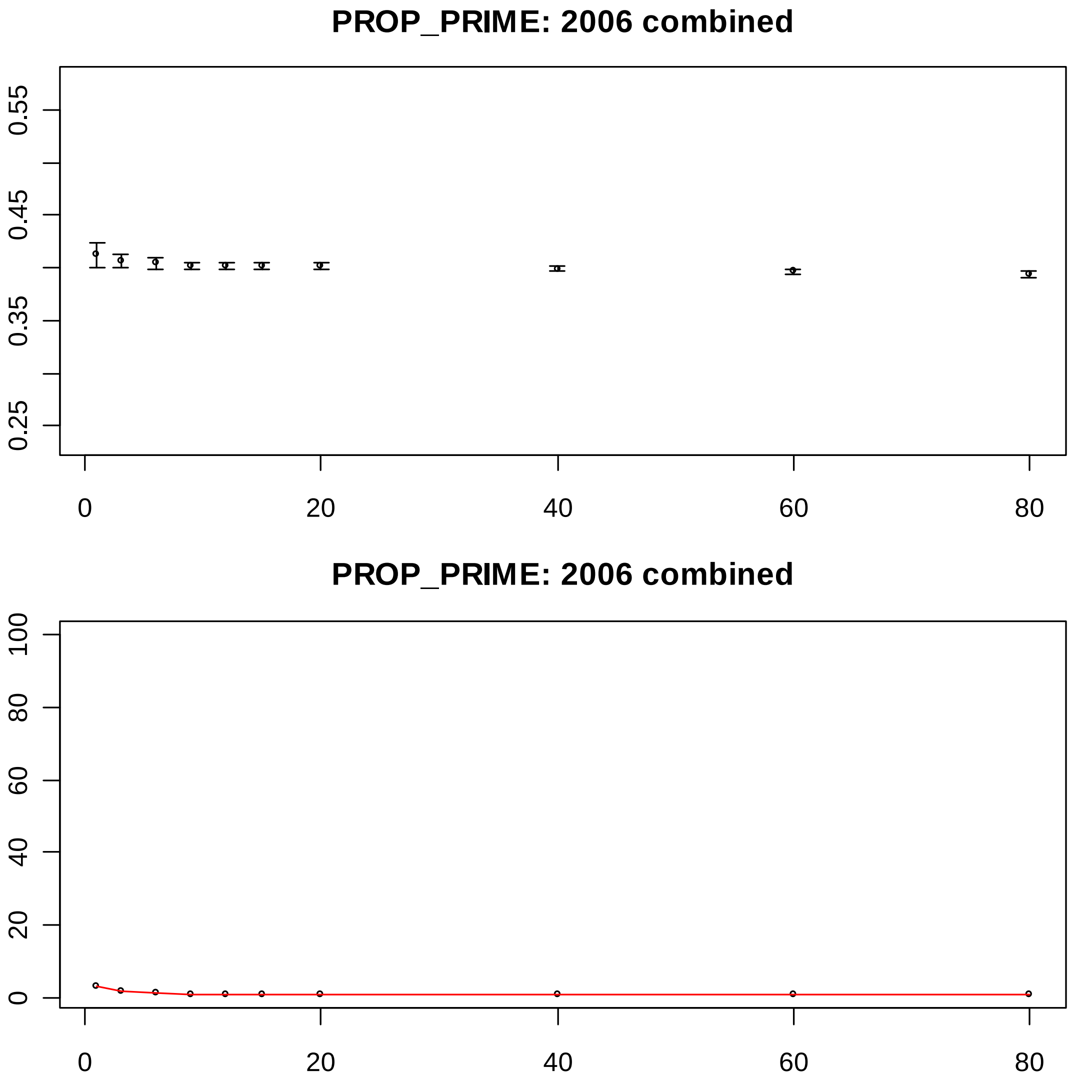


Figure E8: Mean proportion of "prime sized" albacore (± 1 standard deviation) versus number of fish measured per trip, with 100 % of trips sampled, across 100 realisations (top panel), and the coefficient of variation about the mean proportion of "prime sized" albacore, for each number of fish measured per trip that was tested (with 100 % of trips sampled) (lower panel), for the 2006 "combined" (i.e. strata not considered) simulations

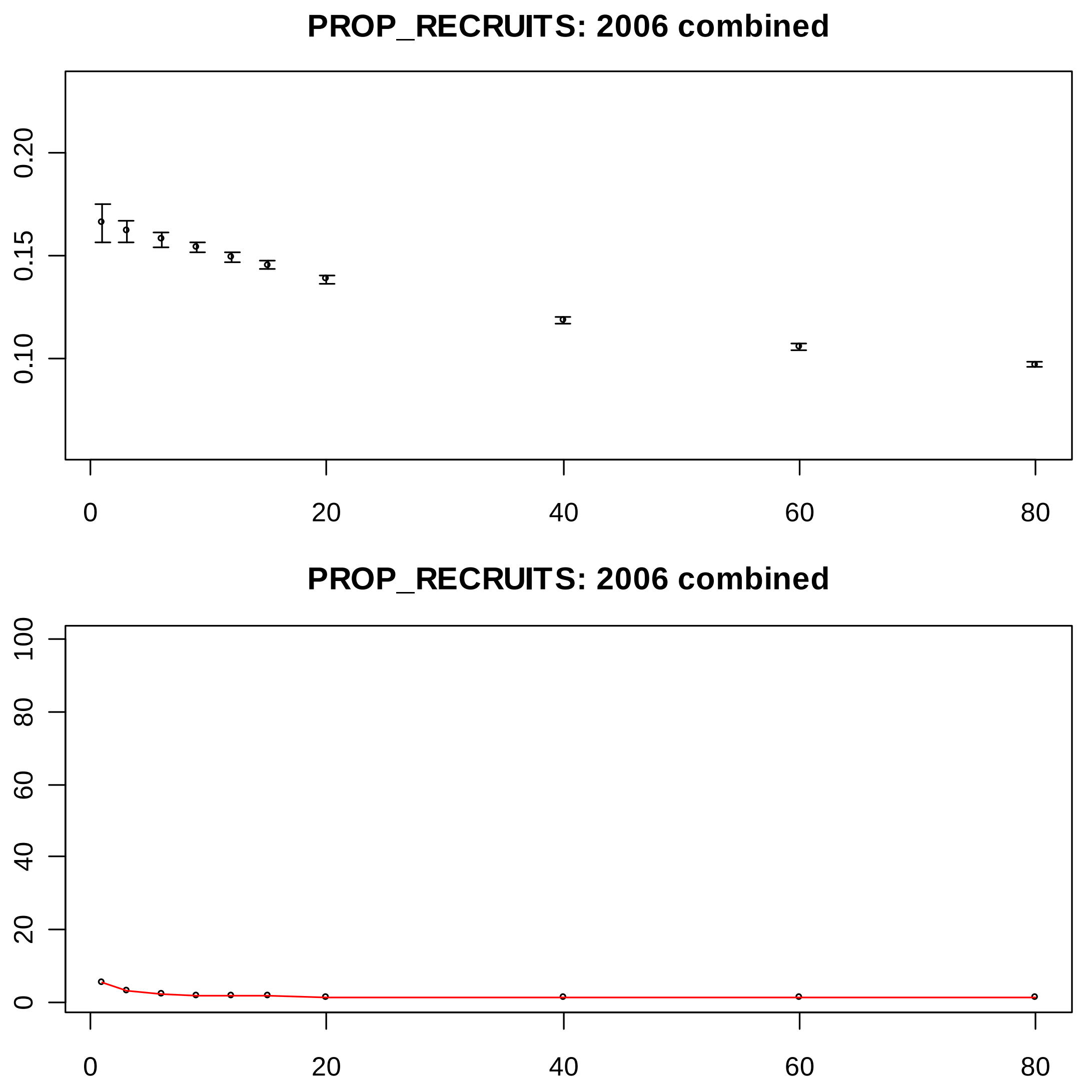


Figure E9: Mean proportion of "recruit sized" albacore (± 1 standard deviation) versus number of fish measured per trip, with 100 % of trips sampled, across 100 realisations (top panel), and the coefficient of variation about the mean proportion of "recruit sized" albacore, for each number of fish measured per trip that was tested (with 100 % of trips sampled) (lower panel), for the 2006 "combined" (i.e. strata not considered) simulations

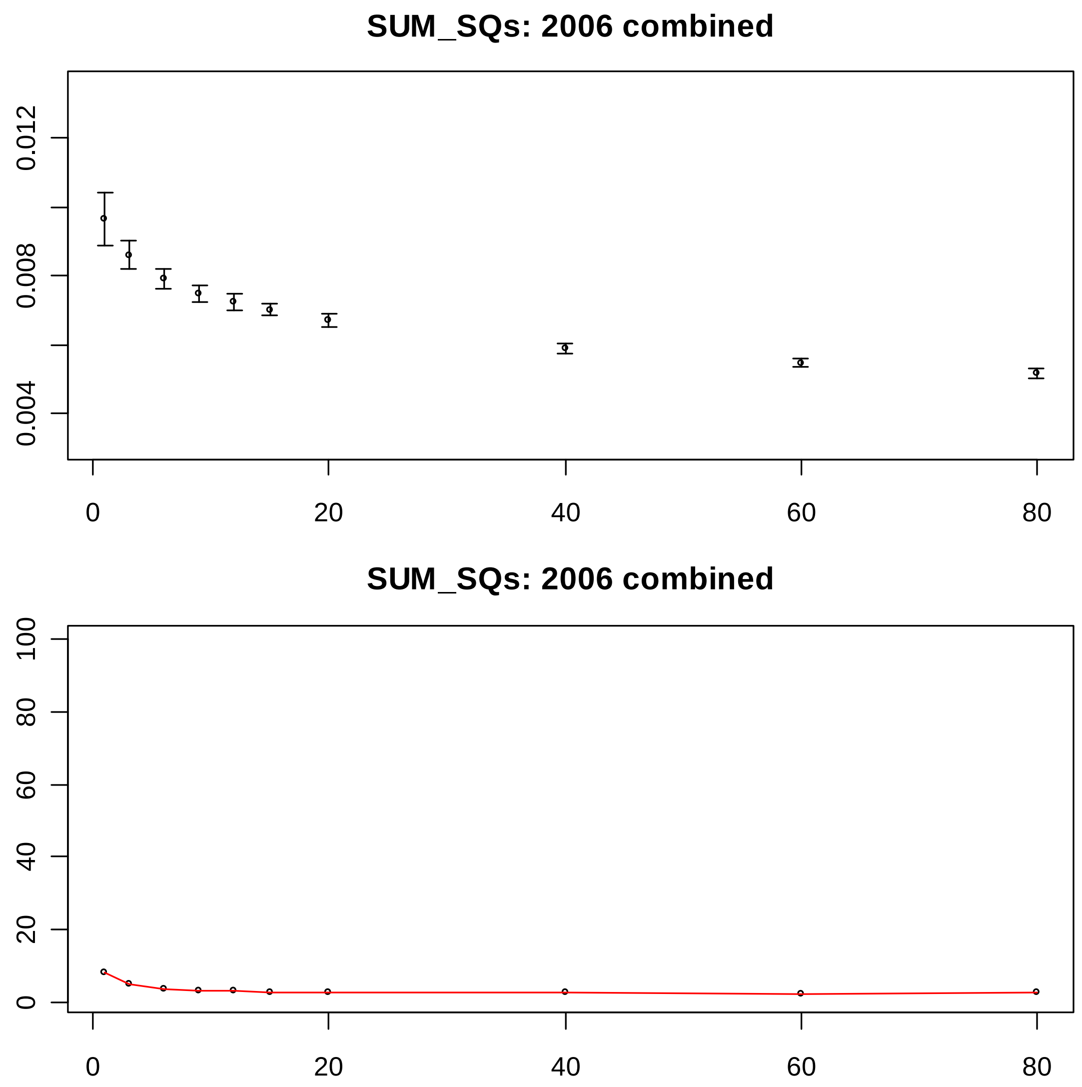


Figure E10: Mean sums of squared differences for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, with 100 % of trips sampled, across 100 realisations (top panel), and the coefficient of variation about the mean sums of squared differences for the overall albacore size distribution, for each number of fish measured per trip that was tested (with 100 % of trips sampled) (lower panel), for the 2006 “combined” (i.e. strata not considered) simulations

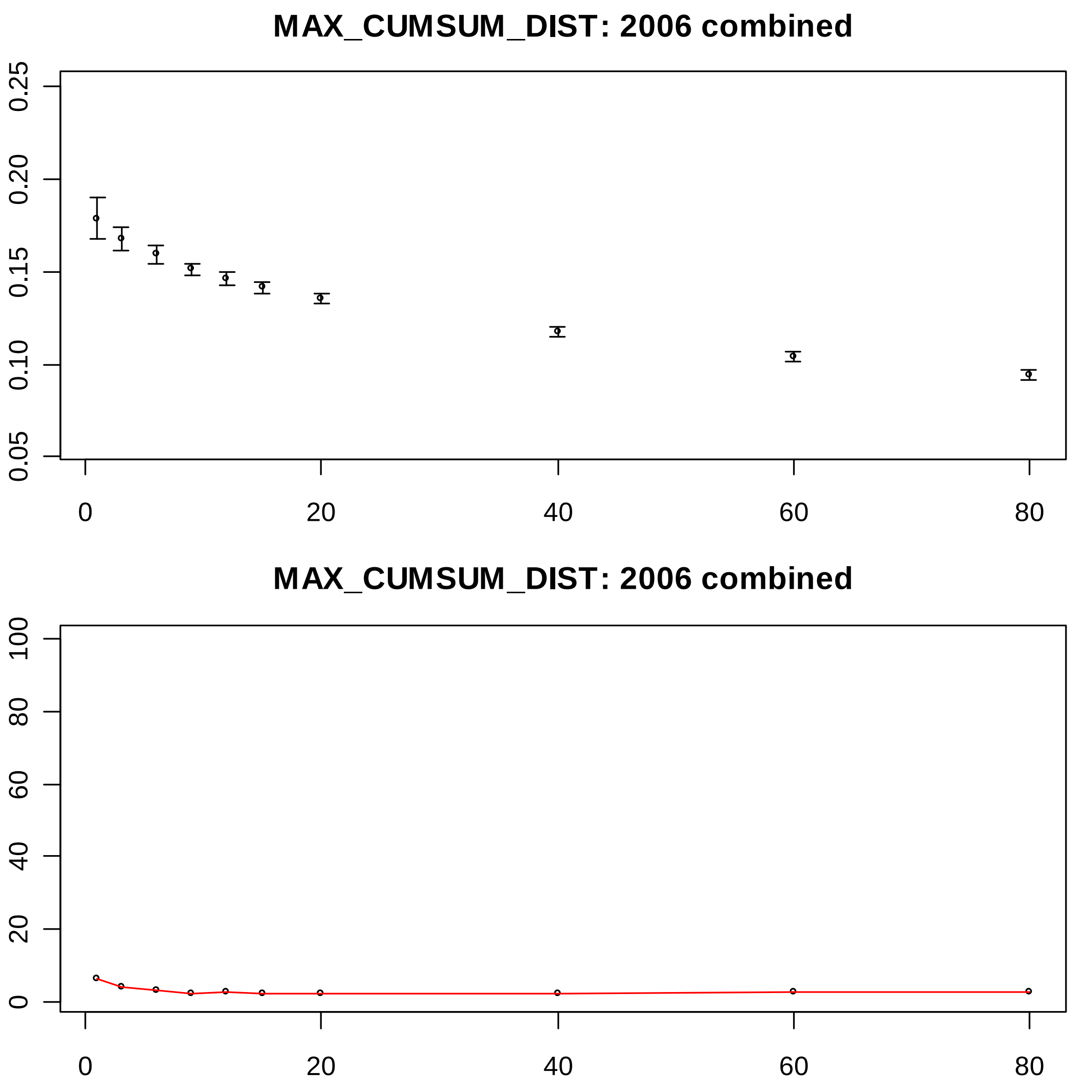


Figure E11: Mean maximum absolute difference between observed and sampled cumulative length distribution functions for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, with 100 % of trips sampled, across 100 realisations (top panel), and the coefficient of variation about the mean maximum absolute difference between observed and sampled cumulative length distribution functions for the overall albacore size distribution, for each number of fish measured per trip that was tested (with 100 % of trips sampled) (lower panel), for the 2006 "combined" (i.e. strata not considered) simulations

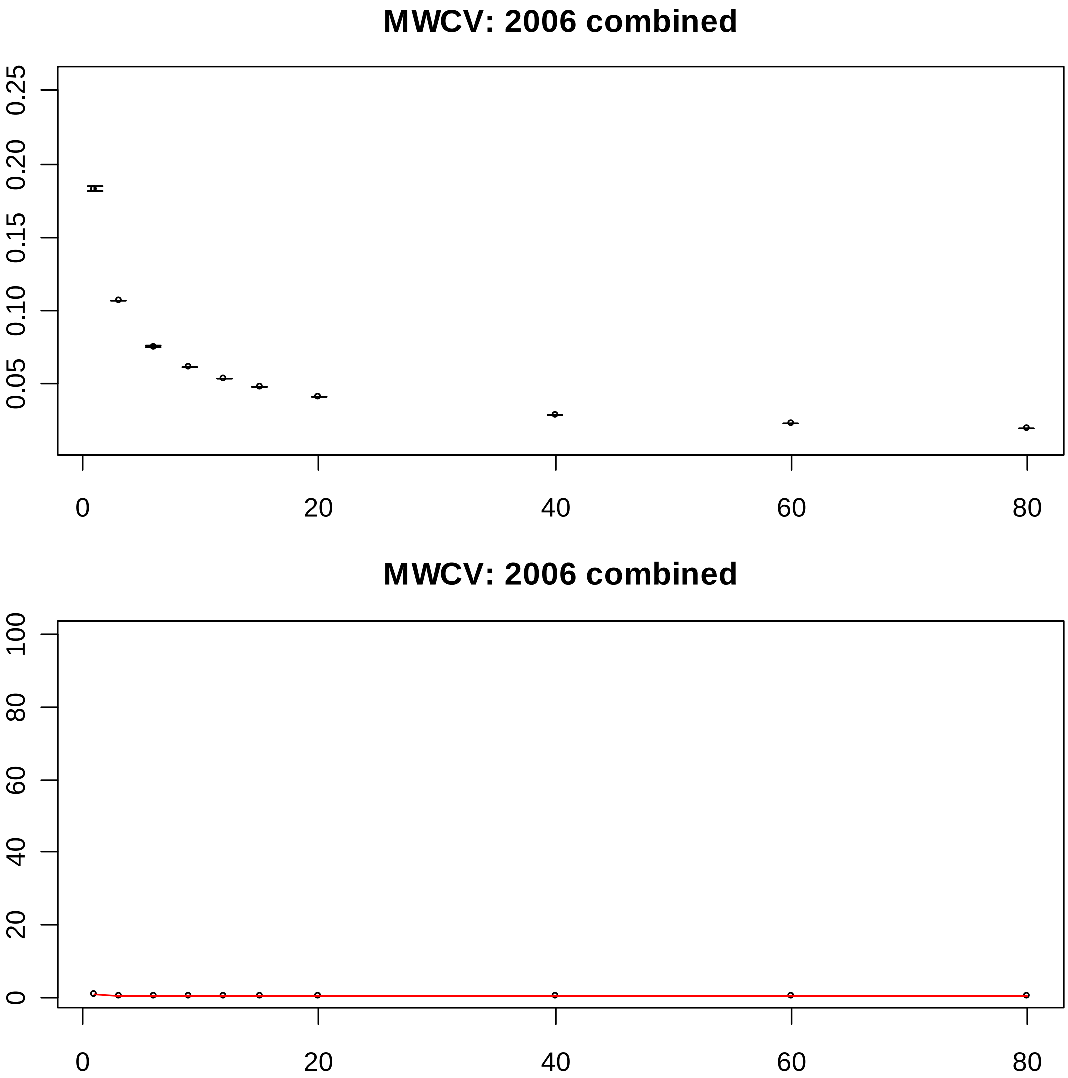


Figure E12: Mean of the mean weighted coefficients of variation for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, with 100 % of trips sampled, across 100 realisations (top panel), and the coefficient of variation about the mean of the mean weighted coefficients of variation for the overall albacore size distribution, for each number of fish measured per trip that was tested (with 100 % of trips sampled) (lower panel), for the 2006 "combined" (i.e. strata not considered) simulations

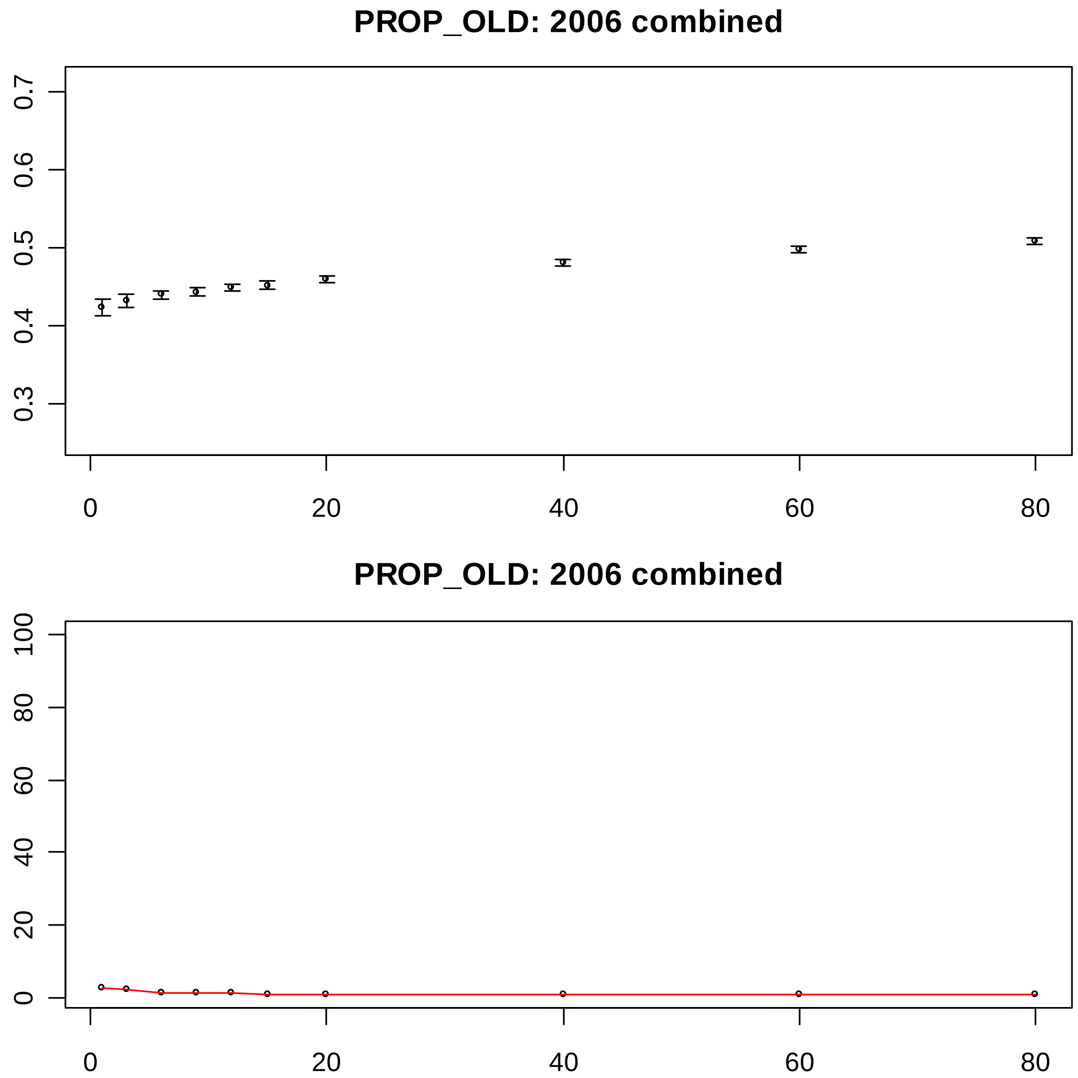


Figure E13: Mean proportion of "old" albacore (± 1 standard deviation) versus number of fish measured per trip, with 90 % of trips sampled, across 100 realisations (top panel), and the coefficient of variation about the mean proportion of "old" albacore, for each number of fish measured per trip that was tested (with 90 % of trips sampled) (lower panel), for the 2006 "combined" (i.e. strata not considered) simulations

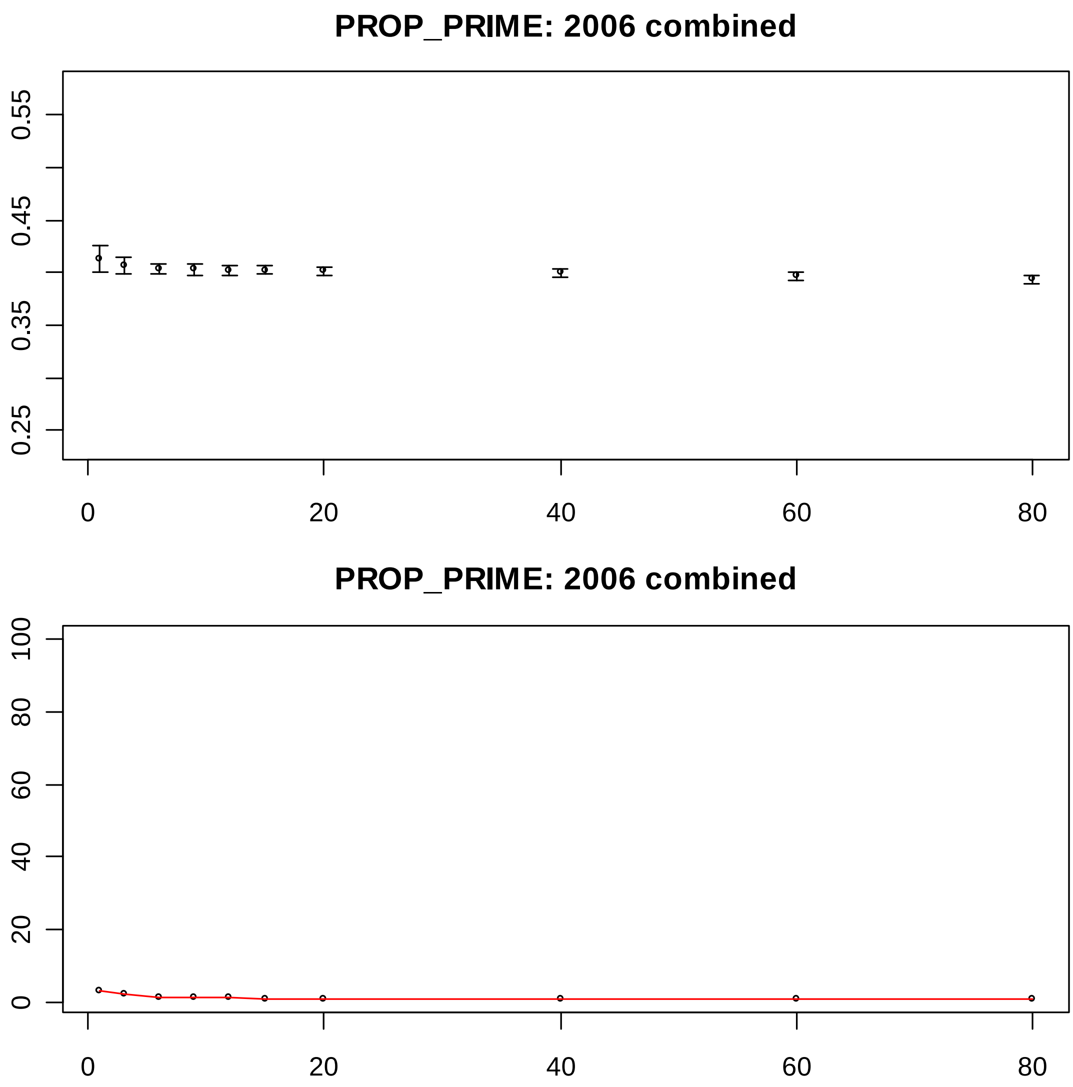


Figure E14: Mean proportion of "prime sized" albacore (± 1 standard deviation) versus number of fish measured per trip, with 90 % of trips sampled, across 100 realisations (top panel), and the coefficient of variation about the mean proportion of "prime sized" albacore, for each number of fish measured per trip that was tested (with 90 % of trips sampled) (lower panel), for the 2006 "combined" (i.e., strata not considered) simulations

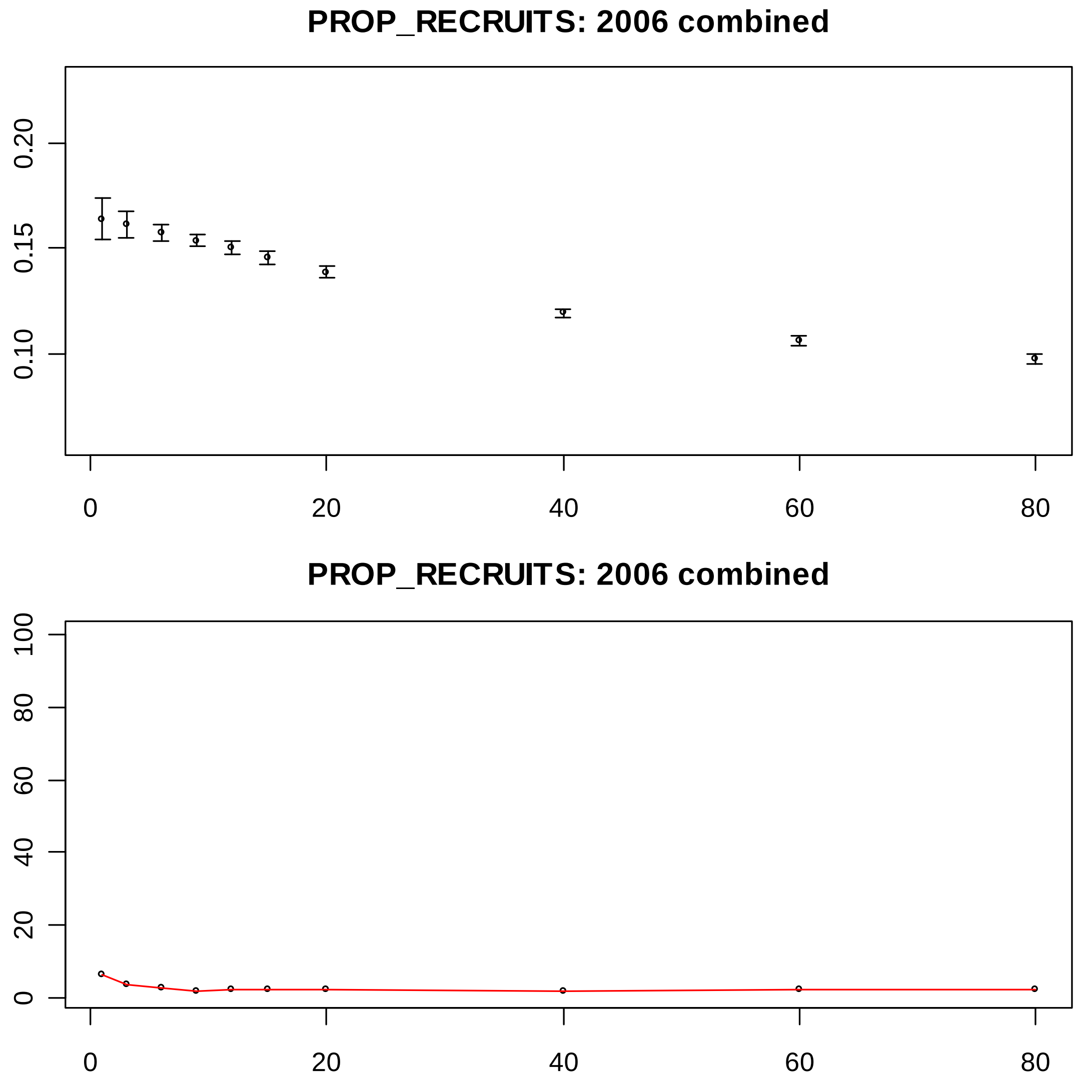


Figure E15: Mean proportion of "recruit sized" albacore (± 1 standard deviation) versus number of fish measured per trip, with 90 % of trips sampled, across 100 realisations (top panel), and the coefficient of variation about the mean proportion of "recruit sized" albacore, for each number of fish measured per trip that was tested (with 90 % of trips sampled) (lower panel), for the 2006 "combined" (i.e. strata not considered) simulations

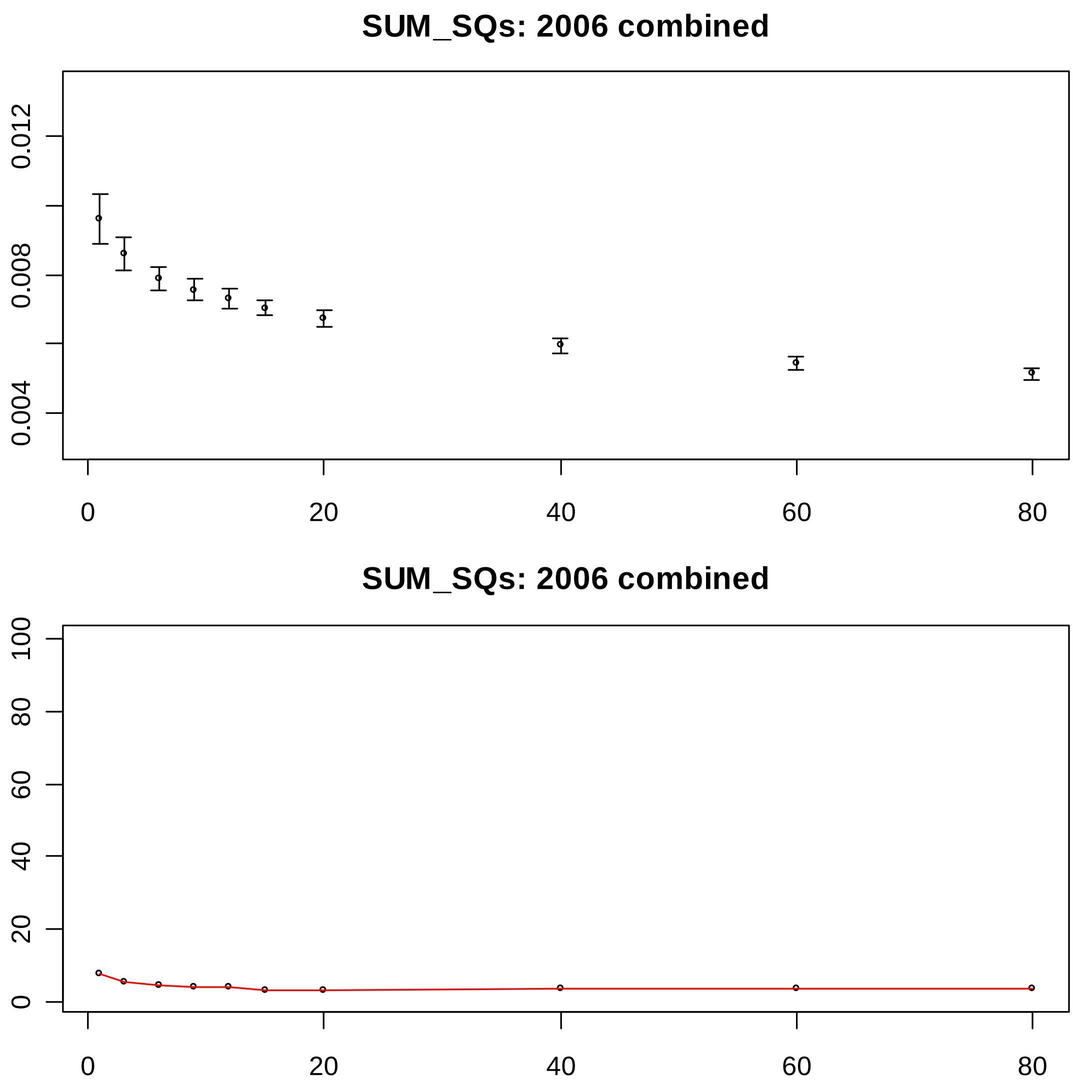


Figure E16: Mean sums of squared differences for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, with 90 % of trips sampled, across 100 realisations (top panel), and the coefficient of variation about the mean sums of squared differences for the overall albacore size distribution, for each number of fish measured per trip that was tested (with 90 % of trips sampled) (lower panel), for the 2006 "combined" (i.e. strata not considered) simulations

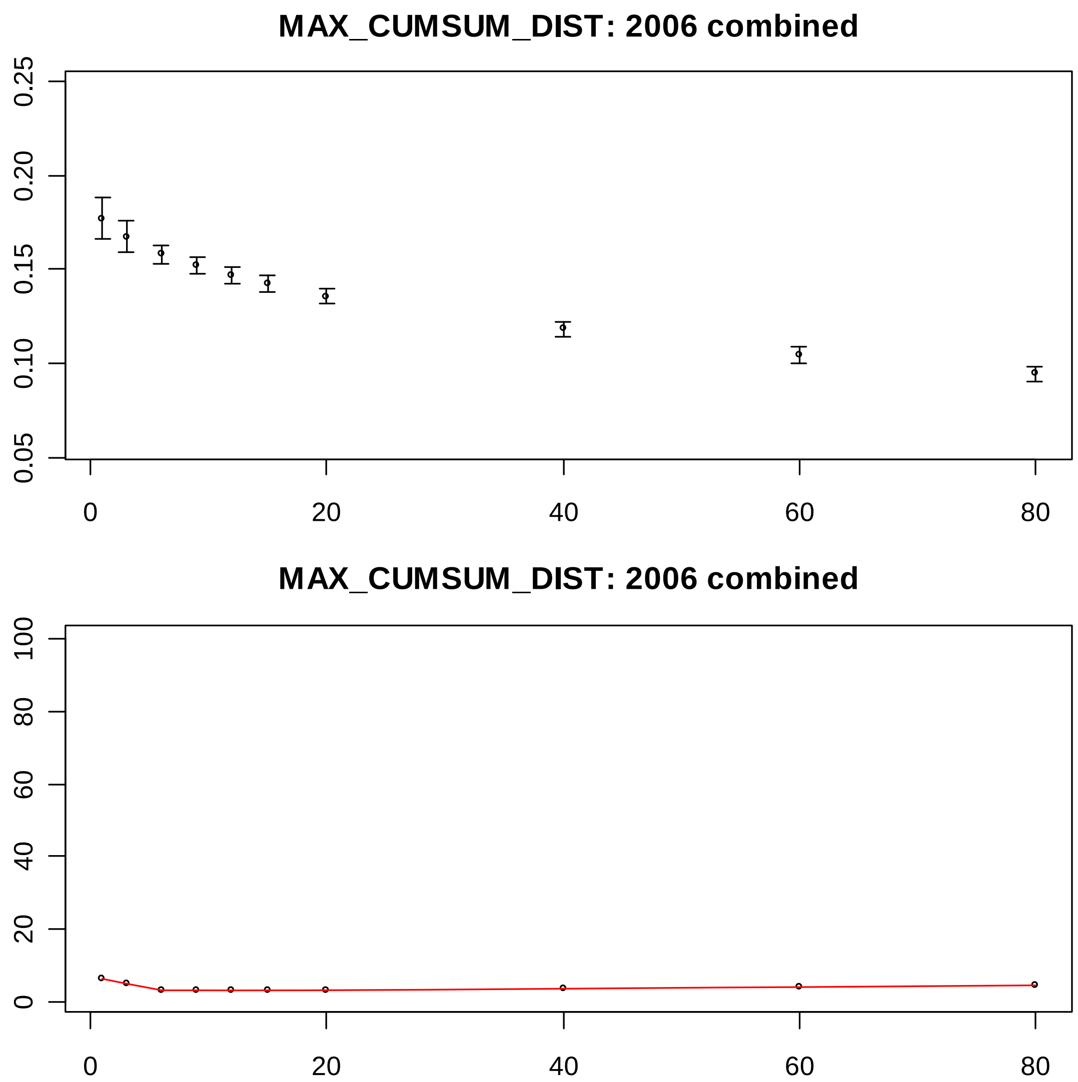


Figure E17: Mean maximum absolute difference between observed and sampled cumulative length distribution functions for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, with 90 % of trips sampled, across 100 realisations (top panel), and the coefficient of variation about the mean maximum absolute difference between observed and sampled cumulative length distribution functions for the overall albacore size distribution, for each number of fish measured per trip that was tested (with 90 % of trips sampled) (lower panel), for the 2006 “combined” (i.e. strata not considered) simulations

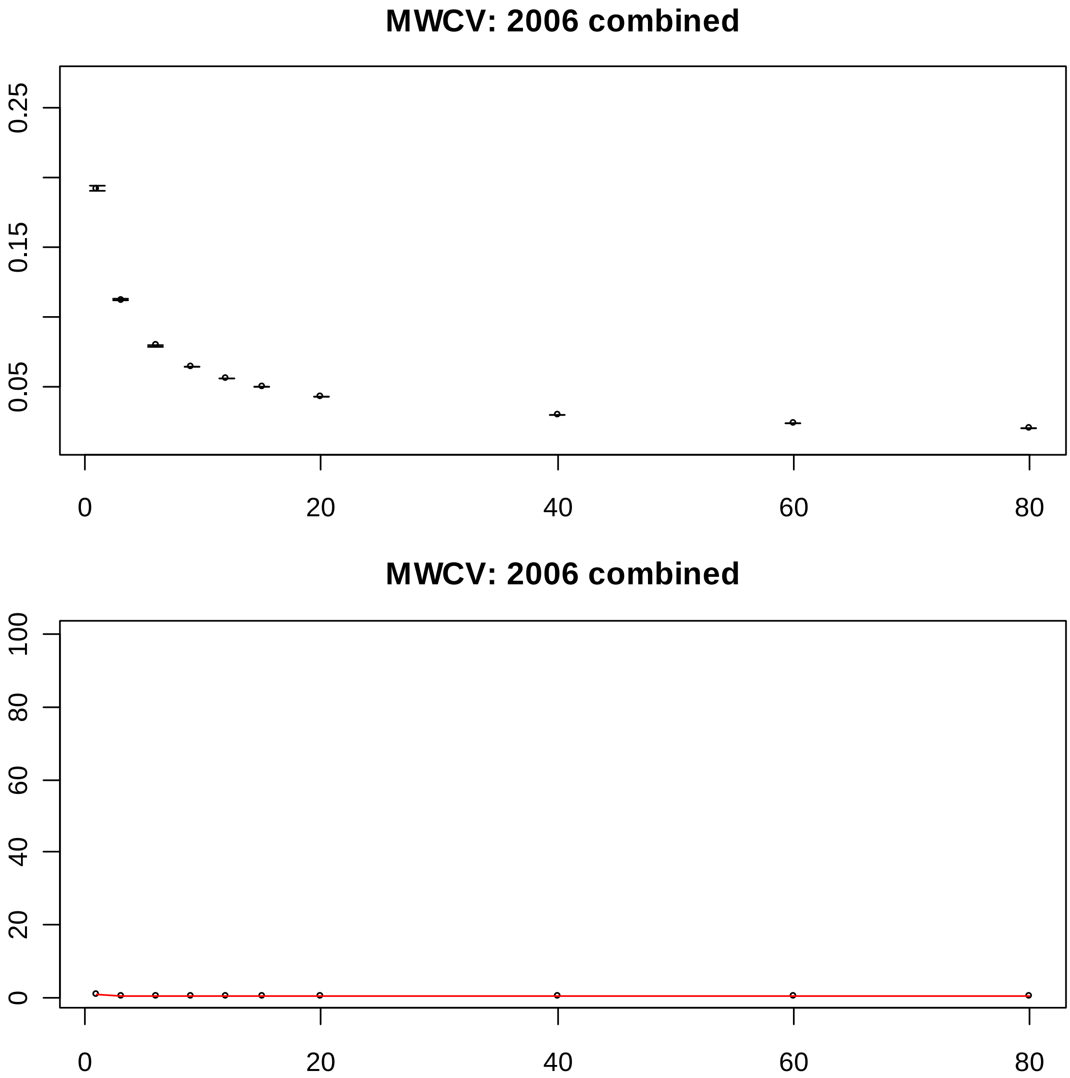


Figure E18: Mean of the mean weighted coefficients of variation for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, with 90 % of trips sampled, across 100 realisations (top panel), and the coefficient of variation about the mean of the mean weighted coefficients of variation for the overall albacore size distribution, for each number of fish measured per trip that was tested (with 90 % of trips sampled) (lower panel), for the 2006 "combined" (i.e. strata not considered) simulations

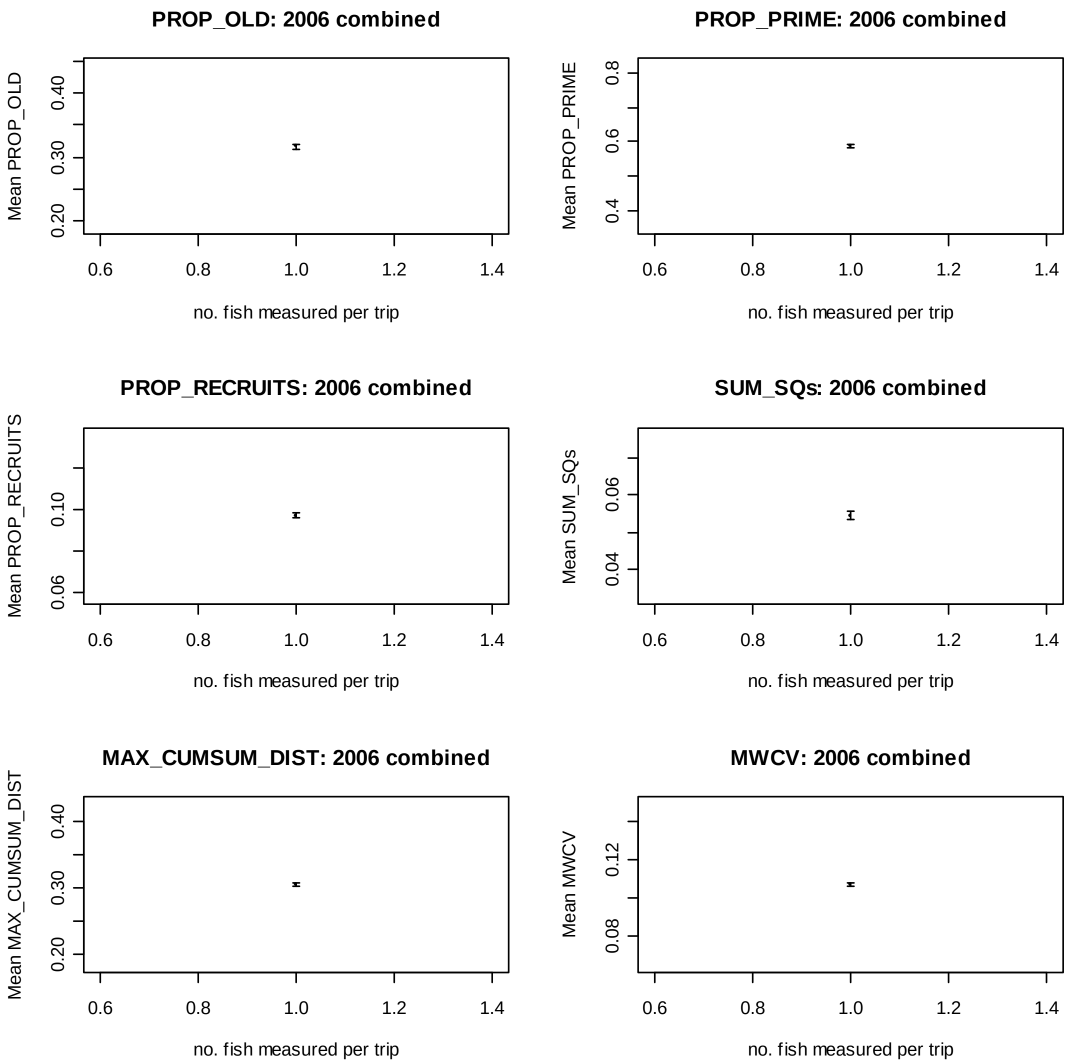


Figure E19: Mean values of all indicators (± 1 standard deviation) based only on knowing the mean length of albacore taken per trip (across all albacore caught on that trip) (as opposed to a subsample consisting of measurements of individual fish), with 100 % of trips sampled, across 100 realisations, for the 2006 “combined” (i.e. strata not considered) simulations.

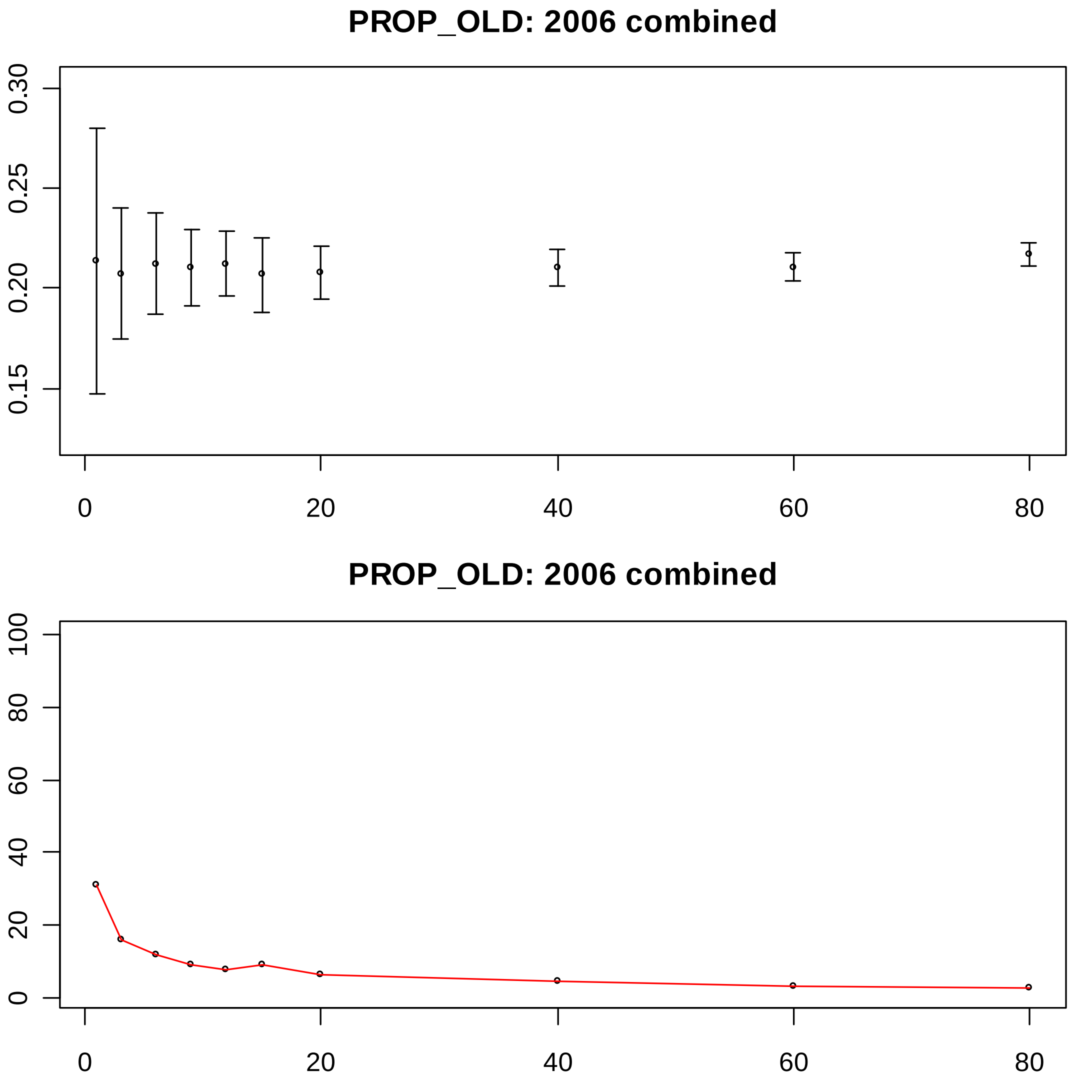
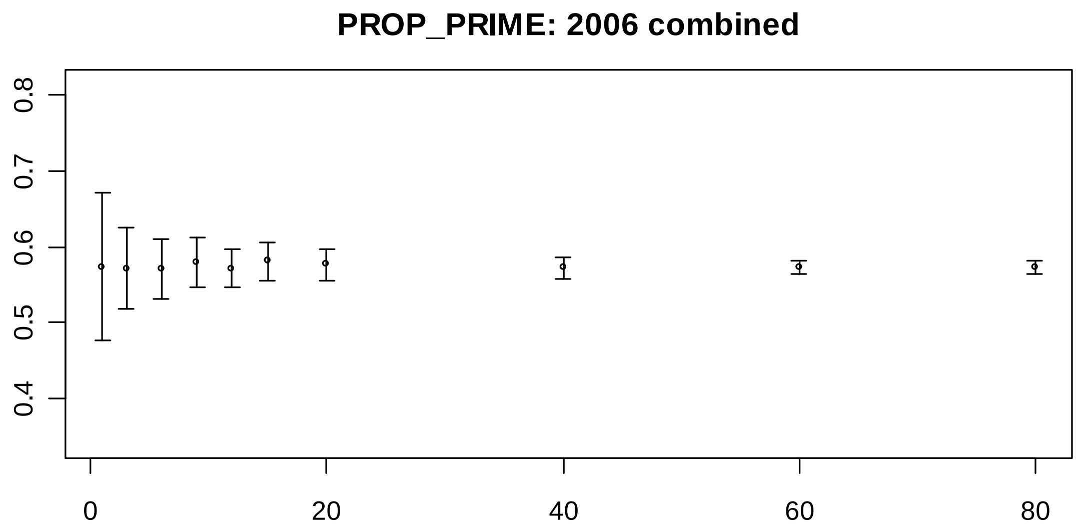


Figure E20: Mean proportion of "old" albacore (± 1 standard deviation) versus number of fish measured per trip, with 100 % of trips sampled, across 100 realisations (top panel), and the coefficient of variation about the mean proportion of "old" albacore, for each number of fish measured per trip that was tested (with 100 % of trips sampled) (lower panel), for the 2006 "combined" (i.e. strata not considered) simulations, where only trips from vessels that had also fished in 2007 were used.



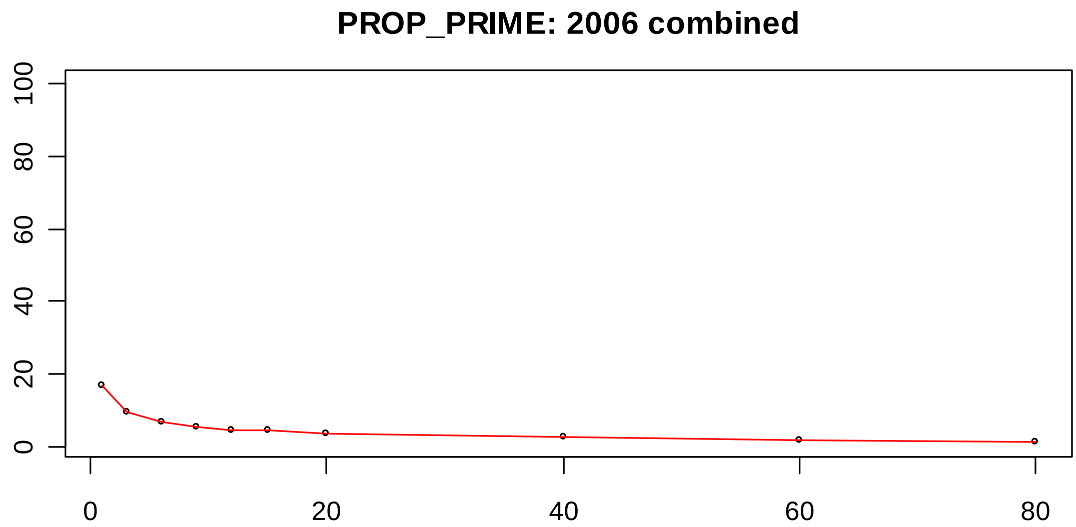


Figure E21: Mean proportion of "prime sized" albacore (± 1 standard deviation) versus number of fish measured per trip, with 100 % of trips sampled, across 100 realisations (top panel), and the coefficient of variation about the mean proportion of "prime sized" albacore, for each number of fish measured per trip that was tested (with 100 % of trips sampled) (lower panel), for the 2006 "combined" (i.e. strata not considered) simulations, where only trips from vessels that had also fished in 2007 were used.

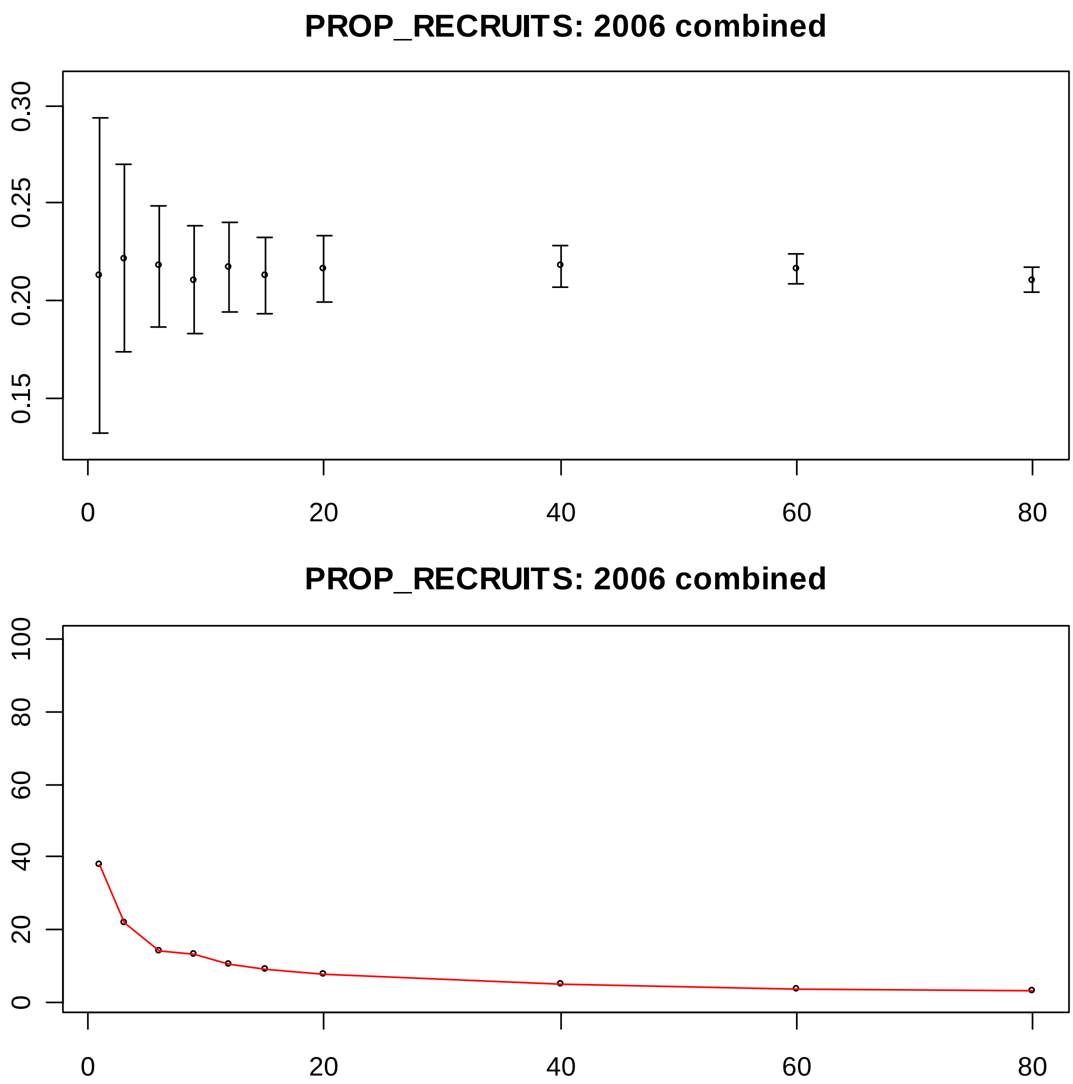
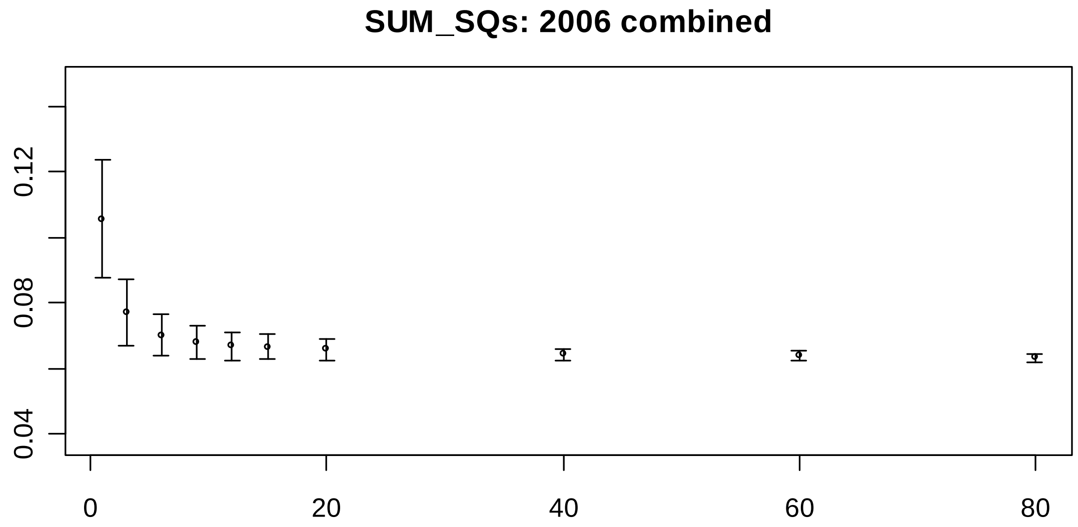


Figure E22: Mean proportion of “recruit sized” albacore (± 1 standard deviation) versus number of fish measured per trip, with 100 % of trips sampled, across 100 realisations (top panel), and the coefficient of variation about the mean proportion of “recruit sized” albacore, for each number of fish measured per trip that was tested (with 100 % of trips sampled) (lower panel), for the 2006 “combined” (i.e. strata not considered) simulations, where only trips from vessels that had also fished in 2007 were used.



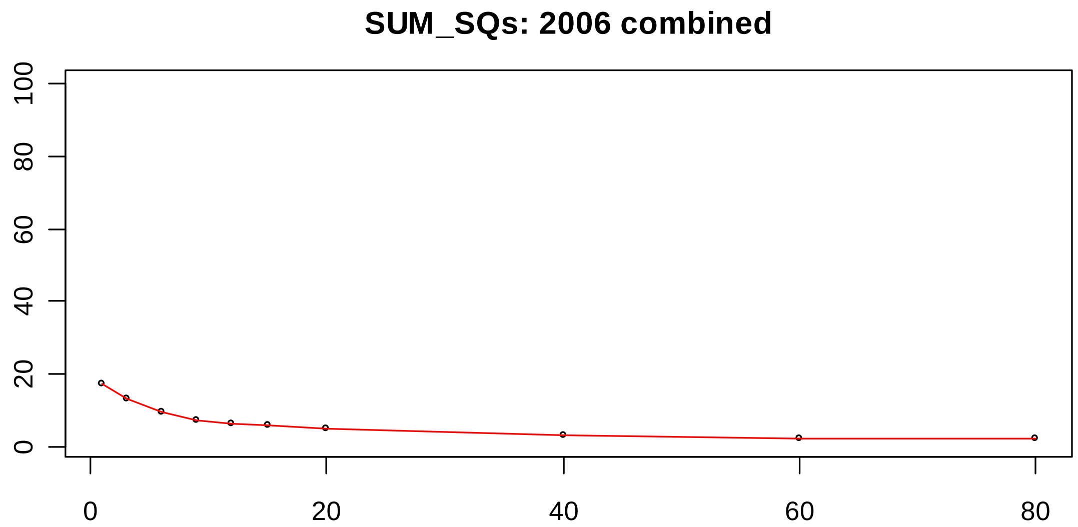


Figure E23: Mean sums of squared differences for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, with 100 % of trips sampled, across 100 realisations (top panel), and the coefficient of variation about the mean sums of squared differences for the overall albacore size distribution, for each number of fish measured per trip that was tested (with 100 % of trips sampled) (lower panel), for the 2006 "combined" (i.e. strata not considered) simulations, where only trips from vessels that had also fished in 2007 were used.

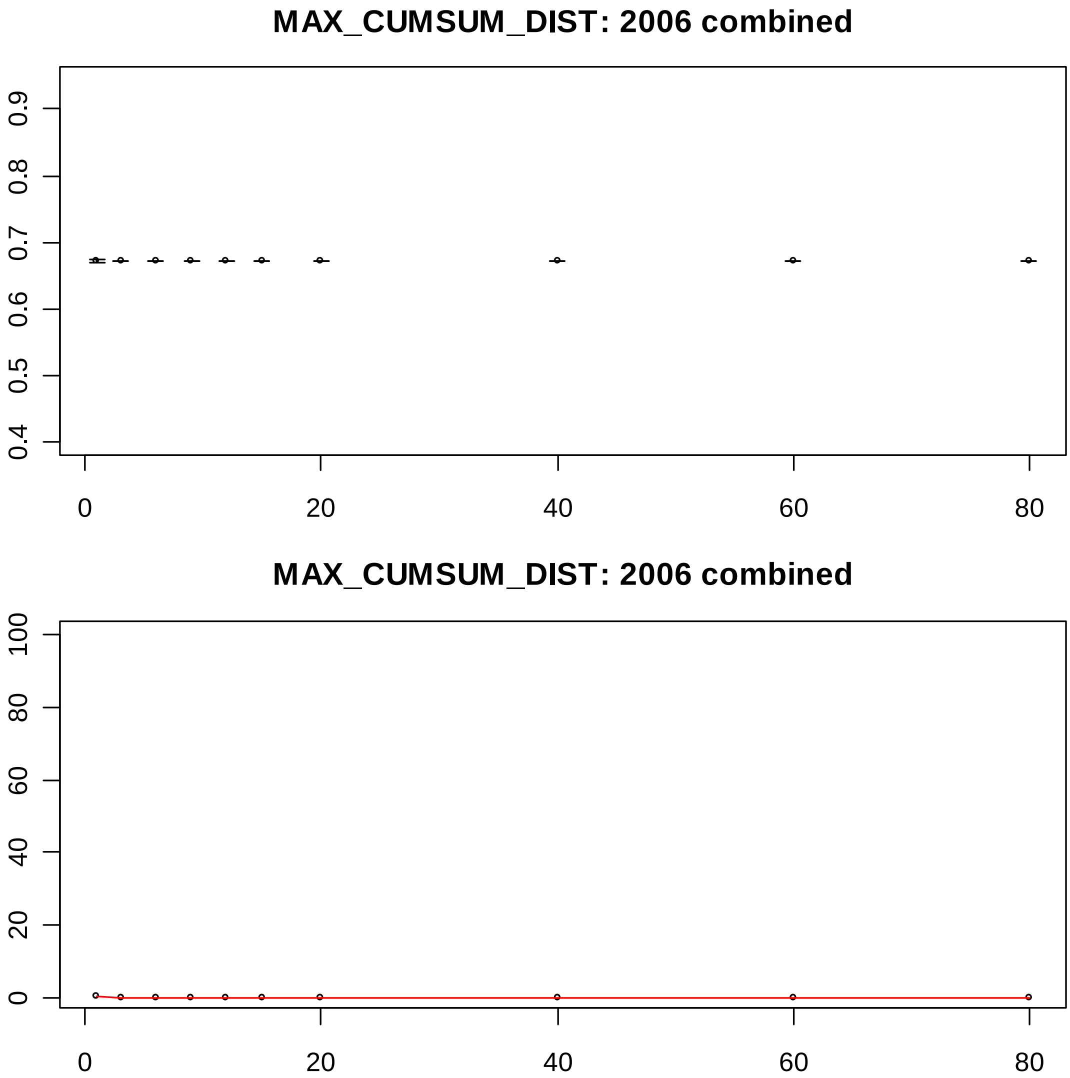


Figure E24: Mean maximum absolute difference between observed and sampled cumulative length distribution functions for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, with 100 % of trips sampled, across 100 realisations (top panel), and the coefficient of variation about the mean maximum absolute difference between observed and sampled cumulative length distribution functions for the overall albacore size distribution, for each number of fish measured per trip that was tested (with 100 % of trips sampled) (lower panel), for the 2006 "combined" (i.e. strata not considered) simulations, where only trips from vessels that had also fished in 2007 were used.

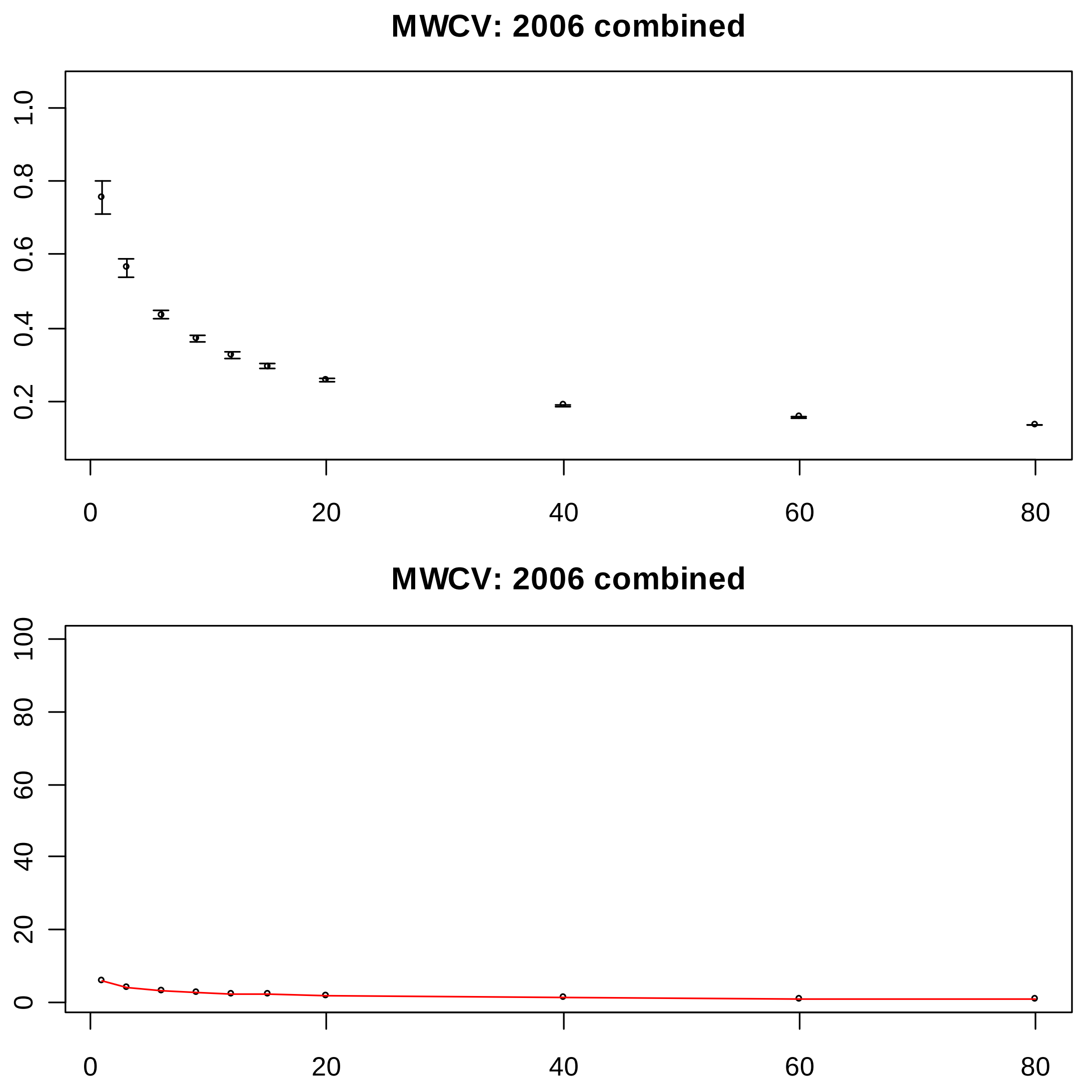


Figure E25: Mean of the mean weighted coefficients of variation for the overall albacore size distribution (± 1 standard deviation) versus number of fish measured per trip, with 100 % of trips sampled, across 100 realisations (top panel), and the coefficient of variation about the mean of the mean weighted coefficients of variation for the overall albacore size distribution, for each number of fish measured per trip that was tested (with 100 % of trips sampled) (lower panel), for the 2006 "combined" (i.e. strata not considered) simulations, where only trips from vessels that had also fished in 2007 were used.

17. Appendix F: Sample size analysis

Marinelle Basson

Some investigations were conducted on the basis of existing biological data for albacore obtained from a pilot study undertaken by CSIRO (Farley and Clear, 2008) to advise on appropriate sample sizes for growth and maturity studies.

Growth

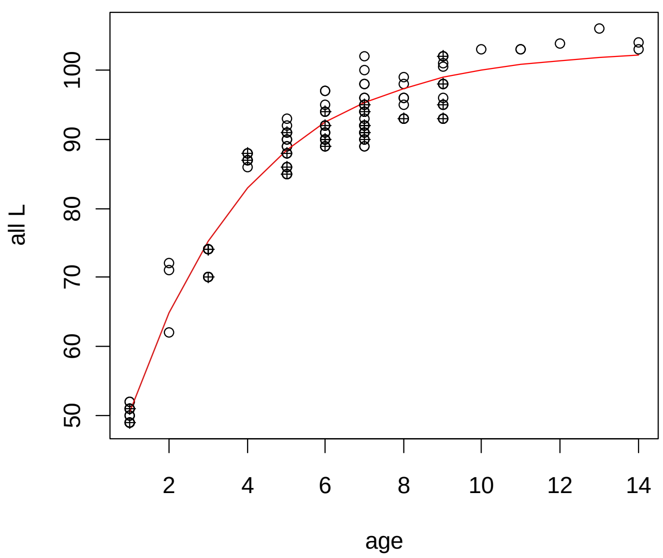
First, von Bertalanffy growth curves were estimated for the observed data on age and length (Figure F1). Then bootstrapping was used to explore the characteristics of parameter estimates (uncertainty, CV in particular) under different sampling levels.

<u>Males, females and unknown combined.</u>

```
alba> tryvb <- nls(LCF.cm ~ L*(1-exp(-k*(Age-t0))),
data=albdat.age,start=list(L=100,k=0.3,t0=-1))
alba> summary(tryvb)
Formula: LCF.cm ~ L * (1 - exp(-k * (Age - t0)))

Parameters:
    Estimate Std. Error t value Pr(>|t|)
L  102.86529    1.19909  85.786  < 2e-16 ***
k    0.32090    0.02166  14.813  < 2e-16 ***
t0  -1.10694    0.13908  -7.959 9.73e-12 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 3.182 on 80 degrees of freedom
Number of iterations to convergence: 5
Achieved convergence tolerance: 1.140e-06
```

Figure F1. Data and growth curve for males, females, unknown combined. Points for females have + inside o. n=83.



The parameter estimates and standard errors imply the following %CVs: ~2 % for Linf, ~7 % for k and ~ 13 % for t0. This is exceptionally low for such a relatively small sample; possibly in part due to the large number of age classes and the 'flattening out' (ie similar sizes) for the oldest five age classes.

Table F1 below gives results for 200 replicates of four types of bootstrap: bootstrapping individuals, bootstrapping by age class and Bayesian bootstraps by individuals and by age class. Differences between individual and age-class bootstraps can show whether there are age class effects (if there are, the bootstraps by age class are preferred). In short, the bootstrap approaches are:

- by individual: use 'sample' in R to pick 83 individuals (ie age and length pairs) from the observed sample of 83, with replacement.
- by age: use 'sample' to pick age classes from the observations; repeat this with replacement until you have 83 sampled observations.
- Bayesian: use the exponential distribution with mean 1 to pick 83 weights (rexp(83,1)); use these weights in the fitting of the growth curve.
- Bayesian by age: assign a weight to each age class using rexp(14,1) (assuming 14 age classes; or however many there are in the sample), and use this with the age of each individual to assign each observation a weight. This implies that all individuals in a given age class will have the same weight in the fit.

Ideally, sampling at the individual and at the age level should lead to similar results, and they do mostly for the interquartile range. The CVs are, however, generally higher when sampling by age class than by individual (Table F2). For k and Linf the increase is between 20 % and 45 %, but for t0 the CV doubles. It is intuitive why leaving out an entire age class (or heavily down-weighting it) – the first, in particular – has a strong effect on the estimation of t0.

The bootstraps were run for the observed sample size of 83. The %CVs for other sample size can be inferred. For example, if the sample size is doubled, the CV is roughly reduced by a factor of sqrt(1/2). Examples are given in the lower part of Table F2.

Table F1. Median and quartiles for 200 bootstraps. Males, females and unknown combined.

	Linf (q1, median, q3)			k (q1, median, q3)			t0 (q1, median, q3)		
point estimates	102.87			0.32			-1.11		
by indiv. n=83	102.0	102.9	103.8	0.30	0.32	0.34	-1.19	-1.10	-1.03
by age n=83	102.2	102.9	103.6	0.31	0.32	0.34	-1.20	-1.11	-1.03
Bayesian n=83	102.1	103.0	103.5	0.31	0.32	0.34	-1.18	-1.10	-1.04
Bayesian by age, n=83	102.1	103.3	104.3	0.29	0.32	0.34	-1.30	-1.14	-1.03

Table F2. %CVs for 200 bootstraps. Males, females, unknown combined.

%CV	Linf	k	t0
from Hessian of fit Observed sample n=83	1.19	6.9	12.7
by indiv. n=83	1.28	7.46	10.76
by age n=83	1.19	8.89	24.34
Bayesian n=83	1.18	7.10	10.36
Bayesian by age n=83	1.55	10.28	20.44
n=150 (Bayesian, inferred)	0.9	5.3	7.7
n=200 (Bayesian, inferred)	0.8	4.6	6.7

Results suggest that even just 100 aged individuals, provided they cover the size / age ranges as in the pilot sample, should give very acceptable CVs for growth parameters. More young and old (small and large) individuals would be of benefit (also see below). So far, no strong cohort effect has been identified, though with more years' worth of data, this should again be checked.

This following section looks a bit closer at the effect of dropping any given age class from the curve fitting. It confirms the importance of the first age class (age 1), and in fact the third age class which is where most of the curvature of the growth curve lies. Although results don't illustrate the effect of removing, say, the oldest two or three age classes, it is obvious that this would have a strong effect; this can be seen further below by comparing results for males and females separately, since most of the larger older individuals are males – this is further discussed below.

Leaving age class 1 out has the biggest effect on the CVs of all three parameters and tends to lead to a higher Linf, lower k and lower t0. Remember that Linf and k tend to be strongly correlated. Dropping age 3 out also has a strong effect on the parameter values, but not really on their CVs. The young ages – 2, 3, 4 – provide most information on the curvature of the growth curve and good representation of those in the samples is desirable.

```
***********
Jacknife results by AGE group: results for L, k, t
tryjack.age <- do.jack()
alba> tryjack.age
The first column shows which age class was dropped from analysis; the
next three give the parameter estimates and the last three columns are
the estimated %CVs of each parameter (from the Hessian of the fit).
   age.out       L     k     t0  cvL   cvk   cvt
1        1 104.662 0.269 -1.846 1.81 13.14 28.12
2        2 103.322 0.313 -1.125 1.16  6.49 11.79
3        3 101.910 0.343 -1.004 1.12  7.09 13.60
4        4 103.877 0.299 -1.232 1.26  6.99 11.97
5        5 103.145 0.313 -1.154 1.28  7.71 13.77
6        6 102.876 0.320 -1.112 1.20  7.11 13.24
7        7 103.320 0.322 -1.081 1.10  6.18 11.72
8        8 103.189 0.318 -1.117 1.24  6.92 12.72
9        9 103.378 0.315 -1.136 1.30  7.02 12.55
10      10 102.613 0.325 -1.090 1.18  6.83 12.78
```

```
11      11 102.390 0.328 -1.071 1.21  7.05 13.19
12      12 102.584 0.325 -1.085 1.19  6.94 12.95
13      13 102.336 0.329 -1.064 1.18  6.92 13.05
14      14 102.426 0.328 -1.070 1.27  7.36 13.61
```

Figure F2. Plotting %CVs vs age dropped out to show which ages, when dropped out, make most difference. Panels from L to R are for Linf, k, t0

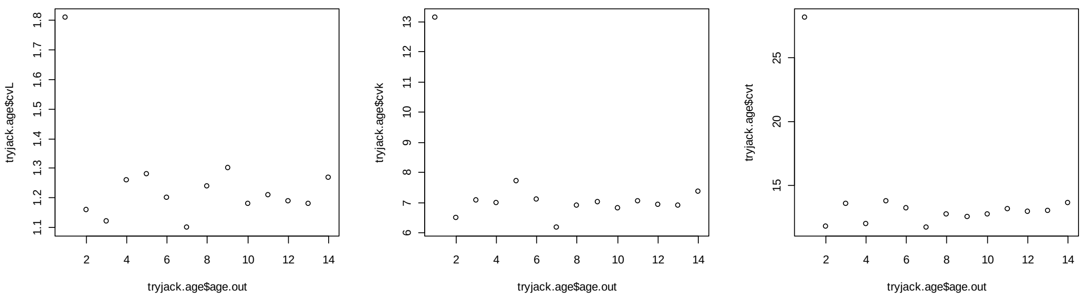
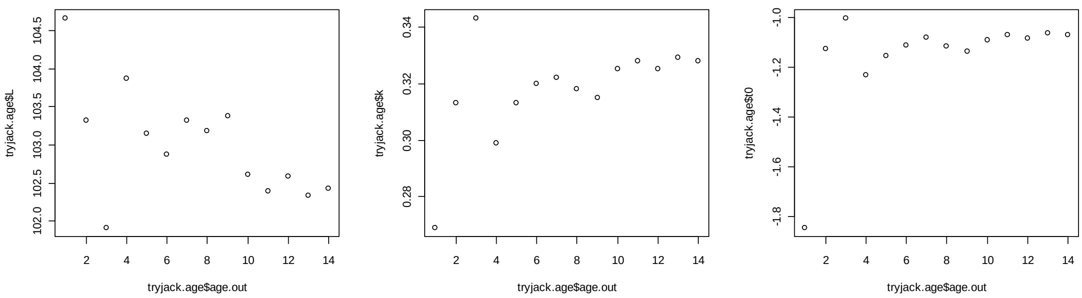


Figure F3. Plots of point estimates for Linf, k, t0 (from L to R)



<u>Growth curve – Males only</u>

The sample of aged males is only 45. The model fitted to the data gives the following results:

```
MALES
alba> vb.male <- nls(LCF.cm ~  L*(1-exp(-k*(Age-
t0))),data=albdat.age[albdat.age$Sex=="Male",],start=list(L=100,k=0.3,
t0=-1))
alba> summary(vb.male)

Formula: LCF.cm ~ L * (1 - exp(-k * (Age - t0)))

Parameters:
    Estimate Std. Error t value Pr(>|t|)
L  104.49394    1.59877  65.359  < 2e-16 ***
k    0.30200    0.03189   9.470 5.57e-12 ***
t0  -1.36228    0.32848  -4.147  0.00016 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 3.263 on 42 degrees of freedom
Number of iterations to convergence: 3
Achieved convergence tolerance: 8.236e-06
```

See Figure F5 of fit.

This implies %CVs of parameters: 1.5 % for L, 10.6 % for k and 24.1 % for t0. Bootstrap results just for males are shown in the tables F3 and F4 below.

Table F3. Median and quartiles for 200 bootstraps. Males.

	Linf (q1, median, q3)	k (q1, median, q3)	t0 (q1, median, q3)
point estimates	104.5	0.30	-1.36
by indiv. n=45	103.60 104.50 105.40	0.28 0.30 0.32	-1.64 -1.32 -1.13
by age n=45	104.00 104.50 105.00	0.29 0.30 0.31	-1.56 -1.39 -1.27
Bayesian n=45	104.00 104.60 105.10	0.28 0.30 0.32	-1.60 -1.36 -1.19
Bayesian by age, n=45	104.10 104.70 105.30	0.28 0.30 0.31	-1.57 -1.36 -1.22

Table F4. %CVs for 200 bootstraps. Males.

%CV	Linf	k	t0
from Hessian of fit observed sample (n=45)	1.53	10.56	24.11
by indiv. n=45	1.29	11.60	36.82
by age n=45	1.02	9.28	41.54
Bayesian n=45	1.00	8.87	25.15
Bayesian by age, n=45	0.96	7.11	17.09

Now the CVs are generally lower when sampling by age rather than individual. The only exception is for t0 under the regular (ie not Bayesian) bootstrap.

Figure F4. Jacknife estimates of (left to right) Linf,k,t0 for males only.

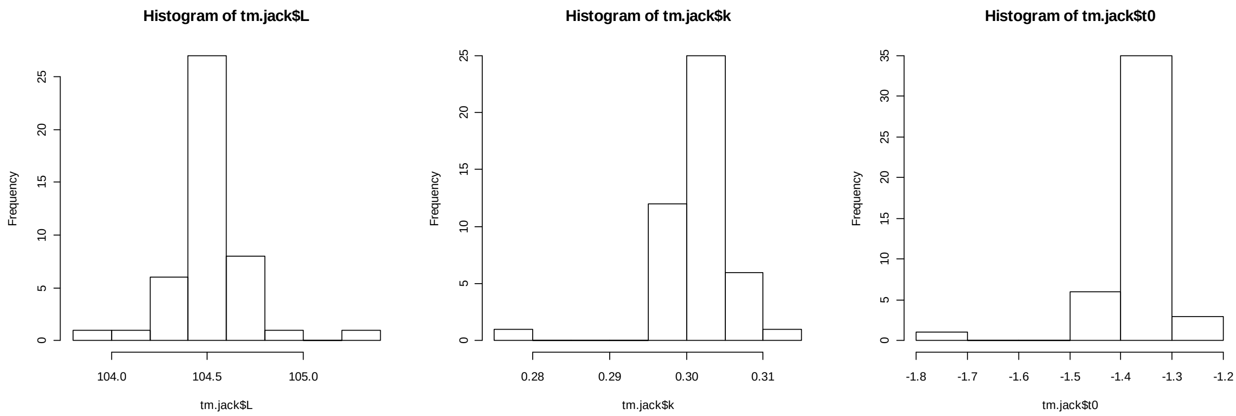
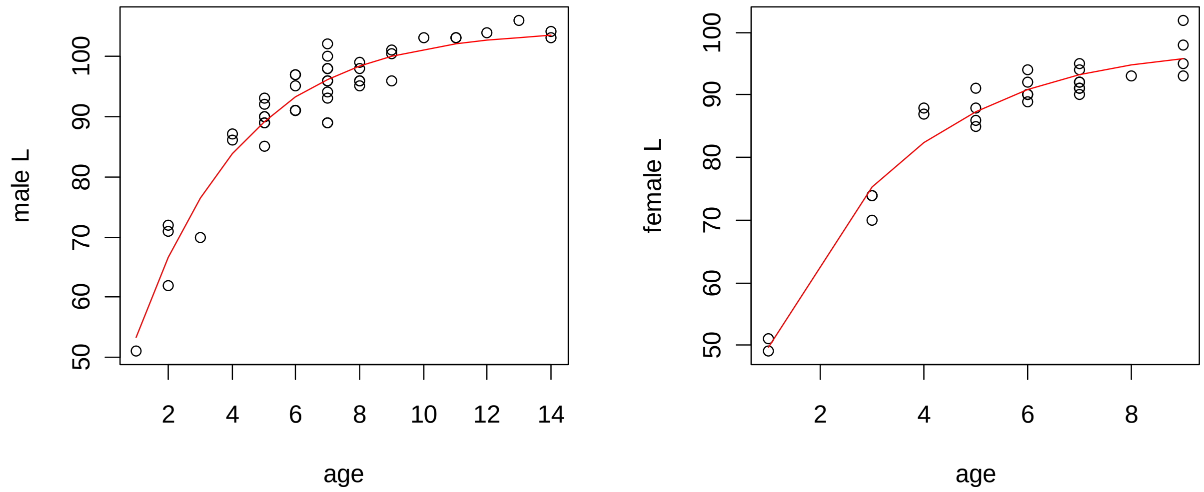


Figure F5. Fitted von Bertalanffy growth curves to males (left, n=45) and females (right, n=28)



<u>Growth curve – Females only</u>

```
FEMALES
alba> vb.female <- nls(LCF.cm ~  L*(1-exp(-k*(Age-
t0))),data=albdat.age[albdat.age$Sex=="Female",],start=list(L=100,k=0.
3,t0=-1))
alba> summary(vb.female)
Formula: LCF.cm ~ L * (1 - exp(-k * (Age - t0)))
Parameters:
   Estimate Std. Error t value Pr(>|t|)
L  98.37936    1.81797  54.115  < 2e-16 ***
k   0.37264    0.04465   8.347 1.08e-08 ***
t0 -0.88323    0.25341  -3.485  0.00183 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 2.842 on 25 degrees of freedom
Number of iterations to convergence: 3
Achieved convergence tolerance: 1.412e-06
```

For the female subsample, the %CVs are: 1.8 % for Linf, 12 % for k and 28.7 % for t0. Figure F5 shows the absence of young (age 2) and old (older than 9) females (assuming they do live to similar ages as males).

Bootstrap results for females are given in the tables below. Now the CVs again increase when sampling by age. The Bayesian bootstrap gives substantially lower CVs than the non-Bayesian bootstrap. This presumably reflects the potentially strong effect of leaving out observations or age classes (rather than just down-weighting them) given the already small sample size of only 28 observations.

Table F5. Median and quartiles for 200 bootstraps. Females.

	Linf (q1, median, q3)	k (q1, median, q3)	t0 (q1, median, q3)
point estimates	98.4	0.37	-0.88
by indiv. n=28	97.13 98.21 99.79	0.34 0.38 0.41	-0.94 -0.82 -0.71
by age n=28	96.69 98.00 99.17	0.35 0.38 0.42	-0.96 -0.83 -0.68
Bayesian n=28	96.91 97.93 99.12	0.35 0.38 0.41	-0.94 -0.82 -0.71
Bayesian by age, n=28	97.02 98.45 99.66	0.34 0.37 0.42	-1.00 -0.84 -0.67

Table F6. %CVs for 200 bootstraps. Females.

%CV	Linf	k	t0
from Hessian of fit observed sample (n=28)	1.85	11.98	28.69
by indiv. n=28	2.56	30.30	69.00
by age n=28	3.43	32.56	172.81
Bayesian n=28	1.81	11.82	23.93
Bayesian by age, n=28	1.87	15.77	30.10

These results show that sample sizes as low as 28 or 45 are not adequate for estimating separate growth curves by sex. Given that there appears to be significant differences in growth rate and Linf (at least on the basis of the existing data), the aim should be to collect sufficient samples to be able to estimate separate growth curves by gender. For females, one main concern is the lack of good coverage over all age classes; for both sexes, better coverage of ages 1 to 5 would be beneficial.

Maturity

L_{50} is the ratio of the two estimated parameters, –apar/bpar.

```
alba> tmat
Call:  glm(formula = mcode ~ LCF.cm, family = binomial, data =
tempdat)
Coefficients:
(Intercept)       LCF.cm
    -53.245        0.621

Degrees of Freedom: 60 Total (i.e. Null);  59 Residual
Null Deviance:      68.05
Residual Deviance: 22.73        AIC: 26.73
alba> 53.245/0.621
L50 = 85.74074
```

Here, only Bayesian bootstrap was undertaken to further explore the CV of L_{50}.

```
test1 <- do.matfit(200,61,bayesboot=T)
alba> summary(test1$L50)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
  81.93   84.79   85.79   85.64   86.65   88.04
# As a check also get direct var and CV of L50 from bootstraps
```

```
alba> var(test1$L50)
[1] 1.705583
alba> sqrt(var(test1$L50))/mean(test1$L50)
CV = 0.01525050  (i.e. %CV is 1.5%)

Via aparam and bparam and log relationship...
j1 = V(a)/E(a)^2
j2 = V(b)/E(b)^2
j3 <-
var(test1$apar)*var(test1$bpar)/(mean(test1$apar)*mean(test1$bpar))
 (j1+j2-2*j3)*(mean(test1$apar)/mean(test1$bpar))^2

another run
alba> test1.bayes <- do.matfit(200,61,bayesboot=T)
Eqns above: meanL50 85.80421232; Var(X/Y)=2.23961269 CV=0.01744126
alba> var(test1.bayes$L50)
[1] 1.681723
alba> sqrt(var(test1.bayes$L50))/mean(test1.bayes$L50)
[1] 0.01511363
```

From this, the %CV via the ratio (-apar/bpar) is 1.7 % and the direct CV of L_{50} is 1.5 %. The CV is again very low for only 60 individuals. What is more of a danger is possible bias due to absence (from catch) of small, immature animals.

Age data and ALKs

The age data are used in estimating growth parameters (see above) and potentially in turning L50 (size at maturity) into an age at maturity. The ALKs can also be used to turn the catch into catch-at-age for use in a VPA-type assessment, for applying catch curve analysis and for estimating total mortality. At this stage, it was not worth ding more substantial explorations with the specific methods and existing small age sample (of 83 fish) regarding sample sizes and CVs of parameter estimates. Some “common sense” advice is provided in this regard.

Conclusions

Regarding growth, even the relatively low samples of 83 individuals provide low CVs for growth parameters. The small and large individuals are particularly relevant to estimation of t0 and Linf in particular and good coverage of ages is desirable. Also note that good sample sizes for ages 2-4, where most of the curvature in the growth curve lies, is desirable.

As seen in the results for males and females separately, any lower sample sizes have increased chances of “gaps” or low numbers at some ages and CVs will increase. If the aim is to estimate separate male and female growth curves, at least 100 of each sex, with as good a coverage of ages, should be collected.

Although the CVs of L_{50} based on only 61 individuals is very small, the concern is that there may be bias because of low sample sizes of small but potentially mature individuals. This is not so much a direct sample size issue, but one of a good ‘spread’ of sizes and ages in the vicinity of estimated L_{50} (from the pilot and other studies).

The age and ALK plus size frequency data can be used in many different ways, and I have not fully explored these other applications (eg catch curve analysis or catch-at-age estimates). Nonetheless, some general advice can be provided.

In general, the advice would be as follows:

1. For growth studies, 100+ individuals (length and age data), with good coverage of ages / sizes should provide acceptable CVs.
2. Data so far strongly suggest differences in growth between males and females, so sufficient data (ie point 1 above) should be collected by gender. If area specific growth curves are the aim, then point 1 applies to each area and gender.
3. Given all the potential uses of length data, these should be sampled randomly from the catch.
4. Hardparts for ageing should be sub-sampled from the length data, stratified by length class. It may be necessary to sample additional large individuals (this should be flagged in the data).
5. The current project has a large planned otolith sample (around 3,000). I would suggest aiming to collect that many (or as close to that as possible), but then reading otoliths in batches of convenient numbers (e.g. 100 or 200) and updating these sample-size checks to avoid reading far more than necessary.
6. For reproductive studies, around 100 individuals seem sufficient for estimating L50 (though aim to collect more than that if at all possible, particularly if you want to compare with estimates from other areas), but attention should be paid to sampling times and sizes of individuals (as far as is practical) to minimise bias. In other words, try to sample as many as possible small-ish, but possibly mature individuals. Coverage of length and age classes is again important, so sub-sampling from the length frequency stratified by length (and possibly taking additional samples, but flagging this) would be recommended.

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