



# Stock assessment of the Australian East Coast Spanish mackerel (*Scomberomorus commerson*) fishery

Alexander B. Campbell, Michael F. O'Neill, Jonathan Staunton-Smith, Jo Atfield, John Kirkwood

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# 1 Executive Summary

The narrow-barred Spanish mackerel, *Scomberomorus commerson*<sup>1</sup>, is an important target species of both commercial and recreational fishers across northern Australia. In Queensland three distinct stocks have been identified: Gulf of Carpentaria, Torres Strait, and the East Coast extending from north Queensland into northern New South Wales. An assessment of the East Coast stock is reported here.

Queensland commercial catch and effort data have been collected since 1988 using compulsory logbooks (CFISH: The Commercial Fisheries Information System). Catch and effort have been variable, however standardised catch rates have been stable over time. The only variations appear to be due to fluctuations in recruitment. The apparent stability of the catch rates is suspect due to potential hyperstability. This is a particular concern as a) catch logs do not contain sufficiently detailed effort information (to be able to confidently detect and correct for hyperstable fisher behaviour, e.g. targeting of schools/aggregations, and b) Spanish mackerel are a strongly schooling species. An alternative standardised index was constructed which was designed to be more sensitive to this issue. This index declined from 2003 to 2008, finishing at 62% of the previous ten year average (1993-2002), and in 2009 it rebounded to 73%. The power of this index is limited by poor effort data, and its recent decline is not consistent with the pattern of harvest over time, however it should not be disregarded entirely.

Commercial catch data (sourced from Queensland Fish Board, CFISH, NSW Fisheries) and recreational catch data (sourced from RFISH: Queensland Recreational Fishing Information System, NRIFS: The National Recreational and Indigenous Fishing Survey of Australia, Queensland charter boat logbooks, NSW Fisheries) for the Queensland East Coast were calculated back to 1937. Age, length and sex data (sourced from Fisheries Queensland, CRC: Cooperative Research Centre for the Great Barrier Reef World Heritage Area, CapReef) were collated from 2002 to 2009, in addition to age, length and sex data from 1977 to 1979 (sourced from Fisheries Queensland). These data, along with the standardised catch rates, were input into a sex-age-length structured population model to estimate fishing mortality rates and trends in stock size.

Due to lack of contrast in the data, the model was sensitive to assumptions about stock-recruitment steepness. This, and issues relating to the catch history, lead to a large number of data scenarios being analysed in order to document full uncertainty in current stock status. Under the 'most plausible' assumptions regarding model inputs and data weighting, two alternate hypotheses for stock status emerged, depending on which of two standardised catch rate series were used: either biomass in 2009 at 51% of virgin biomass (based on a 'baseline' standardisation), or biomass in 2009 at 39% (based on a 'hyperstability-adjusted' standardisation). The 5<sup>th</sup> and 95<sup>th</sup> percentiles for these scenarios were 47%-55%, and 34%-42% respectively. These stock status estimates correspond roughly to fishing at a level that is often used as a proxy for "Maximum Economic Yield" (MEY) in the first instance, or fishing at "Maximum Sustainable Yield" (MSY) in the latter. The full uncertainty cannot be captured by any one scenario in isolation, rather the range of uncertainty across these scenarios should be considered.

---

<sup>1</sup> Hereafter simply referred to as Spanish mackerel.

## 2 Acknowledgements

We would like to acknowledge the contributions that enabled the compilation of this report. Thanks to Geoff McPherson, Stephanie Slade, Bonnie Holmes, Kate Yeomans, Clive Turnbull and George Leigh. Thanks also to everyone involved with Spanish mackerel sampling in the Fisheries Queensland monitoring program and to stakeholders who have provided valuable feedback in meetings.

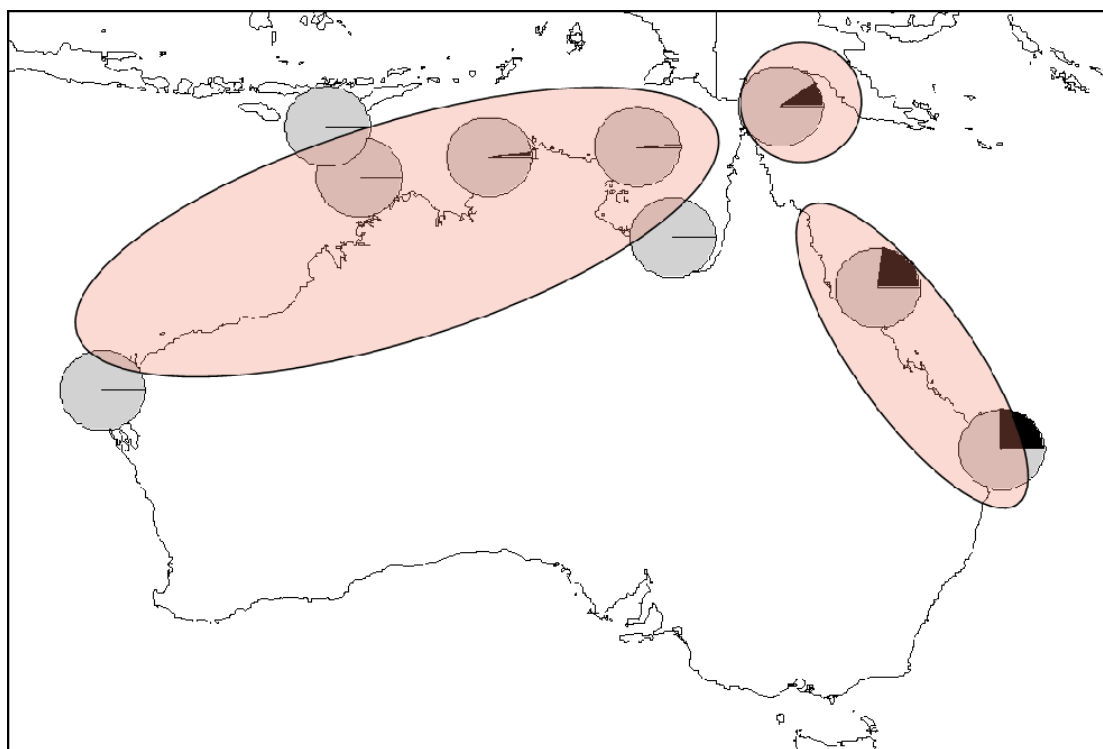
This report is dedicated to Darren Barry Rose (14 July 1972–9 July 2009), a young fisheries biologist who spent many of his waking hours during the best years of his life working in his dream job in northern Queensland. Darren (pictured on report cover) was instrumental in setting up and running the routine monitoring program to collect biological data for several species throughout Queensland, including Spanish mackerel and barramundi. His caring nature, understanding of fish biology and Queensland's commercial and recreational fishing industries, and commitment to collecting quality scientific data made him an ideal person to coordinate and mentor a team of scientists carrying out fishery-dependent sampling at Cairn's Northern Fisheries Centre. Darren's hard work will never be forgotten by his colleagues, and his love of life and his young family will never be forgotten by anyone who knew him.

### **3 A note on document structure**

The sex-age-length-structured population models that were the basis for all stock status estimates in this report are contained in (Campbell and O'Neill in draft). The methods section of the article was attached as Appendix A. The focus of the article is model selection, not stock assessment. Hence this report is a necessary accompaniment to the overall stock assessment reporting. The equations of the models are given solely in the article and are not reproduced in the main body of the report, however all references to parameters in the report are consistent with those in the article.

## 4 Introduction

In Australia the narrow-barred Spanish mackerel, *Scomberomorus commerson*, are widespread throughout tropical and sub-tropical areas. They are a highly mobile pelagic fish commonly schooling around reefs, shoals and headlands. Recent stock structure research identified that Spanish mackerel in Australian waters are made up of at least three genetic populations: 1) East Coast of Australia, 2) Torres Strait and 3) Northern Australia (from the Gulf of Carpentaria west to Northern Territory and north Western Australian waters) (Figure 1, (Ovenden and Street 2007)). This stock assessment focuses on the east Australian Spanish mackerel stock extending from Cape York in north Queensland to their southern extent in northern New South Wales waters. Across the commercial and recreational sectors, harvest landings of eastern Spanish mackerel vary in the order of 700 to 1400 tonnes annually with a commercial value of \$7-14 millions dollars Gross Value of Production (GVP). Further general information on Spanish mackerel can be obtained from the Department of Agriculture, Fisheries and Forestry , Queensland ([http://www.dpi.qld.gov.au/28\\_10717.htm](http://www.dpi.qld.gov.au/28_10717.htm) and <http://www.dpi.qld.gov.au/fishweb>) and the Fisheries Research and Development Corporation (<http://www.frdc.com.au/species.php>).



**Figure 1** Australian Spanish mackerel genetic population structure (Ovenden and Street 2007).

The Queensland component of the East Coast Spanish Mackerel Fishery (ECSMF), operating between northern Queensland and the Queensland-New South Wales border, has undergone two ecological assessments by the Australian Government Department of Sustainability, Environment, Water, Population and Communities (SEWPaC). The first assessment in October 2004 identified several risks that needed to be addressed, including uncertainty in stock assessment; lack of ongoing robust stock assessment process; lack of validation of commercial catch and effort data; lack of performance indicators and measures; inadequate reporting on the status of the fishery; and paucity of information about recreational take. Recommendations in relation to these matters were addressed before the expiry of the Wildlife Trade Operation (WTO) accreditation for the fishery. The ECSMF was re-accredited by SEWPaC in October 2007 with further recommendations relying on stock assessment outcomes. Improved quantitative stock

assessment of the ECSMF will enable Fisheries Queensland to determine and report on fishery status in an accurate manner and ensure that management arrangements are appropriate to provide for sustainability, and maximum economic and social benefit. If a review of management arrangements is required, the assessment outcomes will provide a basis for review.

The objectives of this report are:

To collate available biological, historical fisheries, and commercial and recreational catch and effort data on the ECSMF.

To review the extent and quality of all available data to determine the potential for a formalised assessment of the fishery.

To optimise use of all available data to describe current trends in the fishery, and if data permits, undertake a formalised assessment of the status of the ECSMF.

To advise on monitoring, reporting and/or further research required to improve or enable future assessments of the ECSMF.

Previous assessments of the East Coast Spanish mackerel stock were conducted through age-structured models. At a Spanish mackerel stock assessment workshop conducted by Dr Carl Walters (University of British Columbia, Canada) in Darwin in 1997, the Queensland East Coast stocks were considered to be heavily exploited. While the data used were sparse, conclusions were that spawning stock levels were low. O'Neill and McPherson (2000) piloted the first stock assessment and identified a risk of overfishing. They also noted that Dr Carl Walters recommended a target reference point of  $F \sim 0.5M$  (that is, fishing mortality should be half that of natural mortality; used in this report), and that management should be focused on fishing mortality (i.e. fishing effort) rather than stock biomass (i.e. using quotas).

Another preliminary assessment of the fishery also found a high degree of uncertainty around parameter estimates and data used as input to the model, and concluded that fishing effort should not be increased above 2002 levels which could be effectively achieved through imposing either catch or effort restrictions (Welch, Hoyle *et al.* 2002).

Spanish mackerel have since been regulated by commercial catch quota and recreational possession limits in Queensland. A management strategy evaluation (Hoyle 2002; Hoyle 2003; Welch, Hoyle *et al.* 2002) found that large uncertainty in stock status translated to large uncertainty in the need for, and efficacy of, various management strategies. Recommendations for monitoring included extending the otolith sampling to be more representative, and determining confidence intervals for recreational catch. These early assessments and simulations led to a power analysis study to determine appropriate regional sample sizes for otolith collection and length measurement (Sumpton and O'Neill 2004). In 2007 an assessment was performed and outputs were reported to the Reef Management Advisory Committee (ReefMAC) Scientific Advisory Group (SAG) in March 2008 (DPI&F 2008a). Results suggested that the exploitable stock was most likely being harvested near or exceeding maximum sustainable levels, with biomass levels in 2007 between 30-60% of unfished or virgin biomass levels. The ReefMAC SAG agenda paper containing the assessment results is included as Appendix F.

This assessment extended the previous methodology to an age and length structured approach. The motivation for adding a length component to the model is described in some detail in Appendix A, but in general it was designed to better address issues relating to growth. Spanish mackerel are fast growing in their first years and this growth appears to have strong inter-annual variation. The model was also sex-stratified as there is a considerable difference in growth between the sexes. A length and age structured model was able to maximise use of the available length and age data. The updated methodology achieved relatively good predictions of the data against external assumptions; in particular, uncertain assumptions relating to the productivity of the stock.

## 5 Materials and methods

The standardisation of catch rates, the reconstruction of annual landings, a brief overview of the sampling program data and the sensitivity analyses are described here. The population model and all equations are described in Appendix A.

### 5.1 Standardised catch rates

As advised by Fisheries Queensland's Scientific Advisory Group for offshore line caught species (ReefMAC SAG), two annual time-series of standardised catch rates were considered for indices of abundance (Figure 9):

1) The first time-series (labelled as "base" case) was a standardized commercial line catch rate of Spanish mackerel. This series was derived from an analysis of non-zero daily catches; no fishing effort records on hours fished and hours search time was available for locations of zero or non-zero catch. Spanish mackerel catch rates were standardized through a linear mixed model (REML: restricted maximum likelihood analysis) assuming normally distributed errors on a log scale (GenStat 2008). The model response variable ( $\eta$ ) consisted of the log of the daily catch (kg) from each vessel operation. Explanatory fixed model terms included the two-way interactions between fishing years, regions, and months. Random terms were the individual vessels anonymous identification code. The regions represented latitudinal assessment zones along the East Coast of Queensland (Figure 8). Lunar cycle was represented by two covariates: (i) a calculated luminance measure that followed a sinusoidal pattern, and (ii) the same lunar data replicated and advanced 7 days (O'Neill and Leigh 2007). Together, these patterns modelled the cyclic variation in catches corresponding to the moon phase. The base average annual catch rates were predicted from the linear mixed model using GenStat's marginal weights policy of averaging over the factor levels for month, region and vessels (GenStat 2008). Predicted log-means were rescaled using a common bias-corrected back-transformation of adding half the model residual variance (McCullagh and Nelder 1989). The time series was normalised to a relative (proportion) scale, where catch rates in 1992 were =1.

2) The second time-series explored overcoming hyperstability bias caused by limited effort reporting. The challenge was to determine a surrogate for change in frequency of harvesting (finding-catching-keeping) a Spanish mackerel. A two-component methodology was followed to correspond to presence (harvesting) or absence of Spanish mackerel in the fishery (O'Neill and Faddy 2003). For the first component, the presence or absence of Spanish mackerel harvested on every day by fishing year, month and region was modelled as a binary response (GenStat 2008; McCullagh and Nelder 1989). Explanatory model terms included two-way interactions for fishing-year\*region and region\*month (Table 1). Given that Spanish mackerel occurred in the harvest (second component), the non-zero catch rates from base case analysis 1) above were applicable. The annual predictions from logistic and mixed linear regressions were multiplied together to represent a less hyperstable abundance variant. The time series was normalised to a relative (proportion) scale, where catch rates in 1992 were =1. This index was introduced as a result of discussions at SAG meetings. See Appendix D for more background and motivation on this issue.

**Table 1 GenStat code used to analyse Queensland commercial Spanish mackerel catches.**

---

**Linear mixed model – base analysis**

```
VCOMPONENTS [FIXED=fishyear*region*month+lunar+lunar_adv\
; FACTORIAL=2] RANDOM=boat; INITIAL=1; CONSTRAINTS=none
REML [PRINT=model,components,effects,waldTests,means; PSE=allestimates; METHOD=Al;\
MAXCYCLE=20] logwt
```

```
vpredict [print=description,predictions] fishyear "Predicts standardised catch rates"
```

**Generalised linear model – logistic regression for hyperstability variant**

```
MODEL [DISTRIBUTION=binomial; LINK=logit; DISPERSION=1] spmfished; NBINOMIAL=1
FITindividually [PRINT=model,summary,estimates,accumulated;\,confidence; \PROBABILITY=0.95;\
CONSTANT=estimate; FPROB=yes; TPROB=yes; FACT=2;\
selection=%variance,%ss,adjustedr2,\
r2,seobservations,dispersion,%meandeviance,%deviance,aic,sic;]\
region*fishyear+region*month
RWALD
```

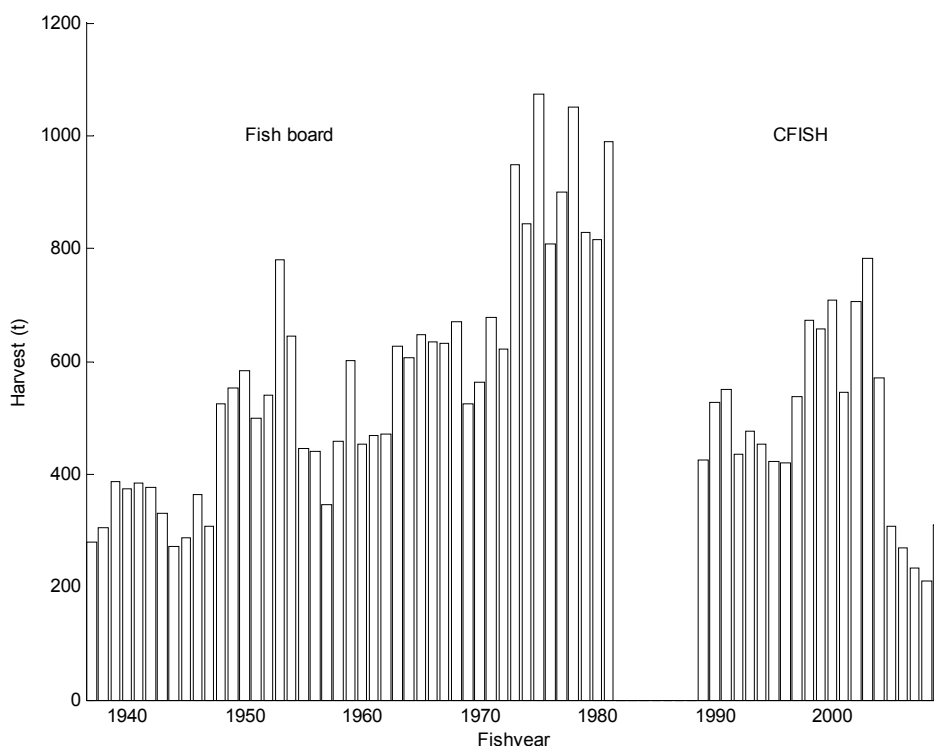
```
predict [print=desc,pred,se] fishyear "Predicts probability of Spanish mackerel harvest in each year"
```

---

## 5.2 Annual landings

Annual landings since the designated beginning of the fishery in 1937 were compiled from a number of sources: Queensland commercial Fish Board landings data; Queensland Commercial Fishing Information System logbooks (CFISH); Queensland charter logbooks; Queensland Recreational Fishing Information System diary program (RFISH), (DEEDI 2010a); FRDC Report 92/144 (FRDC) (Cameron and Begg 2002); National Recreational and Indigenous Fishing Survey (NRIFS) (Henry and Lyle 2003); NSW commercial logbooks; and NSW Recreational Boat Ramp Survey (RBRS) (Steffe, Murphy *et al.* 1996).

Fish Board landings covered the years from 1937 to 1981, with reliable CFISH records starting in 1989 and continuing through to 2009 (Figure 2). All references to years are 'fishing years' where for example 2009 is fiscal year 2008/2009. The Queensland commercial harvests between 1981 and 1989 were linearly interpolated using coefficients based on the best fit of existing data between 1973 and 1996.



**Figure 2** Fish Board and CFISH data.

Queensland recreational catch estimates (harvest plus released fish) from RFISH and NRIFS surveys are given in Table 2. The catch history for this sector was reconstructed as follows: Harvest and release numbers were converted to total catch in weight. Harvest numbers were multiplied by 9.2kg average fish weight (Olyott and Rose 2008) and release numbers were multiplied by 1.86kg which was the average weight of tagged and released fish less than 1 metre total length (data supplied by Infofish Australia from the Suntag database as at June 2007; 1.86kg may appear low compared to average fish weight but there is a rapid acceleration in weight with increasing length (cubic relationship)).

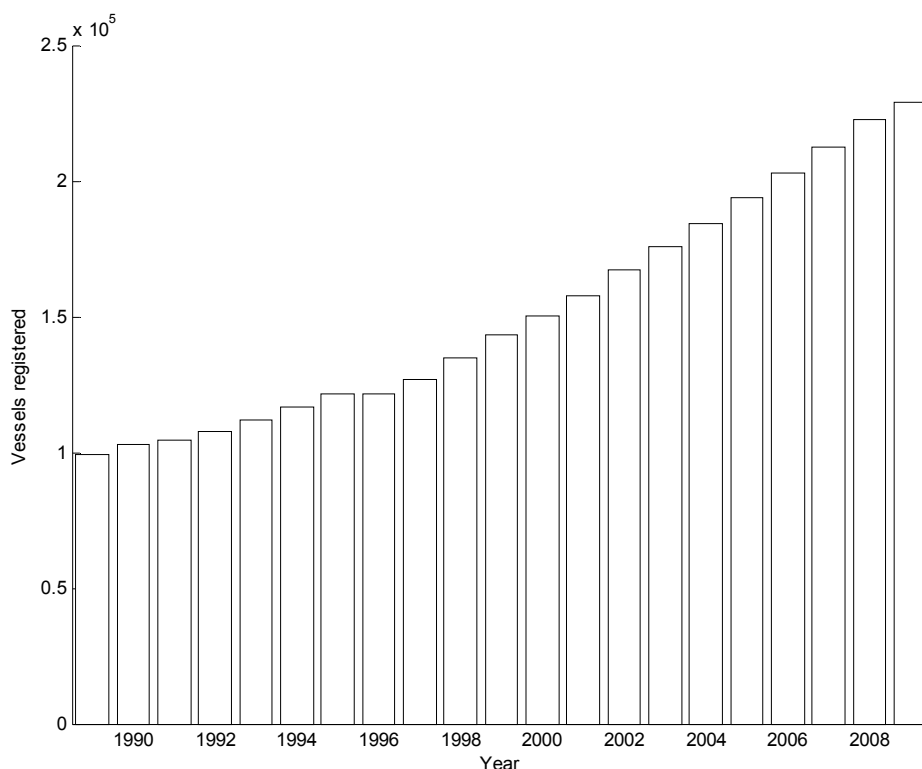
Recreational effort proxies for the period 1989 to 2009 were calculated by dividing the resulting catch weights (in tonnes) by the standardised commercial catch rate for that year. Two alternate scenarios for recreational effort during this period were considered: a) Constant effort equal to the

mean of the calculated effort values, and b) Rising effort proportional to the number of recreational vessels registered in Queensland (Figure 3), where total catch during this period was the effort proxy in each year multiplied by the standardised commercial catch rate.

Total catch for the period 1937 to 1988 was back-calculated as a constant decline of 4% per year from the value in 1989 (Welch, Hoyle *et al.* 2002).

**Table 2** Input data for Queensland recreational catch.

| Year | Source | Harvest (n) | Release (n) |
|------|--------|-------------|-------------|
| 1995 | FRDC   | 7344        | 5333        |
| 1997 | RFISH  | 57260       | 17500       |
| 1999 | RFISH  | 56134       | 26079       |
| 2001 | NRIFS  | 42830       | 9878        |
| 2002 | RFISH  | 37313       | 13210       |
| 2005 | RFISH  | 44912       | 18510       |



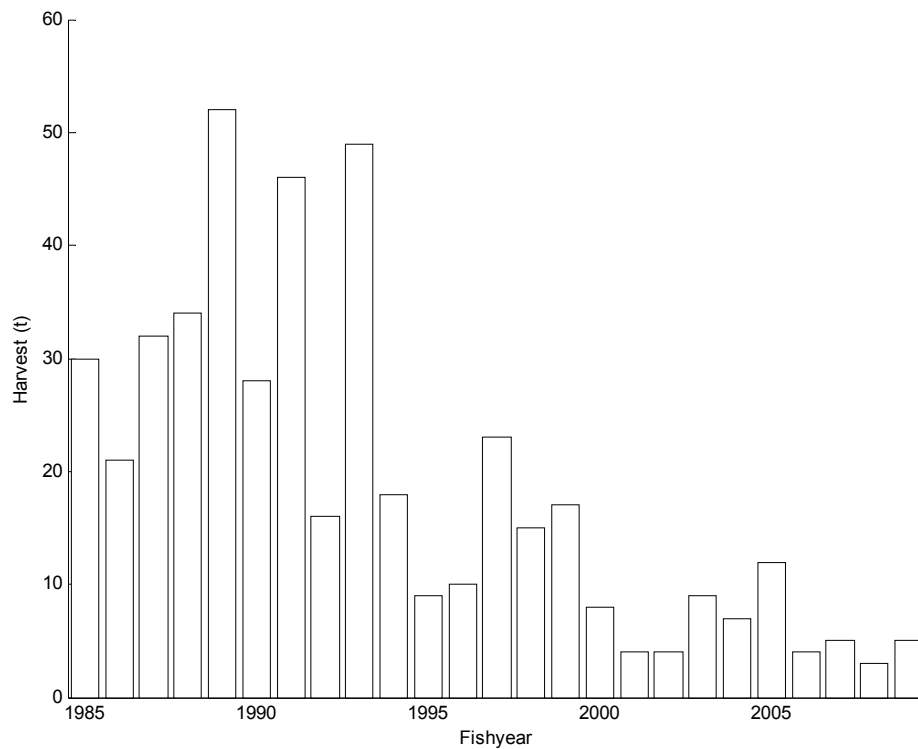
**Figure 3** Number of recreational vessels registered in Queensland.

NSW recreational catch data were provided by Recreational Boat Ramp Surveys (RBRS) and the National Indigenous and Recreational Fishing Survey (NRIFS) Table 3. The NSW catch history was reconstructed in an identical fashion to Queensland. The same average fish weight was used, and the same index of abundance (Queensland commercial catch rates) was used to generate effort proxies. The model was insensitive to these assumptions (at least relative to the larger uncertainties that are examined in this section) due to the small size of the NSW catch relative to the QLD catch (less than 5%, see Figure 6).

**Table 3** Input data for NSW recreational catch.

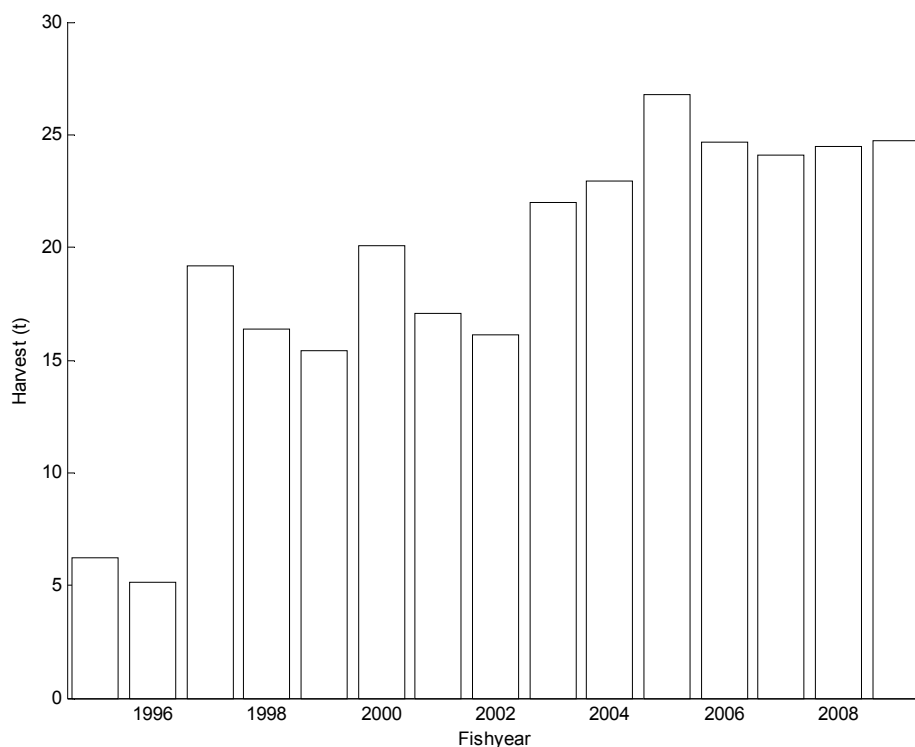
| Year | Source | Harvest (n) | Release (n) | Catch (kg) |
|------|--------|-------------|-------------|------------|
| 1994 | RBRS   | -           | -           | 4797       |
| 1995 | RBRS   | -           | -           | 6719       |
| 2001 | NRIFS  | 7296        | 4194        | -          |

NSW commercial catches were available for the period 1985 to 2009 (Figure 4). Prior to this NSW commercial catch was estimated as a proportion of the Queensland catch, equal to the geometric mean of the ratio of NSW to Queensland catch between 1985 and 2009. This proportion is dependent on the scenario, as some scenarios have different catches, but in the 'base case' (scenarios 1 and 7 through to 26) it was 0.027.



**Figure 4** NSW commercial harvest data 1985 to 2009.

Annual Queensland charter boat harvest increased from approximately 6 tonnes in 1995 to 25 tonnes in 2009 (Figure 5).



**Figure 5** Queensland charter boat logbook data.

Due to uncertainty in a number of data inputs (particularly recreational catch estimates) the sensitivity of the model to a number of alternate scenarios was investigated.

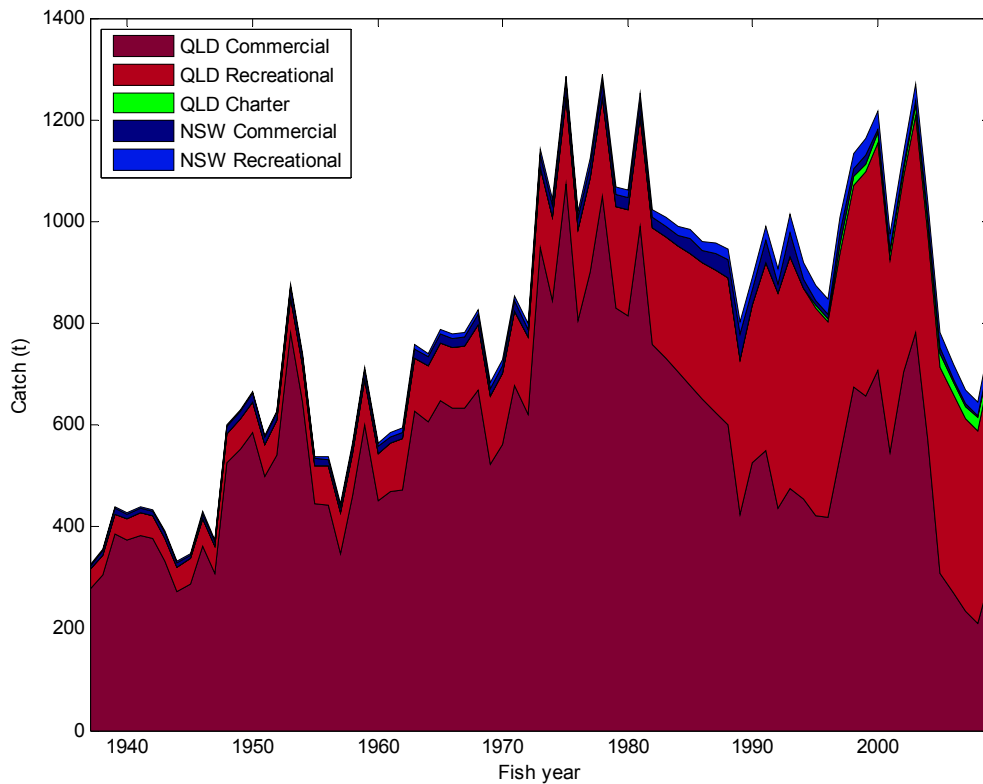
The reliability of catch estimates derived from RFISH surveys has been questioned (DEEDI 2010b). In particular the 1997 and 1999 estimates are considered high. A sensitivity scenario was included where these values were halved.

Recreational effort during the period 1989 to 2009 was either a constant or proportional to Queensland vessel registrations as indicated above.

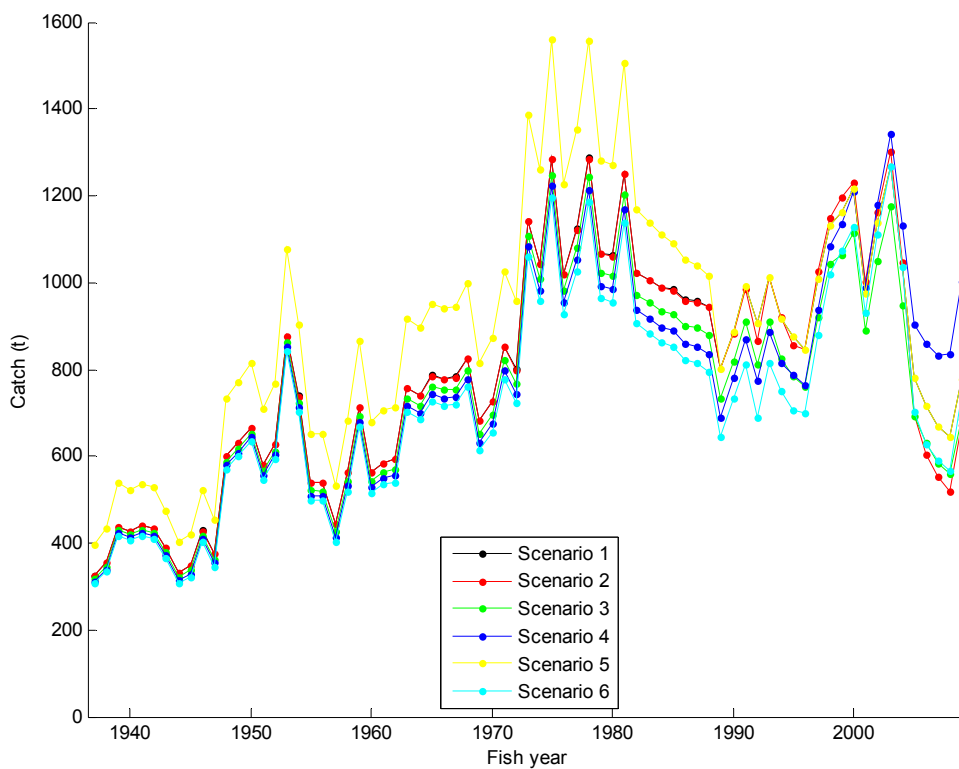
The Fish Board data potentially underestimate commercial catch due to fish only being recorded if they were landed through the main ports (Geoff McPherson, pers. comm.). A sensitivity scenario was included where the Fish Board catches were increased by 25%.

The above three sensitivity tests have the following labels respectively in the sensitivity matrix (Table 4): 97-99fish; receffort; fbunder.

The base case reconstructed catch history by sector showed wide fluctuations, with most Spanish mackerel being taken in Queensland, an increasing proportion of the catch taken by the recreational sector and a general increase in total catch from the late 1930's to early 2000's followed by a sharp decline with the introduction of new management arrangements in 2003/04 (Figure 6). Total catch for six different scenarios showed the same general pattern (Figure 7).



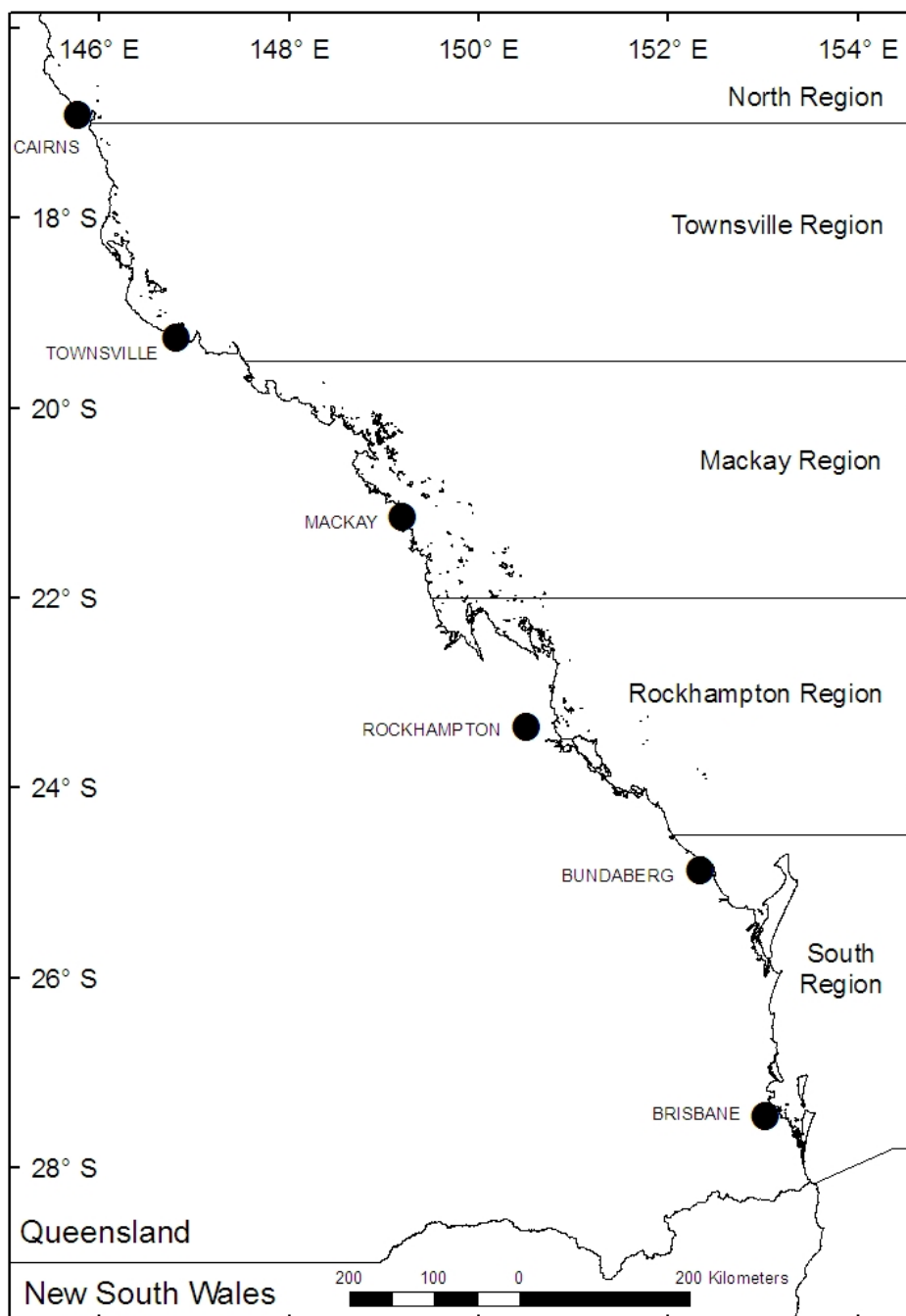
**Figure 6** Reconstructed catch history for scenario 1.



**Figure 7** Reconstructed total catch for six scenarios. See Table 4 for legend codes.

### 5.3 Sampling program data

The model was fit to eight years (2002-2009) of age-length sampling data covering five geographic regions (see Figure 8) and two sectors (for the purpose of this assessment the charter sector is considered to be part of the recreational sector). This data came primarily from Fisheries Queensland, where the objective of the monitoring program for Spanish mackerel was to collect length, sex and age data representative of line-caught Spanish mackerel from the commercial and recreational sectors in Queensland waters. The Fisheries Queensland monitoring program for Spanish mackerel is described in more detail in Appendix E.



**Figure 8** The five geographic regions by which the length-age sampling program data were stratified.

Data were also sourced from a CRC Reef research project (Tobin and Mapleston 2004) in 2002 and 2003, and CapReef length data were available for 2007. The CRC Reef data in 2002 and 2003 helped to compensate for the relatively limited geographic coverage of Fisheries Queensland data prior to 2004. The total raw sample sizes for the number of fish measured, sexed and aged in each region and for each sector are given in Table 2 of Appendix A.

In a separate sensitivity test (Scenario 21 and 22) the model was also fit to two years of age-frequency data from 1977 and 1978; these data are described in McPherson (1992).

## 5.4 Sensitivity analyses

The model was run through a number of scenarios to test sensitivity to various assumptions. A 'scenario matrix' is given in Table 4 and its labels and codes are explained in Table 5.

**Table 4** Scenario matrix. See **Table 5** for explanation of scenario characteristics.

| Scenario | Catch rate (cpue) | 97-99fish | receffort | fbunder | natmort | varrho | steep | recdev | cpuefit | phi | mcp |
|----------|-------------------|-----------|-----------|---------|---------|--------|-------|--------|---------|-----|-----|
| 1        | 1                 | 1         | 1         | 1       | 1       | 1      | 1     | 1      | 1       | 1   | 1   |
| 2        | 2                 | 1         | 1         | 1       | 1       | 1      | 1     | 1      | 1       | 1   | 1   |
| 3        | 1                 | 2         | 1         | 1       | 1       | 1      | 1     | 1      | 1       | 1   | 1   |
| 4        | 1                 | 1         | 2         | 1       | 1       | 1      | 1     | 1      | 1       | 1   | 1   |
| 5        | 1                 | 1         | 1         | 2       | 1       | 1      | 1     | 1      | 1       | 1   | 1   |
| 6        | 2                 | 2         | 2         | 1       | 1       | 1      | 1     | 1      | 1       | 1   | 1   |
| 7        | 1                 | 1         | 1         | 1       | 2       | 1      | 1     | 1      | 1       | 1   | 1   |
| 8        | 1                 | 1         | 1         | 1       | 1       | 2      | 1     | 1      | 1       | 1   | 1   |
| 9        | 1                 | 1         | 1         | 1       | 1       | 3      | 1     | 1      | 1       | 1   | 1   |
| 10       | 1                 | 1         | 1         | 1       | 1       | 1      | 2     | 1      | 1       | 1   | 1   |
| 11       | 1                 | 1         | 1         | 1       | 1       | 1      | 3     | 1      | 1       | 1   | 1   |
| 12       | 1                 | 1         | 1         | 1       | 1       | 1      | 4     | 1      | 1       | 1   | 1   |
| 13       | 1                 | 1         | 1         | 1       | 1       | 1      | 5     | 1      | 1       | 1   | 1   |
| 14       | 1                 | 1         | 1         | 1       | 1       | 1      | 1     | 2      | 1       | 1   | 1   |
| 15       | 1                 | 1         | 1         | 1       | 1       | 1      | 1     | 3      | 1       | 1   | 1   |
| 16       | 1                 | 1         | 1         | 1       | 1       | 1      | 1     | 1      | 2       | 1   | 1   |
| 17       | 1                 | 1         | 1         | 1       | 1       | 1      | 1     | 1      | 3       | 1   | 1   |
| 18       | 1                 | 1         | 1         | 1       | 1       | 1      | 1     | 1      | 4       | 1   | 1   |
| 19       | 1                 | 1         | 1         | 1       | 1       | 1      | 1     | 1      | 1       | 2   | 1   |
| 20       | 1                 | 1         | 1         | 1       | 1       | 1      | 1     | 1      | 1       | 3   | 1   |
| 21       | 1                 | 1         | 1         | 1       | 1       | 1      | 1     | 1      | 1       | 1   | 2   |
| 22       | 1                 | 1         | 1         | 1       | 1       | 1      | 1     | 1      | 1       | 1   | 3   |
| 23       | 1                 | 1         | 1         | 1       | 1       | 1      | 5     | 2      | 2       | 2   | 1   |
| 24       | 1                 | 1         | 1         | 1       | 1       | 1      | 5     | 2      | 2       | 2   | 1   |
| 24a      | 1                 | 1         | 1         | 1       | 1       | 1      | 5     | 4      | 2       | 2   | 1   |
| 25       | 1                 | 1         | 1         | 1       | 1       | 1      | 5     | 2      | 2       | 2   | 1   |
| 26       | 1                 | 2         | 1         | 1       | 1       | 1      | 5     | 2      | 2       | 2   | 1   |
| 26a      | 1                 | 2         | 1         | 1       | 1       | 1      | 5     | 4      | 2       | 2   | 1   |

**Table 5** Sensitivity variables.

| Label             | Meaning and values                                                                                                                            |
|-------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| Catch rate (cpue) | Standardisation of Queensland commercial catch rates. 1=base; 2=hyperstability sensitive.                                                     |
| 97-99fish         | RFISH estimates for 1997 and 1999. 1=unchanged; 2=halved.                                                                                     |
| receffort         | Estimated recreational effort during 1989-2009. 1=constant; 2=proportional to vessel registrations.                                           |
| fbunder           | Fish board data underestimate? 1=unchanged; 2=125%.                                                                                           |
| natmort           | Natural mortality. Pauly schooling equation or Hoenig's equation based on maximum age of 17. 1=0.3217 (F) 0.3445 (M) (Pauly); 2=0.26 (Hoenig) |
| varrho            | Multiplier for the relative weighting of the length data sample-size over the sex-age-                                                        |

|         |                                                                                                                                                                                                                                                                                                        |
|---------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|         | length data. 1=.5; 2=1.0; 3=0.1                                                                                                                                                                                                                                                                        |
| steep   | Stock-recruitment steepness. 1=fixed at .52; 2=estimated, diffuse prior; 3=fixed at .3; 4=estimated, informative prior $N(.52,.24^2)$ matches <i>Scombridae</i> family prior in (Myers, Bowen <i>et al.</i> 1999); 5 informative prior $N(.52,.24^2)$ weighted 10x in overall negative log likelihood. |
| recdev  | Recruitment deviations. 1=none; 2= $\sigma_r \sim 0.4$ , start in 1988; 3= $\sigma_r \sim 0.6$ , start in 1988; 4= $\sigma_r \sim 0.4$ , start in 1983                                                                                                                                                 |
| cpuefit | Fit to cpue data. 1=no; 2=fit to standard cpue series 10x weighting; 3=fit to standard cpue series 100x weighting; 4 fit to hyperstable variant cpue series 100x weighting                                                                                                                             |
| phi     | Parameter that controls the degree to which the sampling data in each region is re-weighted by the estimated catch in that region. 1=number of samples proportional to catch; 2=number of samples 50% re-weighted; 3=number of samples not re-weighted (raw number).                                   |
| mcp     | Fit to Geoff McPherson's age data 1977-78. 1=no; 2=yes, 10x weighting; 3=yes 100x weighting.                                                                                                                                                                                                           |

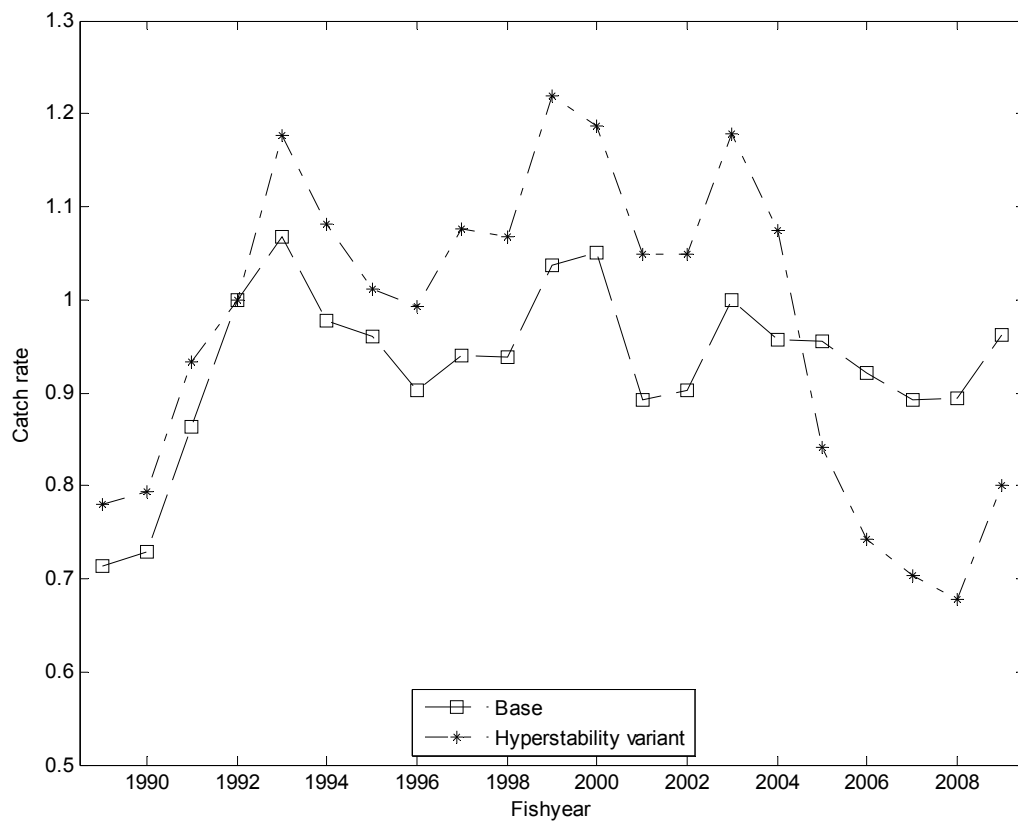
The model scenarios 1 through 22, and scenario 24, used the exponential decreasing function of length as its growth sub-model, described in (Campbell and O'Neill In draft). Models 23 through 25 are models A to C in (Campbell and O'Neill In draft). These models were identical with respect to the sensitivity factors, and differed only in terms of their growth sub-model. The sensitivity factor assumptions for these models were chosen to constitute the 'most plausible' combination: steepness with a weighted prior, recruitment deviations estimated, catch rate data fit to, and 'phi' at 50% reweighting. More details on assumptions relating to 'varrho' and 'phi' are given in Appendix A. Scenario 26 used the same growth sub-model as scenario 24, and was identical to scenarios 23 through 25 in its data inputs apart from the catch rate input which was set to the hyperstable variant.

Two additional runs, 24a and 26a, were added to test the sensitivity of the model to the number of years of recruitment variation, specifically to the year in which recruitment anomalies were initiated. In scenarios 24 and 26 recruitment anomalies began in 1988, the first year in which the catch rate index was present. In scenarios 24a and 26a anomalies began in 1983, five years earlier. The motivation for this is that some cohorts alive in 1988 were recruited a number of years earlier and thus any interaction between the catch rate index and recruitment strength could potentially be operating over this time window. The choice of five years is somewhat arbitrary, and some individuals will be alive in the model for much longer (up to around 18 years); however the aim is simply to probe the sensitivity of the model to this issue.

## 6 Results

### 6.1 Standardised catch rates

Standardised catch rates, as an index of abundance, were compared for two annual time-series (Figure 9). The first time-series (labelled as "base" case) was a standardised commercial line catch rate of Spanish mackerel. This series was derived from an analysis of non-zero daily catches, with no fishing effort records on hours fished and hours search time available. The second time-series explored overcoming hyperstability bias caused by limited effort reporting, using a two-component methodology for the presence (harvesting) or absence of Spanish mackerel in the fishery. The time series were normalised to a relative (proportion) scale where catch rates in 1992 were =1. In comparison, base catch rates were estimated as relatively stable between 1992 and 2009. The 2<sup>nd</sup> index (hyperstability variant) indicated a reduced catch rate between 2005 and 2009.



**Figure 9** Standardised commercial catch per unit effort series (proportion) scaled against mean.

## 6.2 Stock status

Stock status and productivity were quantified using four indices:

- the ratio of 2009 egg production to 1937 egg production ( $E_{ratio}$ ),
- the ratio of 2009 fishing mortality,  $F$ , to  $0.5 \cdot M$ , where  $M$  is natural mortality ( $F_{ratio}$ ),
- the maximum sustainable yield (MSY), and
- the yield such that exploitable stock biomass is maintained at  $1.2 \cdot B_{MSY}$  ( $Y_{1.2Bmsy}$ ).

The first index is a spawning stock size ratio and is a more accurate indicator of stock sustainability than a biomass ratio in the presence of inter-annual recruitment variation. A useful reference in interpreting this ratio is the Commonwealth Fisheries Harvest Strategy Policy (Australian Government 2007), see Box 1. The second index compares current fishing mortality,  $F_{2009}$ , to a level of  $F$  considered to be sustainable for pelagic fish stocks such as Spanish mackerel (Welch, Hoyle *et al.* 2002). A value for this index greater than one indicates overfishing.

Sensitivity of stock status to the 11 groups of factors described in Table 4 is depicted graphically in terms of egg production ratio in Figure 10 through Figure 17. These figures show a single deterministic stock trajectory using the maximum likelihood estimate of the parameters, except in the case of scenarios 14 and 15 for which 95% confidence envelopes are graphed. Stock status and management outputs with 95% confidence intervals are given in

Table 7.

**Box 1: Commonwealth Fisheries Harvest Strategy Policy (CFHSP)<sup>2</sup>**

The CFHSP defines 'limit' and 'target' reference points for the biomass ratio. It recommends that restrictions be placed on fishing if the ratio is less than the target reference point, and these restrictions increased in severity if the biomass ratio continues to drop, culminating in complete closure of the fishery if the limit is reached. The limit reference point is usually 0.2. The target reference point is defined as the biomass consistent with maximum economic yield, or more often a proxy for this of 20% greater than the biomass consistent with maximum sustainable yield, which in turn is often a proxy, taken to be 0.4 (thus implying a target reference point proxy of 0.48). Serious restrictions are not mandated unless the stock drops below the MSY proxy.

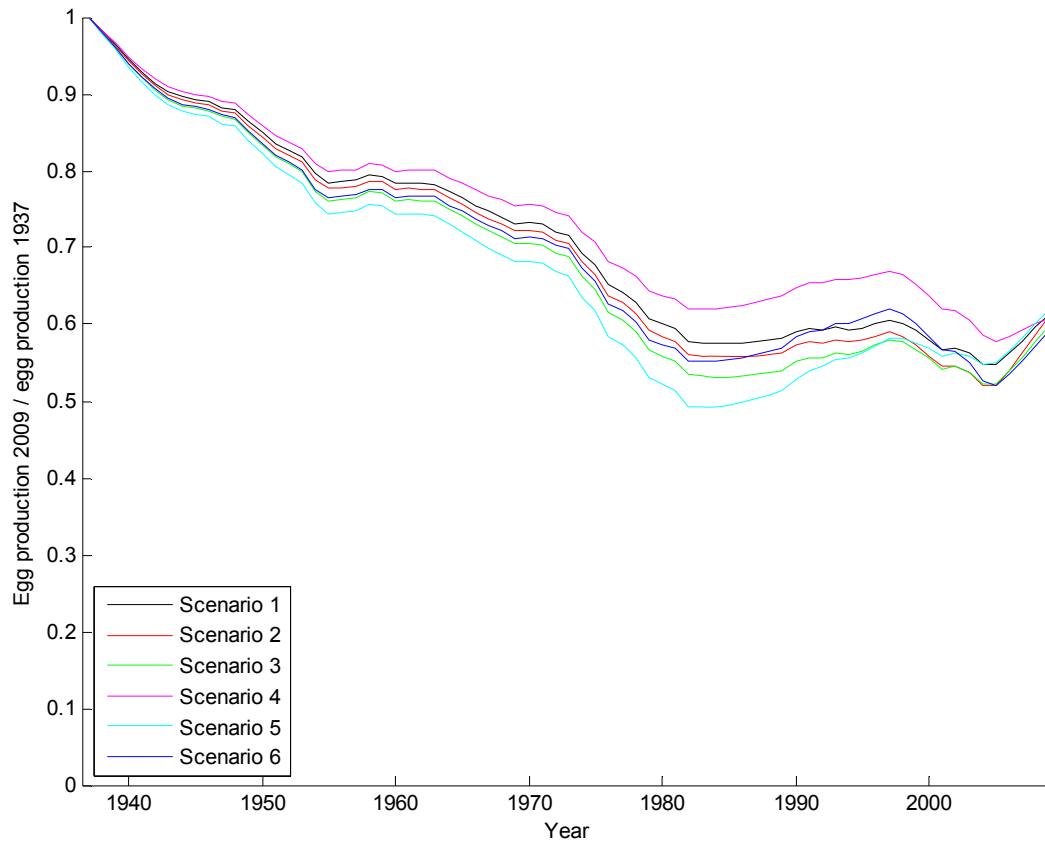
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<sup>2</sup> Note that the CFHSP is not currently Fisheries Queensland policy

### 6.2.1 Catch reconstruction

Stock status in 2009 was not sensitive to the various catch reconstruction scenarios, however MSY was sensitive. This situation is normal and arises because virgin biomass and current biomass are correlated – a lower (or higher) virgin biomass leads to a lower (or higher) current biomass. Stock status, which is a ratio of the two, is minimally affected. MSY however is a direct function of biomass, so it will increase or decrease proportionally. Although this may appear to lead to the paradoxical situation in which equilibrium levels of harvest are independent of stock status, it must be remembered that MSY is a function of total historical catch and current catch estimates are not usually independent of historical estimates. For example, MSY will go up if the historical catch is inflated (for example because it was thought to be an underestimate), and this will generally mean that current catches will also be revised upwards, so the increase in MSY is not necessarily able to be ‘used’. So while MSY is uncertain because historical catch levels are uncertain, current catch estimates are highly correlated with both and cannot be considered independently. Of course this correlation doesn’t apply if current catch estimates are thought to be correct while a historical period is underestimated (or overestimated). However, in this fishery, because the majority of the catch is now taken by the recreational sector, whereas it was originally taken by the commercial sector (during the Fish Board years), it is unlikely that current catch estimates are more accurately known, and they could actually be more uncertain than the peak historical catches (1970s). Due to this interrelation between MSY and current catch estimates, the stock status results in

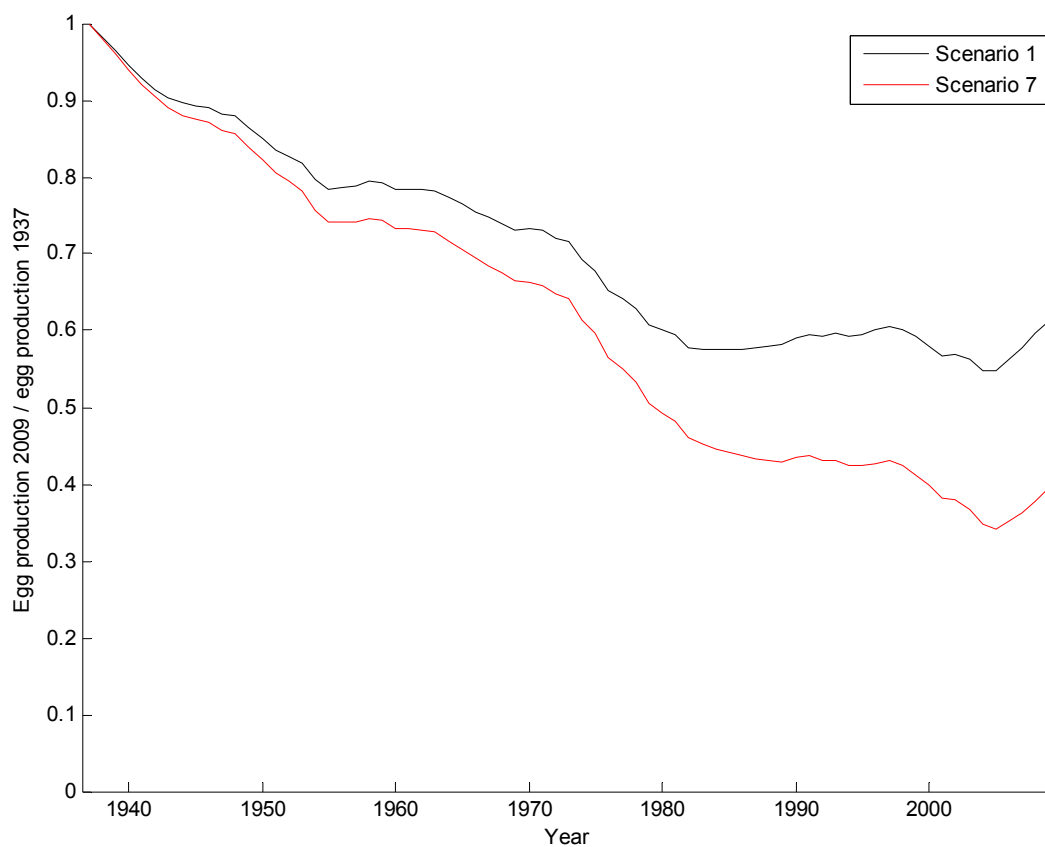
Table 7 are presented along with the current estimated catch implied by the scenario.



**Figure 10** Egg production as a proportion of virgin for different catch history scenarios.

### 6.2.2 Natural mortality

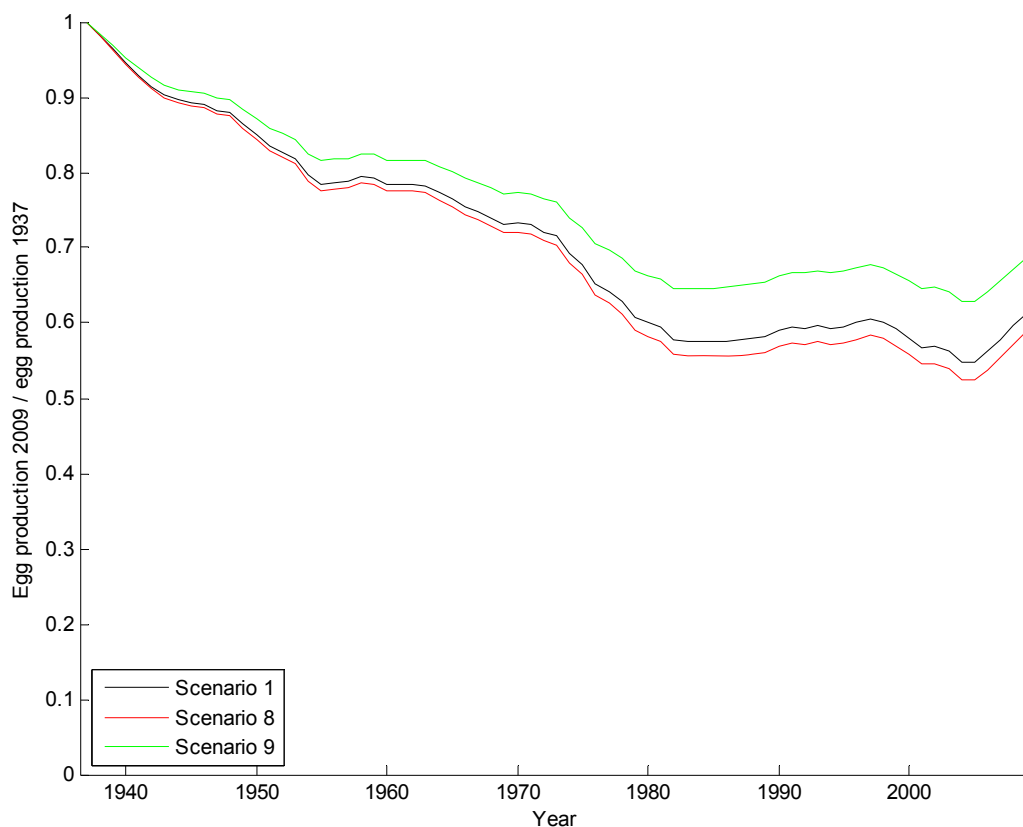
Stock status was highly sensitive to assumptions about natural mortality as in (Welch, Hoyle *et al.* 2002) . Scenario one used values of  $M=0.3217$  for females, and  $M=0.3445$  for males, derived from the Pauly equation involving growth rate and water temperature (Pauly 1980). Scenario seven used a value of  $M=0.26$  based on the oldest fish observed being 17 years (Hoenig 1983). The Welch (2002) assessment used a value of  $M=0.34$  based on the longevity approach with the oldest fish observed at the time being 13. Natural mortality was discussed extensively by the ReefMAC SAG in October 2007 and there was a desire expressed to maintain a consistency of value with the previous assessment (as opposed to a consistency of method), however the scenario one values should not be considered a base case in the sense of being intrinsically more plausible. This uncertainty must be considered in interpreting overall stock status.



**Figure 11** Egg production as a proportion of virgin for different values of natural mortality.

### 6.2.3 Sex-age-length data weighting

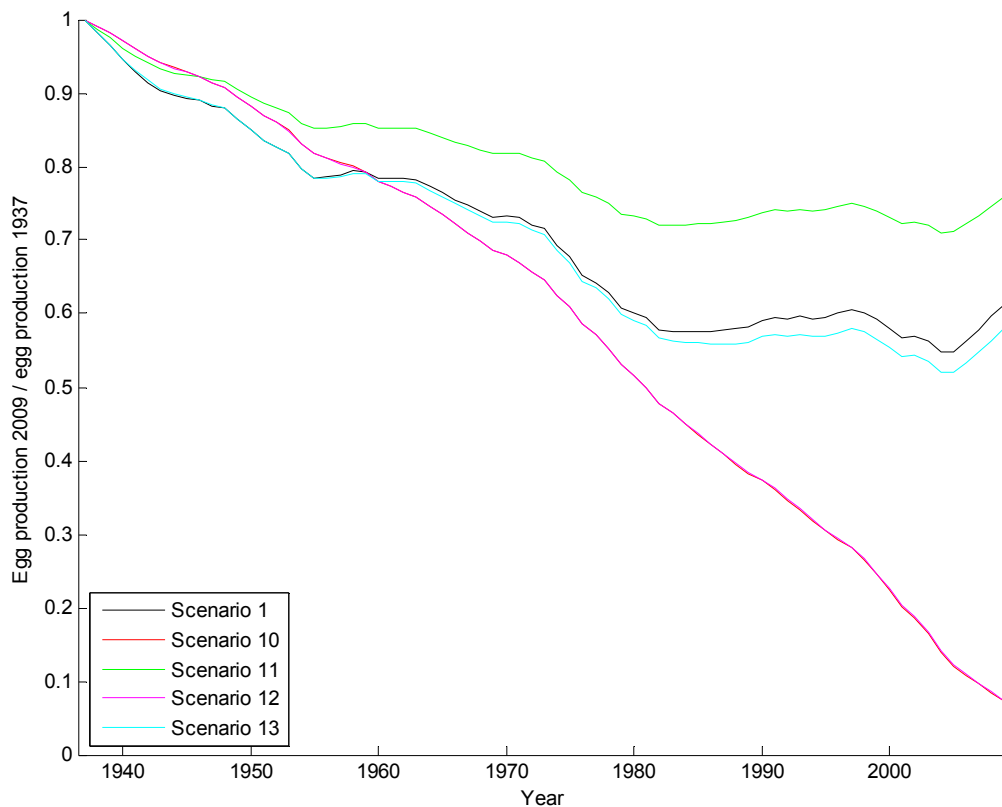
Stock status was moderately sensitive to different weightings of length to sex-age-length data. The more weight that was put on the sex-age-length data versus the length data, the higher the estimated stock status. A strong weighting on the sex-age-length likelihood vs. the length-only likelihood implies a model that is less trusting of length-only data and is relying more heavily on the length-age data (which could be sensible for strong variation in length-at-age species like Spanish mackerel) with the trade-off that the model must rely on a smaller effective number of samples. This had the effect of increasing stock status in 2009 (scenario 9). However, giving the sex-age-length data ten times the weight (on a per-data point basis), as in scenario 9, is very extreme and there is no justification for it. Sex-age-length double the weighting (scenario 1) or equal weighting are more sensible choices, and there is little between them. We still prefer to enhance the sex-age-length data weighting somewhat and therefore marginally prefer scenario 1.



**Figure 12** Egg production as a proportion of virgin for different weightings of length frequency data to sex-age-length frequency data.

#### 6.2.4 Stock-recruitment steepness

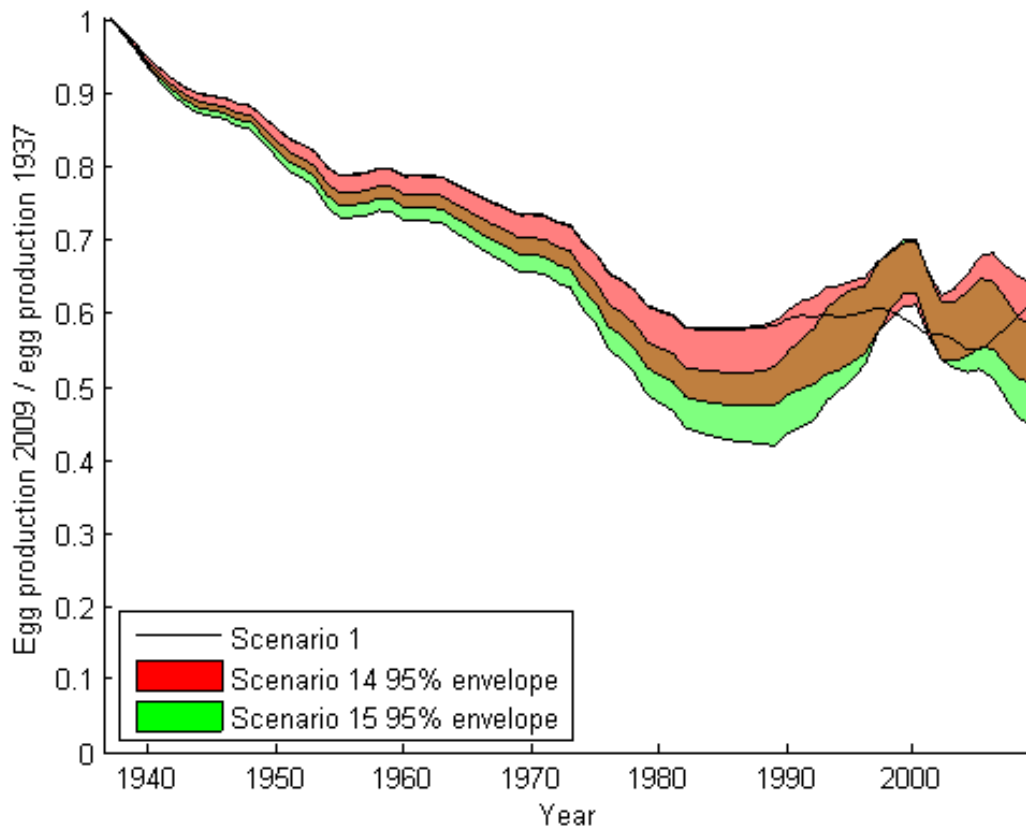
Stock status was very strongly sensitive to assumptions relating to stock-recruitment steepness. The eight years of sampling program data do not appear to contain enough contrast for the model to estimate both a stock productivity parameter (steepness, 'z' in article) and a stock capacity parameter (virgin recruitment, 'R' in article). For scenarios 1 to 9, and 14 to 22, steepness was fixed at the mode of the empirical prior distribution for the *Scombridae* family in (Myers, Bowen *et al.* 1999). In these cases the stock appears to be under very little pressure from fishing ( $E_{ratio}$  approximately 0.6). When estimated with a non-informative prior (scenario 10) the stock-recruitment relationship becomes almost linear and the stock crashes. When steepness is fixed at 0.3 (scenario 11), the lower 20<sup>th</sup> percentile of the empirical prior, the estimation procedure fails if the initial guess for R is low (around 500,000); if the initial guess for R is higher the estimation procedure stabilises with stock status very high ( $E_{ratio} > 0.7$ ). Using the full empirical prior without weighting (scenario 12) the stock crashes (essentially no difference from an uninformative prior). Weighting the prior 10x in the overall likelihood (scenario 13) results in stock status only marginally lower than the base case (steepness fixed at empirical mode 0.52).



**Figure 13** Egg production as a proportion of virgin for different values of stock-recruitment steepness. Scenarios 10 and 12 overlap.

### 6.2.5 Recruitment variation

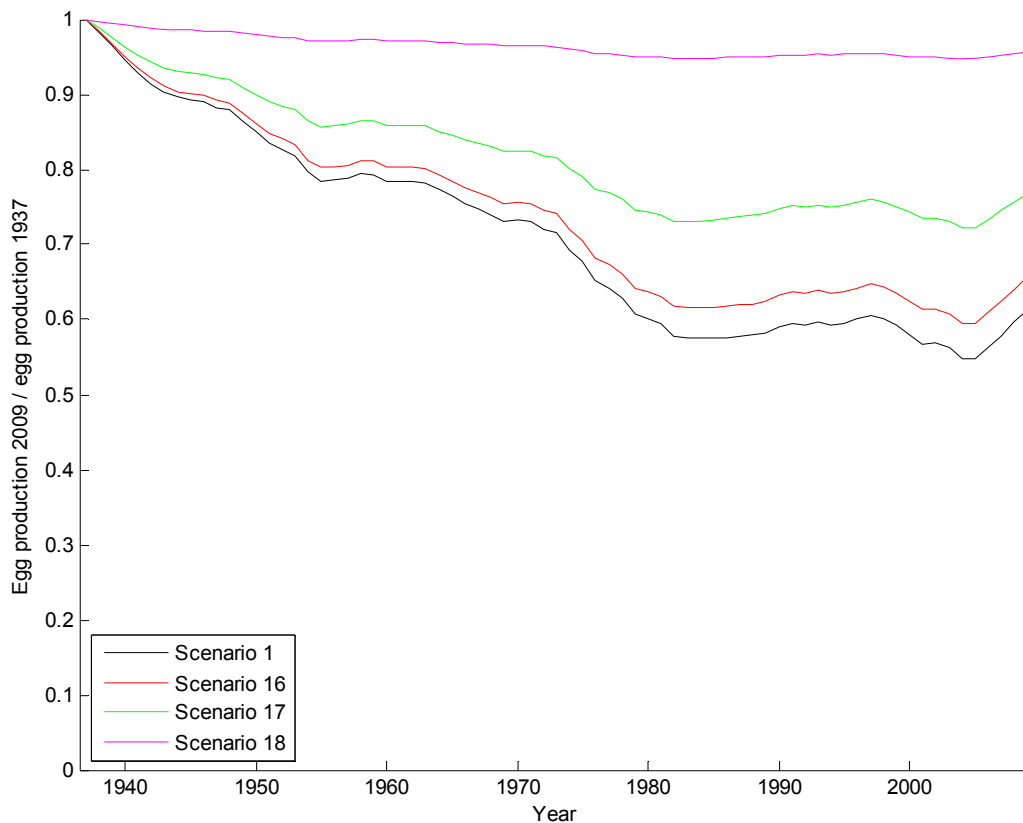
The introduction of annual recruitment deviations for the years 1990 to 2009 tended to depress current stock status. Scenario 14 considered recruitment variability with a standard deviation of 0.4, scenario 15 considered 0.6. In general the trend was to introduce a significant negative deviation in 2002, a positive one in 2004 and negative deviations over the past few years. Although stock status is depressed in these scenarios, the models' explanation for this is that the last few years have been unusually poor due to exogenous (i.e. environmental, non-fishing related) factors.



**Figure 14** Egg production as a proportion of virgin for different recruitment variation (process error) scenarios.

### 6.2.6 Catch rate weighting

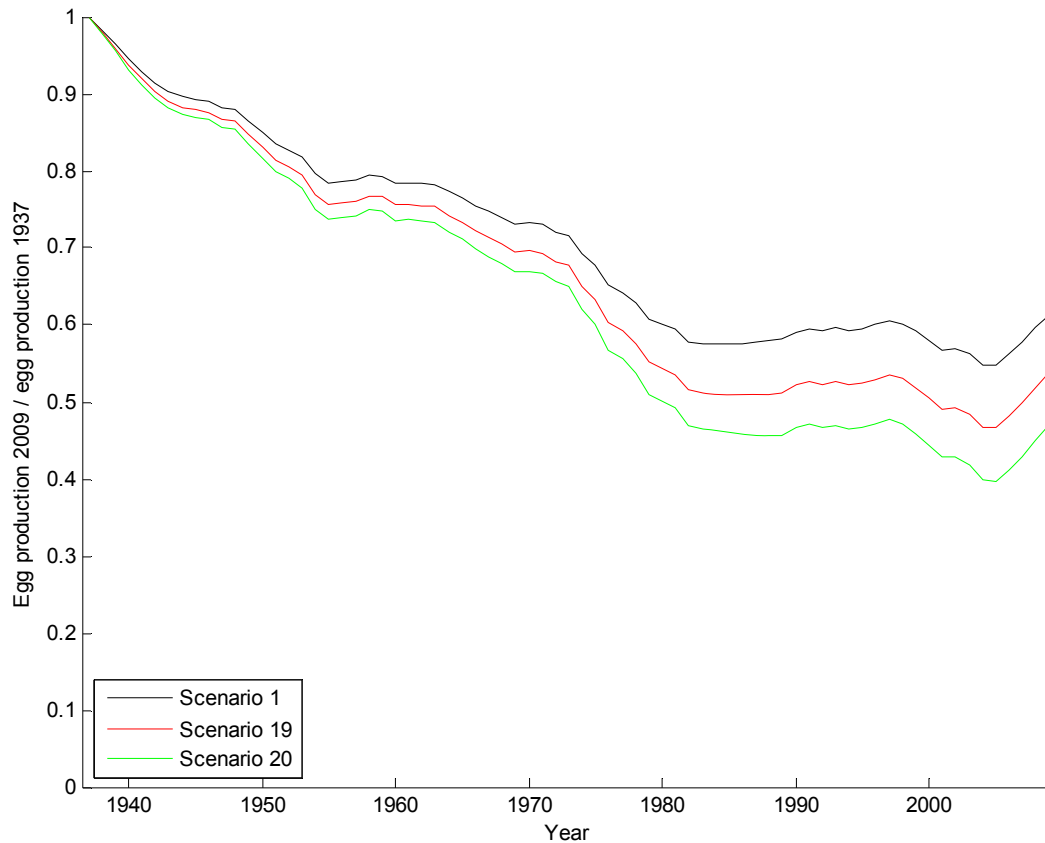
The standardised catch rate series both imply a stock that is largely unaffected by fishing; the more weighting put on the catch rate fit the higher the estimated stock status. The hyperstable variant with catch rate weighted 100x in the likelihood (scenario 18) did not lead to a significant fit and converged to an implausibly large stock size.



**Figure 15** Egg production as a proportion of virgin for different catch rate scenarios.

### 6.2.7 Regional re-weighting of length and sex-age-length data

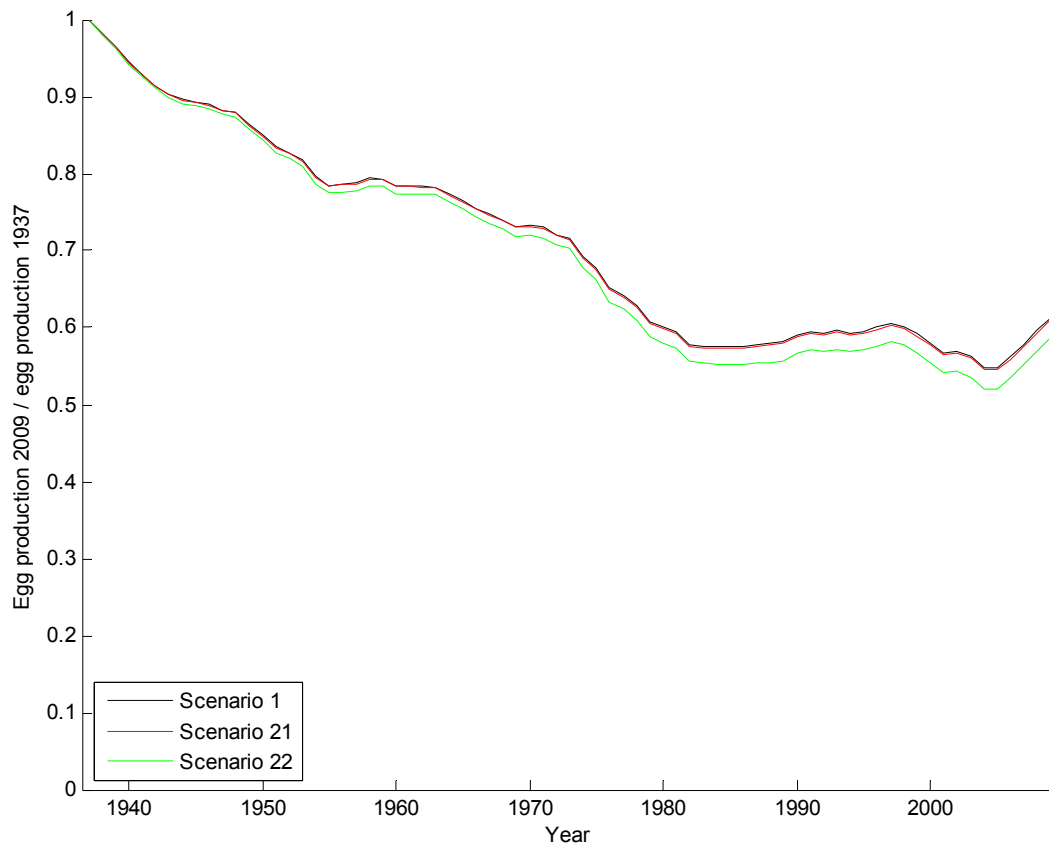
Stock status was moderately sensitive to different values of the parameter  $\phi$ . This parameter controls to what extent the length and sex-age-length data is re-weighted in each region/sector by the total catch from that region/sector. This is elaborated on in the discussion section “messages for monitoring”.



**Figure 16** Egg production as a proportion of virgin for different values of  $\phi$ .

### 6.2.8 McPherson 1977-78 age structure data

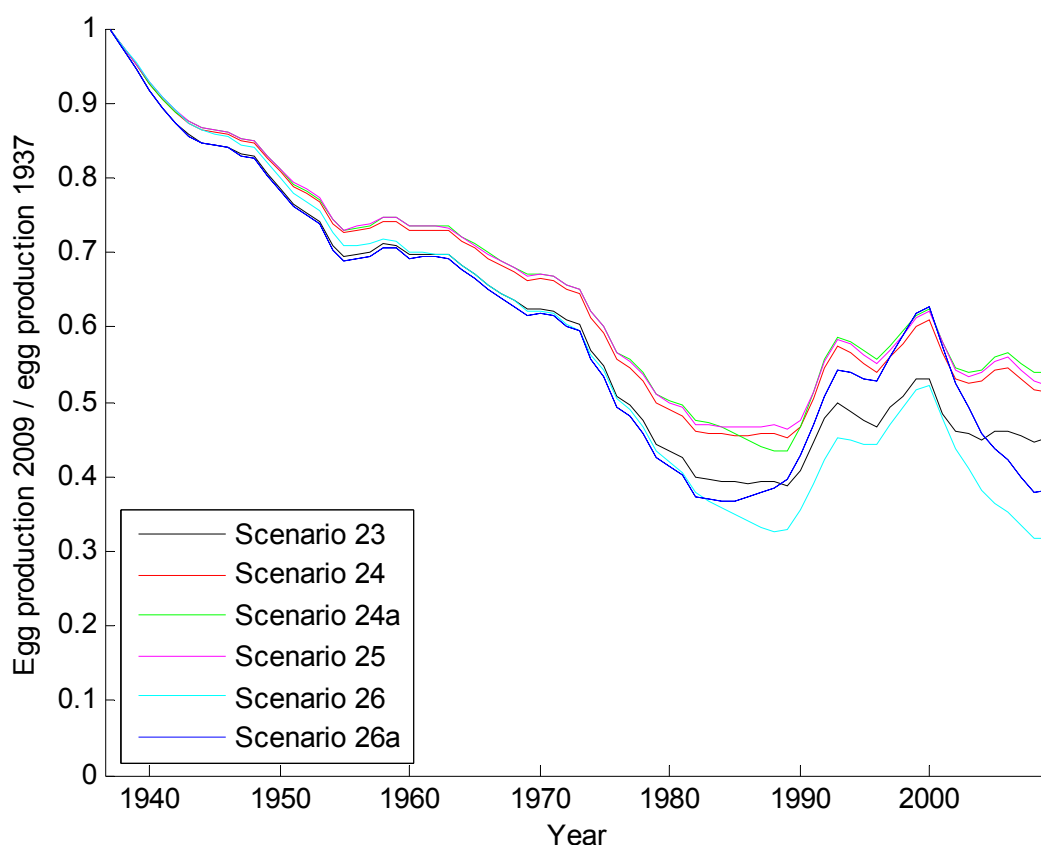
The presence or absence of the McPherson 1977-78 age structure data has very little impact on stock status.



**Figure 17** Egg production as a proportion of virgin for scenarios that compare the impact of the 1977-78 age structure data.

### 6.2.9 Scenarios 23 to 26

Scenarios 1 through 22 were primarily sensitivity tests as opposed to ‘live’ analyses. Scenarios 23 through 26, however, were designed to make the best use of all available data, and constitute the most plausible model runs. They incorporated standardised catch rate fitting with length and sex-age-length fitting, recruitment variation, and steepness estimation using a weighted informative prior. They differed in the sub-model used to describe growth: scenario 23 modelled growth as a von Bertalanffy function of length, whereas scenarios 24 and 25 modelled growth as a decreasing exponential function of length. Scenario 24 had growth variability a constant function of length whereas scenario 25 allowed growth variability to vary as function of length. These models are described in more detail in Appendix A. Scenario 26 used the standard growth sub-model, and was identical to scenarios 23 through 25 in its data inputs apart from the catch rate input which was set to the hyperstable variant. Goodness of fit plots for runs 23 through 26 are given in Appendix B. The von-Bertalanffy growth model (model 23) is clearly a poor fit, but scenarios 24, 24a, 25, 26 and 26a are quite good fits overall. Stock status for these scenarios is depicted graphically in terms of egg production ratios in Figure 18.



**Figure 18** Egg production as a proportion of virgin for the six ‘all-in’ scenarios.

Scenario 23 fits poorly relative to scenarios 24 and 25, and those two scenarios lead to almost identical conclusions, so the focus for management consideration should be on scenario 24 and scenario 26, along with their variants. These runs still cover a wide range of stock status hypotheses - 36% to 54% of virgin biomass in 2009. In the case of scenarios 24 and 26 this difference is easily interpreted in terms of the different catch rate indices – 24 uses a relatively stable catch rate, whereas 26 used the hyperstability variant which shows a rapid decline from 2003 to 2008. However when comparing 24 with 24a, and 26 with 26a, the interpretation is more

subtle. In the case of scenario 24 the additional years of recruitment variation prior to the first year of catch rate in 1988 are all negative, thus allowing a better fit to the first few years of the catch rate indices which are depressed. The total recruitment variation must remain zero on average, so this results in more positive recruitment anomalies towards the other end of the series, which increases the estimate of current stock status. There is a similar, and larger, effect in the case of scenario 26. There is also an effect on steepness, the point estimate increasing from 0.597 (S24) to 0.613 (S24a) and 0.476 (S26) to 0.617 (S26a). This sensitivity serves to highlight the fact that steepness is poorly informed by the data.

Despite this sensitivity all key parameters across these runs are significant according to t-statistics (Table 6).

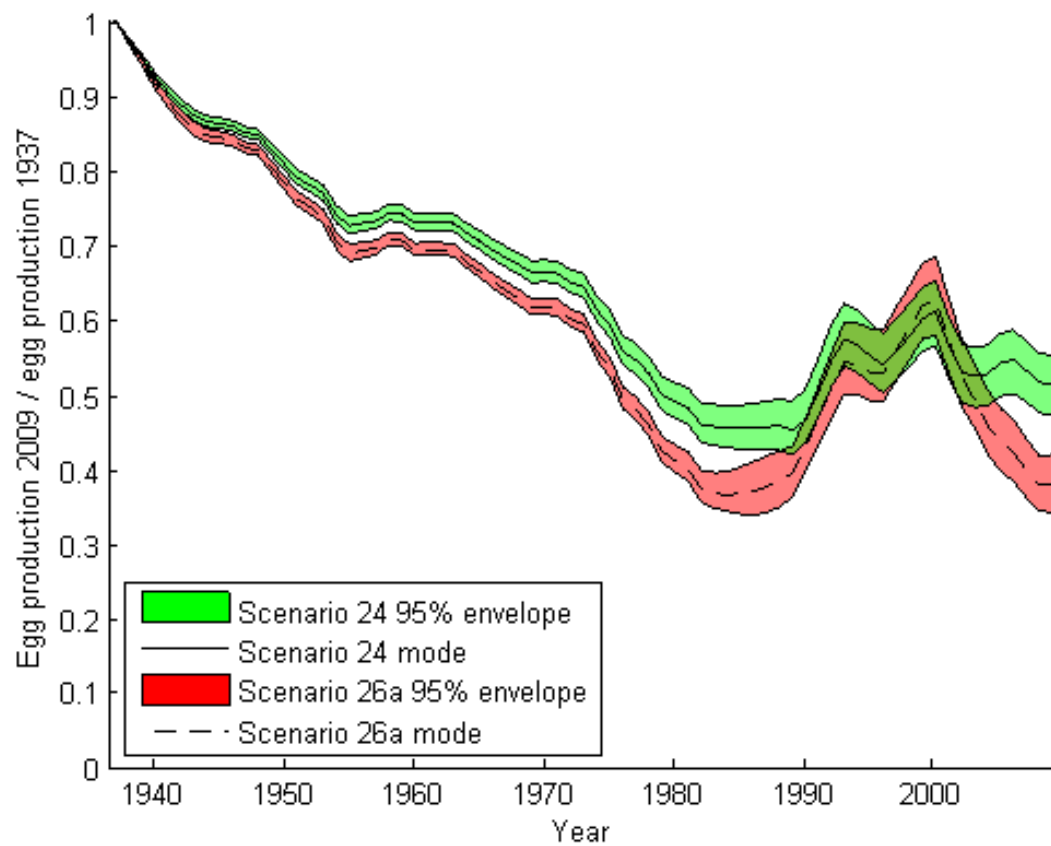
**Table 6** T-statistics (estimate / standard error) of key parameters from scenarios 24, 26 and variants.

|              | R0     | z      | Bratio |
|--------------|--------|--------|--------|
| Scenario 24  | 23.165 | 13.811 | 22.631 |
| Scenario 24a | 20.981 | 10.981 | 19.882 |
| Scenario 26  | 18.204 | 14.477 | 12.368 |
| Scenario 26a | 18.189 | 9.858  | 15.087 |

Egg production ratios through time for scenario 24 and 26a are re-displayed along with their 95% confidence envelopes in Figure 19.

**Table 7** Management outputs:  $E_{ratio}$  is the ratio of current 2009 egg production to 1937 egg production;  $F_{ratio}$  is the ratio of current fishing mortality to  $0.5 \times M$ ; MSY is the maximum sustainable yield (tonnes);  $Y_{1.2Bmsy}$  is the yield such that exploitable biomass is maintained at 1.2 times the value at MSY;  $F_{1.2Bmsy}/F_{msy}$  is the ratio of fishing mortality at 1.2Bmsy to fishing mortality at MSY (provided only for runs 23 to 25). Catch in 2009 is provided as a reference as some scenarios estimate the catch history differently. 5<sup>th</sup> and 95<sup>th</sup> percentile confidence intervals are in parentheses.

| Scenario | $E_{ratio}$       | $F_{ratio}$       | MSY               | $Y_{1.2Bmsy}$     | $F_{1.2Bmsy}/F_{msy}$ | 2009 Catch |
|----------|-------------------|-------------------|-------------------|-------------------|-----------------------|------------|
| 1        | 0.62 (0.58; 0.66) | 0.55 (0.47; 0.65) | 1201 (1133; 1294) | 1177 (1111; 1267) | -                     | 778        |
| 2        | 0.62 (0.58; 0.66) | 0.49 (0.42; 0.59) | 1164 (1097; 1250) | 1141 (1075; 1225) | -                     | 671        |
| 3        | 0.60 (0.56; 0.64) | 0.58 (0.48; 0.68) | 1066 (1010; 1142) | 1045 (991; 1119)  | -                     | 687        |
| 4        | 0.61 (0.57; 0.67) | 0.69 (0.55; 0.84) | 1235 (1144; 1381) | 1210 (1121; 1352) | -                     | 1001       |
| 5        | 0.62 (0.59; 0.66) | 0.53 (0.45; 0.62) | 1244 (1183; 1327) | 1219 (1159; 1299) | -                     | 778        |
| 6        | 0.59 (0.56; 0.64) | 0.65 (0.53; 0.77) | 1043 (985; 1125)  | 1023 (966; 1102)  | -                     | 742        |
| 7        | 0.40 (0.37; 0.43) | 1.11 (0.97; 1.30) | 931 (913; 952)    | 911 (894; 932)    | -                     | 778        |
| 8        | 0.60 (0.55; 0.64) | 0.59 (0.49; 0.73) | 1159 (1086; 1258) | 1136 (1065; 1232) | -                     | 778        |
| 9        | 0.70 (0.65; 0.76) | 0.41 (0.30; 0.52) | 1413 (1264; 1694) | 1384 (1238; 1658) | -                     | 778        |
| 10       | 0.08 (0.05; 0.14) | 2.47 (1.52; 4.48) | 581 (519; 636)    | 566 (508; 620)    | -                     | 778        |
| 11       | 0.26 (0.20; 0.32) | 0.96 (0.71; 1.34) | 736 (717; 764)    | 716 (697; 744)    | -                     | 778        |
| 12       | 0.08 (0.05; 0.14) | 2.50 (1.46; 4.39) | 578 (517; 638)    | 564 (506; 621)    | -                     | 778        |
| 13       | 0.60 (0.47; 0.67) | 0.57 (0.47; 0.70) | 1148 (925; 1394)  | 1123 (902; 1372)  | -                     | 778        |
| 14       | 0.57 (0.50; 0.64) | 0.63 (0.50; 0.78) | 1092 (1012; 1198) | 1070 (992; 1173)  | -                     | 778        |
| 15       | 0.51 (0.45; 0.58) | 0.77 (0.62; 0.95) | 1013 (953; 1080)  | 992 (933; 1058)   | -                     | 778        |
| 16       | 0.66 (0.63; 0.70) | 0.46 (0.38; 0.53) | 1308 (1225; 1434) | 1281 (1199; 1404) | -                     | 778        |
| 17       | 0.77 (0.74; 0.80) | 0.26 (0.23; 0.31) | 1791 (1630; 1999) | 1753 (1595; 1956) | -                     | 778        |
| 18       | 0.96 (0.96; 0.96) | 0.03 (0.03; 0.03) | 8526 (8440; 8610) | 8334 (8250; 8417) | -                     | 671        |
| 19       | 0.54 (0.50; 0.57) | 0.78 (0.70; 0.92) | 1073 (1029; 1115) | 1053 (1010; 1094) | -                     | 778        |
| 20       | 0.46 (0.44; 0.48) | 1.16 (1.05; 1.30) | 992 (970; 1006)   | 975 (954; 989)    | -                     | 778        |
| 21       | 0.62 (0.57; 0.65) | 0.55 (0.47; 0.66) | 1199 (1120; 1289) | 1175 (1098; 1262) | -                     | 778        |
| 22       | 0.58 (0.55; 0.62) | 0.60 (0.52; 0.68) | 1138 (1087; 1199) | 1114 (1065; 1174) | -                     | 778        |
| 23       | 0.51 (0.50; 0.51) | 1.12 (1.11; 1.14) | 1151 (839; 1609)  | 1136 (827; 1587)  | 0.82                  | 778        |
| 24       | 0.51 (0.47; 0.55) | 0.92 (0.82; 1.05) | 1157 (831; 1633)  | 1139 (817; 1606)  | 0.82                  | 778        |
| 24a      | 0.54 (0.50; 0.59) | 0.87 (0.76; 0.98) | 1219 (856; 1755)  | 1198 (841; 1730)  | 0.82                  | 778        |
| 25       | 0.52 (0.47; 0.56) | 0.86 (0.76; 1.01) | 1173 (847; 1650)  | 1153 (832; 1622)  | 0.82                  | 778        |
| 26       | 0.36 (0.32; 0.39) | 1.17 (1.06; 1.31) | 975 (685; 1374)   | 956 (672; 1346)   | 0.82                  | 778        |
| 26a      | 0.39 (0.34; 0.42) | 1.24 (1.11; 1.39) | 1066 (760; 1536)  | 1049 (746; 1514)  | 0.82                  | 778        |



**Figure 19** Egg production as a proportion of virgin for the two of the most plausible scenarios, showing 95% confidence regions. Scenario 24 uses on the baseline standardised catch rate series, whereas scenario 26a uses the 'hyperstability variant' catch per unit effort series, and recruitment anomalies begin in 1983.

## 7 Discussion

A number of methodological improvements have been made over previous assessments, most notably the incorporation of length and sex into the models. The significance of this is discussed in (Campbell and O'Neill In draft). There has also been significantly more data to feed in to the models, and due to an expanded sampling program the age and length data should be more representative of the fishery. Despite these advances significant uncertainty remains regarding stock status. Scenarios 1 and 10 through to 13 highlight the sensitivity of the model to assumptions related to the productivity of the stock. While scenarios 24, 24a, 26 and 26a provide a good fit to the data, and incorporate estimation of the critical steepness parameter, they use a weighted prior for steepness (taken from estimates of steepness for a range of fisheries targeting the Scombridae family (Myers, Bowen *et al.* 1999)), and the weighting is somewhat arbitrary (the weighting on the prior was 10x in the runs reported above, further sensitivity tests revealed that the model outputs were almost identical at 5x and 2.5x weighting, and below this value estimation was unstable). Furthermore, given the sensitivity of the models to various other data inputs and parameterisations (Scenarios 1 to 22), the posteriors for stock status and maximum sustainable yield are likely underestimating the uncertainty. Uncertainty should be considered in terms of the range of stock status and MSY estimates across the scenarios.

### 7.1 Management

Scenarios 24 and 26 and their recruitment anomaly variants represent the most plausible hypotheses on stock status – fishing at ‘MEY’ (around 50% of virgin) in the case of 24 and 24a, and fishing at ‘MSY’ (around 40% of virgin) or just below in the case of 26a and 26 respectively. The only differences between these scenarios were the catch rate input – baseline standardisation or hyperstability variant – and the starting year for recruitment anomalies – 1988 for 24 and 26, 1983 for 24a and 26a. There is little evidence to suggest whether the recent decline in catch rates picked up by the hyperstability variant is real, or an artefact (e.g. of management changes, effort displacement to target other species, fuel prices etc.). There is also little evidence to suggest whether the recruitment anomalies should start in 1988 or earlier – the sensitivity of the models to this issue mainly serves to highlight the lack of contrast in the data and therefore the limited information available with which to determine the key model parameters, in particular steepness. In general the anomalies give the model more room to ‘explain-away’ catch rate fluctuations as exogenous (e.g. due to environmental changes), so it may be possible to interpret scenario 26a as more optimistic because it is discounting the recent drop in catch rates in this fashion, however this interpretation should be made cautiously as the issue is complex (for example it also depends on the pattern of catches during the extra anomaly years).

Given this uncertainty it is useful to consider a risk-management approach in which the annual quota is the target exploitation rate times a conservative stock-size estimate (Walters and Martell 2004, p. 73), that is, a stock-size estimate near the lower tail of the stock-size probability distribution. As in (Walters and Martell 2004) we consider both the 15% and 20% cumulative probability point (CPP), that is, there is a less than 15% (or 20%) chance that the current stock is actually smaller. The target exploitation rate was taken to be that which sustains biomass at 1.2Bmsy. The target yields that result are given in Table 8. One issue with this approach is that, for these models the uncertainty for any specific scenario is likely underestimated, so even though a conservative CPP is used, the estimate of current biomass may still be optimistic. The third row of the table attempts to deal with this issue by basing the target yields on a biomass distribution which is an amalgam of the distributions from each scenario.

Given the degree of uncertainty a precautionary approach would suggest the yields and harvest rates of scenarios 26 and 26a are more appropriate than those associated with 24 and 24a. A

decision that the fishery can be sustainably fished at levels according to scenarios 24 and 24a implies an assumption that the sharp decline in the hyperstability-adjusted catch rate from 2003 through to 2008 is not "real" - that is, it was not caused by high fishing pressure but by natural variation in recruitment strength, or changes in fishing behaviour in response to management changes, or fuel prices, or weather conditions, or any of a myriad of factors other than a reduction in stock biomass. If this assumption proved to be incorrect there is a risk that this yield will be unsustainable.

**Table 8** Target yields based on the x% cumulative probability point (CPP) of the biomass distribution multiplied by the exploitation rate that sustains biomass at  $1.2B_{MSY}$  for the four most plausible scenarios. The third row of the table provides target yields based on a biomass distribution that is a combination of the four individual distributions, with each component given equal weighting. The scenario specific yields are then due only to differences in exploitation rate.

|               | Scenario 24 | Scenario 24a | Scenario 26 | Scenario 26a |
|---------------|-------------|--------------|-------------|--------------|
| 15% CPP       | 1258        | 1450         | 702         | 914          |
| 20% CPP       | 1275        | 1467         | 710         | 923          |
| 20% CPP comb. | 903         | 980          | 715         | 985          |

It is important to note that while the yield required to maintain biomass at  $1.2B_{MSY}$  is only very slightly lower than yield for  $B_{MSY}$ , the corresponding reduction in fishing mortality is substantial. This is because in this region of the yield - fishing mortality curve the stock is not heavily depleted and the density-dependent nature of the stock-recruitment relationship (which pushes back against depletion, up to a point) is not being strongly activated. Consequently, a given reduction in fishing mortality will lead to a smaller reduction in yield.

## 7.2 Monitoring

The assessment, and in particular the updated modelling methodology, investigated the following issues which are relevant to monitoring.

The standard approach to combining length- and age-frequency samples taken from different regions is to up-weight the number sampled in each region/sector by the total catch in that region/sector. This is problematic for region/sectors where a very small number of fish have been collected (e.g. the far north region in 2002), perhaps only 10-20 fish. This number might be too small to be statistically reliable (e.g. the fish are all from the same catch, and therefore may be very highly correlated in terms of their length) so to up-weight by catch in this sense would be up-weighting an unreliable sample.

Another reason for concern with up-weighting by catch is if catch itself is very uncertain (e.g. recreational sector). However, there are still good reasons for up-weighting if the sampling is representative of that region. Therefore it is useful to consider a parameterisation of this concept. Phi is 0 when no re-weighting is performed (length structures are based on raw samples), and 1 when a standard total catch re-weighting is performed. It can also take any value in between.

The review of stock assessment requirements for Spanish mackerel (O'Neill and McPherson 2000; Sumpton and O'Neill 2004) highlighted that it is important to consider spatial and possibly sectoral variation in the age and length sampling program. It is therefore not surprising that the catch-size versus sample size weighting parameter, phi, appears to have an impact on the model (Scenarios 1, 19 and 20). In particular the non-re-weighted method leads to lower estimates of productivity. One possible explanation for this is that smaller region/sector sampled catches relate to bigger fish. When weighted up, this would push Z down, whereas no re-weighting leaves Z higher (in other words more truncated length structures for non-re-weighting; therefore more importance on smaller fish).

An age-length key is not needed in a fully length- and age-structured model. A parameter in the pre-processing of the length and age-structured data was introduced to balance the relative weight given to length-only versus length-age-sex samples. A strong weighting on the sex-age-length likelihood over the length-only likelihood implies a model that is less trusting of length-only data and is relying more heavily on the length-age data (which could be sensible for strong variation in length-at-age species like Spanish mackerel) with the trade-off that the model must rely on a smaller 'effective' number of samples. This modelling approach enables the investigation of the most cost-effective balance in terms of how many fish are aged, sexed and measured, how many are only measured etc.

Another issue that was highlighted in the construction of the updated modelling approach was that more information associated with the samples could be used if available. In particular an important piece of information is the number of fish sampled from the same catch. There is some existing literature on 'intra-haul correlation' which could be applied here.

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## 9 Appendix A – Model equations

## 2. Material and Methods

### 2.1. Population dynamics

The population was modelled in annual time steps, with population state stratified by length class, age class and sex. The number of fish at the start of year  $y$ , at age  $a$ , length  $l$  and sex  $s \in \{f = \text{female}, m = \text{male}\}$ ,

$$n_{y las} = \begin{cases} .5r_y p_{l1s} & \text{for } a = 1 \\ n''_{(y-1)l(a-1)s} & \text{for } a = 2..a_{\text{Max}} - 1 \\ n''_{(y-1)l(a-1)s} + n''_{(y-1)las} & \text{for } a = a_{\text{Max}} \end{cases} \quad (1)$$

where  $r_y$  is recruitment in year  $y$  and  $p_{l1s}$  is the proportion of fish of age 1 and sex  $s$  that are in length class  $l$ . Peak spanish mackerel spawning is September-December so a nominal birthday is 1 November. Fish accumulate in the  $a_{\text{Max}}$  age class if they are still alive. The double dash on  $n_{y las}$  indicates the state of the population after both mortality and growth have been applied.

The population is first subject to fishing and natural mortality:

$$n'_{y las} = e^{-M_s} (1 - S_l U_y) n_{y las} \quad (2)$$

where  $M_s$  is natural mortality,  $S_l$  is length-based selectivity and  $U_y$  is the annual harvest rate. Then growth occurs:

$$n''_{y l' as} = \begin{cases} \sum_{l=l_{\text{Min}}, l_{\text{Min}}+2, \dots}^{l'} \left[ n'_{y las} \int_{\max(0, l'-l-1)}^{l'-l+1} \lambda(\Delta l | l, a, s) d(\Delta l) \right] & \text{where } l' < l_{\text{Max}} \\ \sum_{l=l_{\text{Min}}, l_{\text{Min}}+2, \dots}^{l'} \left[ n'_{y las} \int_{\max(0, l'-l-1)}^{\infty} \lambda(\Delta l | l, a, s) d(\Delta l) \right] & \text{where } l' = l_{\text{Max}} \end{cases} \quad (3)$$

where  $\lambda(\Delta l | l, a, s)$  is the probability density function for non-negative growth increment  $\Delta l$  for a fish of a given length, age and sex. The growth increment density function is integrated to give the transition proportions from length class  $l$  into each higher length class. Length classes proceed in 2 cm intervals from  $l_{\text{Min}} = 48$  to  $l_{\text{Max}} = 170$  cm and all fish in length class  $l$  are taken to be exactly  $l$  cm, so the probability that a fish stays in the same length class is the integral of  $\Delta l$  from zero to 1cm, the probability of growing one length class is the integral from 1 cm to 3 cm etc. Because the growth density function changes slowly relative to the 2 cm spacing of the length classes the integrals are safely approximated by evaluating the density only at the midpoint of the integral limits and re-normalizing.

The model is not sensitive to the order in which these updates occur (ageing/recruitment, mortality, growth). The following sections contain more details on these processes.

## 2.2. Recruitment

Fish enter the length-age-sex matrix at 1 years and with length given by a normal distribution of mean  $\mu_{l_1}$  and standard deviation  $\sigma_{l_1}$ . Two alternative approaches were tried - lognormally distributed and deterministic entry at 0 years followed by one year of growth - but they did not fit the data as well. These fish are termed recruits (despite not being fully recruited to the fishery until about 2 years of age). Their number was modelled as a Beverton-Holt function of the previous years' egg production with annual lognormal stochastic variation:

$$r_y = \frac{E_{y-1}}{\tilde{\alpha} + \tilde{\beta}E_{y-1}} e^{\epsilon_y - 0.5\sigma_r^2} \quad (4)$$

where  $\epsilon_y \sim \mathcal{N}(0, \sigma_r^2)$  was the annual recruitment deviation. Egg production in year  $y$ ,

$$E_y = \sum_l e^{-vM} n_{yl.1} \text{fec}_l \text{mat}_l \quad (5)$$

where  $v$  is the proportion of annual natural mortality that occurs before spawning,  $\text{fec}_l = \varepsilon w_{lf}$ , is the fecundity at length and  $\text{mat}_l = e^{c+d(10l)} / (1 + e^{c+d(10l)})$  the maturity at length;  $w_{ls} = a_s l^{b_s}$  is the weight at length and sex in kilograms per fish. Throughout this article we use the notational convention that a period in the subscript indicates the dimension is summed over, so  $n_{yl.f}$  refers to the total number of female fish of length  $l$  in year  $y$ . The stock recruitment function was re-parameterized in terms of steepness and virgin recruitment (Francis, 1992):

$$\tilde{\alpha} = \frac{E(1-z)}{4zR} \text{ and } \tilde{\beta} = \frac{5z-1}{4zR} \quad (6)$$

where  $z$  is steepness (proportion of maximum recruitment achieved when stock is 20% of maximum),  $R$  is virgin (unfished equilibrium) recruitment and  $E$  is virgin egg production. This allowed us to make use of the empirical prior distribution of steepness for the *Scombridae* family given in Myers et al. (1999).

Table 1: Model parameters - description and values

| Description                                | Parameter              | Status    | Prior / Fixed value       |
|--------------------------------------------|------------------------|-----------|---------------------------|
| Virgin recruitment                         | $R$                    | Estimated | $\mathcal{U}(0, \infty)$  |
| Stock-recruitment steepness                | $z$                    | Estimated | $\mathcal{N}(.52, .24^2)$ |
| Selectivity                                |                        |           |                           |
| Length at 50% (cm)                         | $l_{50}$               | Estimated | $\mathcal{U}(0, \infty)$  |
| Steepness                                  | $\beta$                | Estimated | $\mathcal{U}(0, \infty)$  |
| Natural mortality (year <sup>-1</sup> )    |                        |           |                           |
| Female                                     | $M_f$                  | Fixed     | .3217                     |
| Male                                       | $M_m$                  | Fixed     | .3445                     |
| Recruitment standard deviation             |                        |           |                           |
| Models A to C                              | $\sigma_{rABC}$        | Fixed     | 0.4                       |
| Model D                                    | $\sigma_{rD}$          | Fixed     | 0.2                       |
| Annual growth standard deviation (model D) | $\sigma_g$             | Fixed     | 0.2                       |
| CPUE standard deviation                    | $\sigma_{CPUE}$        | Fixed     | 0.2                       |
| Mean growth at 80 cm (cm)                  |                        |           |                           |
| Female                                     | $g_{80f}$              | Estimated | $\mathcal{U}(0, \infty)$  |
| Male                                       | $g_{80m}$              | Estimated | $\mathcal{U}(0, \infty)$  |
| Mean growth at 120 cm                      |                        |           |                           |
| Female                                     | $g_{120f}$             | Estimated | $\mathcal{U}(0, \infty)$  |
| Male                                       | $g_{120m}$             | Estimated | $\mathcal{U}(0, \infty)$  |
| Standard deviation                         |                        |           |                           |
| Base                                       | $\varsigma$            | Estimated | $\mathcal{U}(0, \infty)$  |
| Power                                      | $\psi_{AB}, \psi_{CD}$ | Fixed     | 0, -0.27                  |
| Length at one year (cm)                    |                        |           |                           |
| Mean (models A, B, C)                      | $\mu_{l_1}$            | Estimated | $\mathcal{U}(0, \infty)$  |
| Annual (model D)                           | $\mu_{yl_1}$           | Estimated | $\mathcal{U}(0, \infty)$  |
| Standard deviation (all models)            | $\sigma_{l_1}$         | Estimated | $\mathcal{U}(0, \infty)$  |
| Sampling program likelihood control        |                        |           |                           |
| Down-weight all samples                    | $\vartheta$            | Fixed     | 0.33                      |
| Sex-age-length vs length balance           | $\varrho$              | Fixed     | 0.5                       |
| Catch-size vs sample-size balance          | $\phi$                 | Fixed     | 0.5                       |
| Proportion of $M$ before                   |                        |           |                           |
| Fishing                                    | $\tau$                 | Fixed     | 0.5                       |
| Spawning                                   | $v$                    | Fixed     | 0.5                       |
| Weight-length relationship                 |                        |           |                           |
| Female                                     | $a_f, b_f$             | Fixed     | 7.075e-6, 3.0398          |
| Male                                       | $a_m, b_m$             | Fixed     | 2.346e-6, 3.2766          |
| Maturity                                   | $c, d$                 | Fixed     | -10.349, 0.0128           |
| Fecundity (eggs/kg)                        | $\varepsilon$          | Fixed     | 76539                     |

### 2.3. Fishing mortality and selectivity

Fishing was modelled as an instantaneous mid-year pulse, occurring after a certain fraction ( $\tau$ ) of annual natural mortality has been applied. This allowed the annual harvest rate to be calculated directly from the observed catch:

$$U_y = \frac{C_y^{\text{OBS}}}{e^{-\tau M} \sum_{ls} S_l w_{ls} n_{yl.s}} \quad (7)$$

where  $C_y^{\text{OBS}}$  is the observed total catch in kilograms. The annual catch is modelled without an error term; sensitivity analyses (not reported here) have shown the growth sub-model to be insensitive to details of the catch history.

The fishing selectivity was modelled using the logistic form:

$$S_l = \frac{1}{1 + e^{\delta(l_{50}-l)}} \quad (8)$$

where  $\delta$  governs the initial steepness of the curve and  $l_{50}$  is the length at 50% selectivity.

### 2.4. Growth

Growth is a fundamental quantity in both age structured and age-length structured population models. As shown by Francis (1988), it is confounded with size-selective fishing mortality, and the ability of the model to estimate it accurately is dependent on the type of data available (i.e. length-age data or tag-recapture data). Therefore it is important to include growth parameters in the model to be estimated alongside fishing mortality parameters, and to parameterize the growth sub-model in a way that minimizes bias - particularly if only one type of growth data is available as was the case here.

The non-negative growth density function,  $\lambda(\Delta l)$ , is, by definition, a function of length. In reality growth will vary to some extent as a function of both length and age. To take an extreme example: of two 75 cm fish, the one year old will very likely grow more in the next year than the two year old. However for the east coast Spanish mackerel we didn't find this additional complexity to be justified as good fits were obtained with growth a function of length and sex alone.

Four growth sub-models were tested, models A-D. In model A, growth over one year was modelled as a von-Bertalanffy function of length:

$$g_l = (L_\infty - l)(1 - e^{-\kappa}) \quad (9)$$

where  $L_\infty$  is generally interpreted as the asymptotic maximum body size and  $\kappa$  is a growth rate coefficient. Because  $L_\infty$  and  $\kappa$  tend to be strongly correlated, we followed Francis (1988) and Gilbert et al. (2006) in reparameterizing growth in terms of expected growth at two reference lengths. Reference lengths 80 cm and 120 cm were chosen for this purpose as they were well separated but well within the range of the data. We also differentiated between the sexes:

$$g_{ls} = g_{80s} + (l - 80) \frac{(g_{120s} - g_{80s})}{40} \quad (10)$$

where the parameters  $g_{80s}$  and  $g_{120s}$  are the expected growth increments at lengths 80 and 120 cm.

Models B to D instead represented growth as a decreasing exponential function of length, also reparameterized in terms of expected growth at 80 and 120 cm:

$$g_{ls} = \frac{g_{80s}^{12/4}}{g_{120s}^{8/4}} \left( \frac{g_{120s}}{g_{80s}} \right)^{\frac{l}{40}} \quad (11)$$

The density function for the growth increment  $\Delta l$  for fish in year  $y$ , of sex  $s$ , age  $a$  and length  $l$ , was lognormal:

$$\lambda(\Delta l|y, l, a, s) = \frac{1}{\sqrt{2\pi}\sigma_{ls}\Delta l} \exp \left[ -\frac{1}{2} \left( \frac{\log(\Delta l) - \log(g_{ls}) + .5\sigma_{ls}^2}{\sigma_{ls}} \right)^2 \right] \quad (12)$$

The standard deviation parameter for models C and D varied as a function of expected growth:

$$\sigma_{ls} = \varsigma(g_{ls})^{\psi_{CD}} \quad (13)$$

where  $\varsigma$  was the estimated quantity and  $\psi_{CD}$  was fixed at -0.27. This value was the posterior mode estimate of  $\psi$  when  $\varsigma$  was estimated with a uniform prior upper bounded at 0.9. Estimating both  $\psi$  and  $\varsigma$  simultaneously with non-informative priors was not possible. In models A and B the standard deviation was not a function of expected growth ( $\psi_{AB}$  was fixed at zero).

Model D attempted to capture the apparent significant annual variation in length at one year,

$$g_{yl_1} = g_{l_1} e^{\zeta_y - 0.5\sigma_g^2} \quad (14)$$

where  $\zeta_y \sim \mathcal{N}(0, \sigma_g^2)$  was the annual growth deviation. Half the total process error was directed into this growth deviation component ( $\sigma_{rD} = \sigma_g = 0.5\sigma_{rABC}$ ).

In summary: Model A used a von-Bertalanffy growth sub-model (linear function of length); Model B incorporated the flexibility of an exponentially decreasing function of length; Model C added a standard deviation for the growth density function that depended on expected growth; and Model D added lognormally distributed annual deviations in expected length at one year.

### 2.5. Model selection

Three tools were used to decide between models: visual inspection of goodness-of-fit plots, convergence of MCMC chains, and the deviance information criteria (DIC). DIC is a generalization of Akaike’s information criterion to select among complex hierarchical models where the number of effective parameters is not readily apparent (Spiegelhalter et al., 2002). Simulation studies suggest it is a useful metric for model selection, including in a fisheries statistical catch-at-age context (Wilberg and Bence, 2008). The DIC was calculated as  $\bar{D} + p_D$ .  $\bar{D}$  is the average deviance,

$$\bar{D} = \frac{1}{C} \sum_{c=1}^C 2\Lambda(\theta_c) \quad (15)$$

where  $C$  is the number of MCMC steps saved, and  $\Lambda(\theta_c)$  is the negative log likelihood of the model for MCMC parameter vector  $\theta_c$ .  $p_D$  is the effective number of parameters, calculated as the difference between the average deviance and the deviance evaluated at the mean of the posterior parameter estimates:  $p_D = \bar{D} - D(\bar{\theta})$ .

### 2.6. Fitting to length and sex-age-length data

The model was fit to eight years of sampling program data covering five geographic regions and two sectors (Table 2). Due to the significantly increased costs associated with ageing and sexing fish over simply measuring them, the sampling program followed the common practice of a length-only component in conjunction with a full sex-age-length component. For an age-structured model the standard approach is then to use an age-length key to transform the more numerous length-only samples into age (or sex-age) samples. This is problematic if there are no fish aged in the corresponding length bin, requiring the gap to be filled somehow, which is often done in an *ad hoc* manner. For a length- and age-structured model this is not necessary, and in fact is sub-optimal as it ignores the opportunity to incorporate the functional

relationship between length and age distribution into the modelling process and investigate the plausibility of the assumption that the length data can act as a proxy for age data.

Specifically, by using a multinomial likelihood for fitting to the length-only data, and a separate multinomial for fitting to the sex-age-length data, we investigated this tradeoff by the weighting given to each component in the overall likelihood. A strong weighting on the sex-age-length likelihood vs the length-only likelihood implies a model that is less trusting of length-only data and is relying more heavily on the length-age data (which could be sensible for strong variation in length-at-age species like Spanish mackerel) with the tradeoff that the model must rely on a smaller ‘effective’ number of samples.

Another common cost-related idiosyncrasy of the sampling program was the way fish to be aged were chosen. The sampling program merely aimed to age enough fish in each length bin to obtain a representative distribution of age at length, and this number was therefore capped. This meant the number of sampled fish in each sex-age-length bin was not a representative reflection of the fished population, rather it was conditional on length. For this reason the likelihoods for those sampled fish that were aged, sexed and sized was based on the predicted proportion-at-age, for a given gender and length class:

$$p_{ylas} = \frac{c_{ylas}}{\sum_l c_{ylas}} \quad (16)$$

This proportion was matched to an observed ‘effective’ number,  $\eta_{ylas}$ , which was down-weighted from the actual number observed to account for the non-independence of samples (McAllister and Ianelli, 1997). This effective number was calculated in two steps. Firstly we obtained an equally-weighted combination of the raw proportions in each strata,

$$p_{ylas}^{\text{OBS}} = \frac{1}{2} \sum_{r=1}^2 p_{ylasr}^{\text{OBS}} \quad (17)$$

where  $p_{ylasr}^{\text{OBS}}$  was the observed sex-age-length proportion for strata  $r$  in year  $y$ . Secondly the ‘effective’ number was calculated as

$$\eta_{ylas} = \varrho_{\text{SAL}} \left( \sum_r \nu_{yr} \right) p_{ylas}^{\text{OBS}} \quad (18)$$

where  $\varrho_{\text{SAL}}$  is a factor that down-weights the raw sample size for the sex-age-length data (see below).

Table 2: Raw sample sizes for input data by year and strata: for numbers caught at length, and numbers at sex, age and length. Megaregion 1 (‘M1’ in table) is Rockhampton and South, megaregion 2 (‘M2’) is the rest - North, Townsville, Mackay. - indicates no data.

| Type             | Length                |                            |                        |                             |                       |                       |                            |                        |                             |                        | Sex-age-length   |                  |  |
|------------------|-----------------------|----------------------------|------------------------|-----------------------------|-----------------------|-----------------------|----------------------------|------------------------|-----------------------------|------------------------|------------------|------------------|--|
| Sector           | Commercial            |                            |                        |                             |                       | Recreational          |                            |                        |                             |                        | Combined         |                  |  |
| Region<br>Symbol | North<br>$\iota_{.1}$ | Townsville<br>$\iota_{.2}$ | Mackay<br>$\iota_{.3}$ | Rockhampton<br>$\iota_{.4}$ | South<br>$\iota_{.5}$ | North<br>$\iota_{.6}$ | Townsville<br>$\iota_{.7}$ | Mackay<br>$\iota_{.8}$ | Rockhampton<br>$\iota_{.9}$ | South<br>$\iota_{.10}$ | M1<br>$\nu_{.1}$ | M2<br>$\nu_{.2}$ |  |
| 2002             | 107                   | 2844                       | -                      | 234                         | 287                   | 13                    | 133                        | 25                     | 35                          | 112                    | 579              | 194              |  |
| 2003             | -                     | 3977                       | 161                    | 693                         | 16                    | 5                     | 96                         | 61                     | 42                          | 9                      | 1249             | 59               |  |
| 2004             | -                     | 1196                       | -                      | 63                          | -                     | -                     | -                          | -                      | -                           | -                      | 539              | -                |  |
| 2005             | -                     | 1483                       | 201                    | 788                         | 203                   | -                     | 59                         | 18                     | 49                          | 173                    | 804              | 564              |  |
| 2006             | -                     | 1690                       | 134                    | 965                         | 95                    | -                     | 93                         | 58                     | 77                          | 125                    | 460              | 846              |  |
| 2007             | -                     | 1043                       | 391                    | 304                         | 278                   | -                     | 75                         | 47                     | 648                         | 108                    | 584              | 357              |  |
| 2008             | -                     | 937                        | -                      | 348                         | 599                   | -                     | 179                        | 80                     | 58                          | 95                     | 590              | 321              |  |
| 2009             | -                     | 1938                       | 239                    | 298                         | 780                   | -                     | 161                        | 100                    | 83                          | 286                    | 785              | 539              |  |

The negative log-likelihood term followed a multinomial distribution,

$$\Lambda_{\text{SAL}} = - \sum_{y,l,a,s} \eta_{ylas} \log p_{ylas} \quad (19)$$

although as in Gilbert et al. (2006) the quantity  $\eta_{ylas}$  was not necessarily an integer and therefore  $\Lambda_{\text{SAL}}$  is not strictly multinomial.

The proportion,

$$p_{yl..} = \sum_{a,s} p_{ylas} \quad (20)$$

corresponded to the observed ‘effective’ number,  $\zeta_{yl}$ . This was calculated in a similar fashion to the effective number at sex-age-length, although in this case the relative contribution of each strata to the overall proportion at length was modulated with the relative catch amongst strata. Firstly we obtained a weighted combination of raw proportions in each strata,

$$\rho_{yl}^{\text{OBS}} = \sum_{r=1}^{10} \rho_{ylr}^{\text{OBS}} * (\phi \varpi_{yr} + (1 - \phi) \kappa_{yr}) \quad (21)$$

where  $\rho_{ylr}^{\text{OBS}}$  was the observed length proportion for strata  $r$  in year  $y$ ,  $\varpi_{yr}$  was the proportion of catch taken in strata  $r$  in year  $y$ ,  $\kappa_{yr} = \iota_{yr} / \sum_r \iota_{yr}$  was the proportion of samples taken in strata  $r$  and  $\phi$  is a term that balances the catch-size vs sample-size contribution. Catch by strata is given in 3. Secondly the ‘effective’ number was calculated as

$$\zeta_{yl} = \varrho_L \left( \sum_r \iota_{yr} \right) \rho_{yl}^{\text{OBS}} \quad (22)$$

where  $\varrho_L$  is a factor that down-weights the raw sample size for the length frequency data.

The negative log-likelihood term also followed a multinomial,

$$\Lambda_L = - \sum_{y,l,a,s} \zeta_{yl} \log \rho_{ylas} \quad (23)$$

As discussed, the relative weighting for the sex-age-length data versus the length data was considered to be an important variable. The weights ( $\varrho_{\text{SAL}}$  and  $\varrho_L$ ) were defined in terms of a ‘balance’ variable,  $\varrho$ , and an absolute

Table 3: Total catch by strata (tonnes).

| Region | Commercial |     |     |     |     | Recreational |     |     |     |     |
|--------|------------|-----|-----|-----|-----|--------------|-----|-----|-----|-----|
|        | Nth        | Tsv | Mac | Roc | Sth | Nth          | Tsv | Mac | Roc | Sth |
| 2002   | 178        | 349 | 73  | 62  | 43  | 12           | 134 | 61  | 95  | 81  |
| 2003   | 161        | 382 | 75  | 85  | 79  | 13           | 148 | 68  | 106 | 89  |
| 2004   | 110        | 281 | 65  | 57  | 57  | 13           | 142 | 65  | 101 | 86  |
| 2005   | 36         | 146 | 44  | 35  | 46  | 13           | 141 | 65  | 101 | 85  |
| 2006   | 26         | 145 | 28  | 27  | 43  | 12           | 136 | 63  | 97  | 82  |
| 2007   | 40         | 116 | 33  | 22  | 21  | 12           | 132 | 61  | 94  | 80  |
| 2008   | 40         | 109 | 23  | 22  | 16  | 12           | 132 | 61  | 95  | 80  |
| 2009   | 68         | 164 | 28  | 25  | 23  | 13           | 142 | 65  | 102 | 86  |

multiplier,  $\vartheta$ :

$$\varrho_{\text{SAL}} = \vartheta \frac{\sum_{yr} \iota_{yr} + \sum_{yr} \nu_{yr}}{\left( \sum_{yr} \iota_{yr} \right) \varrho + \sum_{yr} \nu_{yr}} \quad (24)$$

$$\varrho_{\text{L}} = \varrho * \varrho_{\text{SAL}}$$

The absolute multiplier down-weighted all the sampling program data in the overall likelihood. The value of 0.33 was found using the method described in Appendix 2 of McAllister and Ianelli (1997).

### 2.7. Fitting to CPUE

The mid-year exploitable biomass in year  $y$ ,

$$B_y = \prod_{l,a,s} n_{ylas} e^{-.5M} (1 - S_l U_y / 2) w_{ls} \quad (25)$$

The expected value of the CPUE abundance index for year  $y$ ,  $I_y$ , is the product of  $B_y$  and a catchability coefficient,  $q$ . The negative log-likelihood term for these indices, based on the lognormal distribution,

$$\Lambda_{\text{CPUE}} = \sum_y \left[ \log(\sigma_{\text{CPUE}}) + \frac{1}{2\sigma_{\text{CPUE}}^2} \left( \log \left( \frac{I_y^{\text{OBS}}}{q B_y} \right) + \frac{\sigma_{\text{CPUE}}^2}{2} \right)^2 \right] \quad (26)$$

The catchability was estimated directly using the closed form solution

$$q = \exp \left[ \frac{1}{n} \sum_y \log \left( \frac{I_y^{\text{OBS}}}{B_y} \right) + \frac{\sigma_{\text{CPUE}}^2}{2} \right] \quad (27)$$

### 2.8. Objective function

The overall likelihood for models A, B and C was

$$\Lambda = \Lambda_{\text{SAL}} + \Lambda_{\text{L}} + \Lambda_{\text{CPUE}} + 10 * \sum_y \log(\sigma_r) + \frac{\epsilon_y^2}{2\sigma_r^2} + 10 * \frac{(z - .52)^2}{2 * 0.24^2} \quad (28)$$

For model D it was as in Equation 28, with an additional penalty to constrain the growth deviations:  $10 * \sum_y \log(\sigma_g) + \frac{\xi_y^2}{2\sigma_g^2}$ .

$\Lambda$  was minimized using AD Model Builder version 9.0 (ADMB Project, 2009).

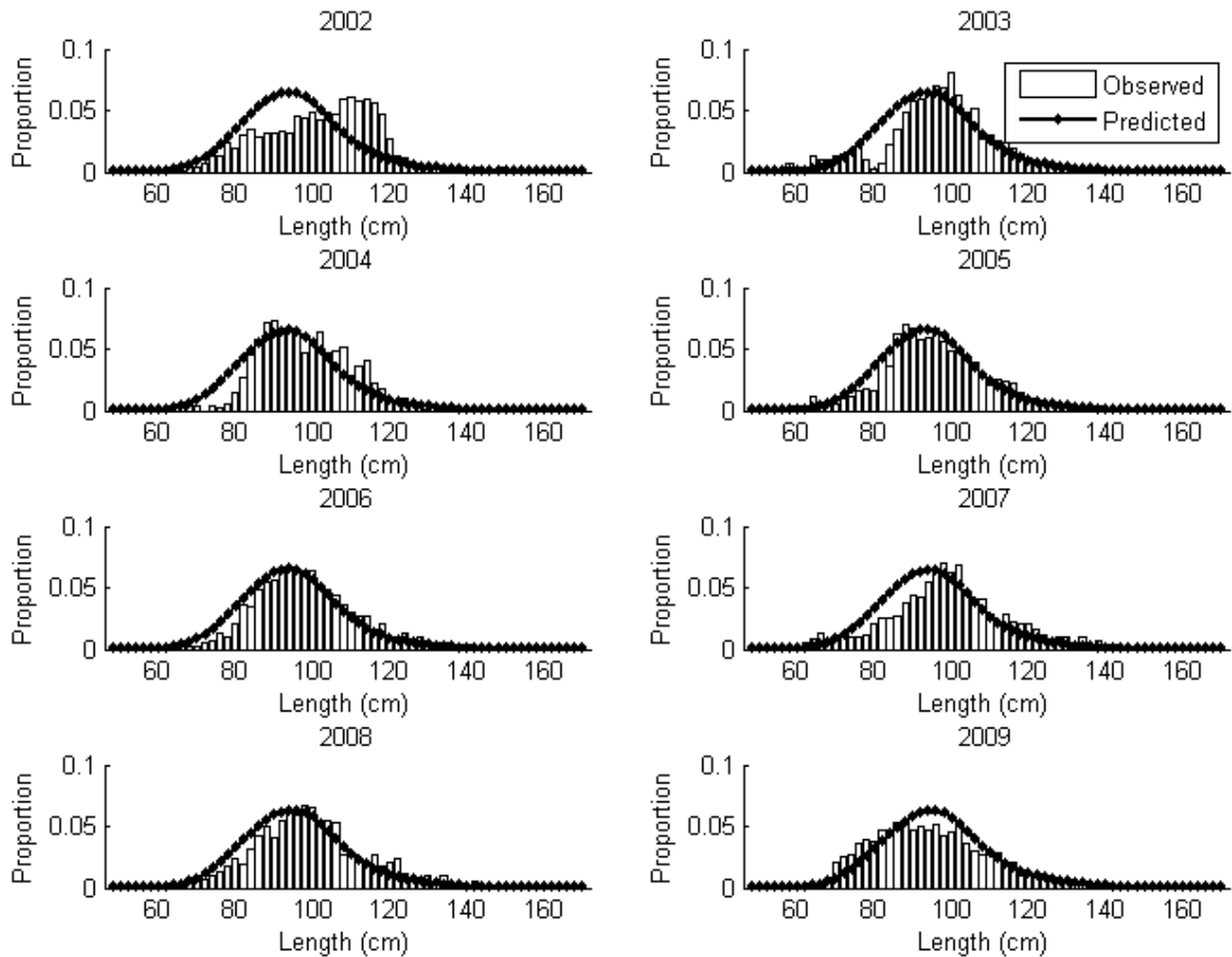
## References

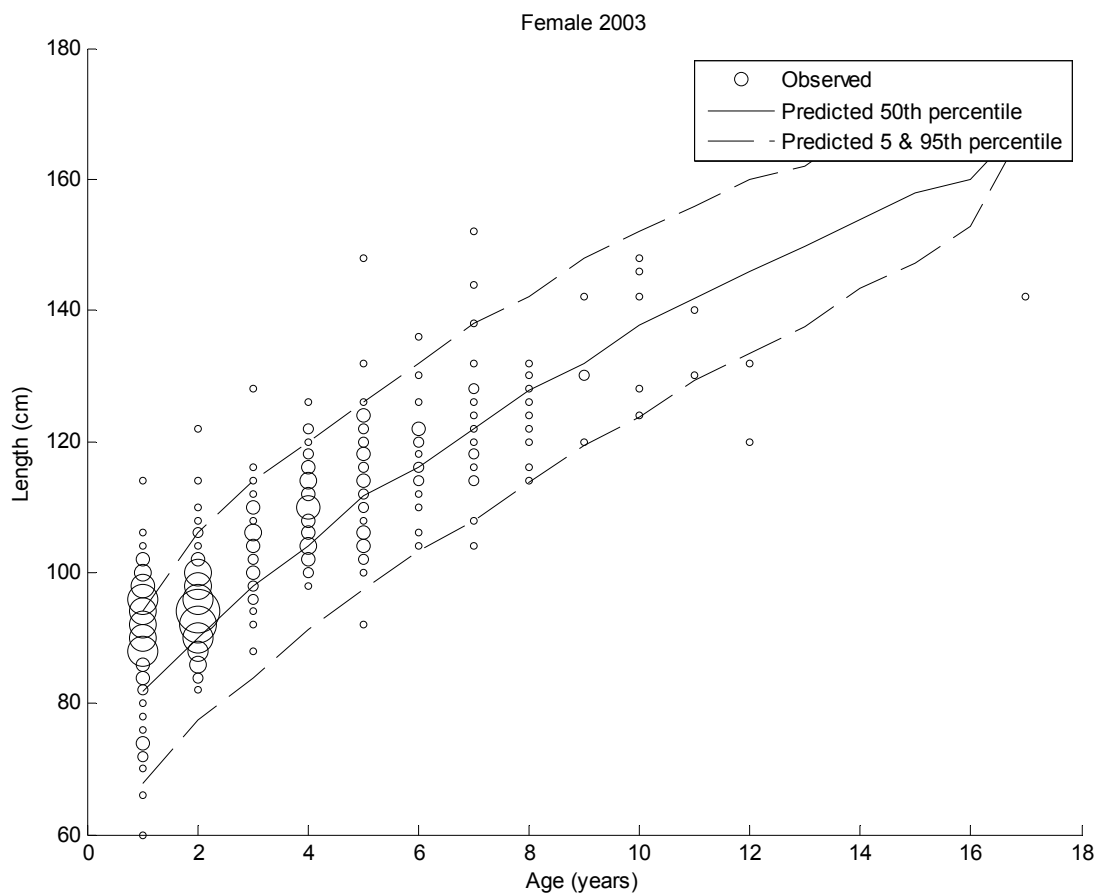
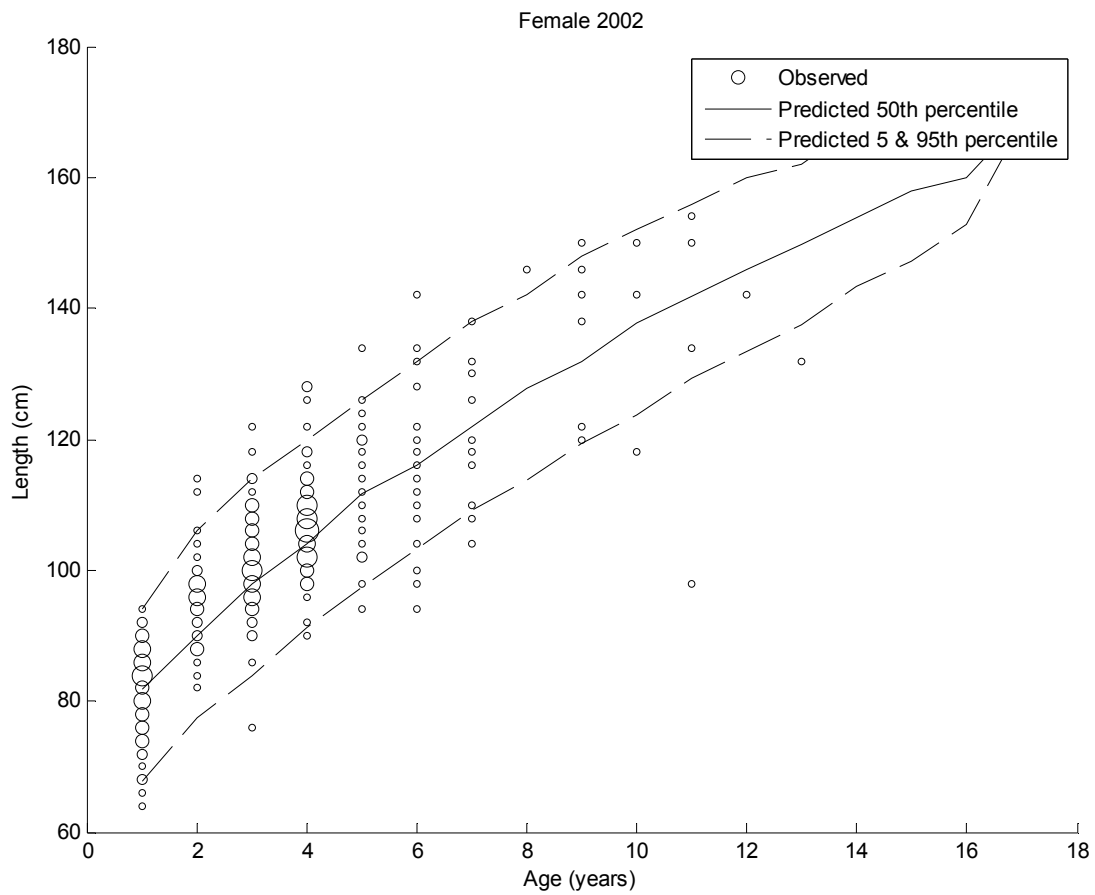
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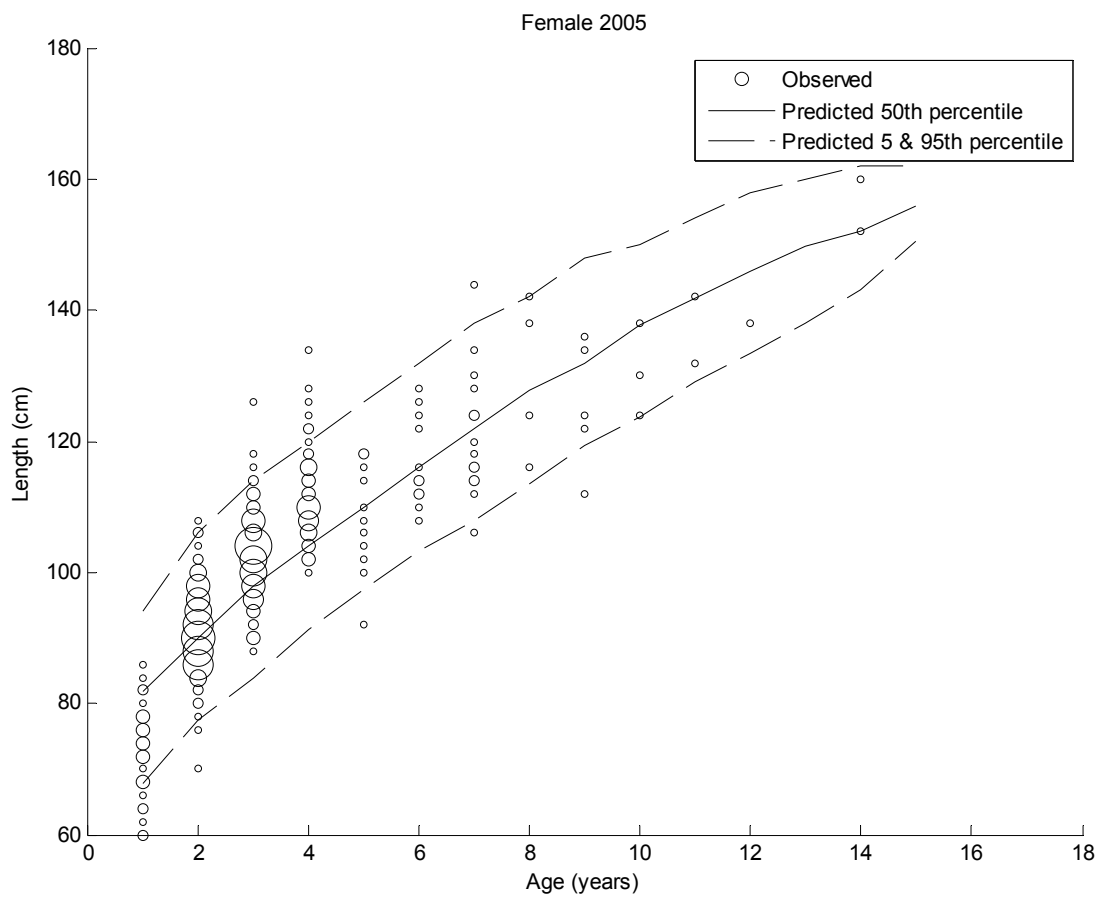
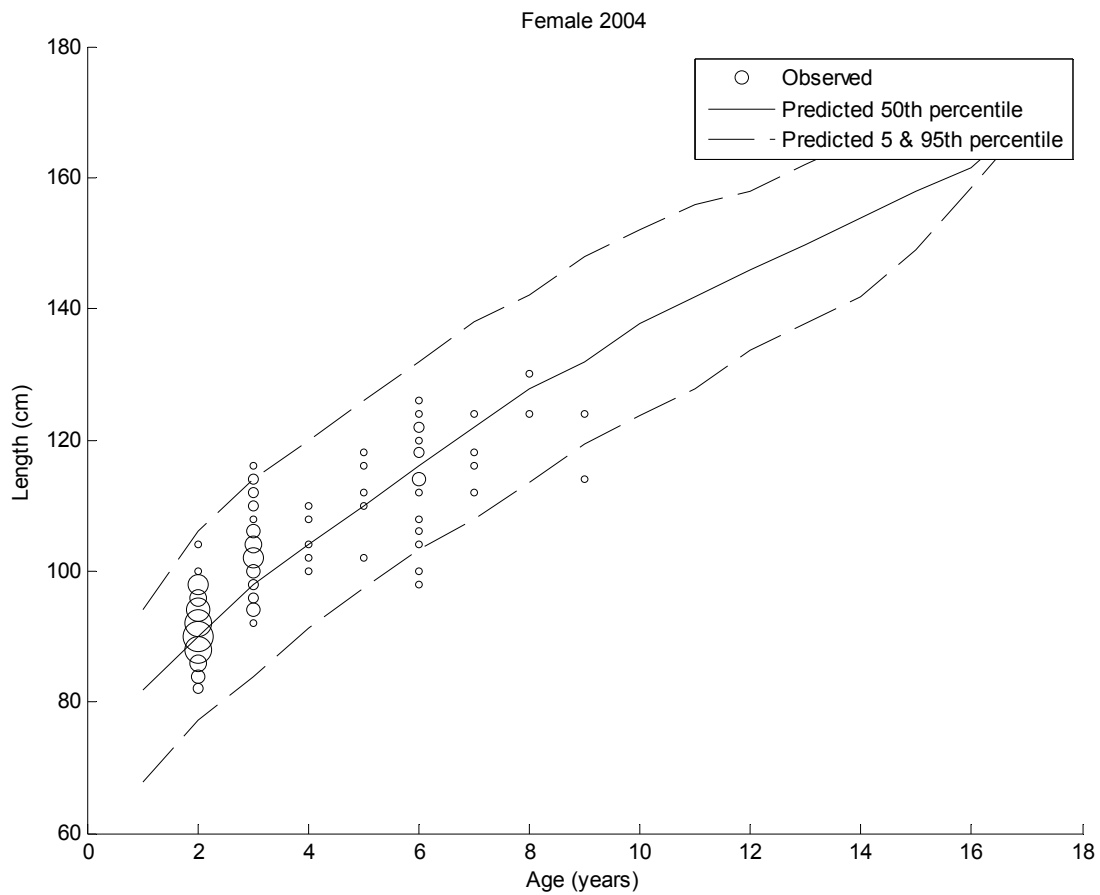
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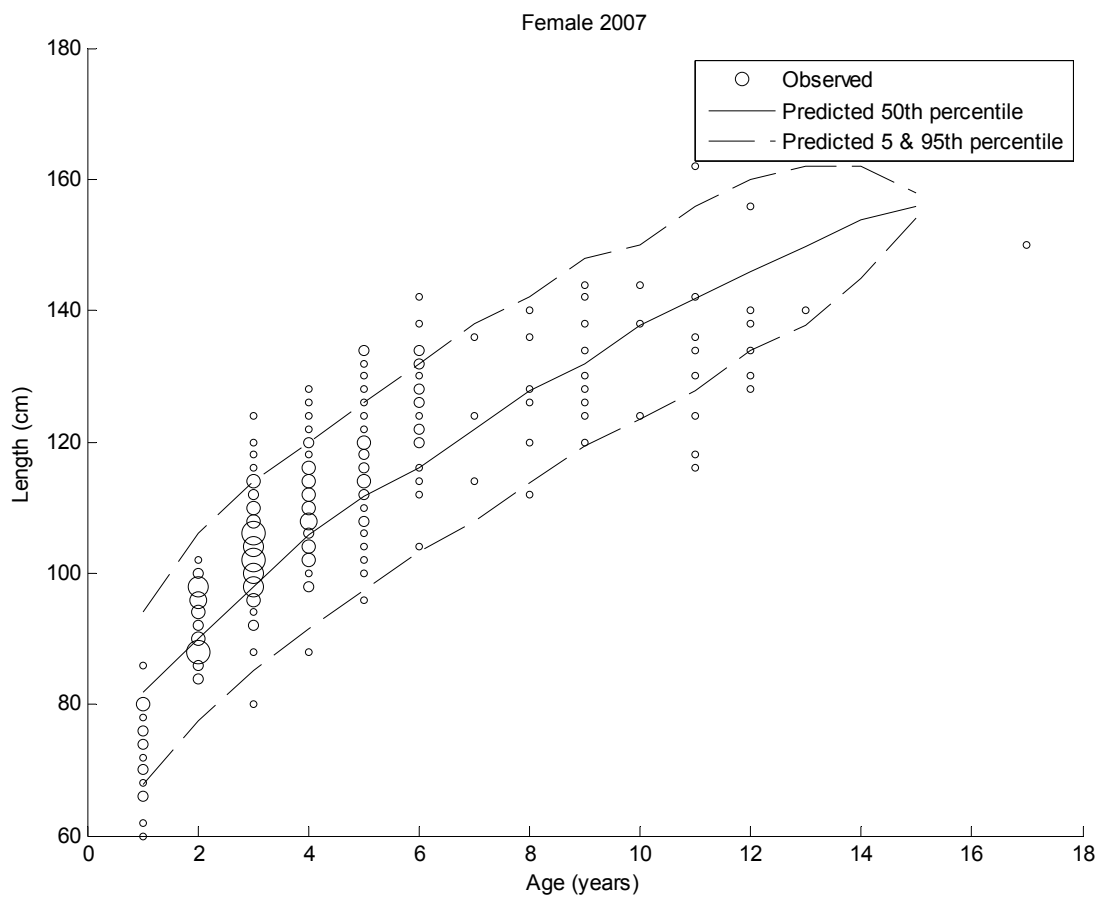
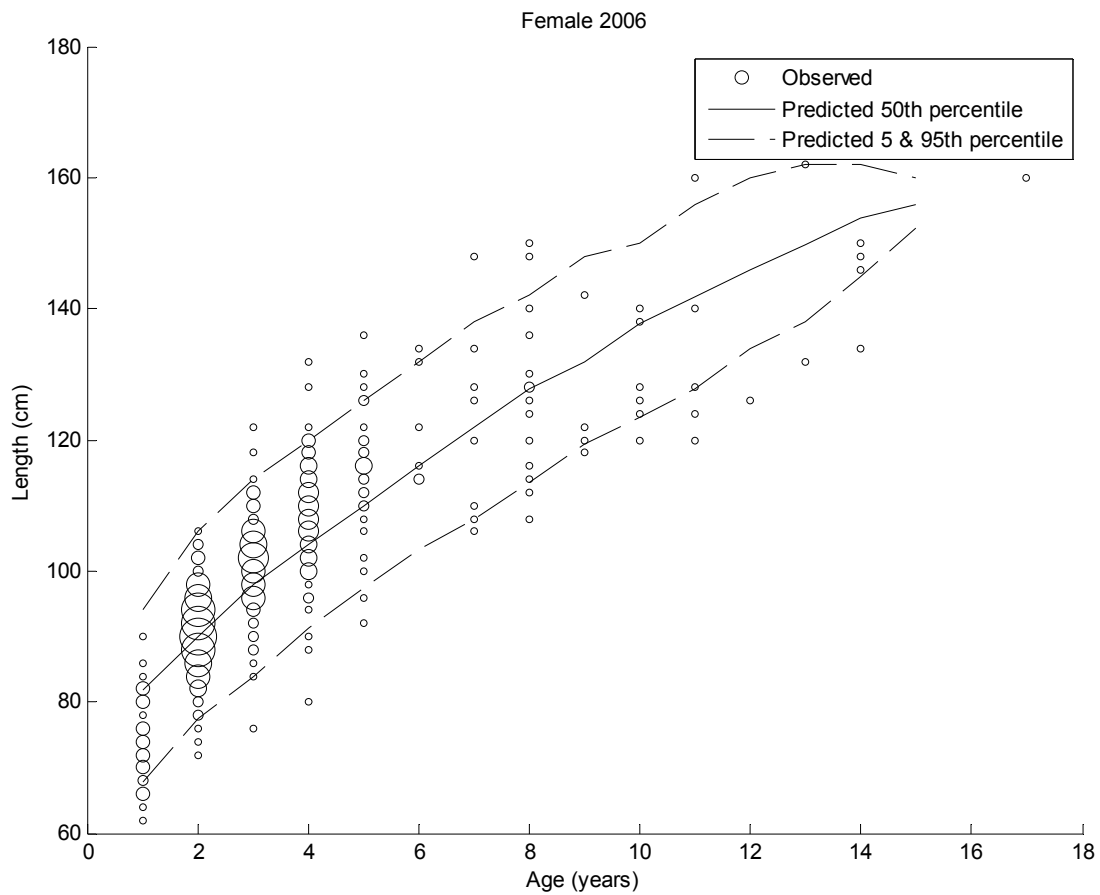
## 10 Appendix B – Goodness of fit

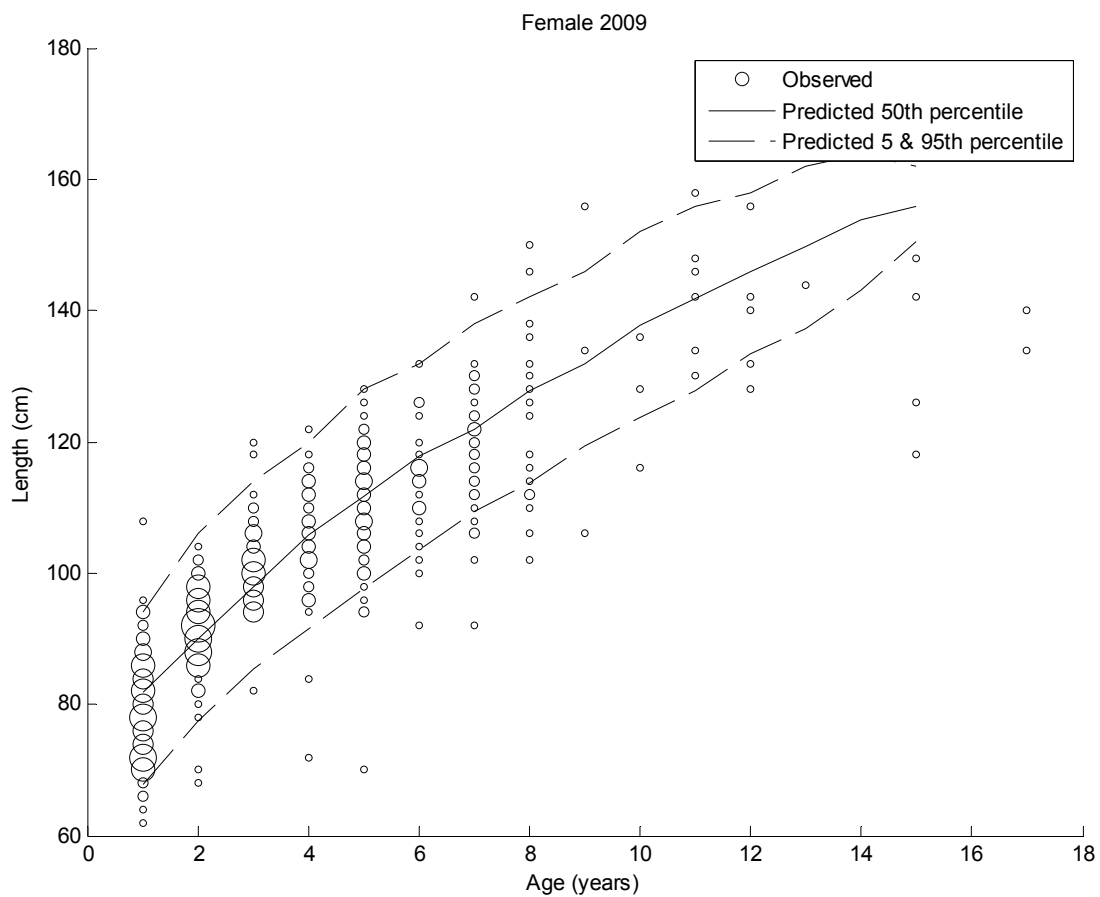
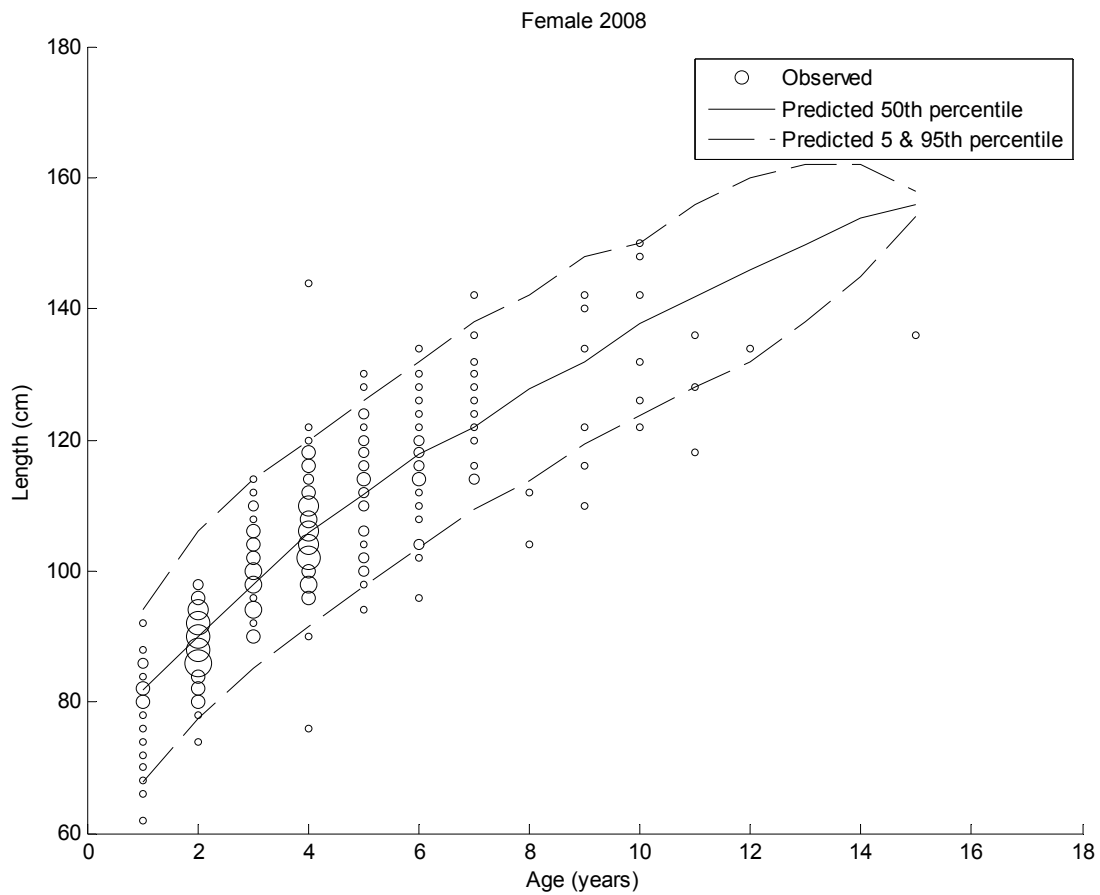
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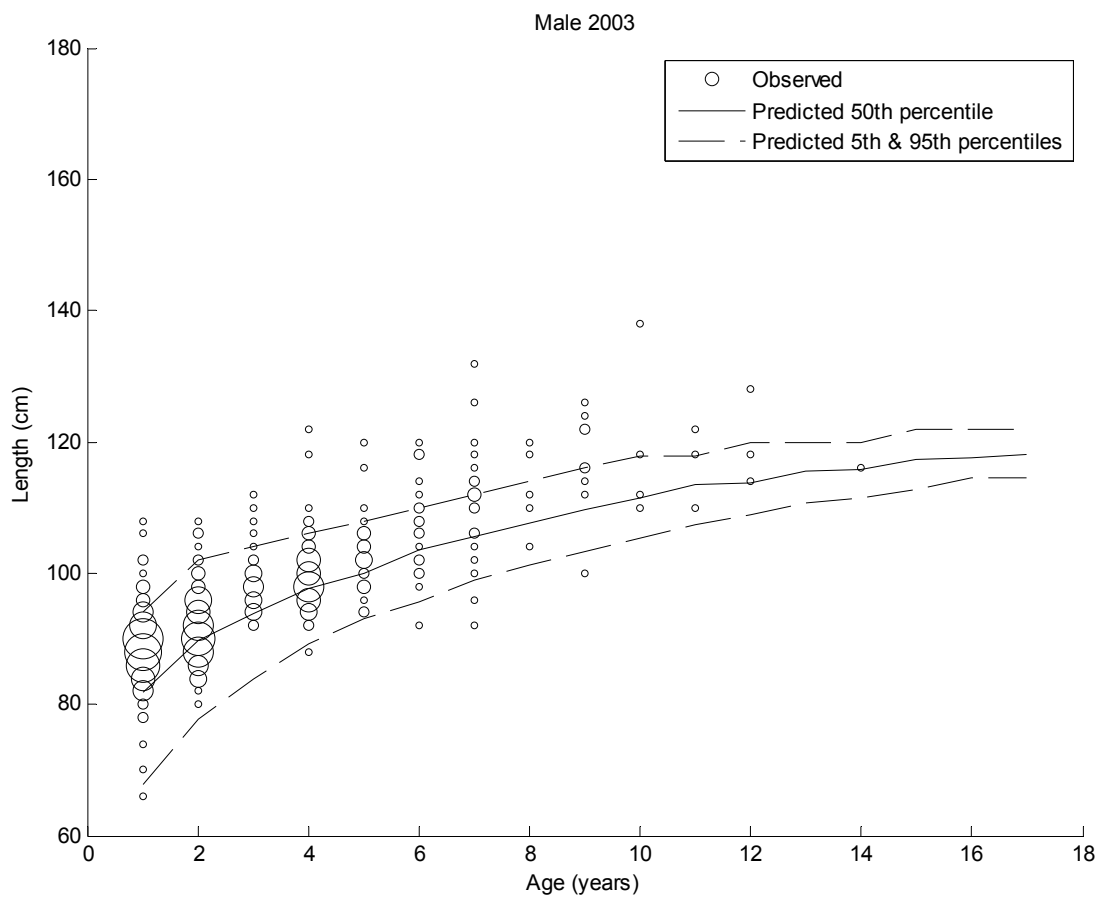
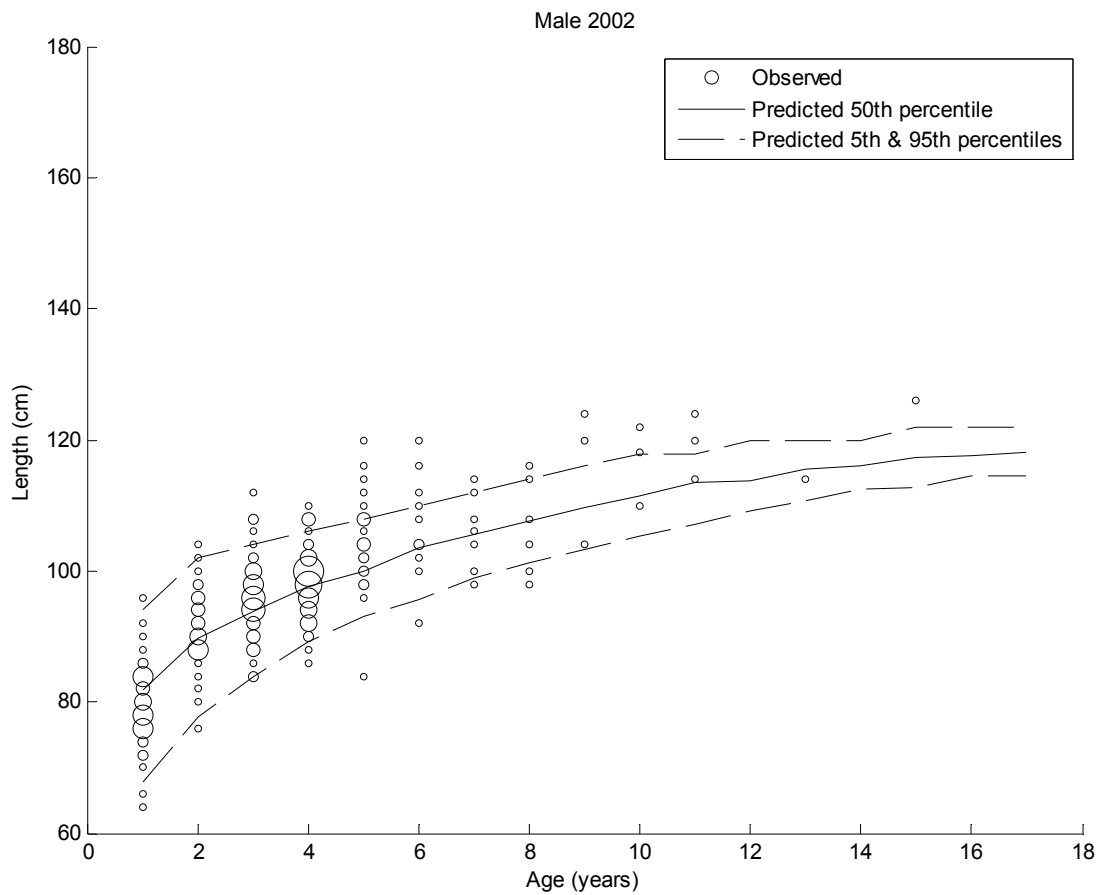


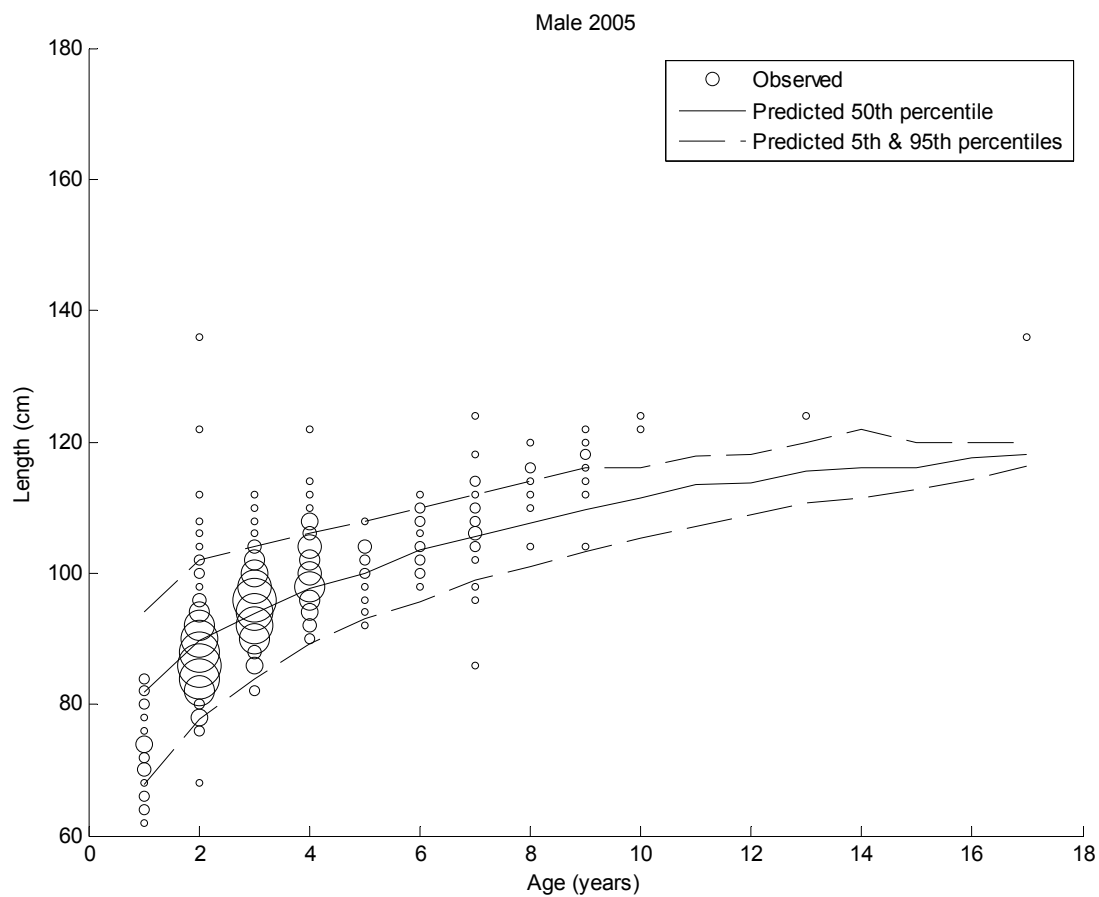
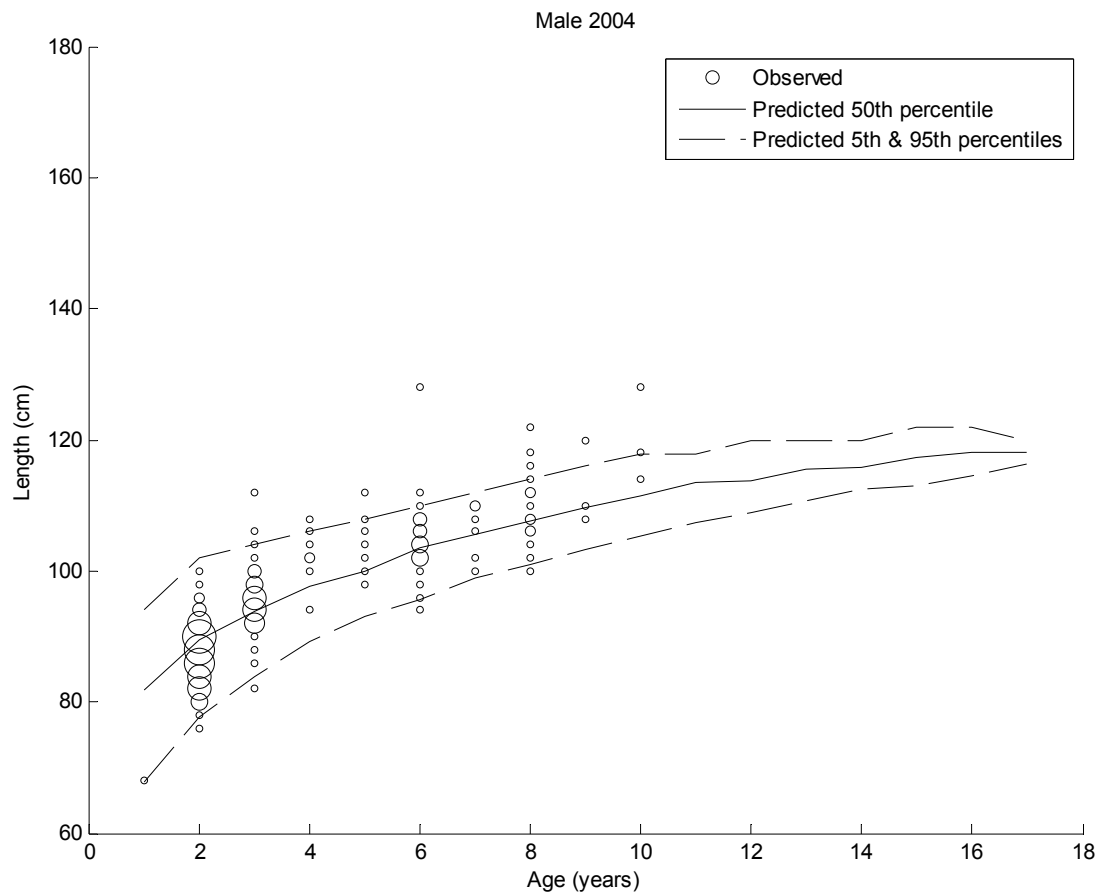


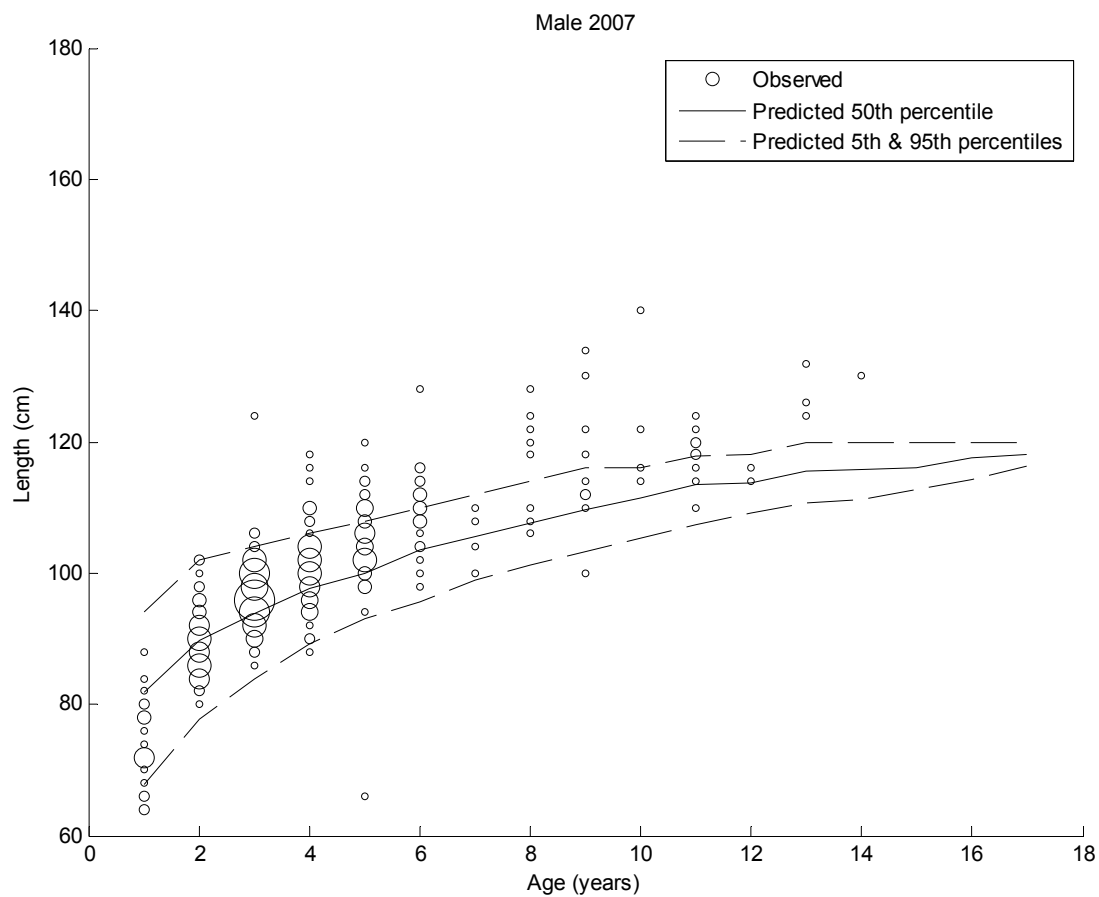
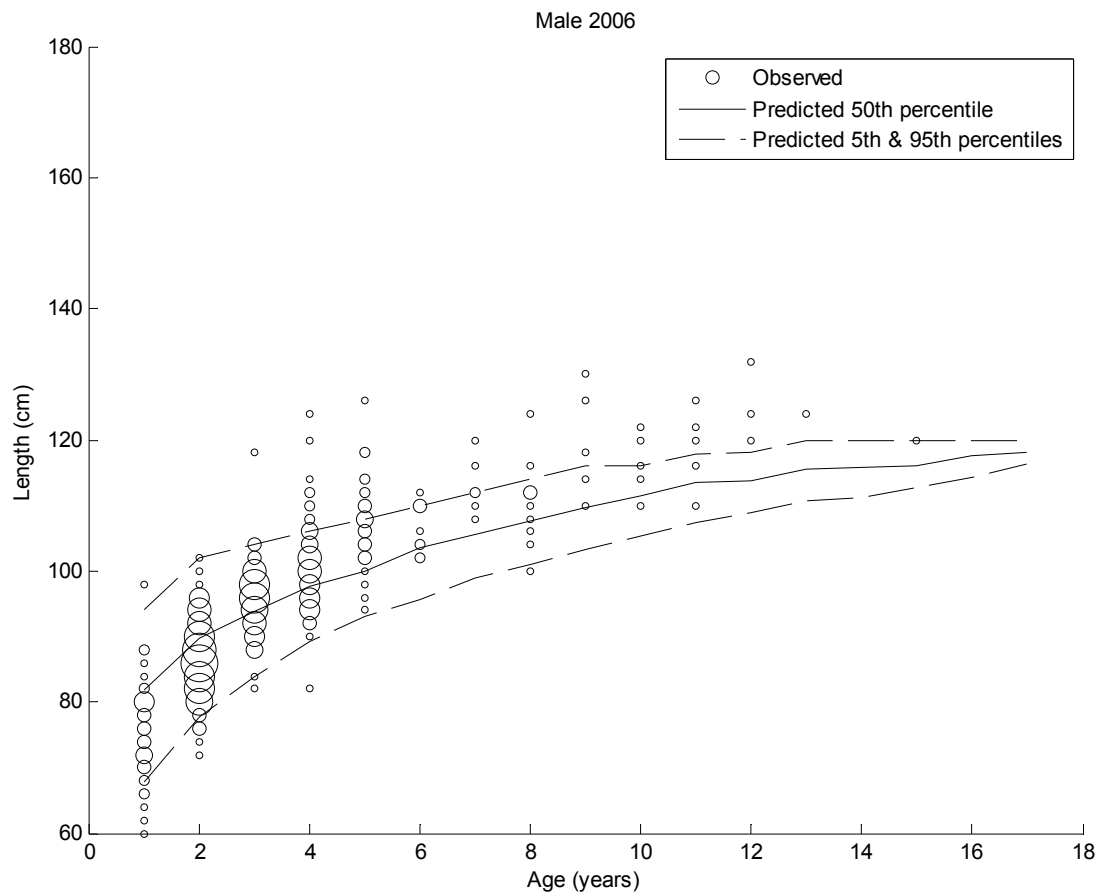




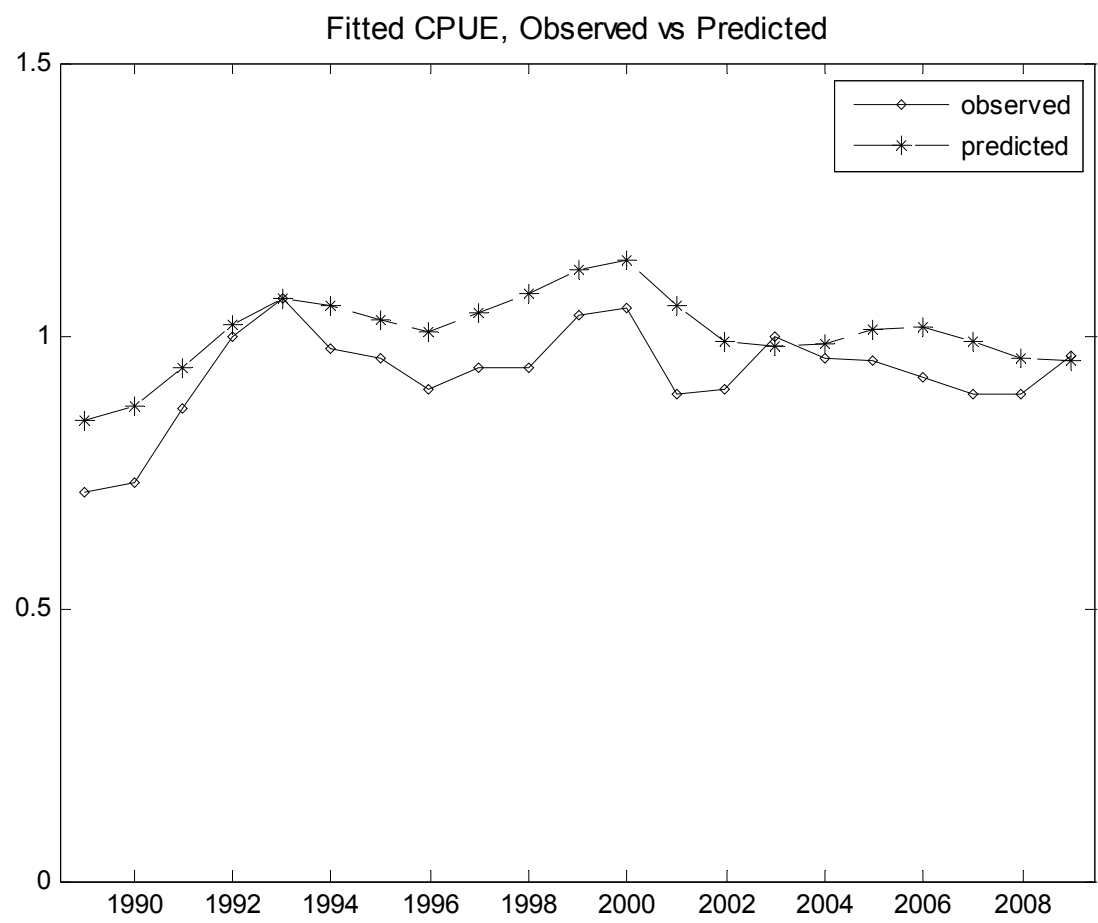


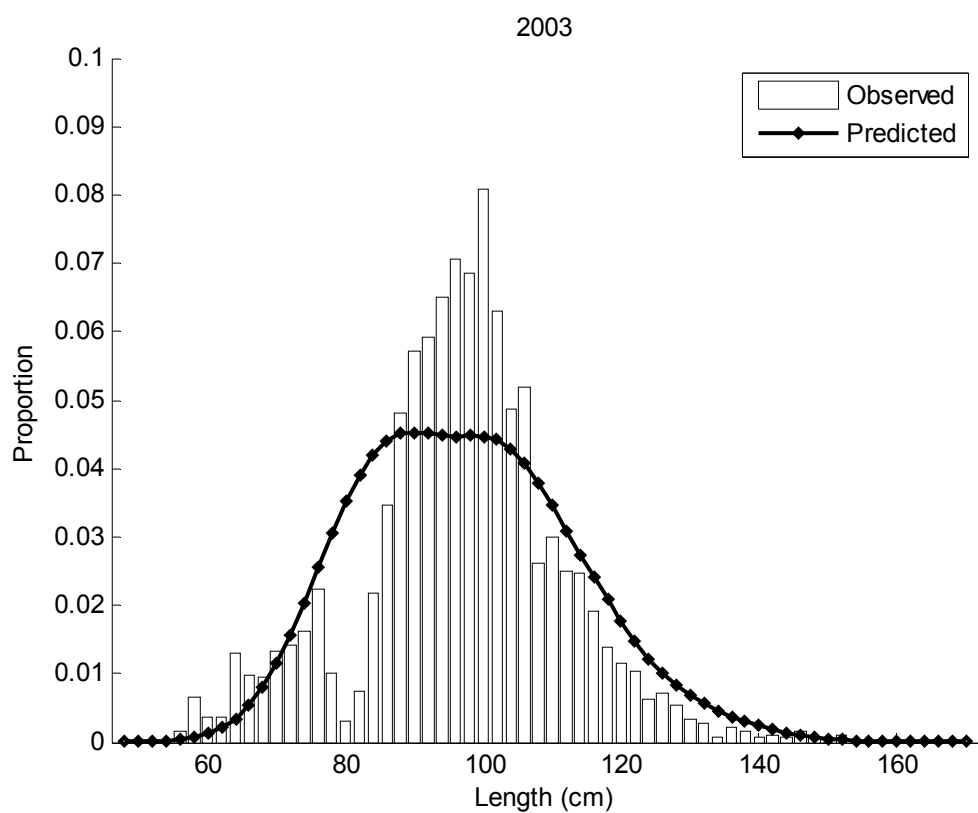
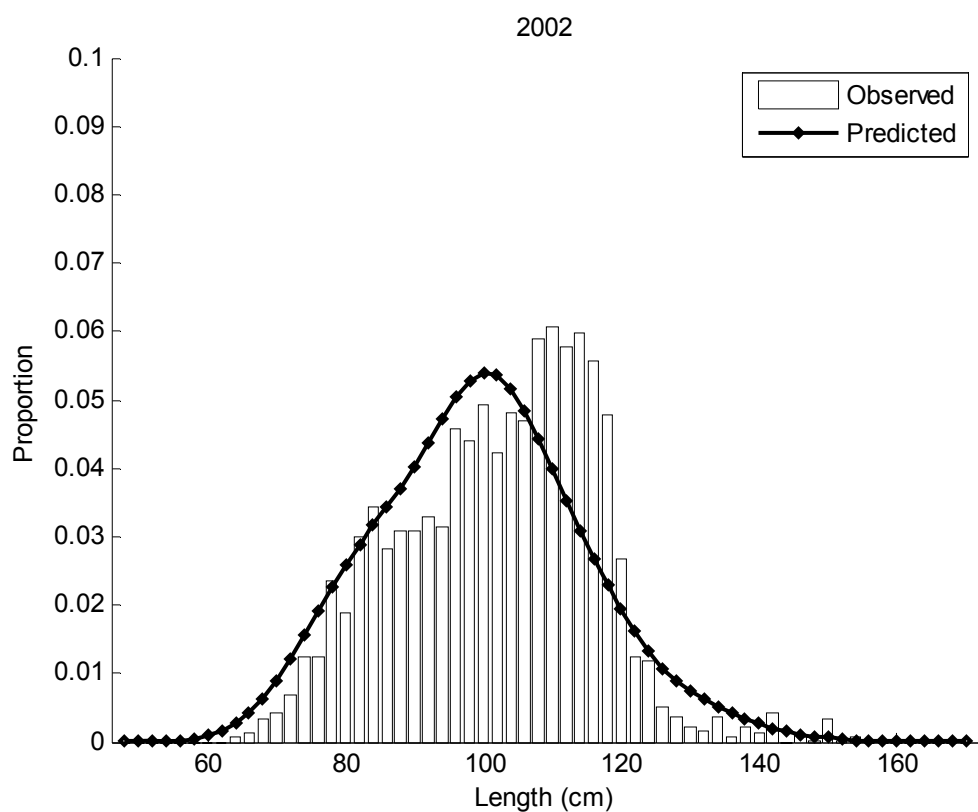


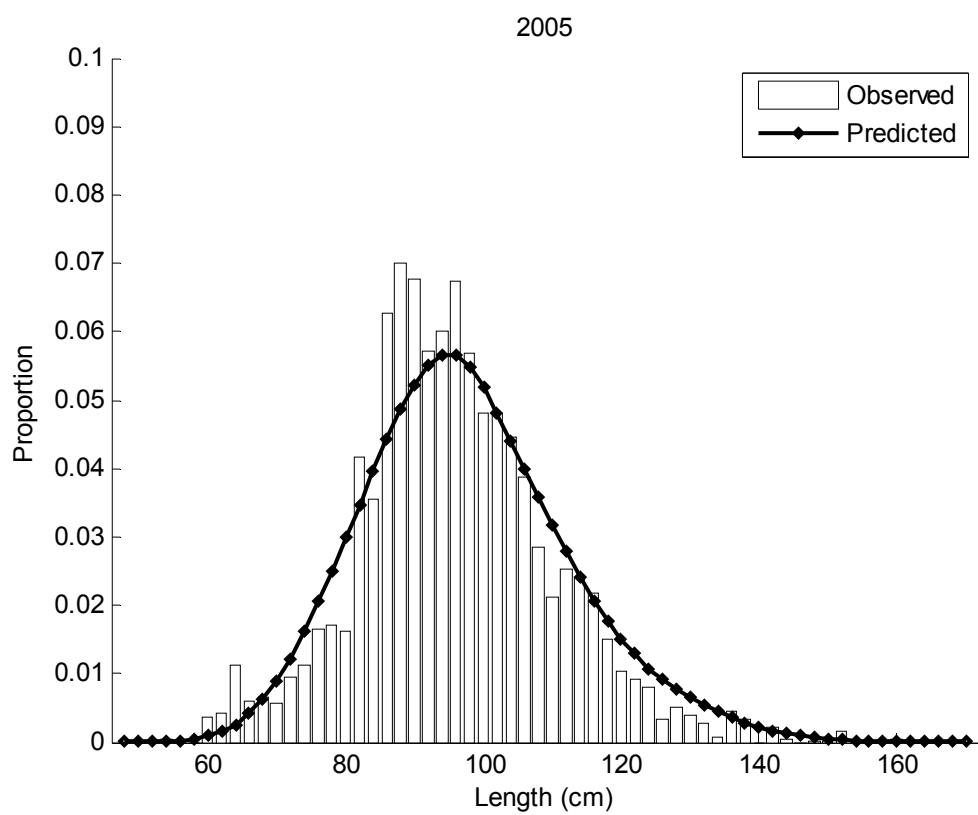
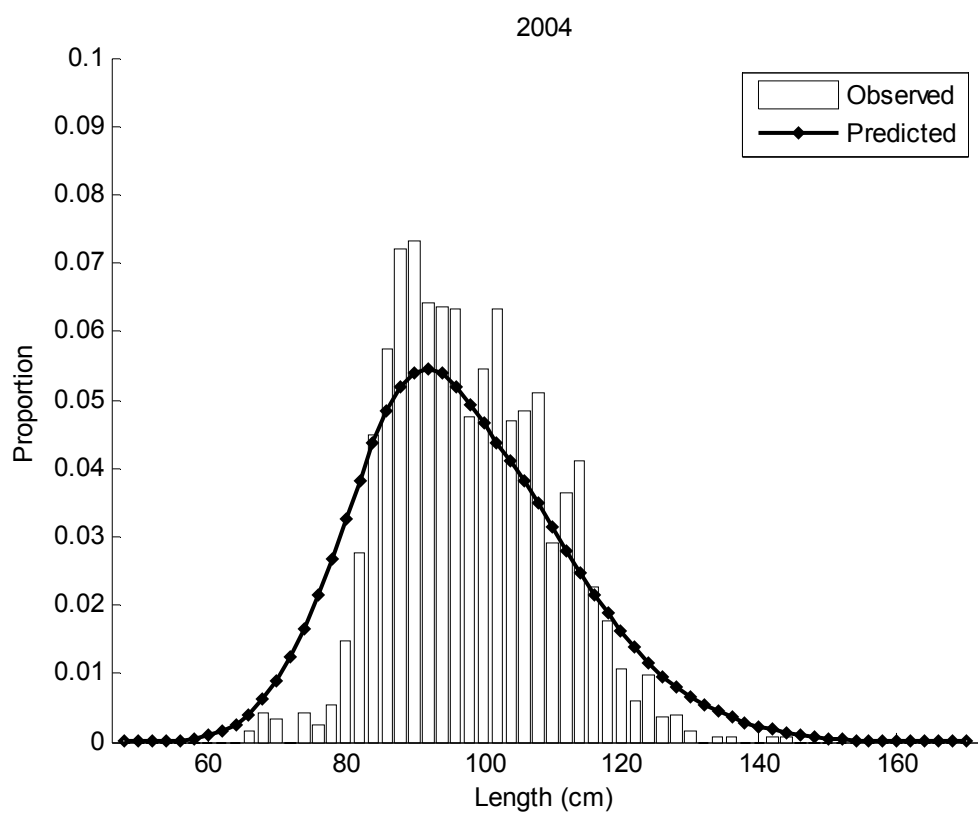


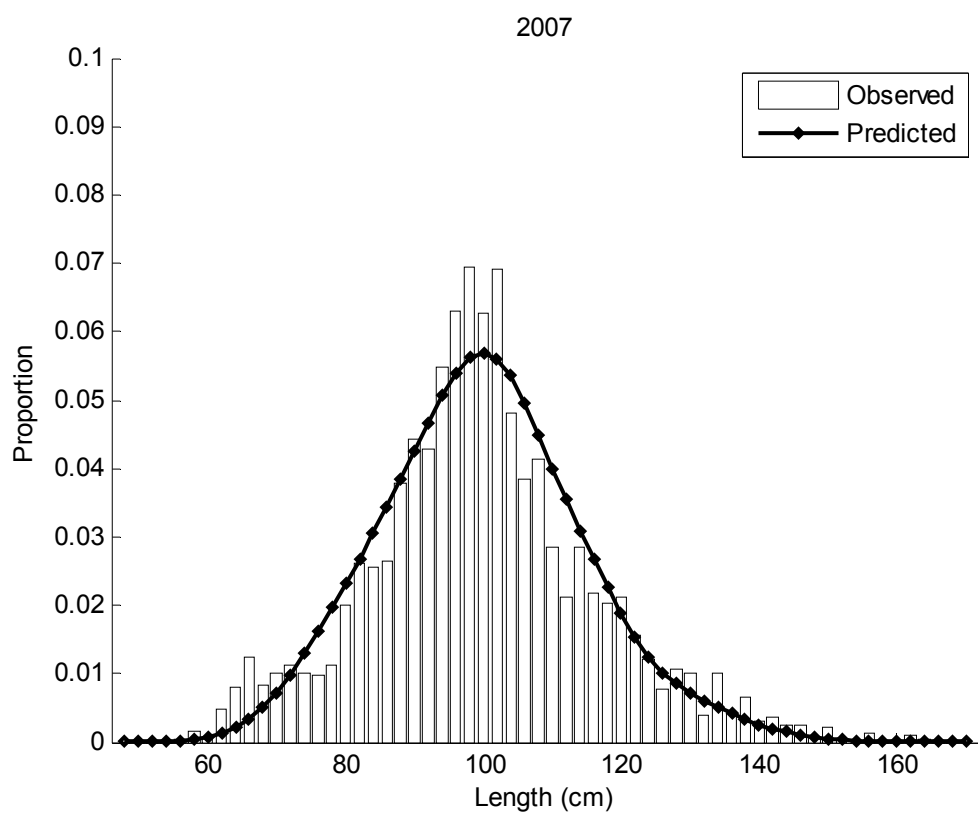
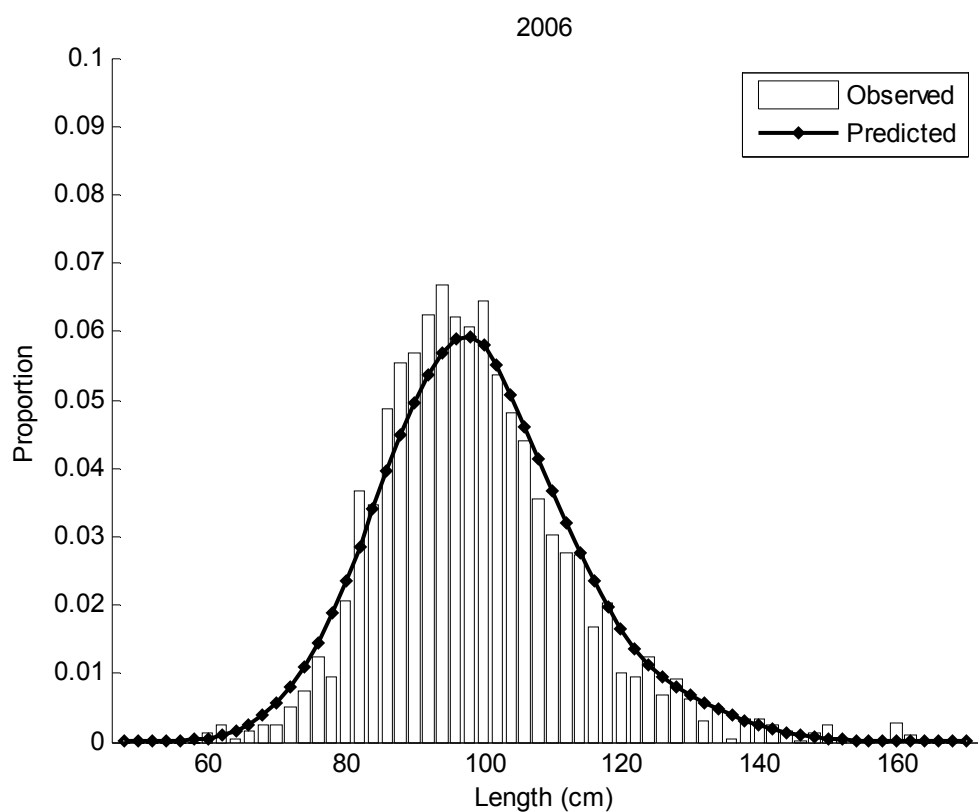


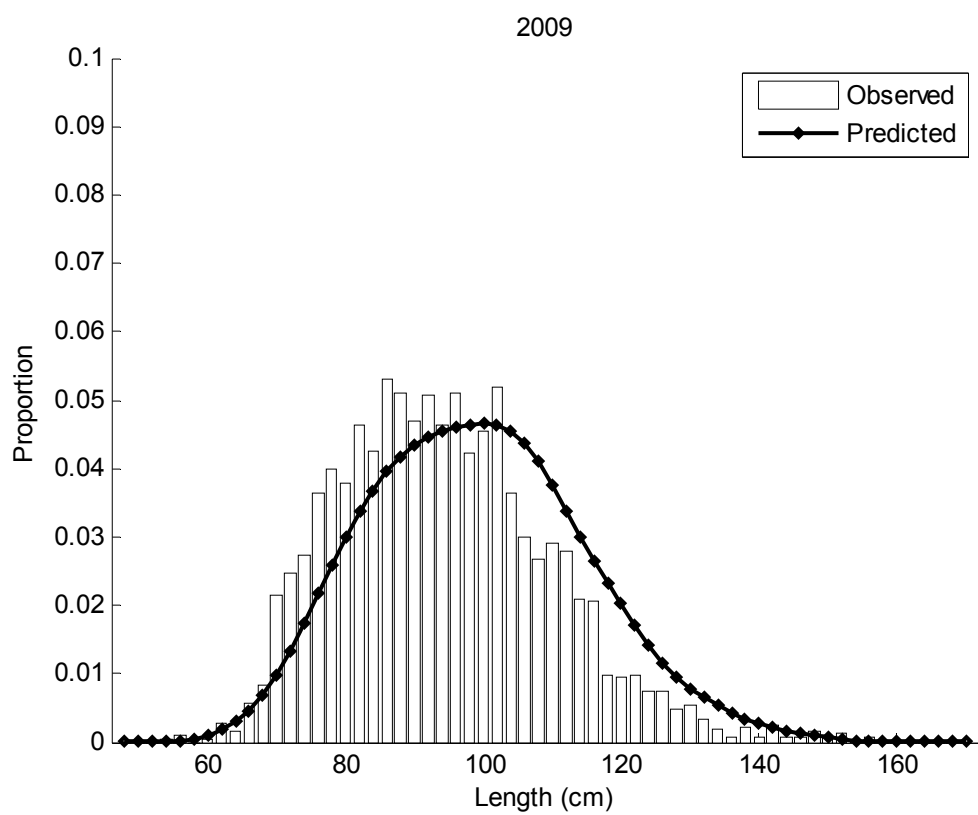
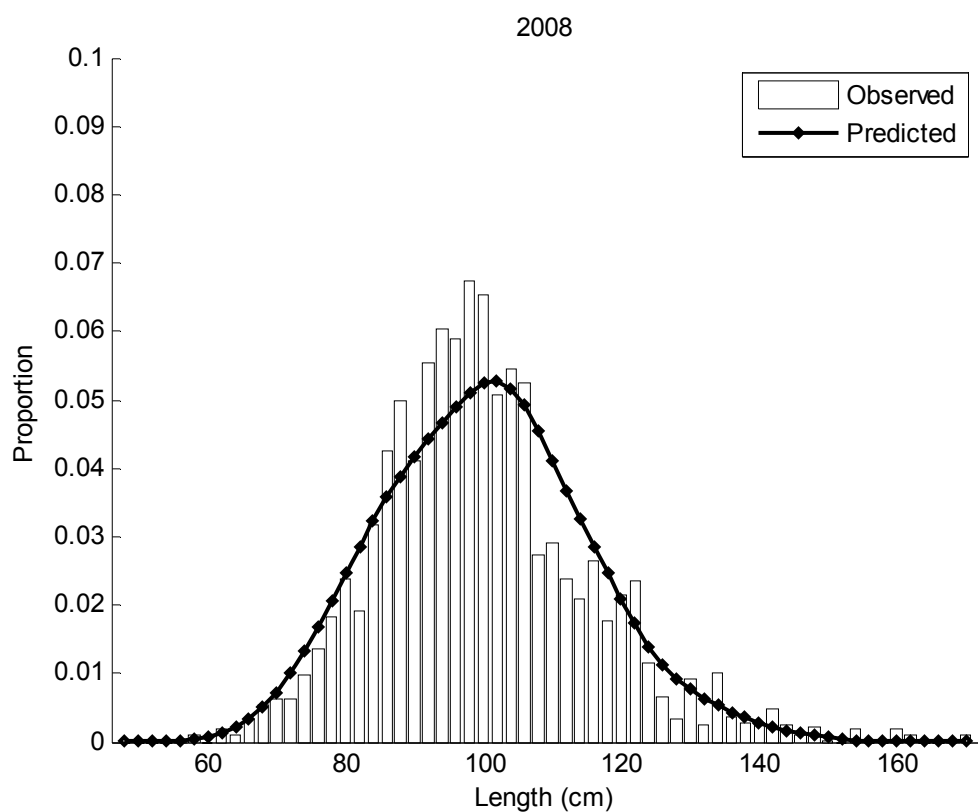
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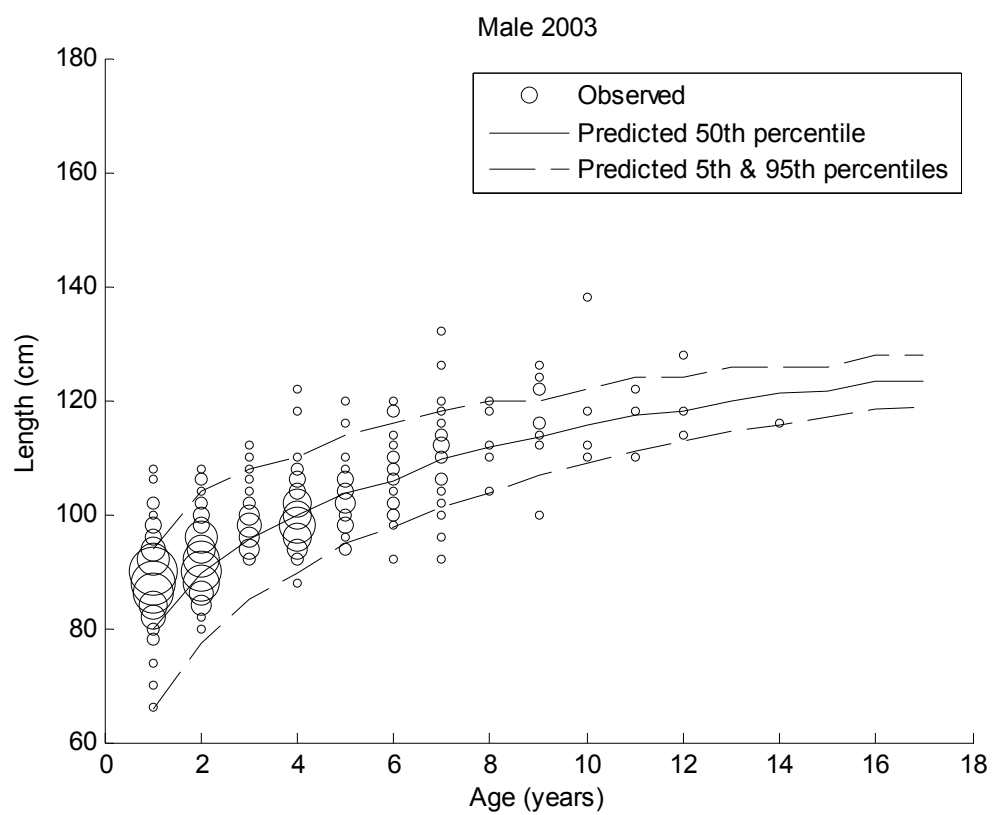
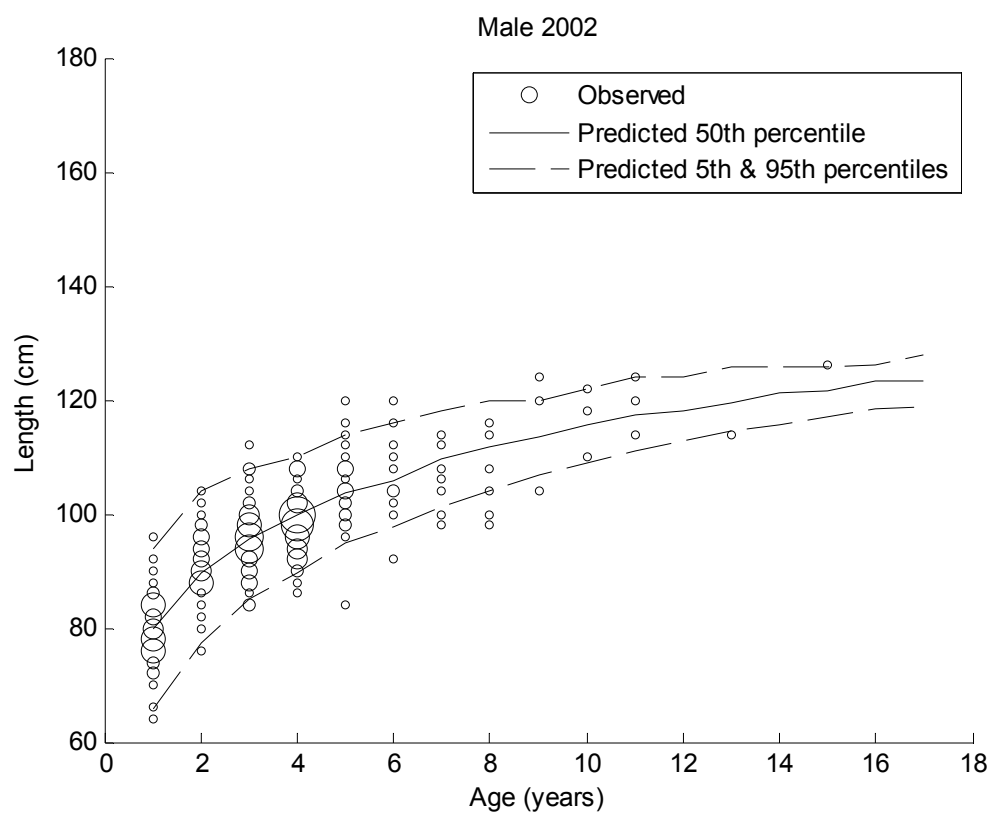


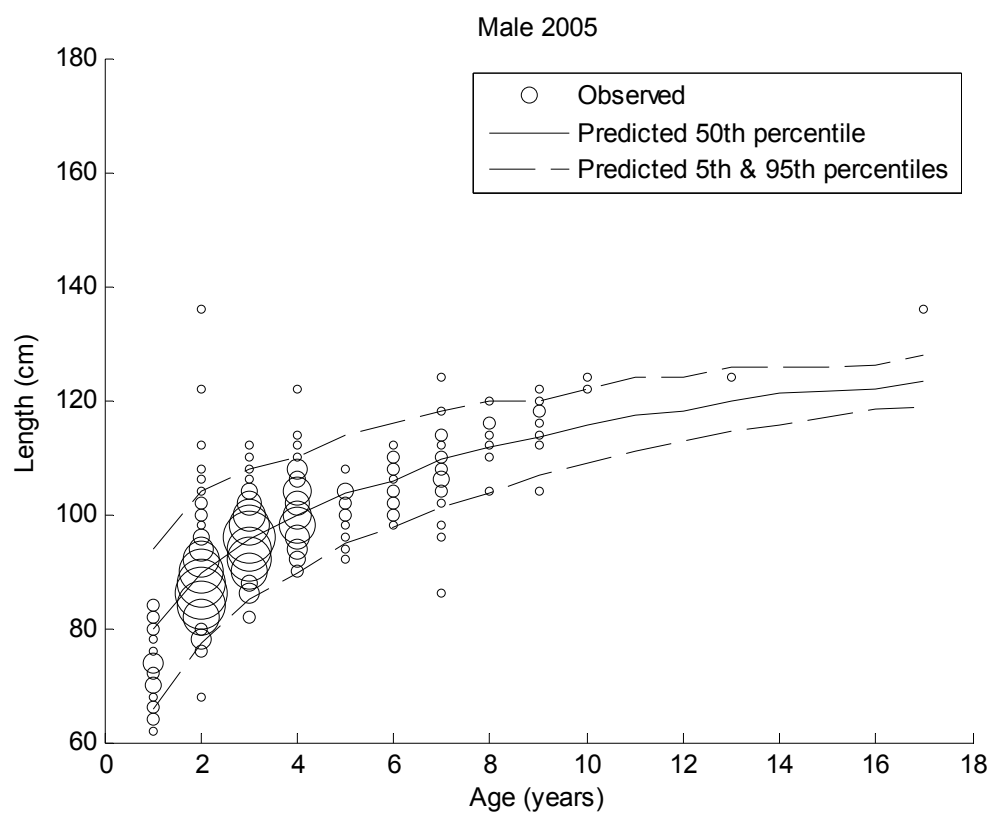
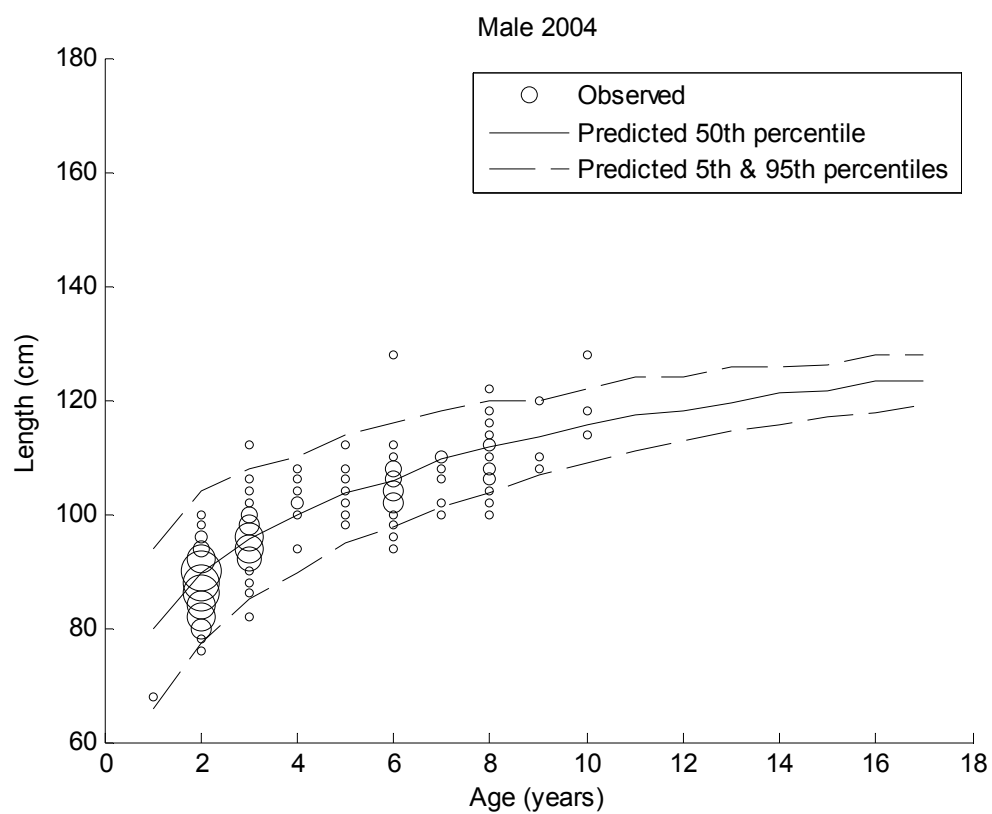


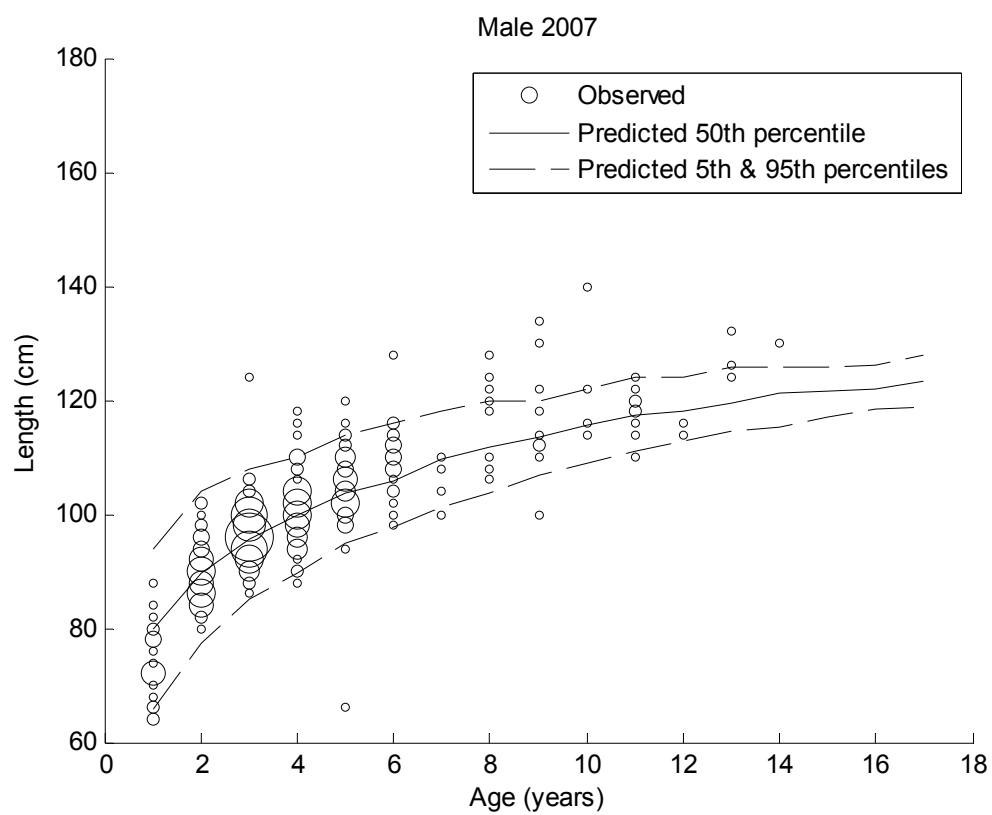
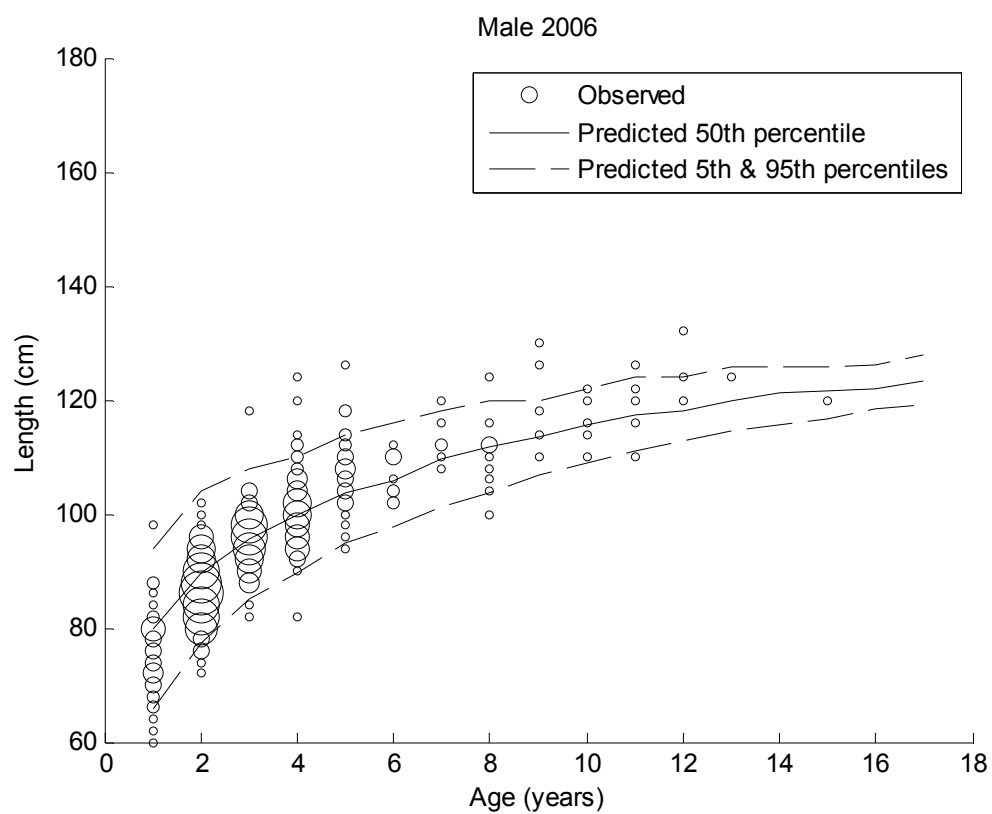


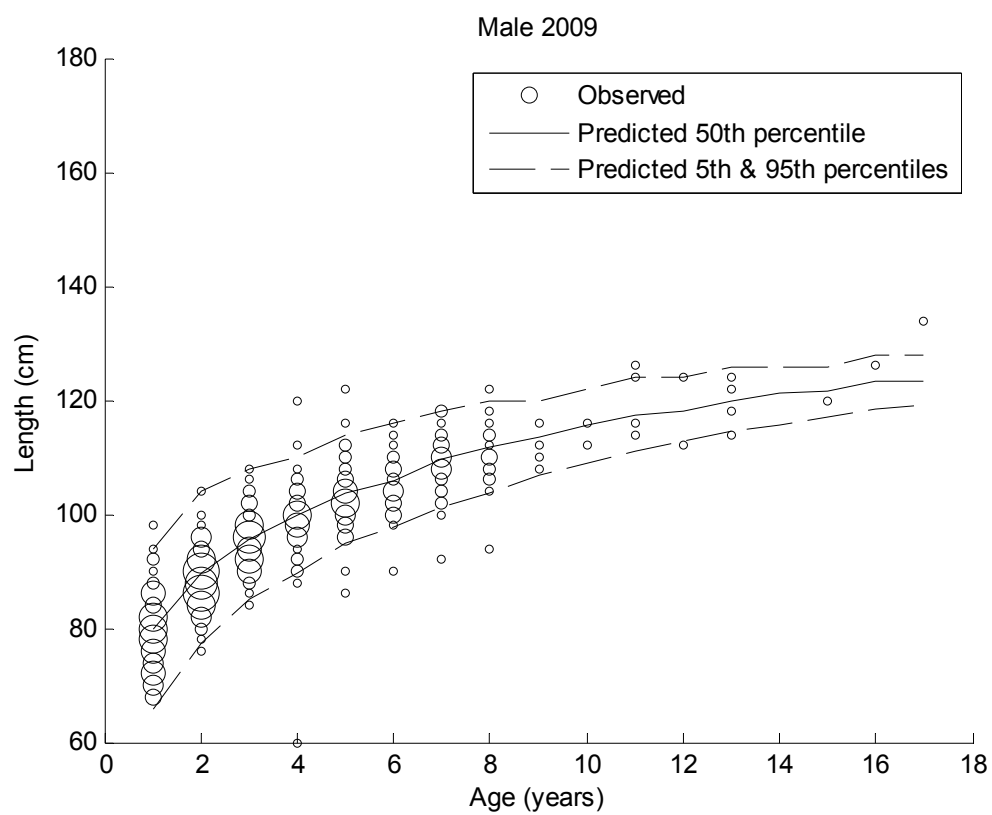
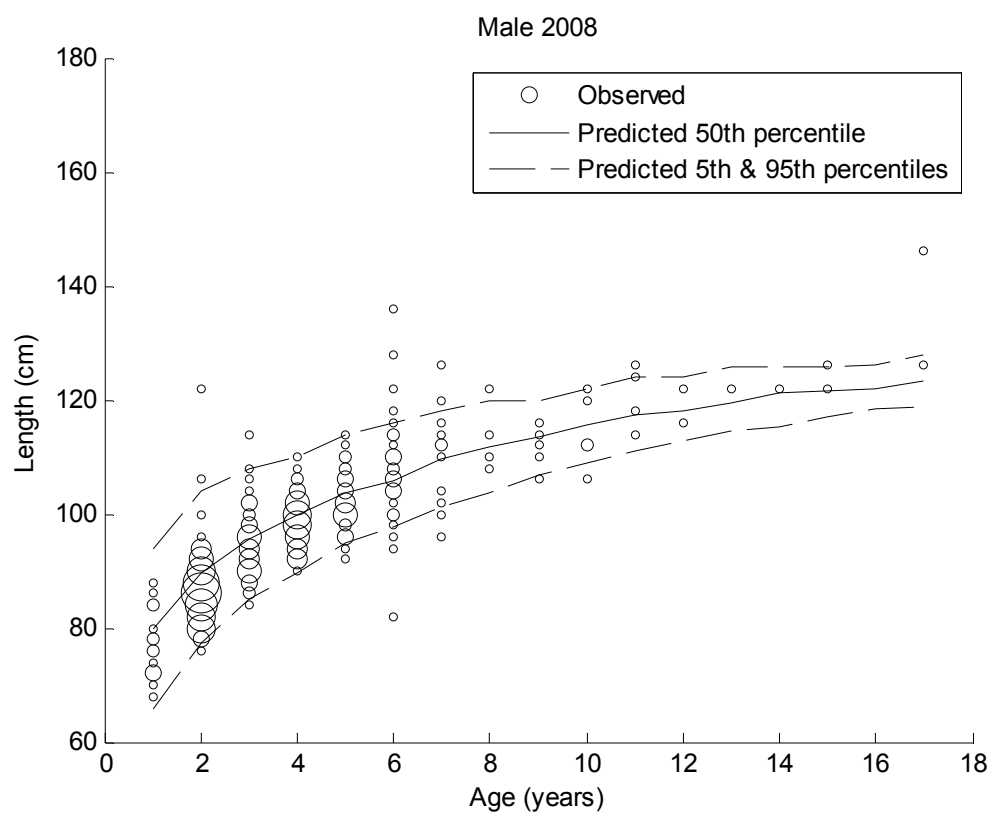


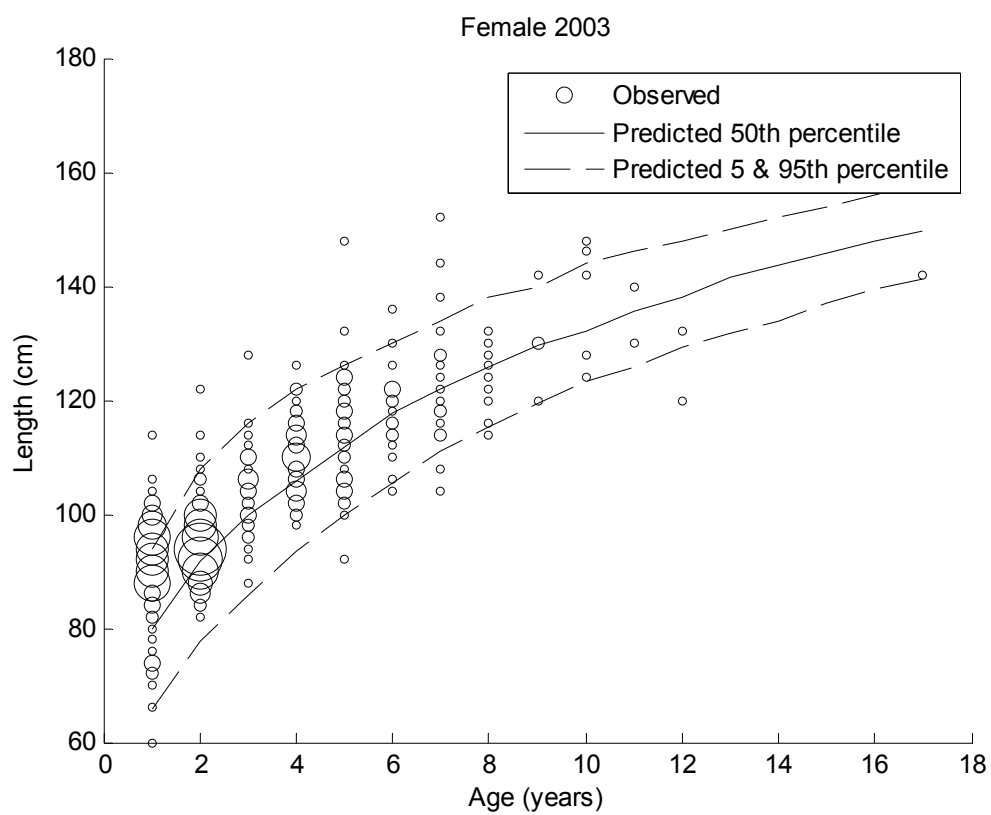
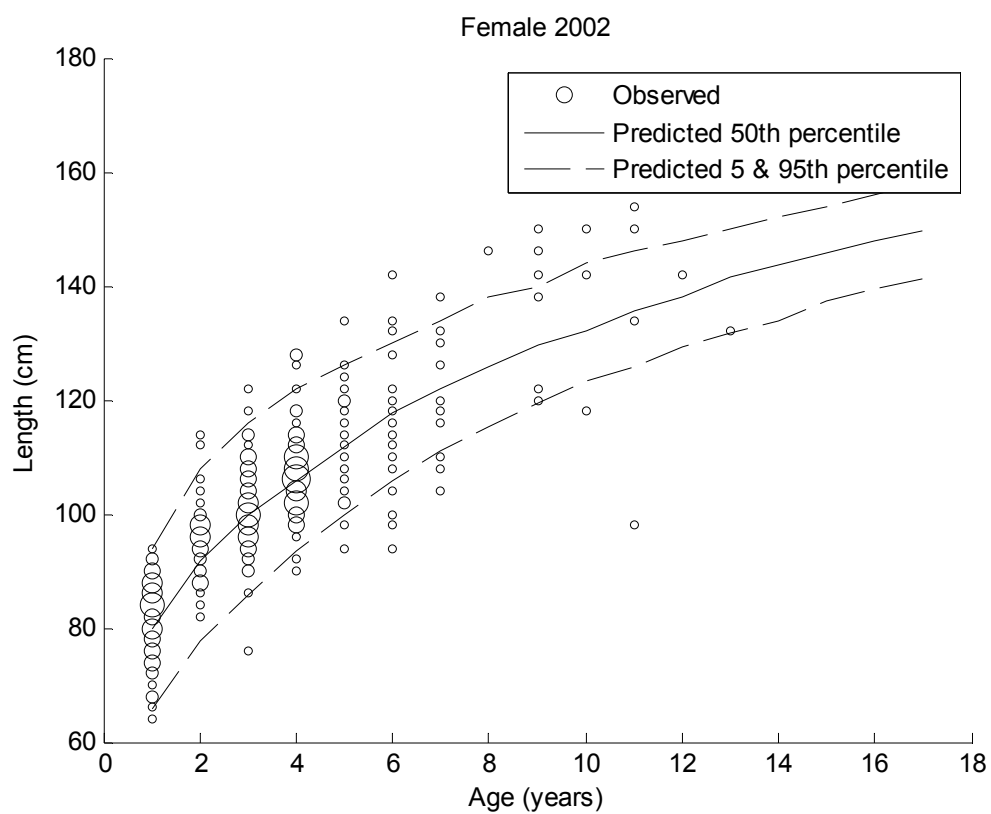


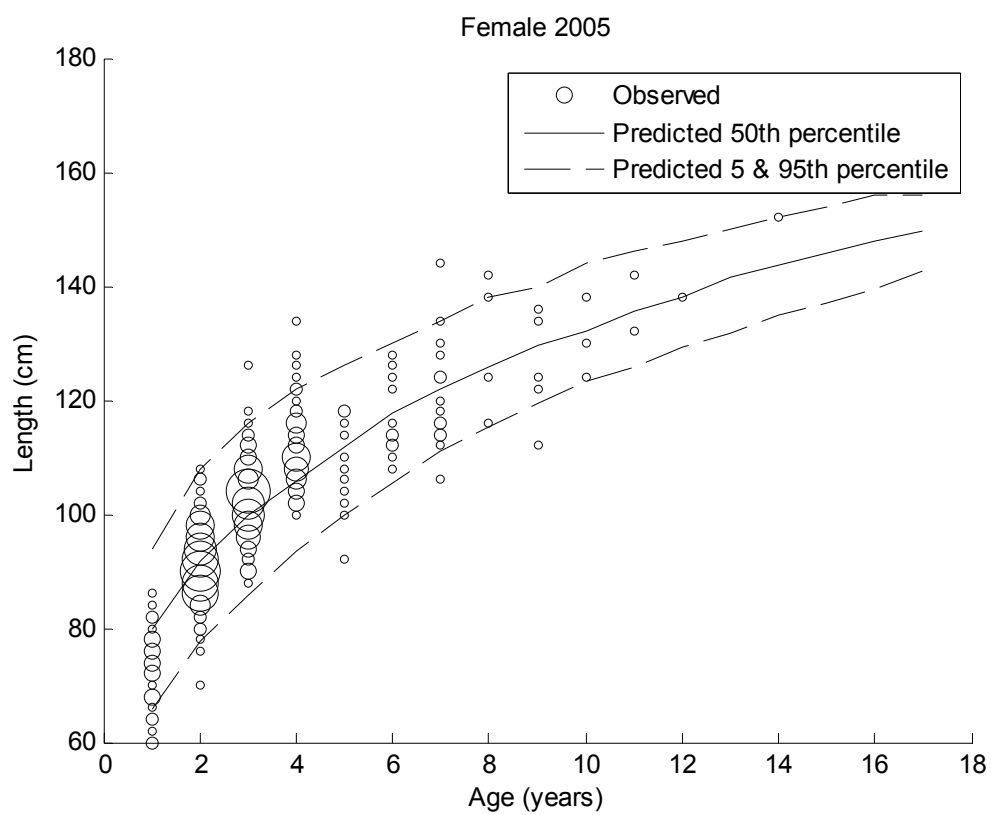
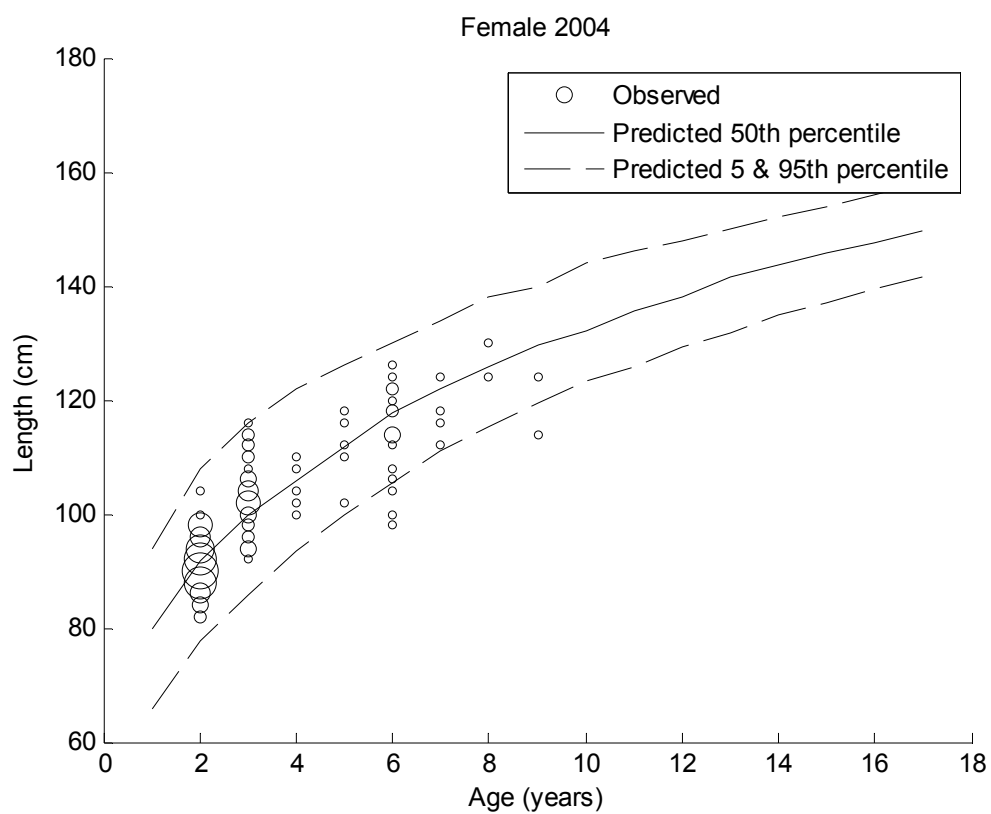


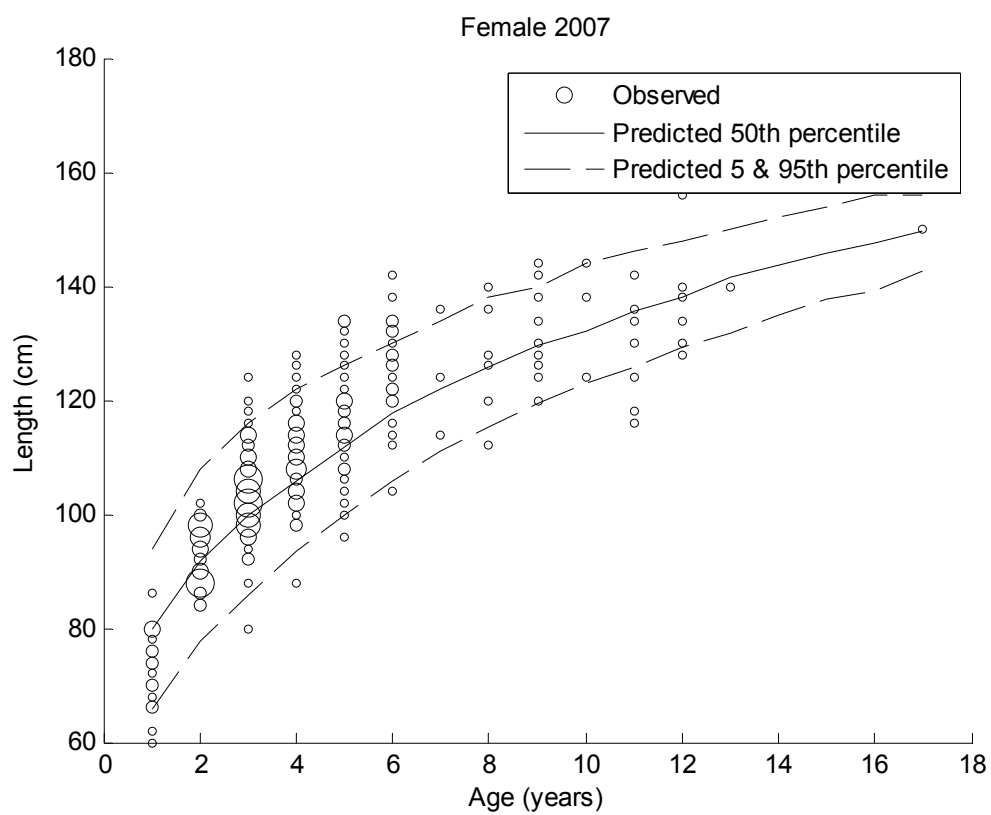
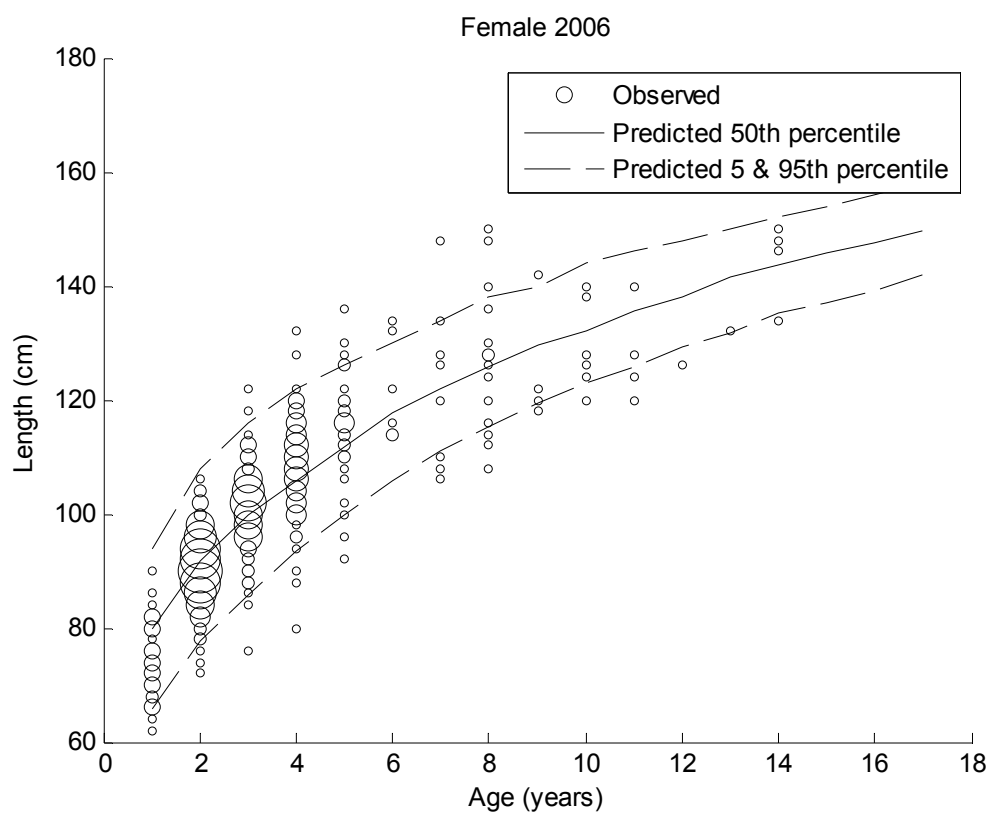


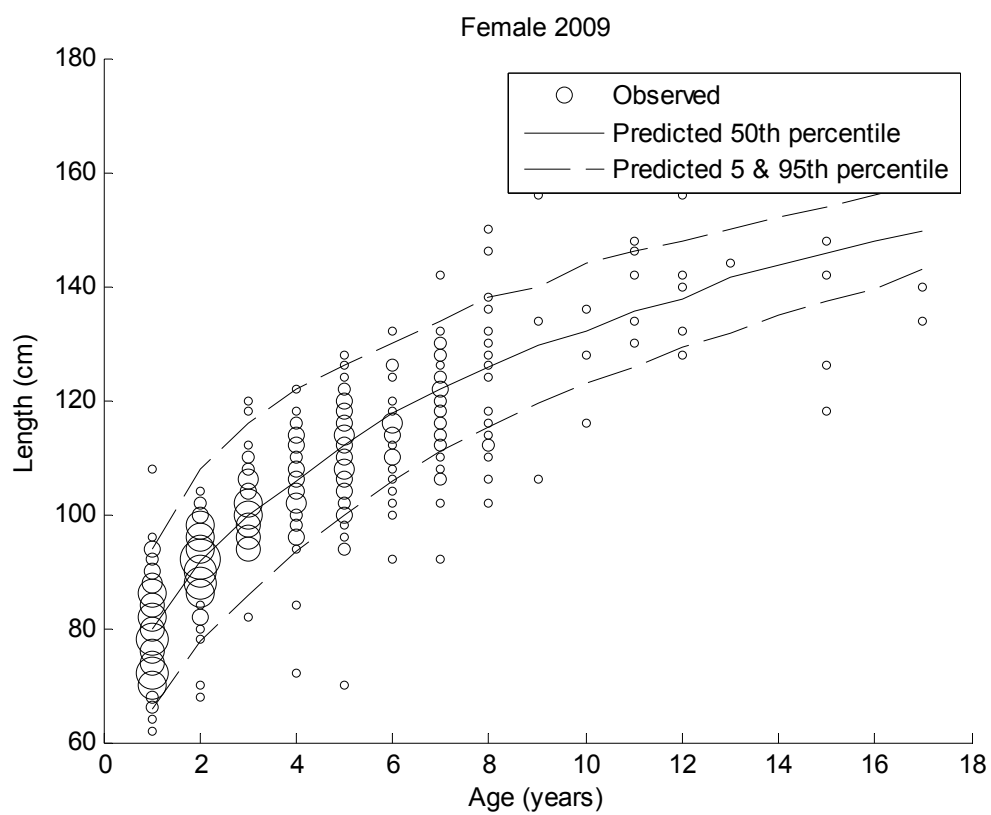
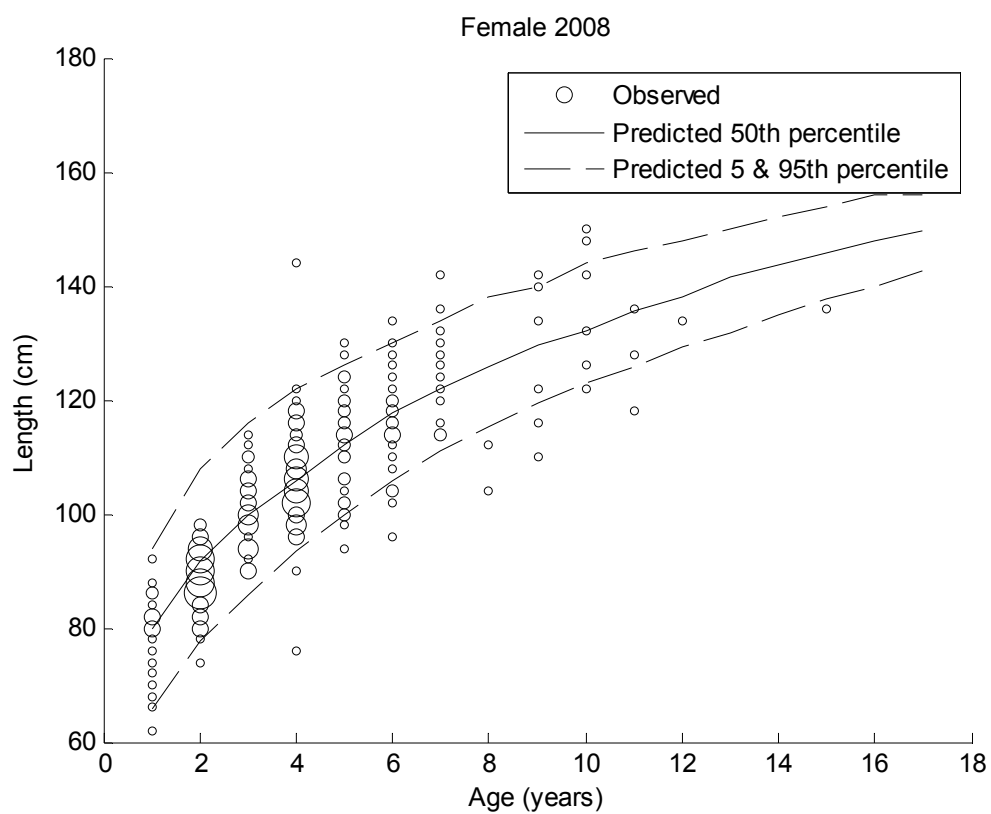




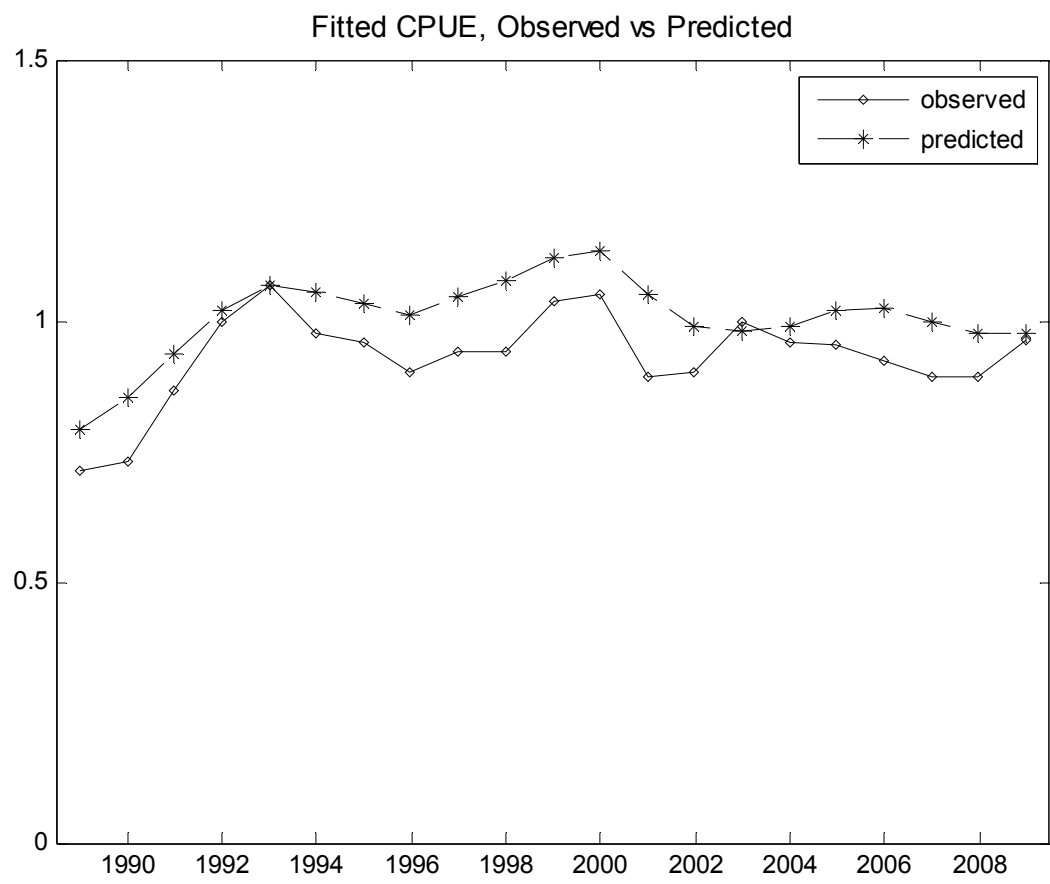


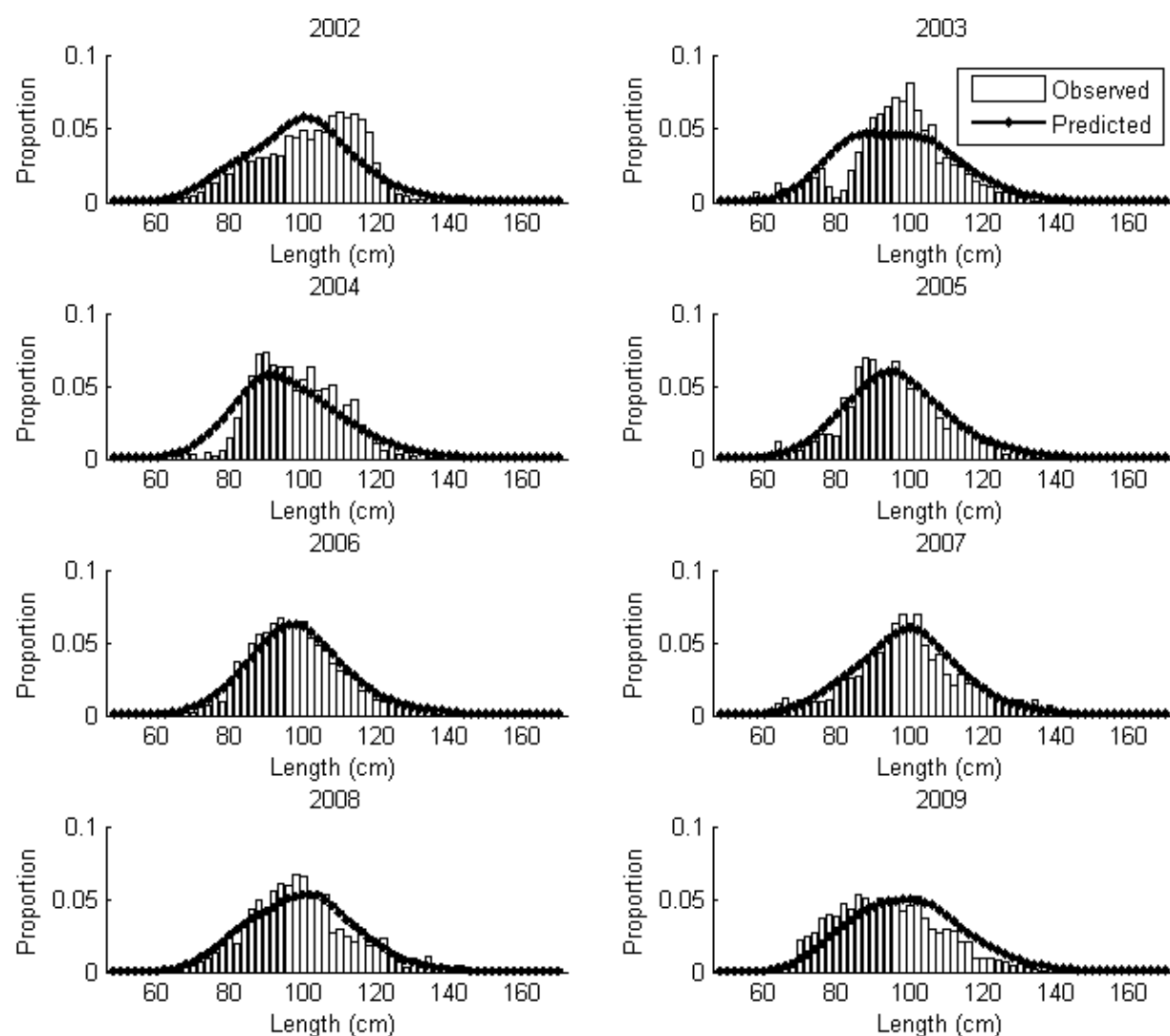


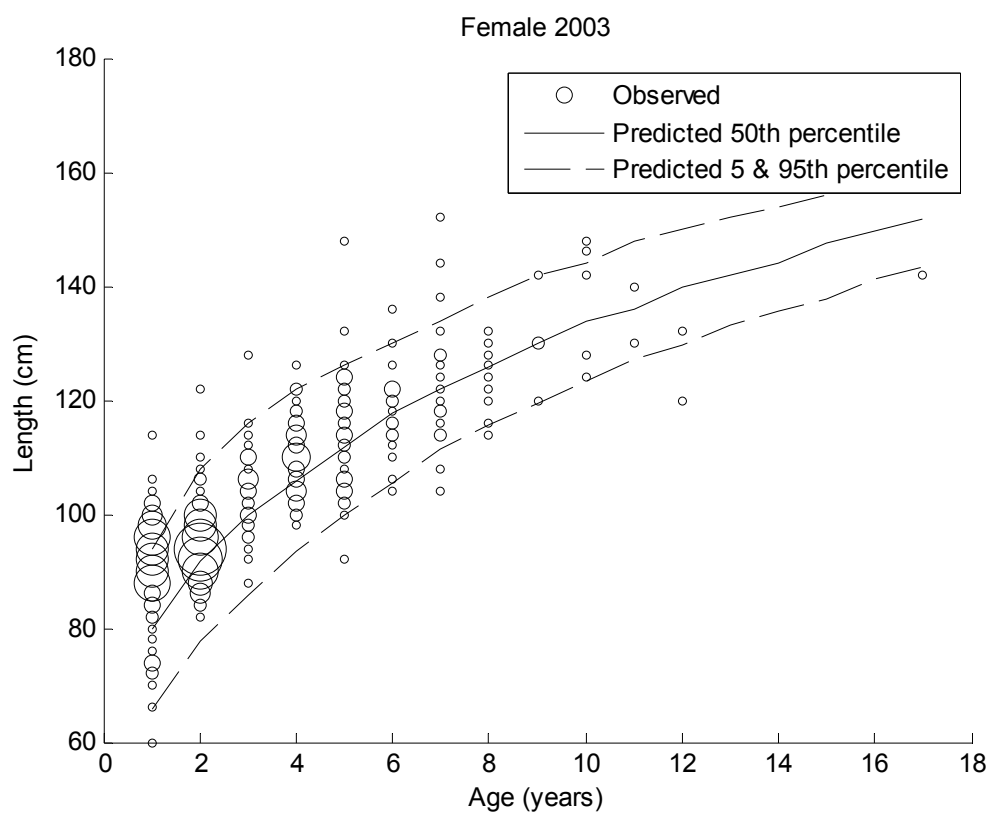
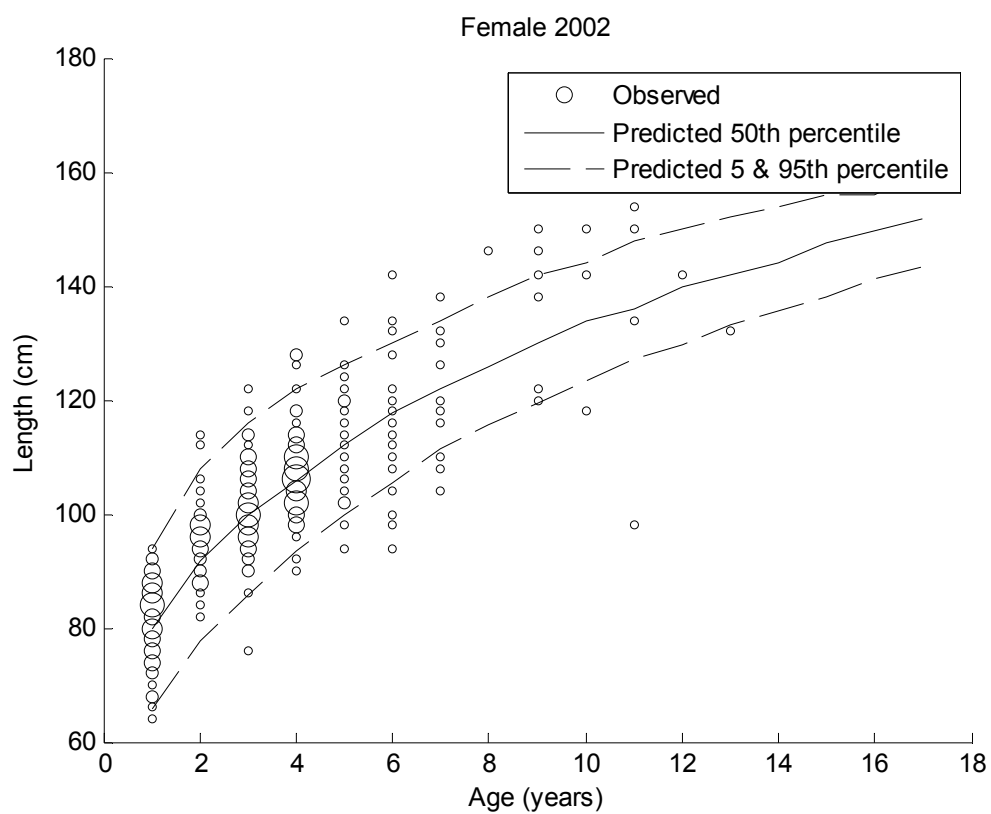


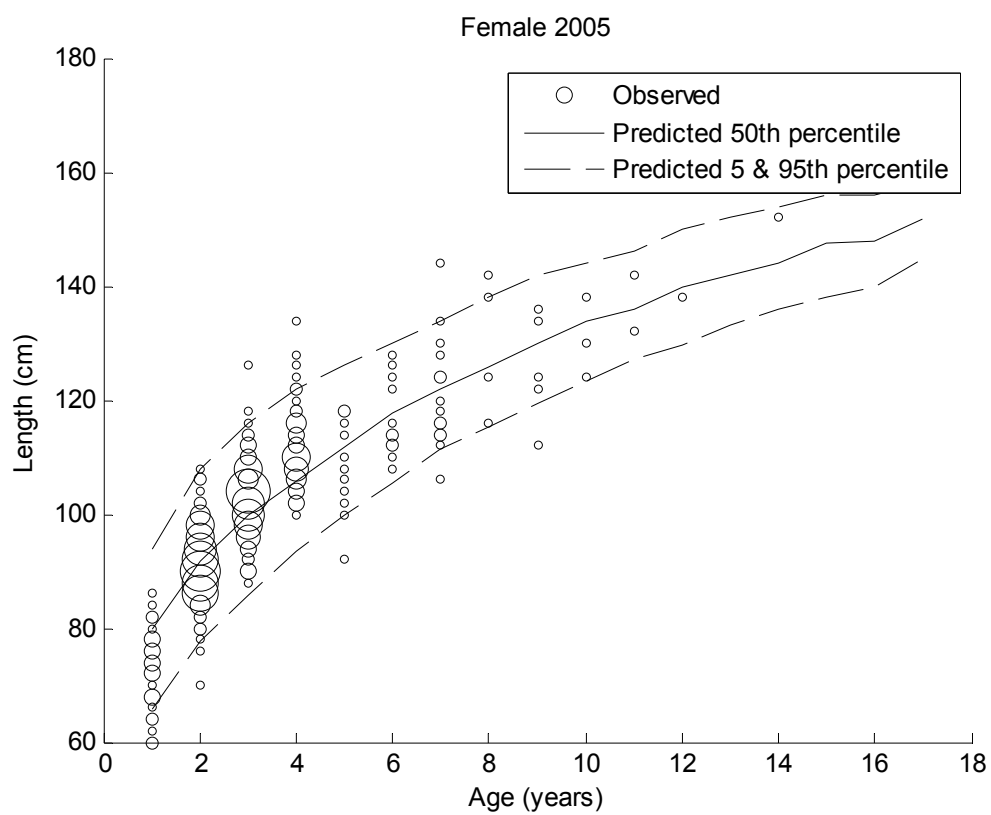
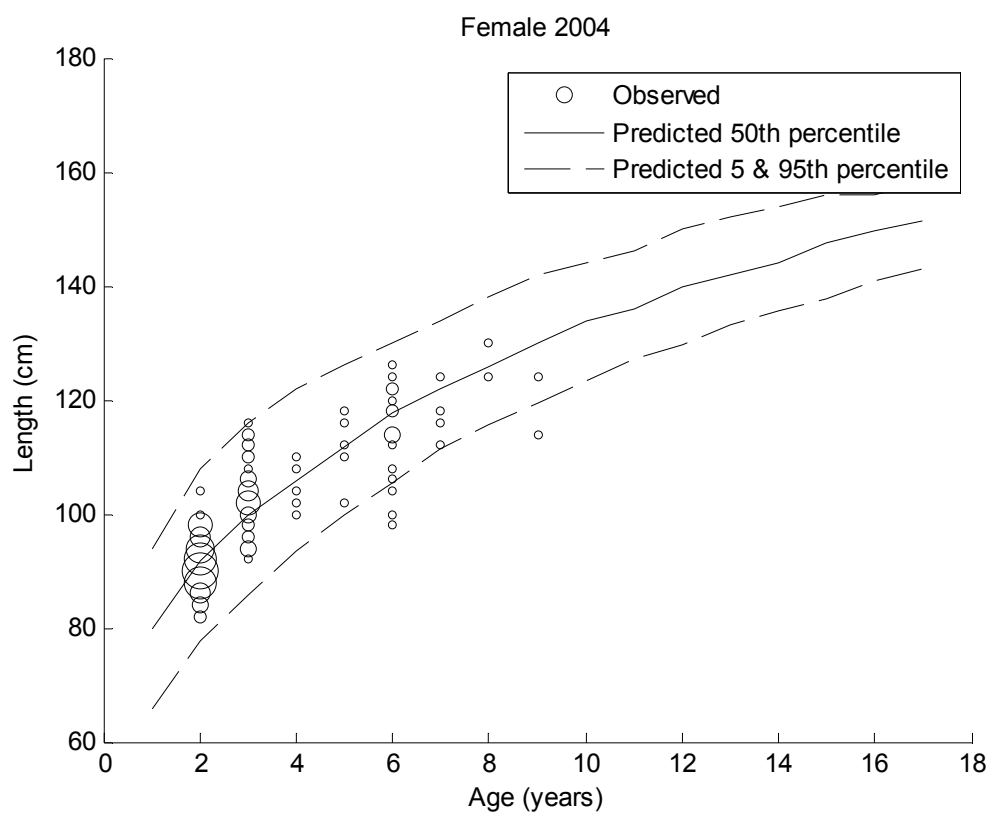


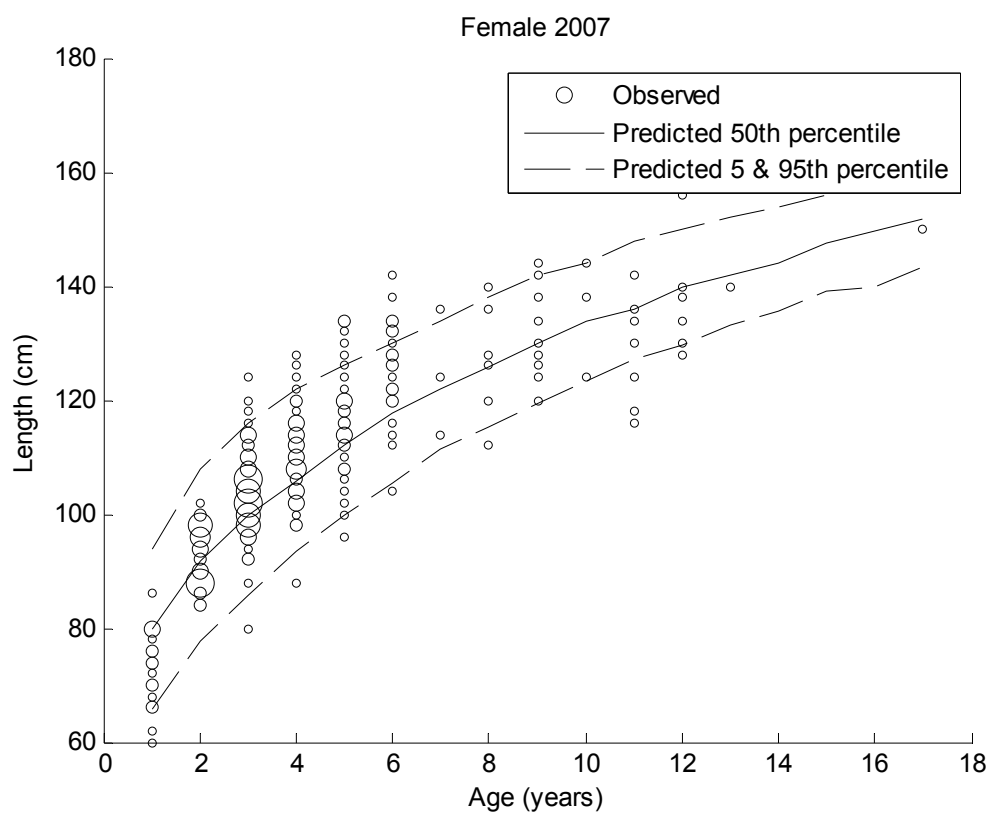
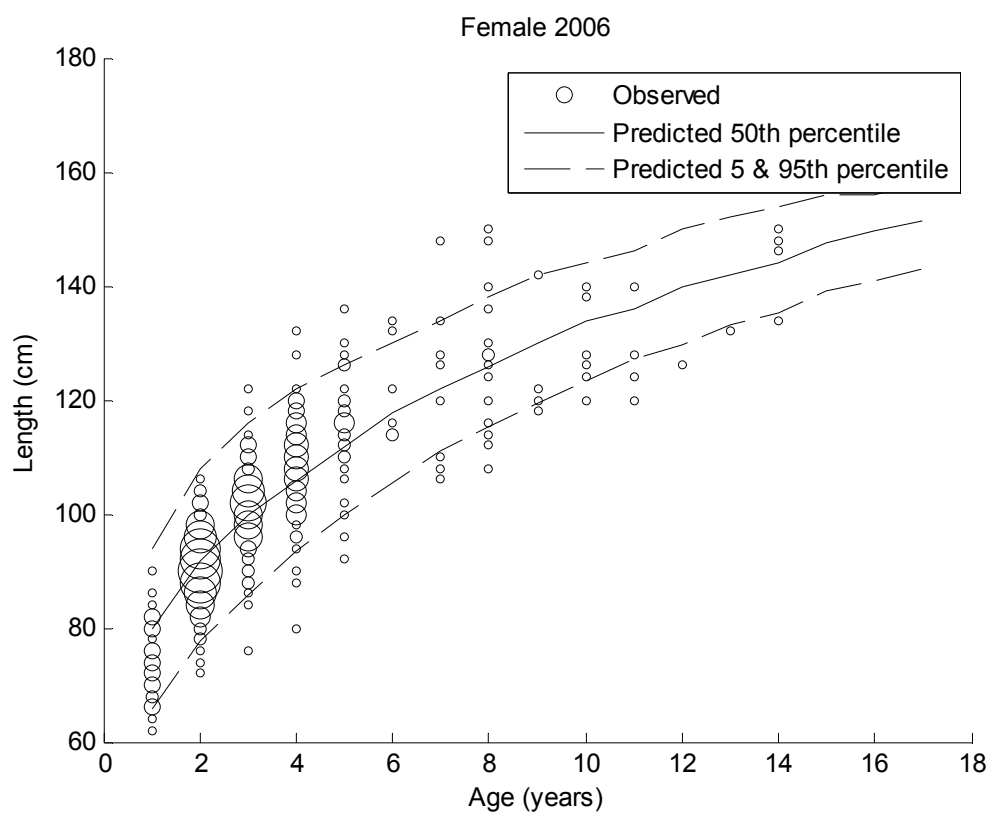
10.3 Scenario 24a

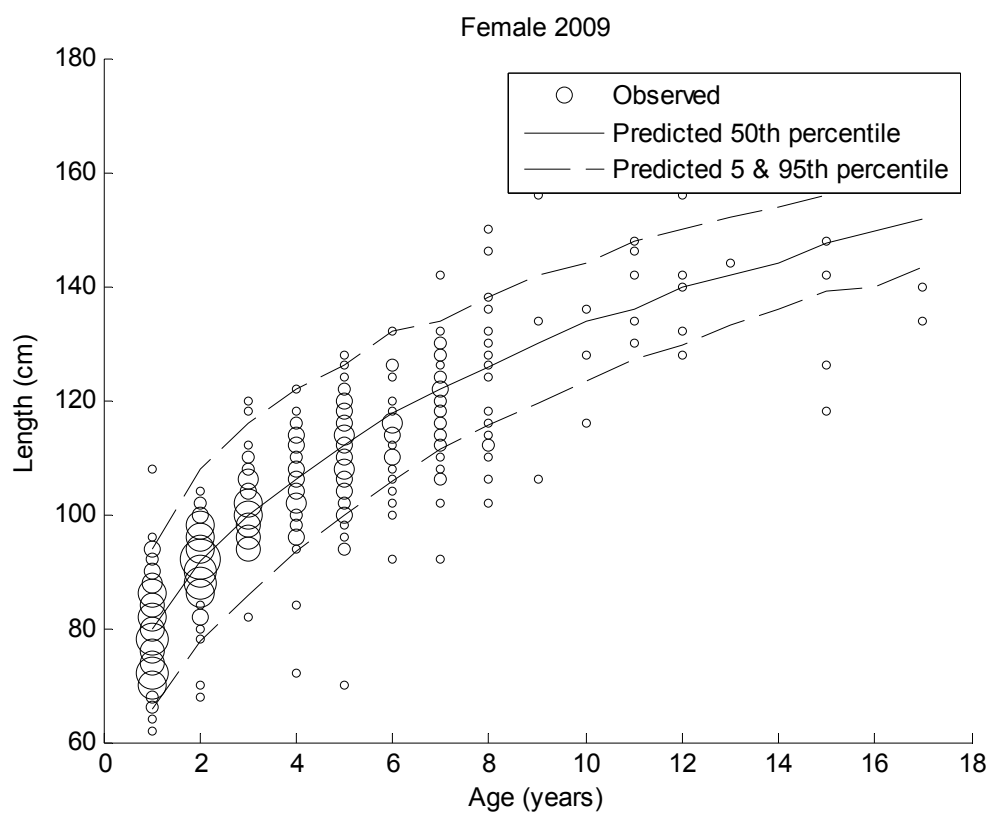
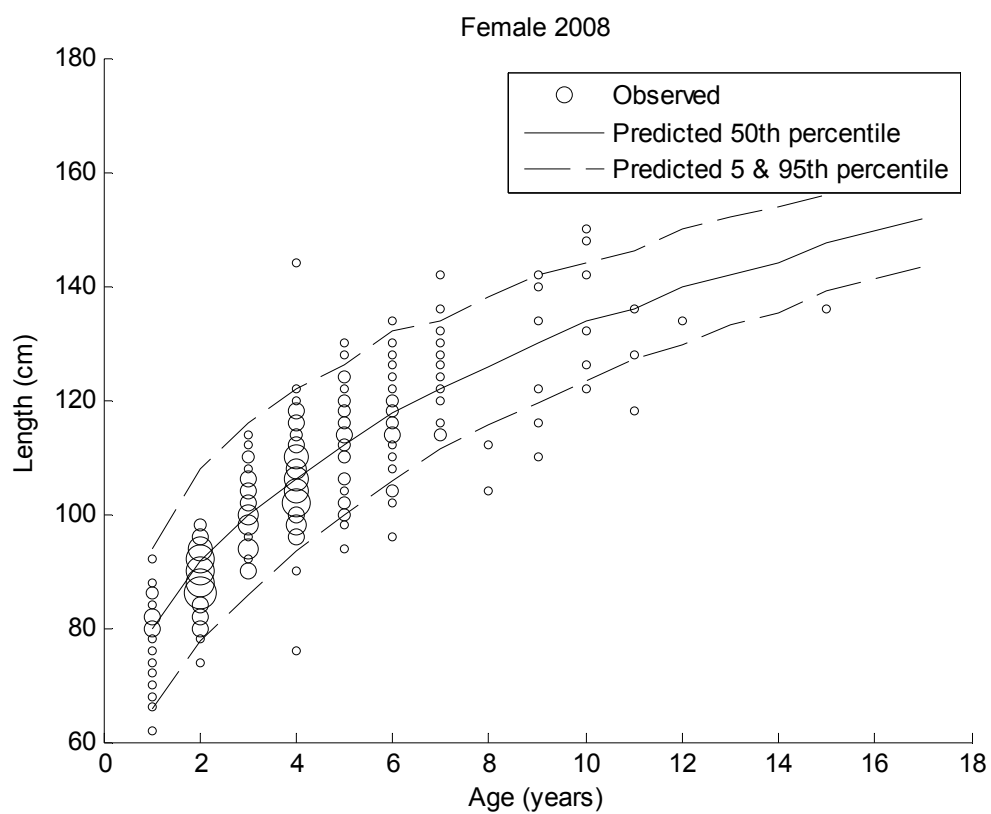


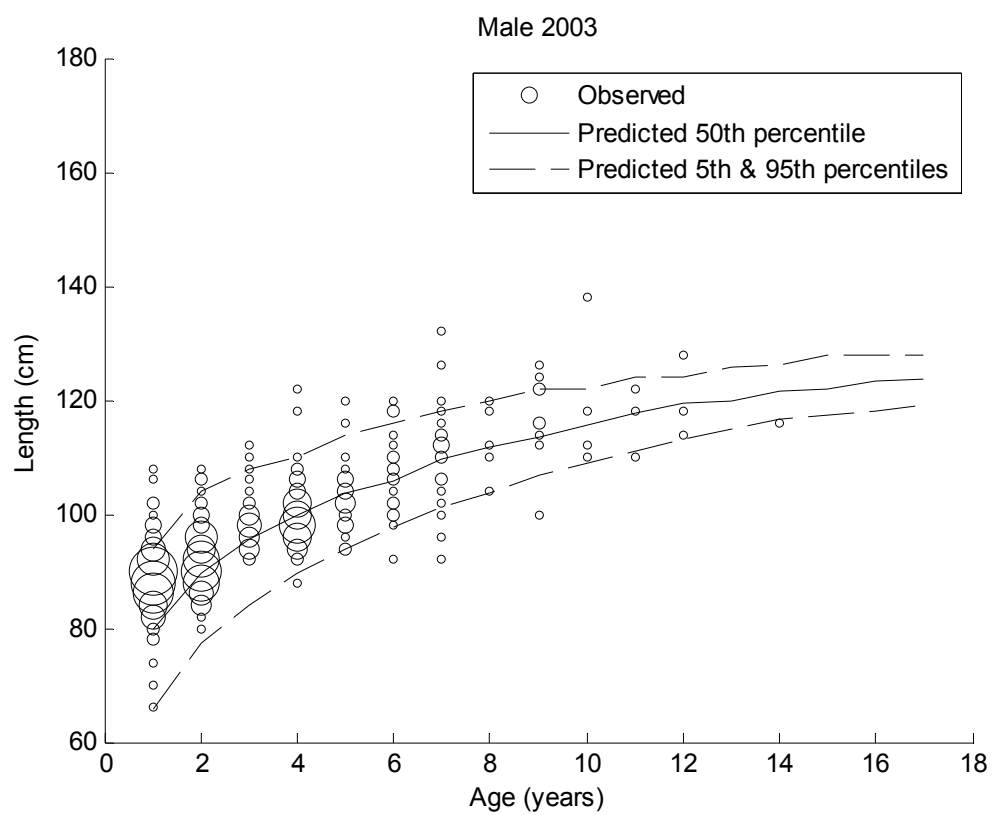
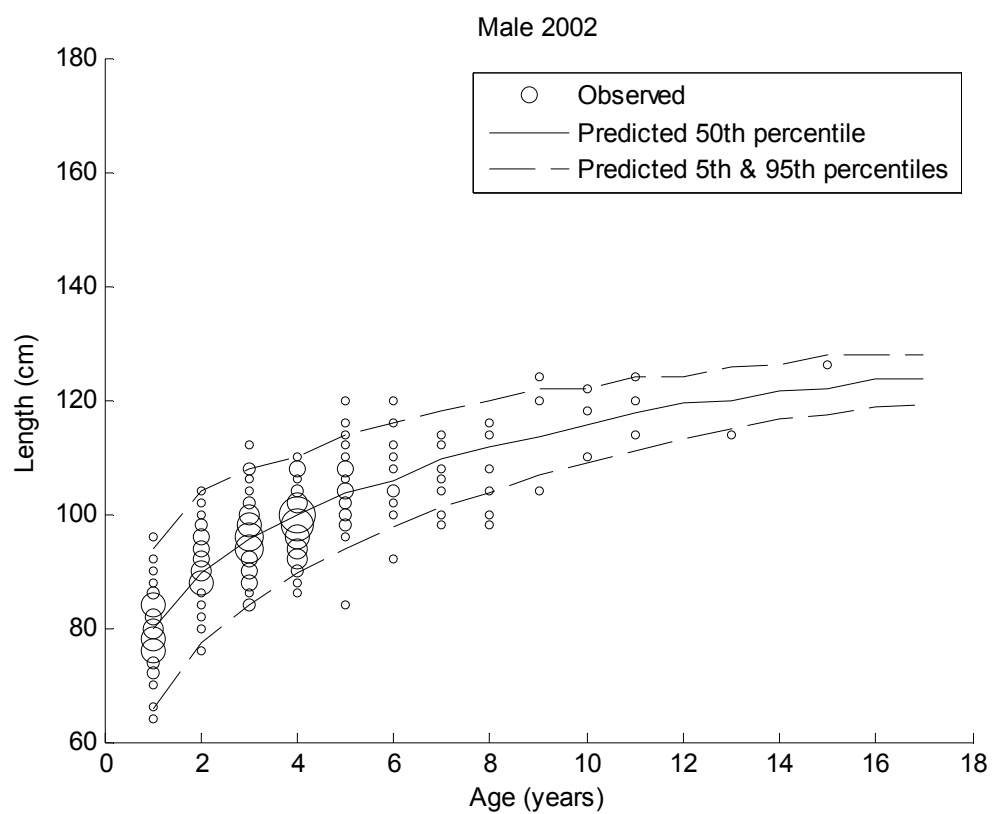


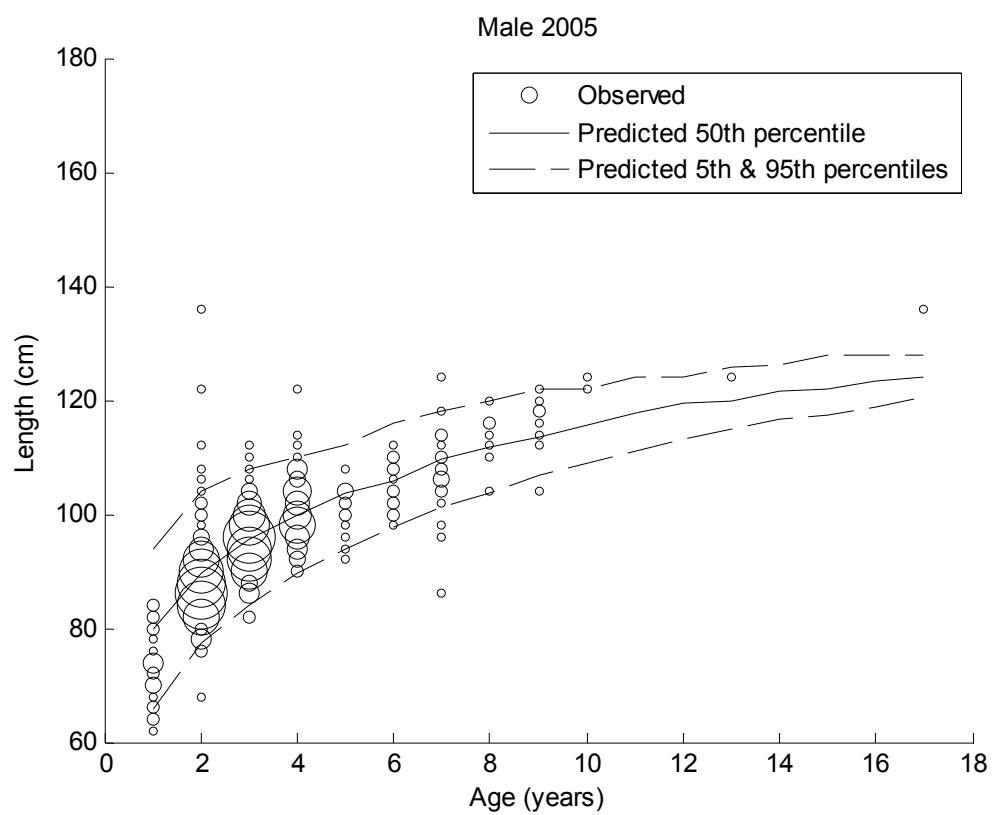
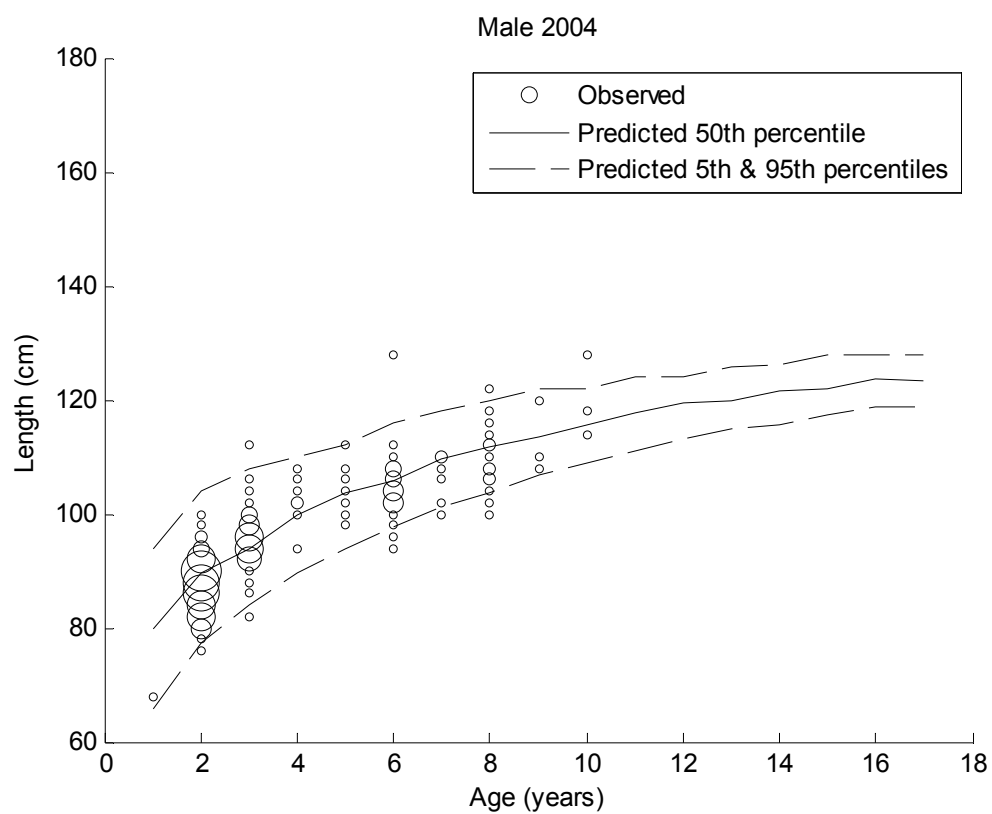


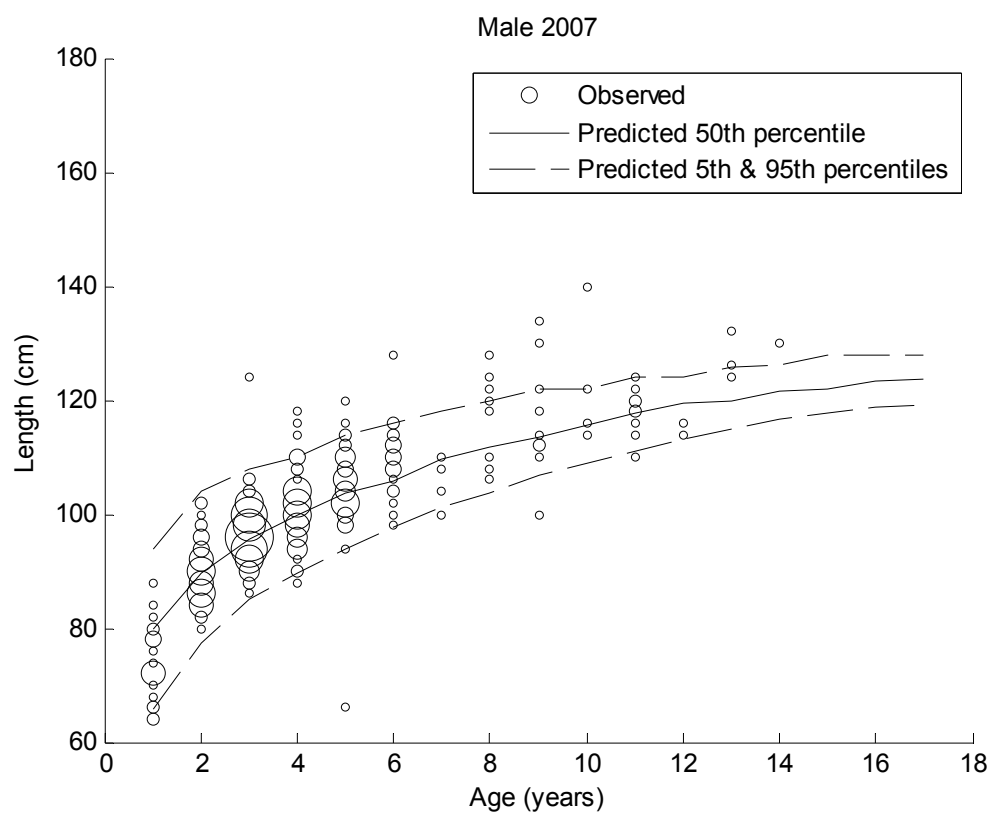
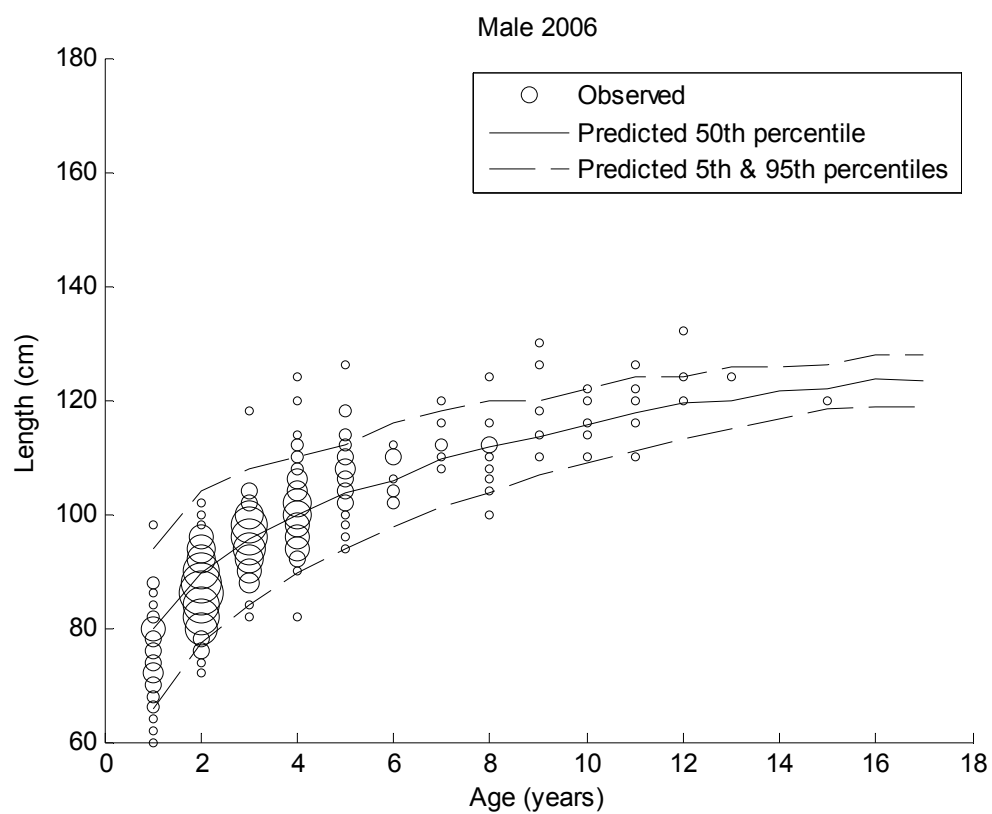


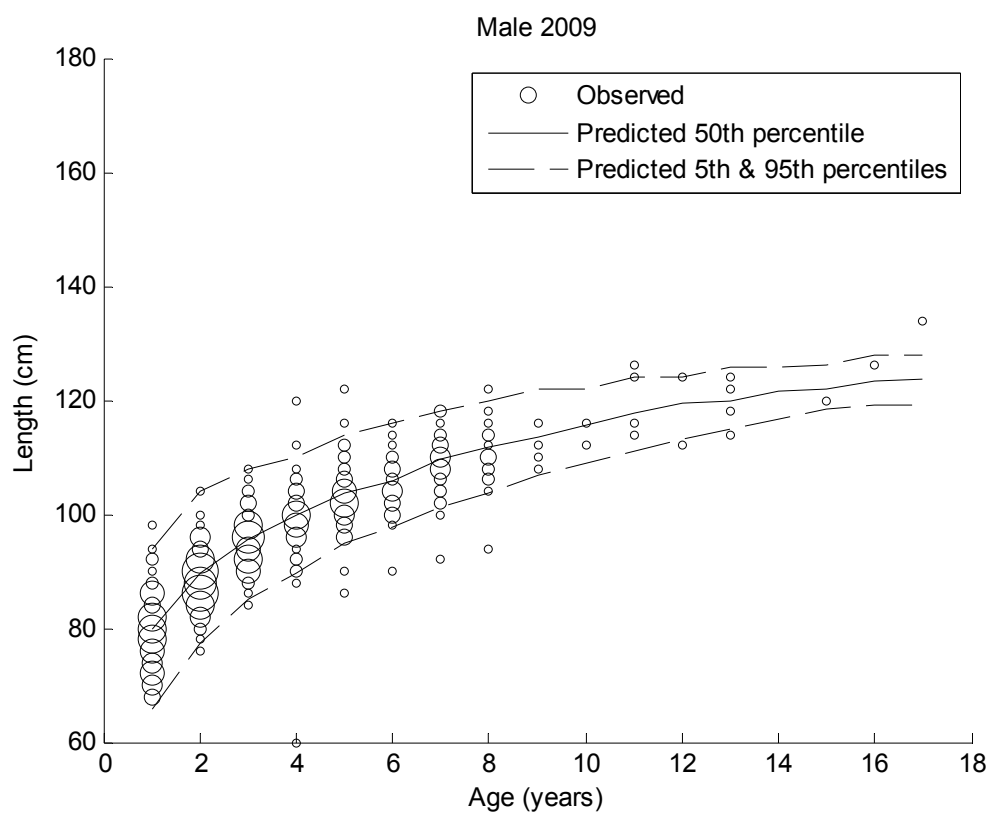
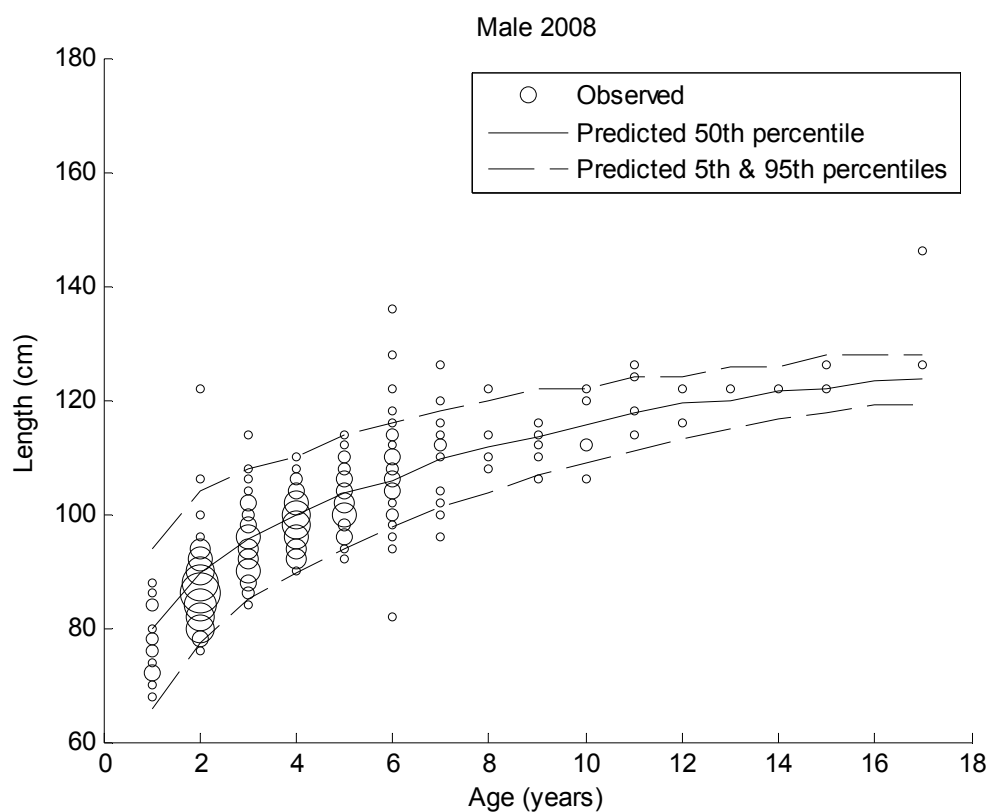




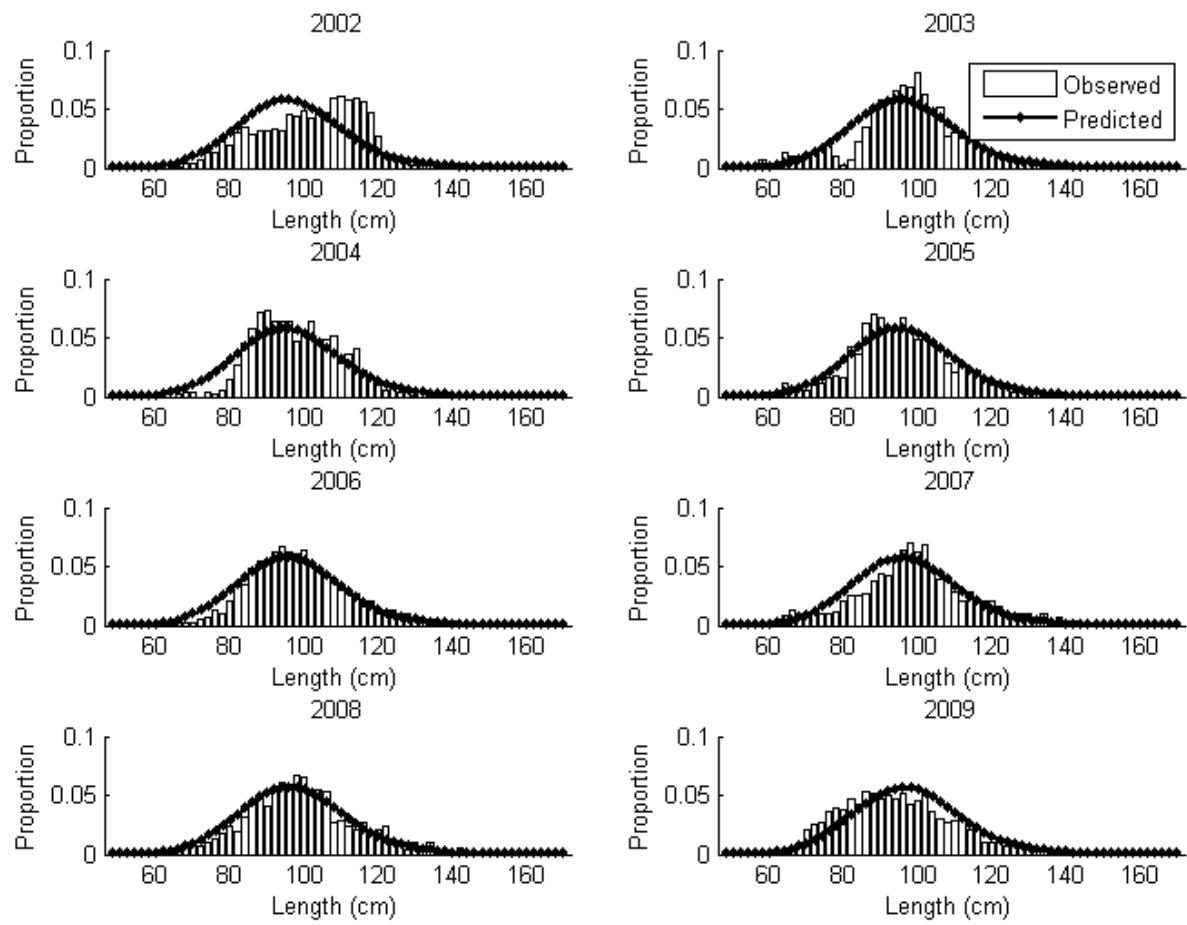


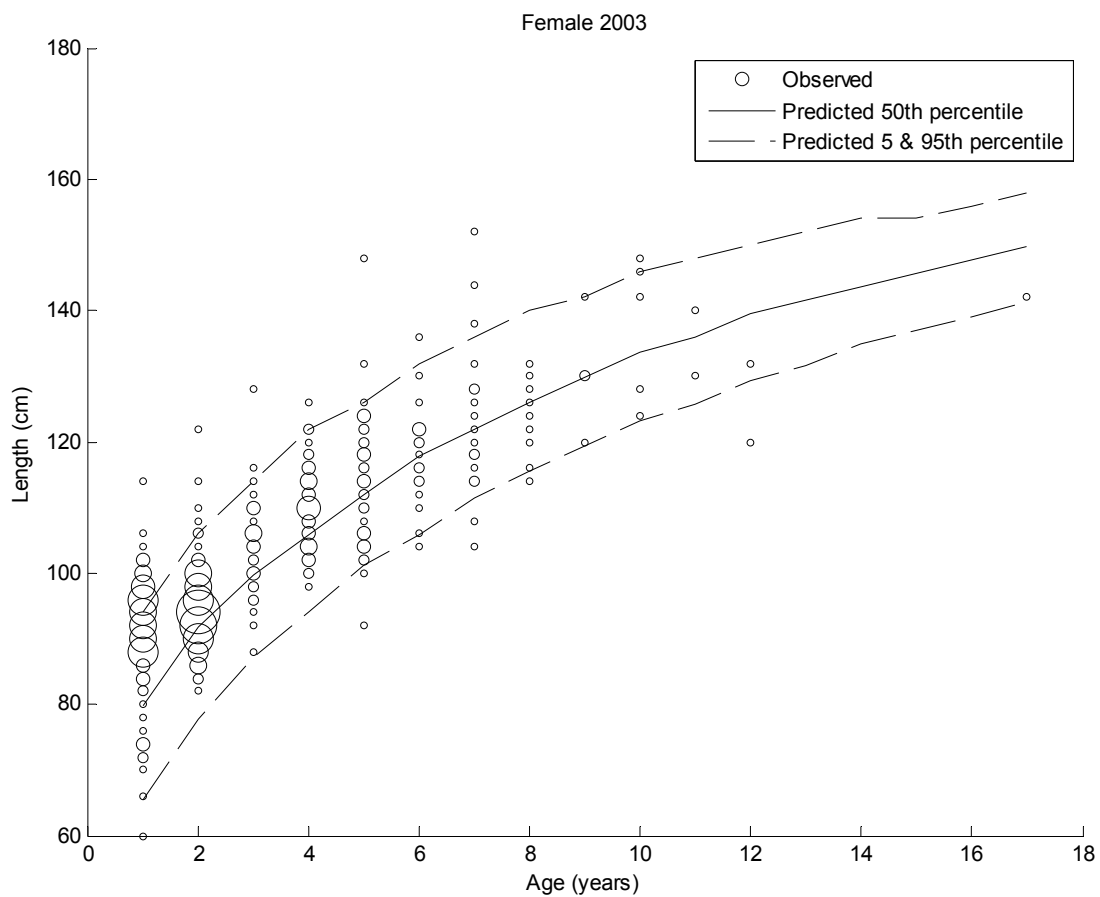
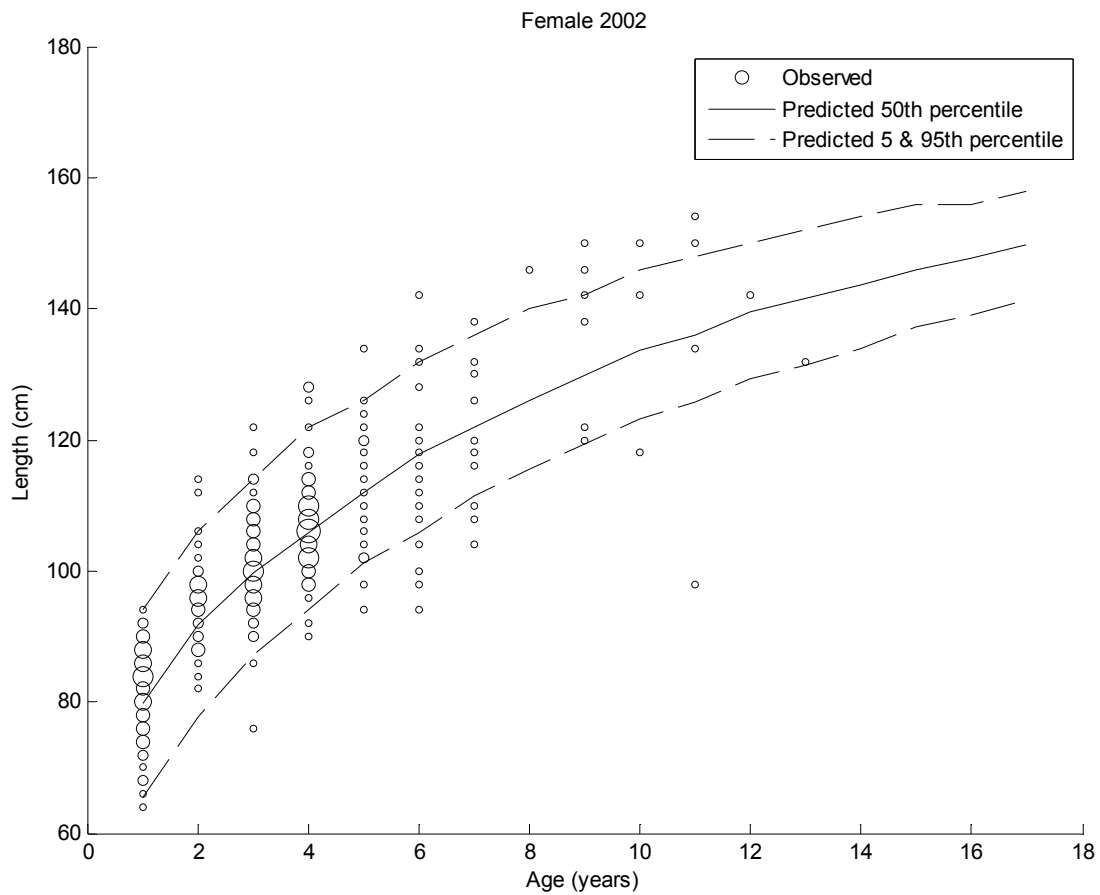


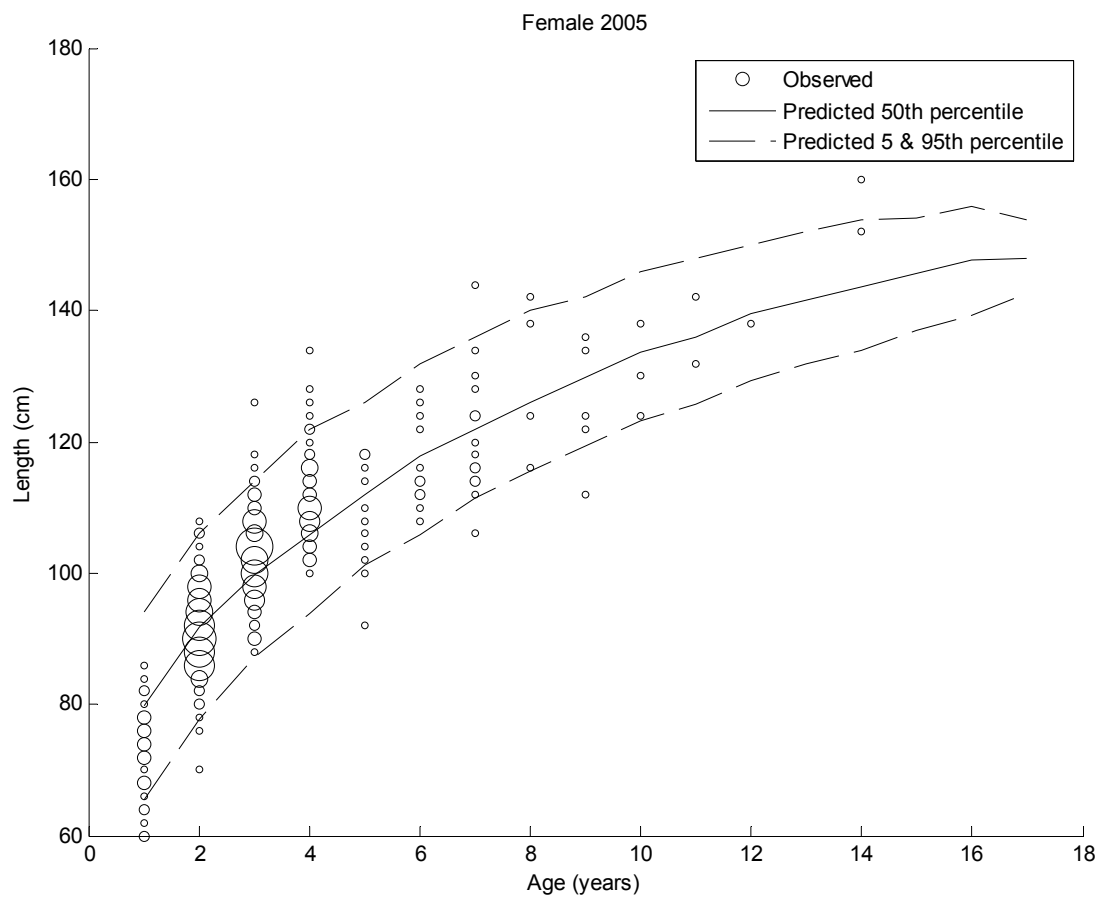
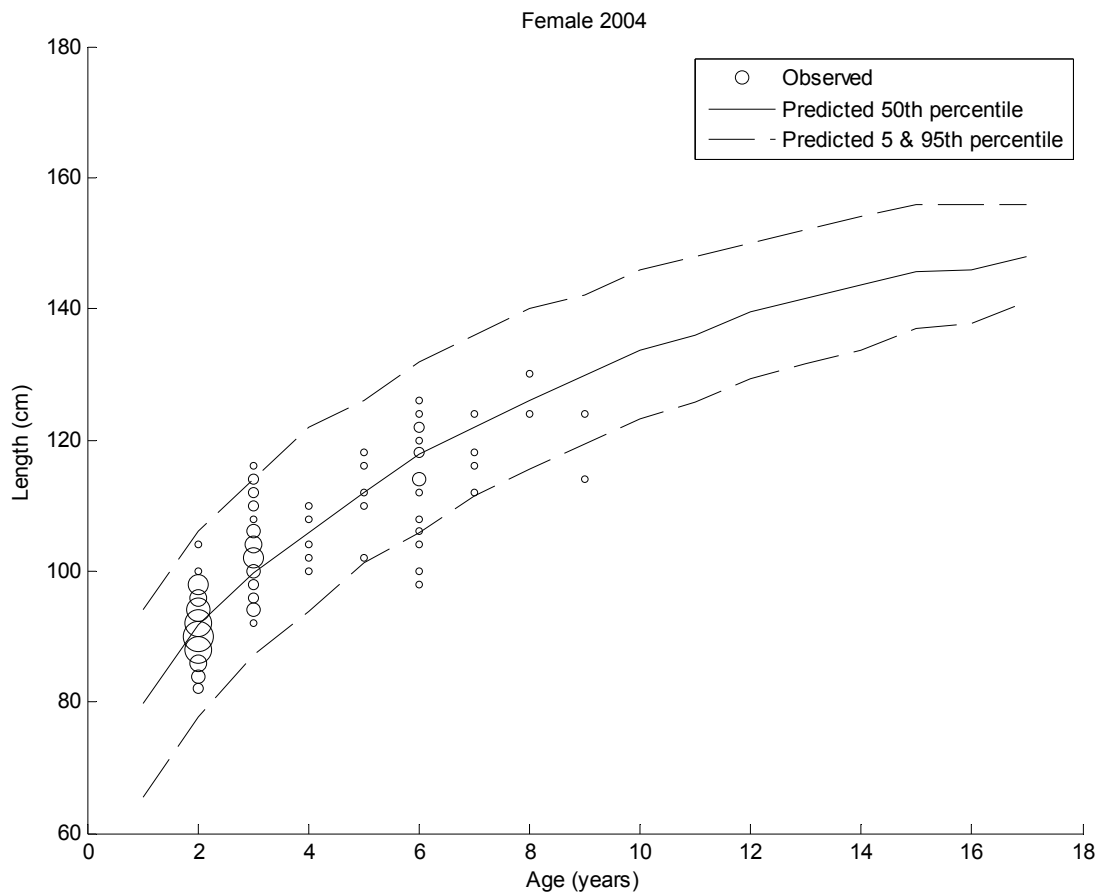


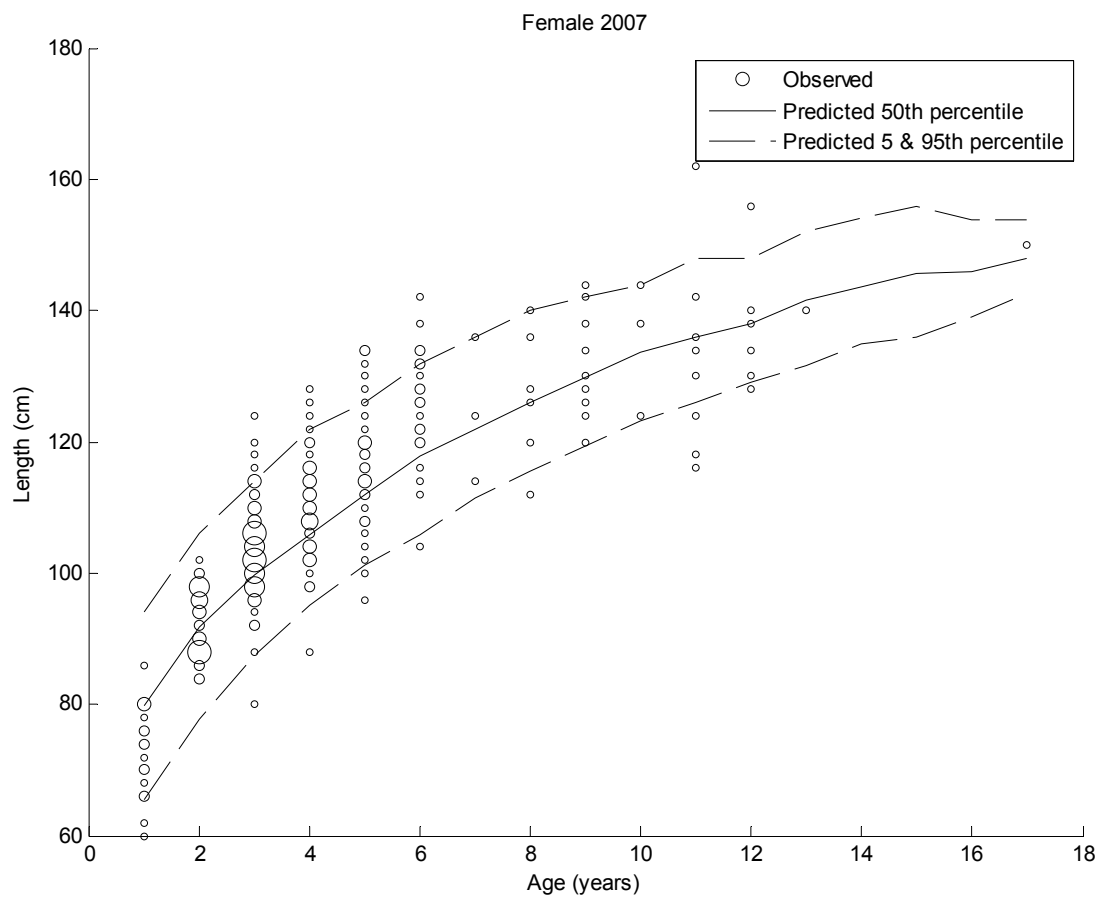
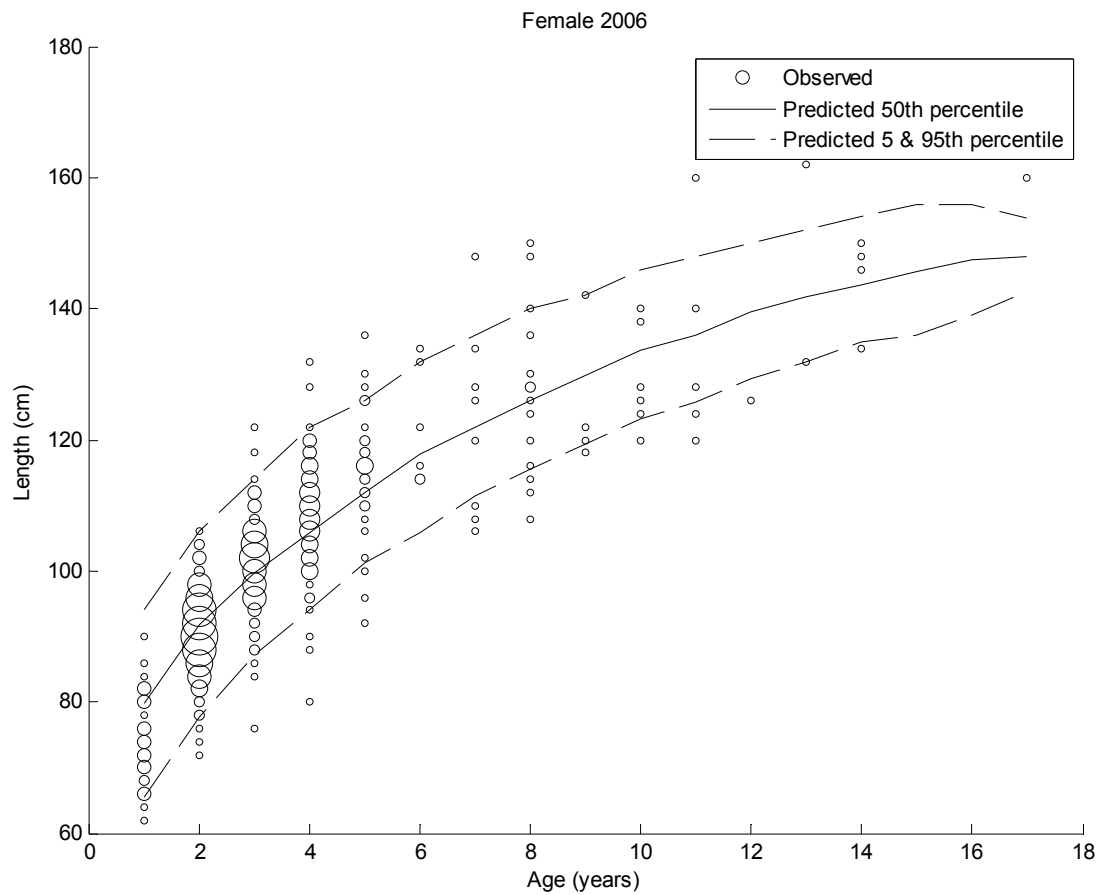


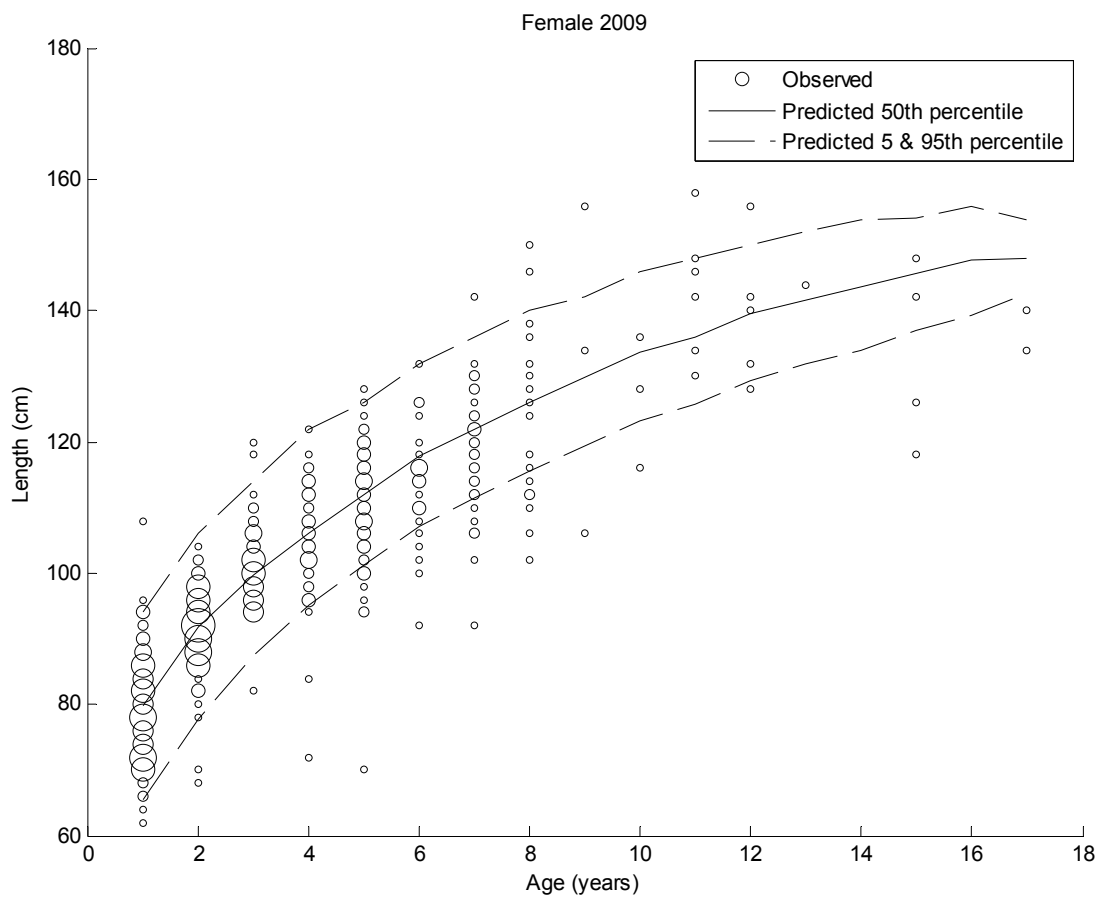
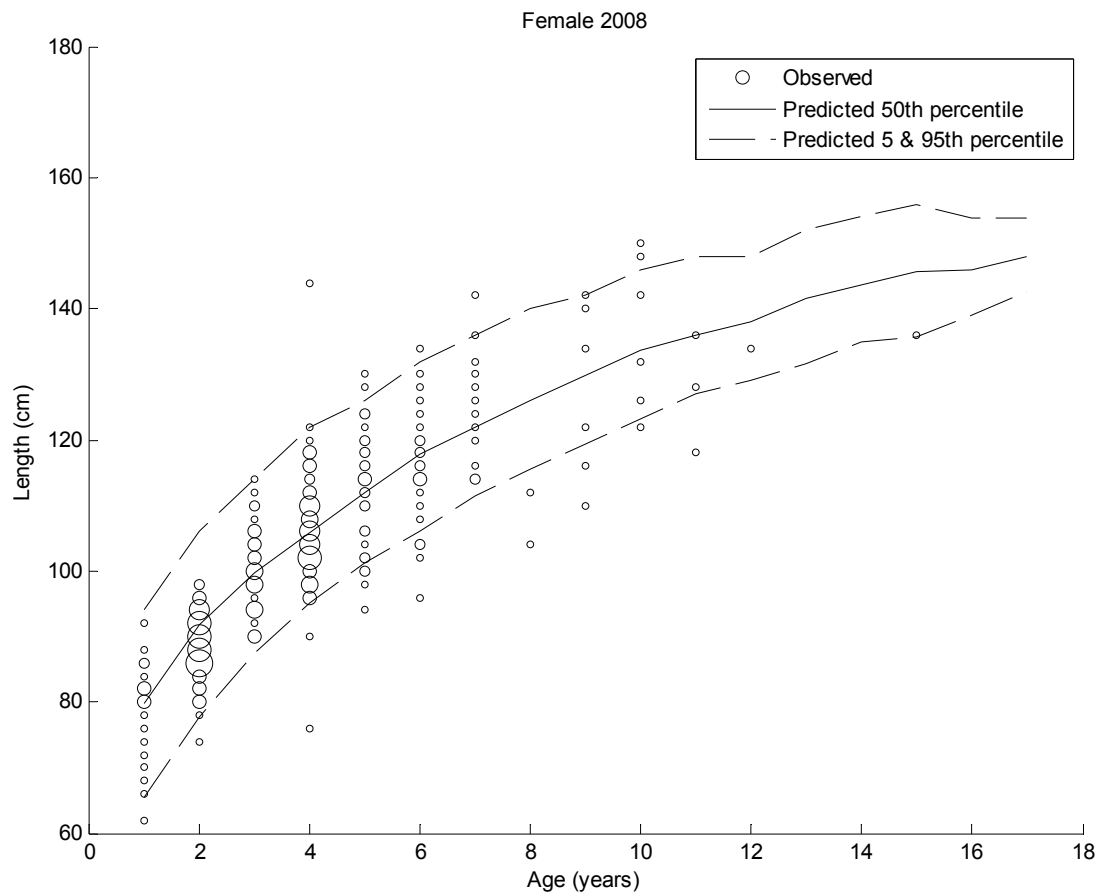
# 10.4 Scenario 25

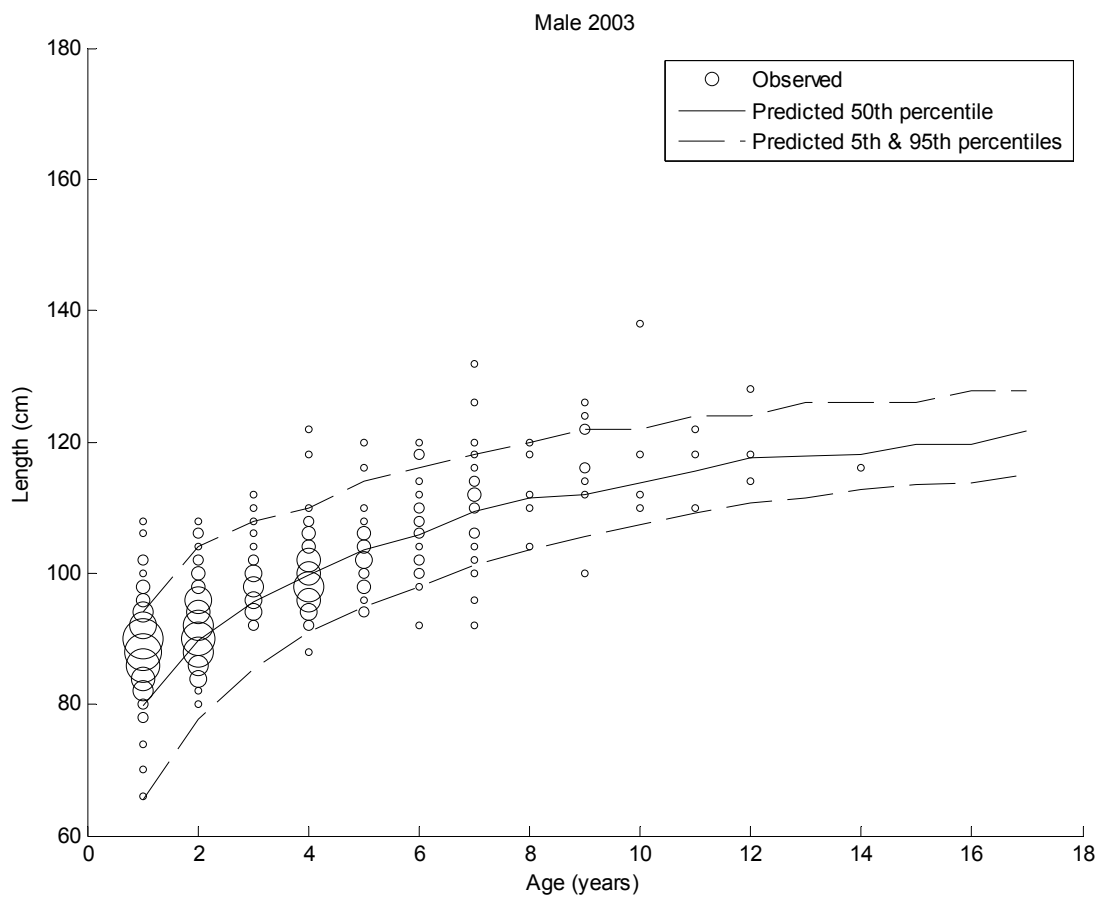
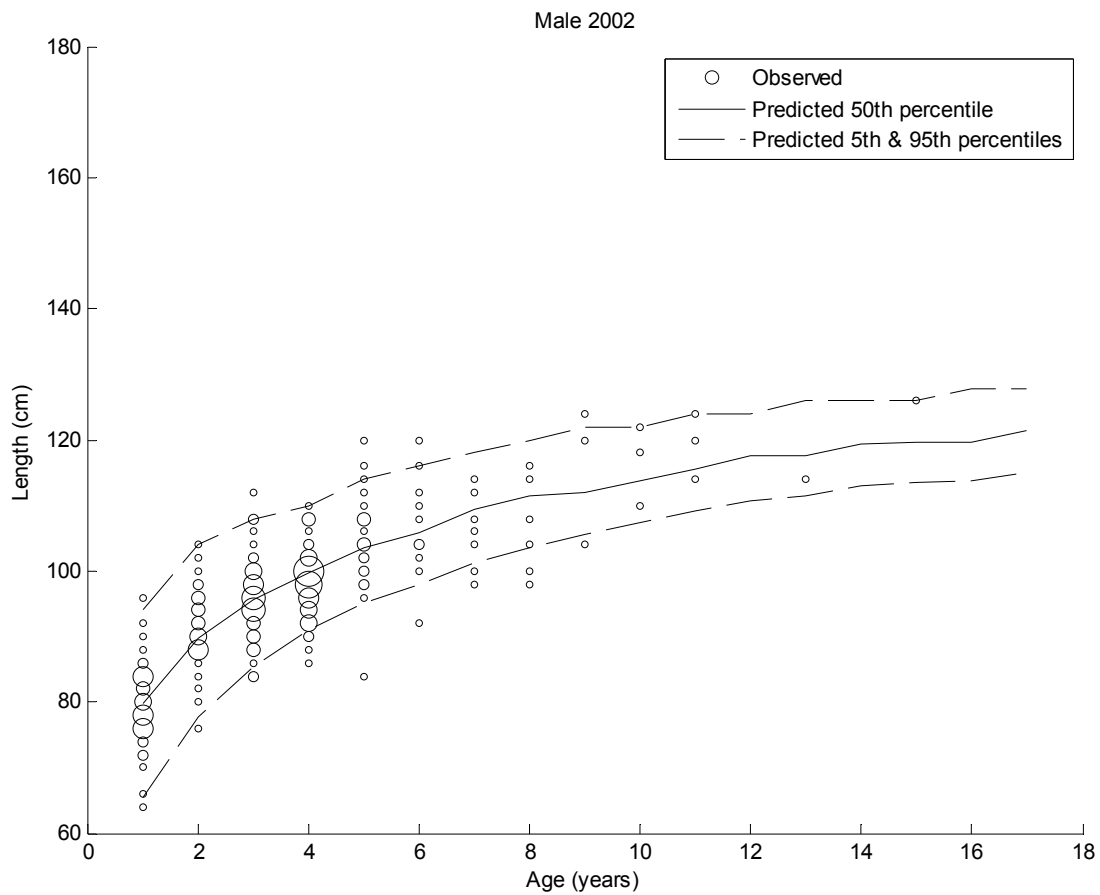


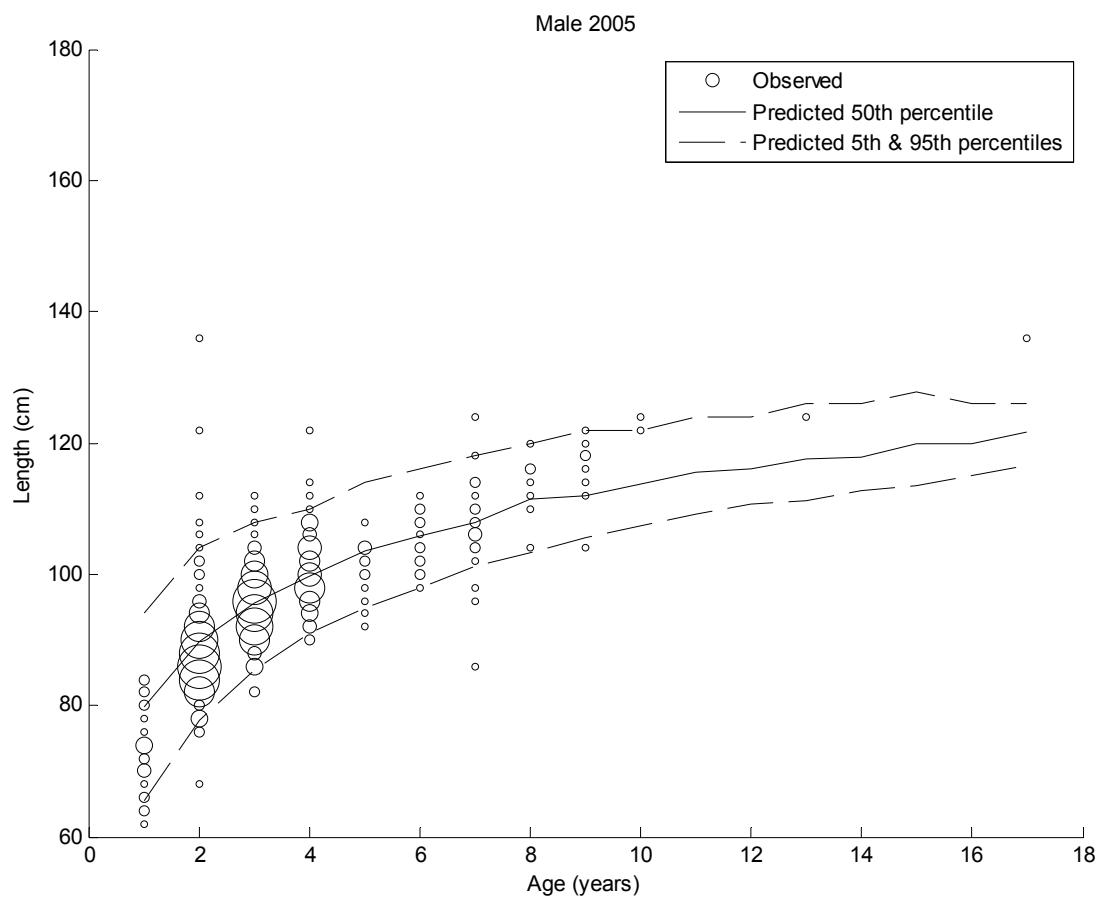
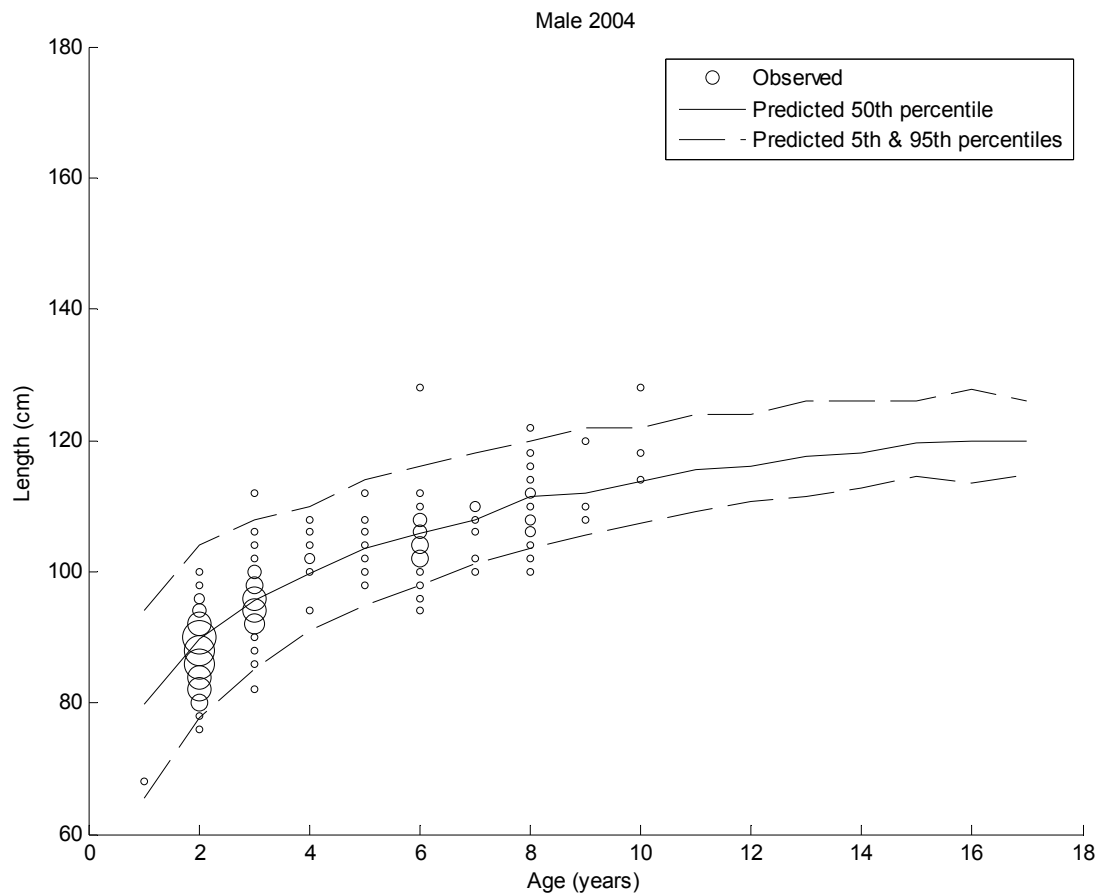


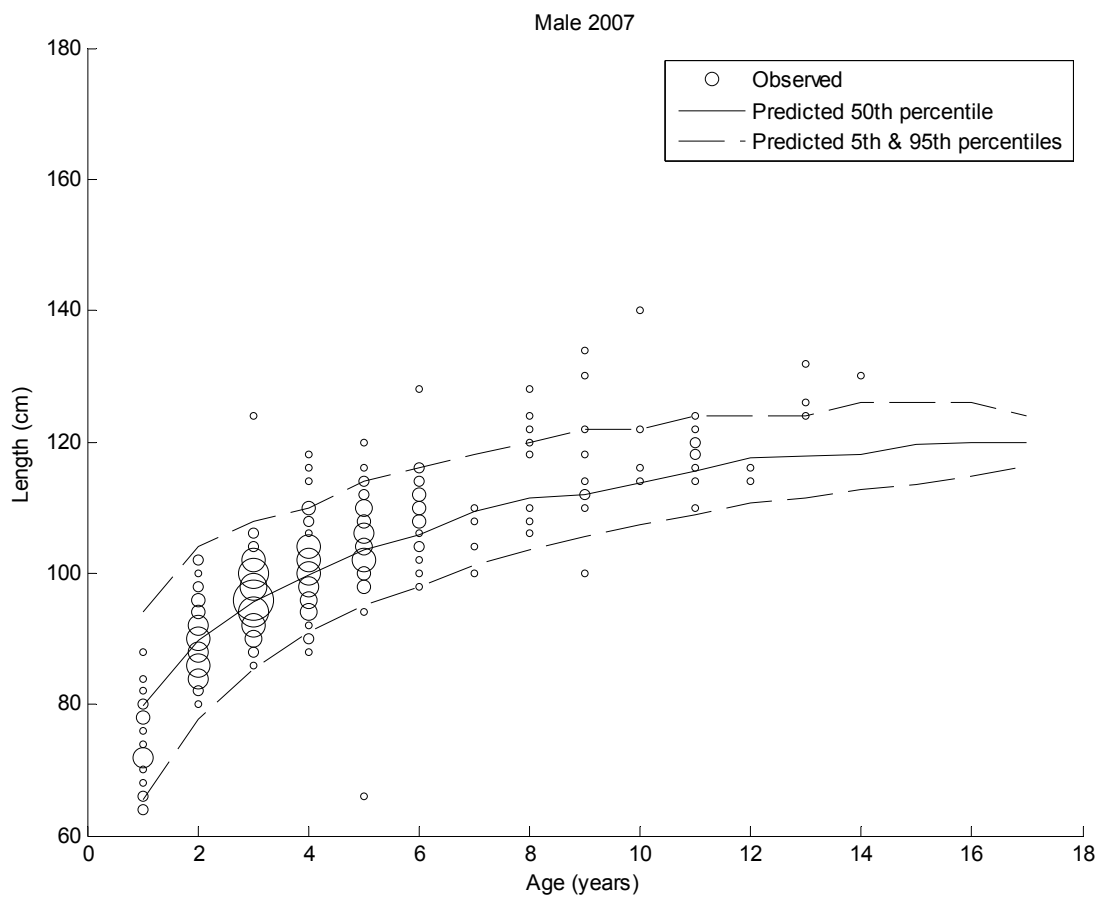
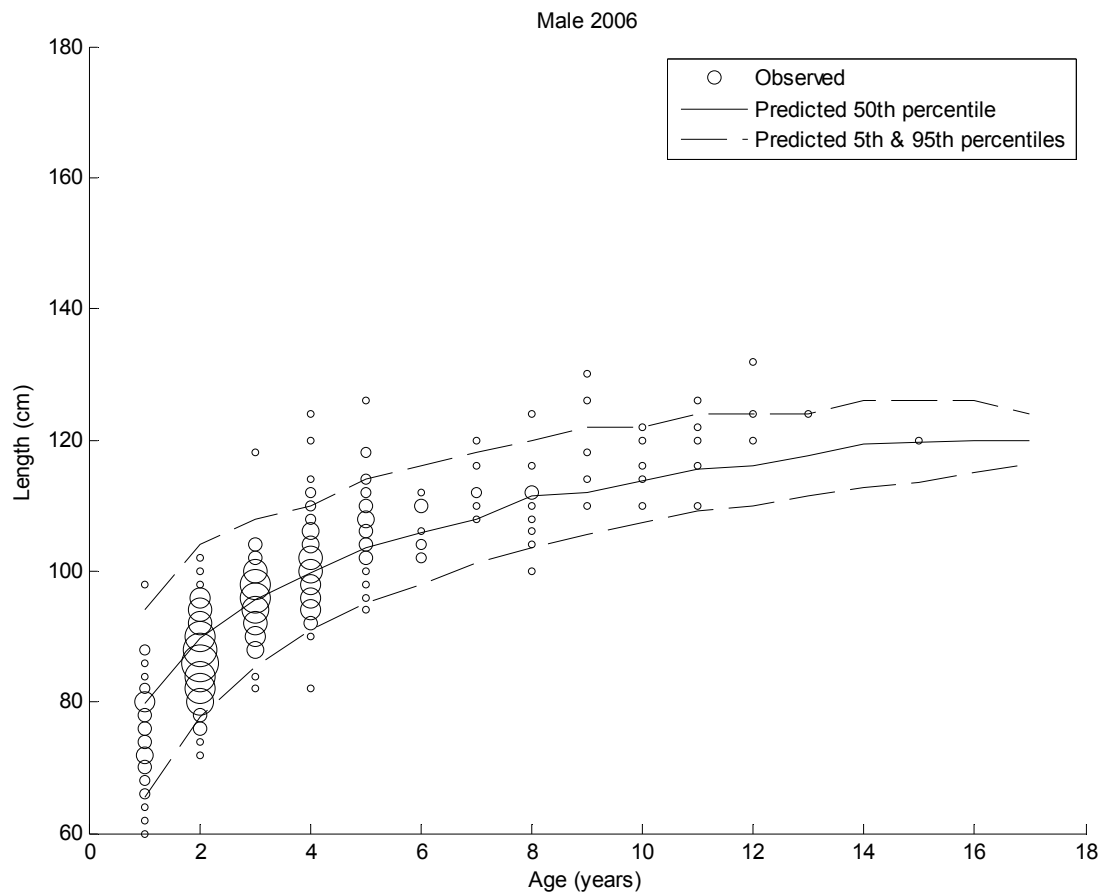


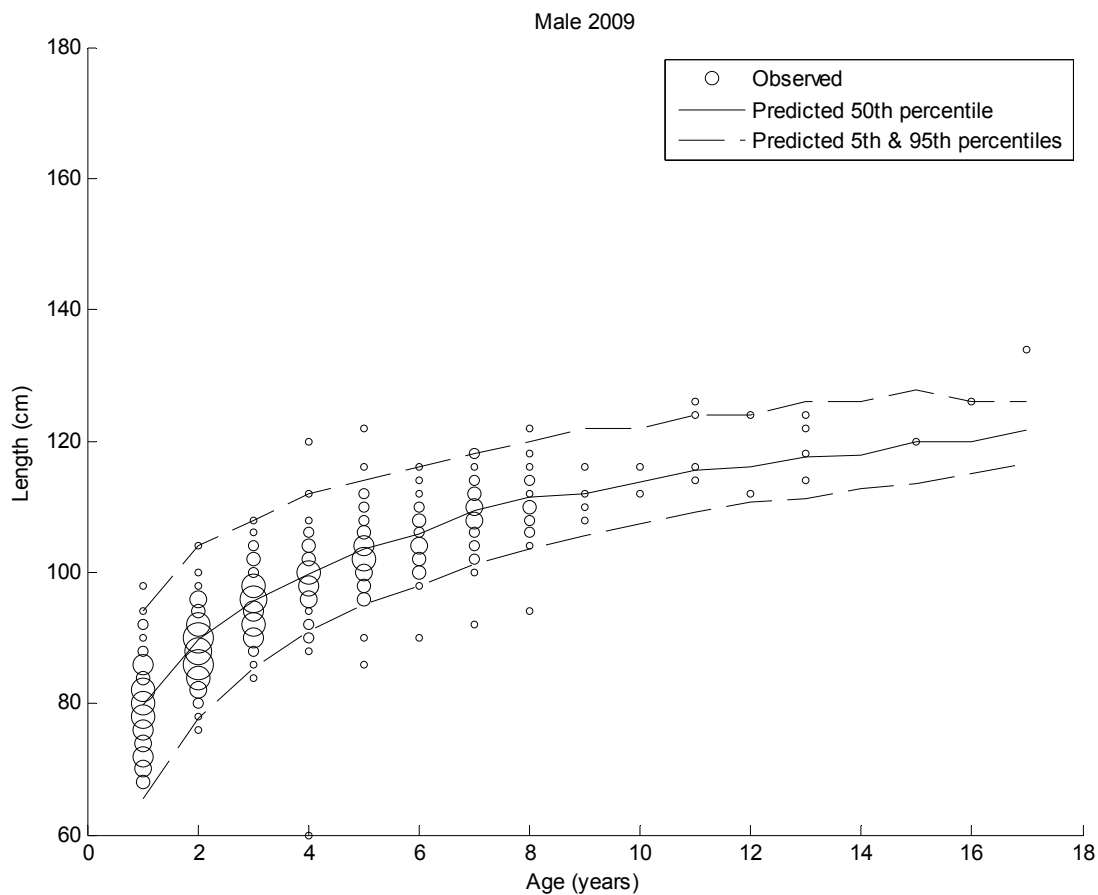
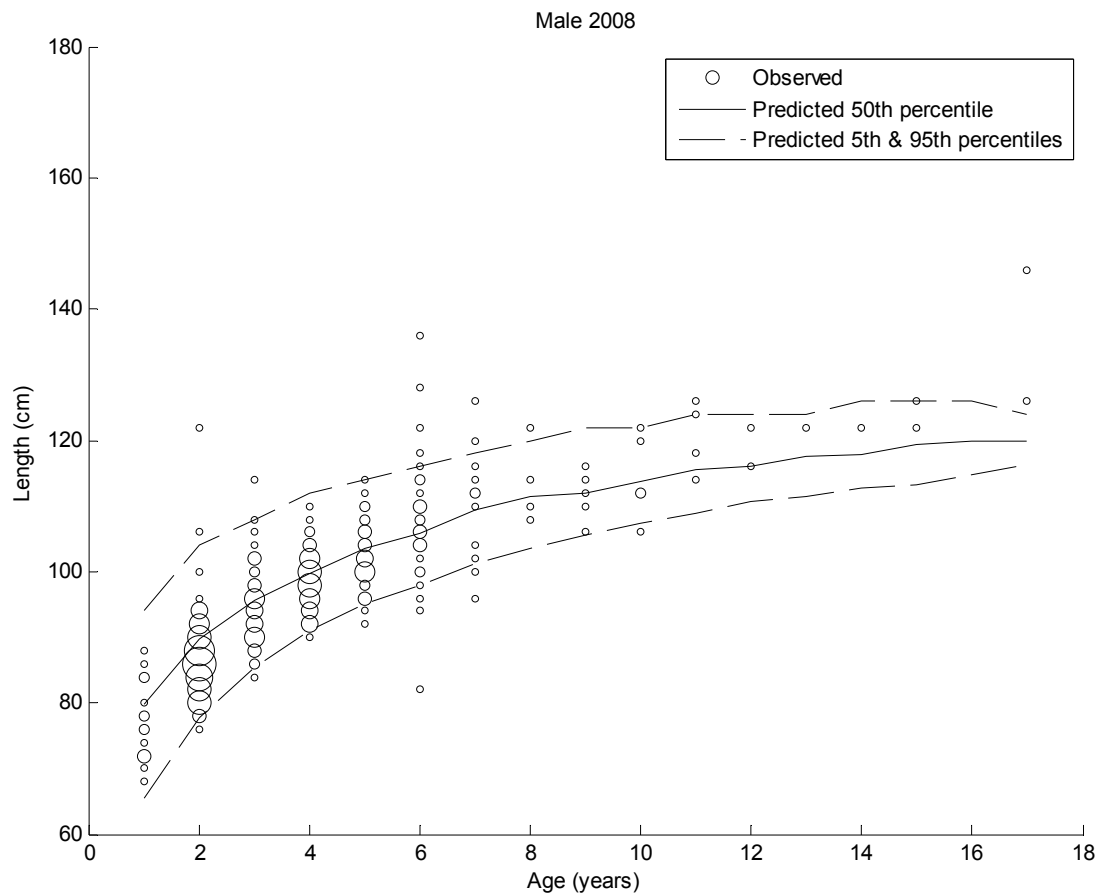




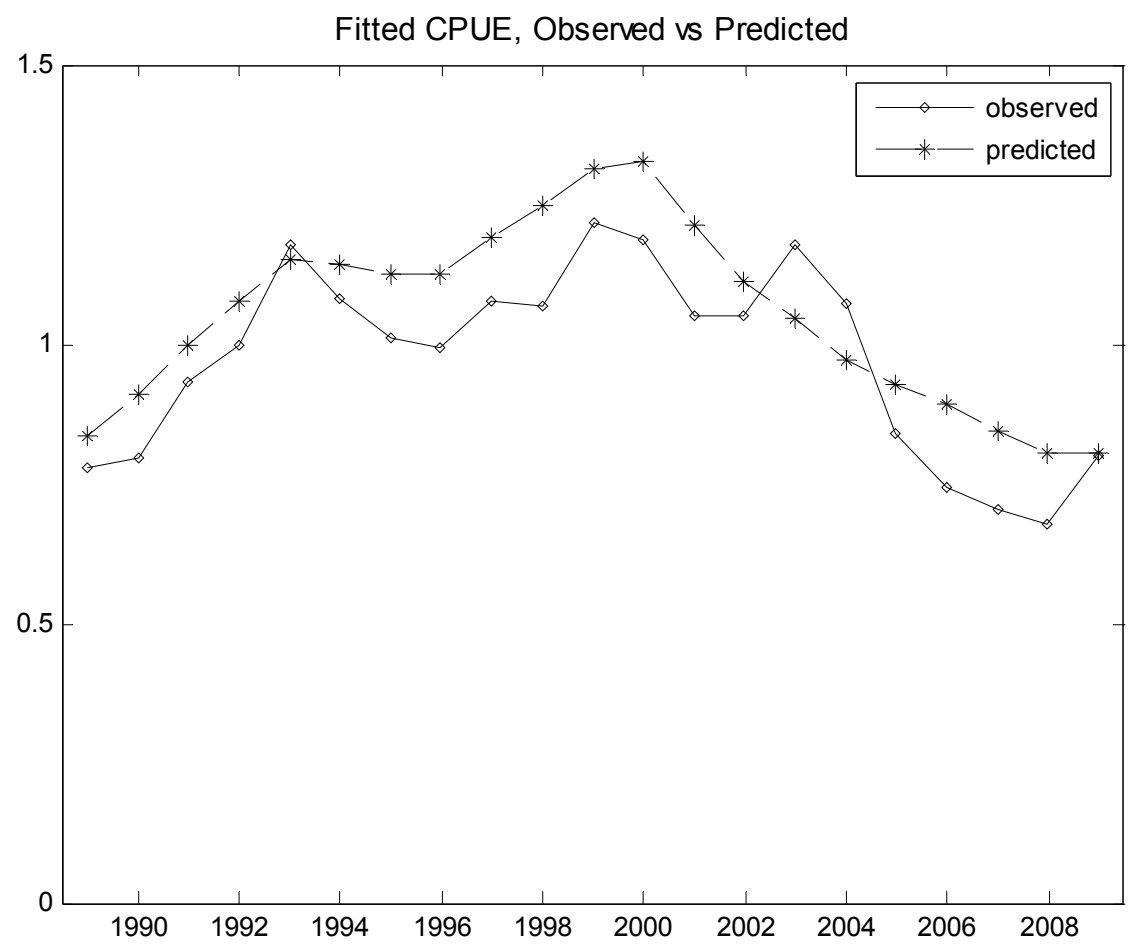


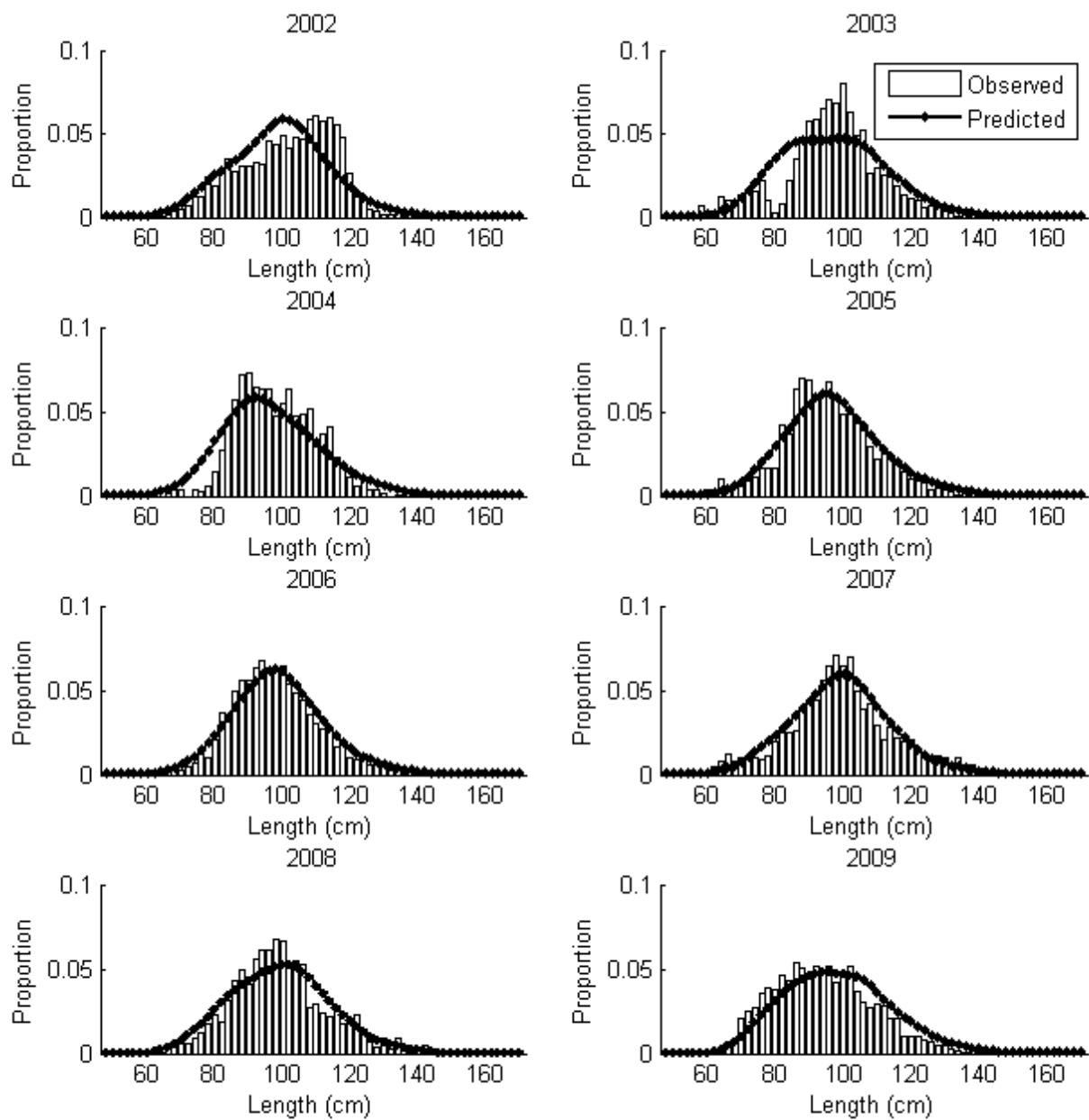


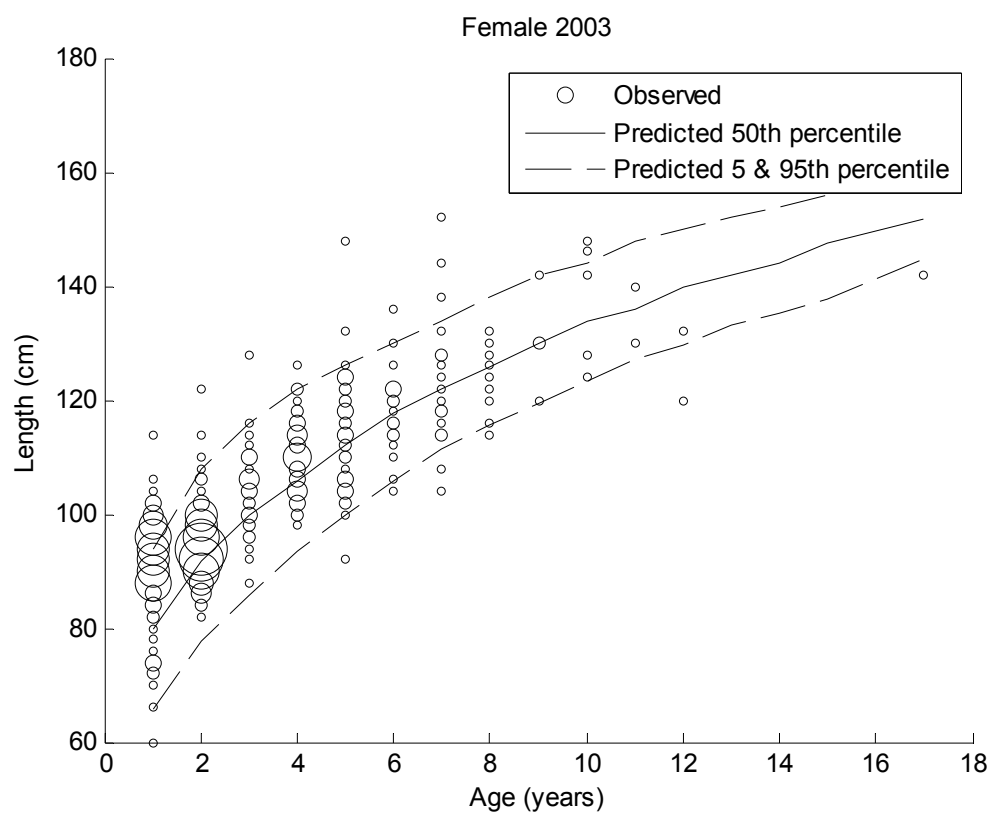
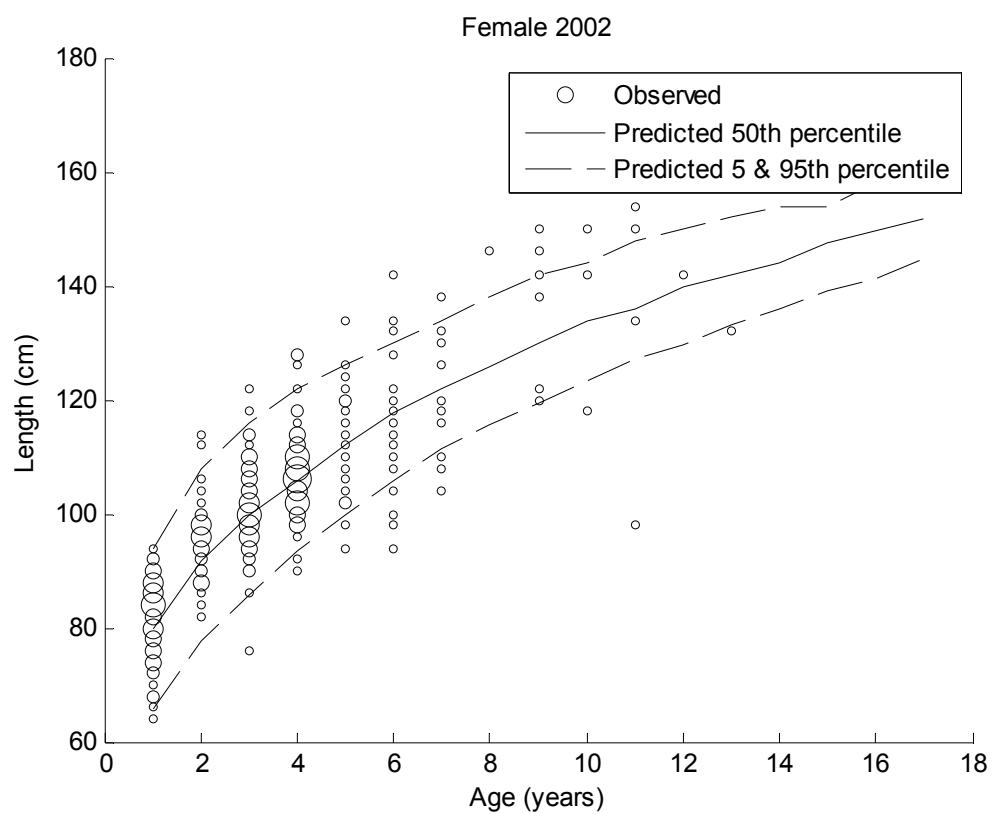


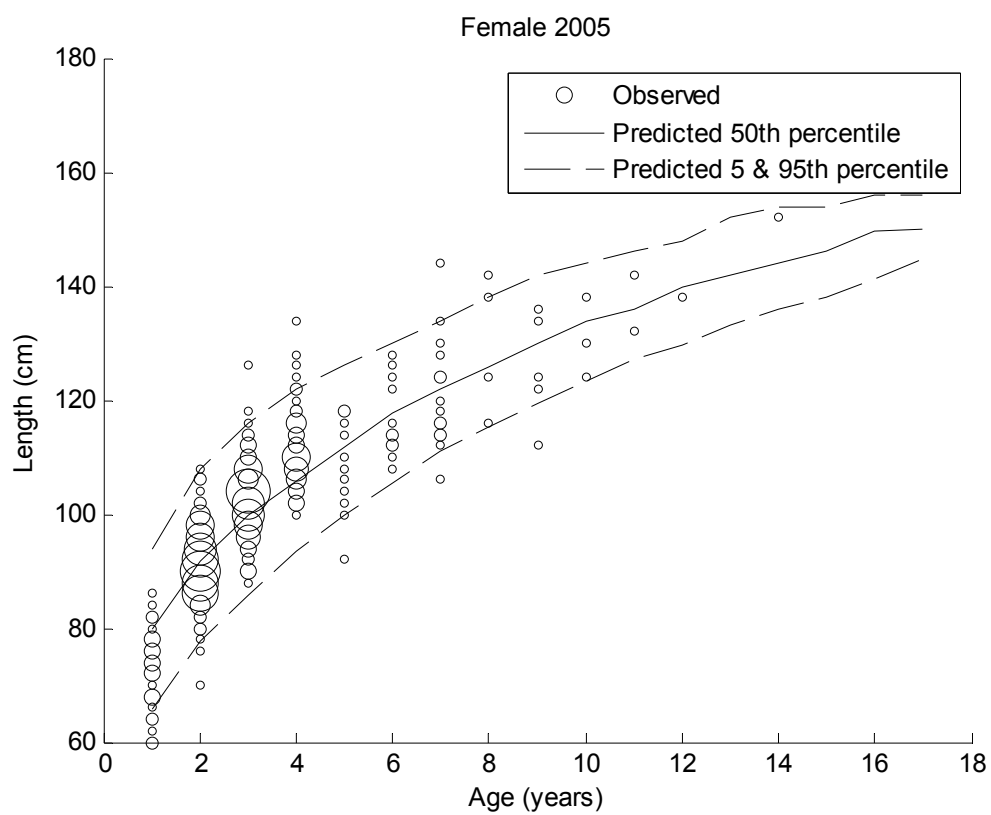
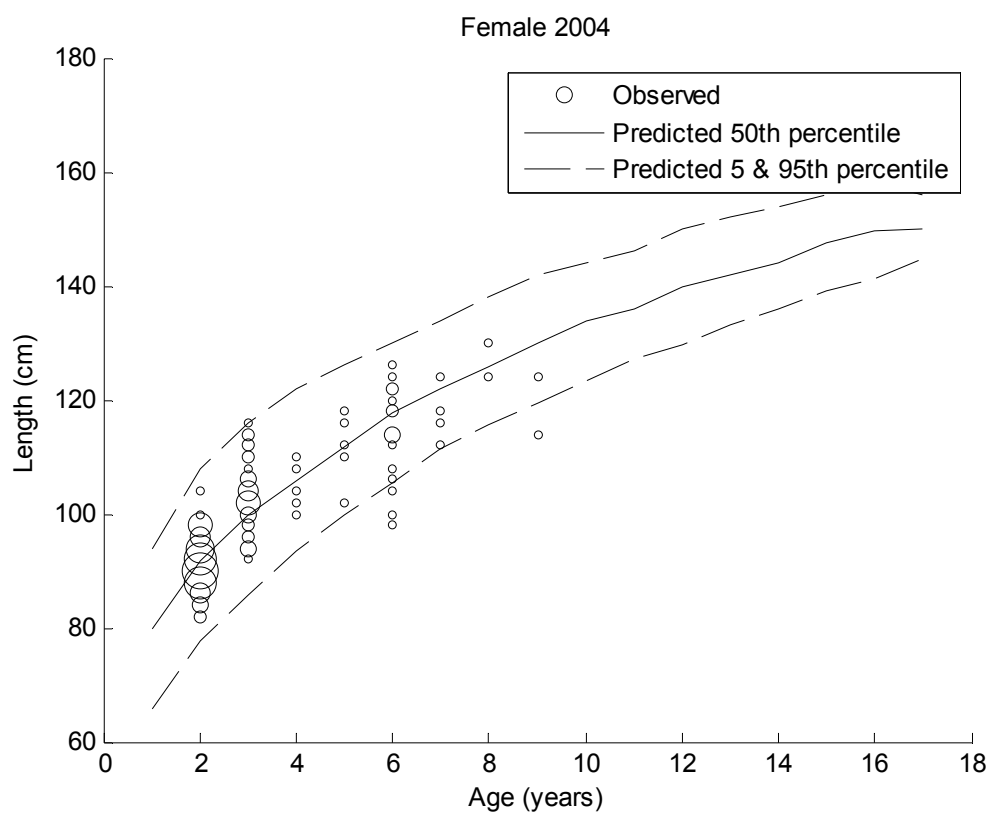


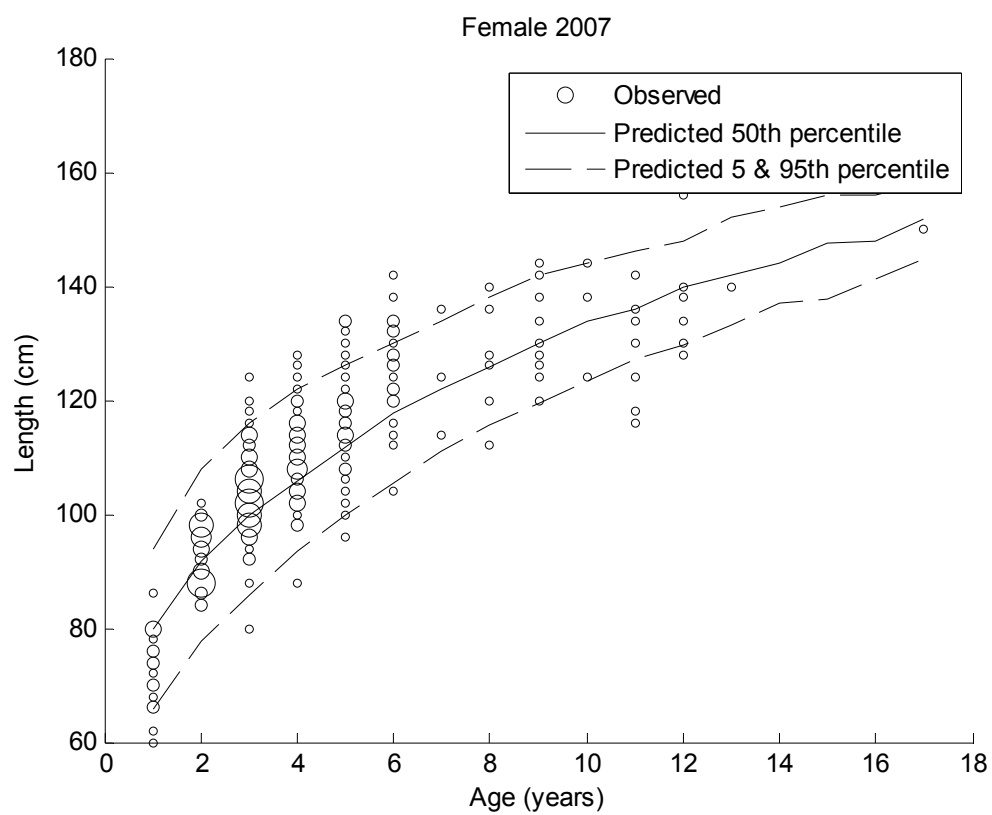
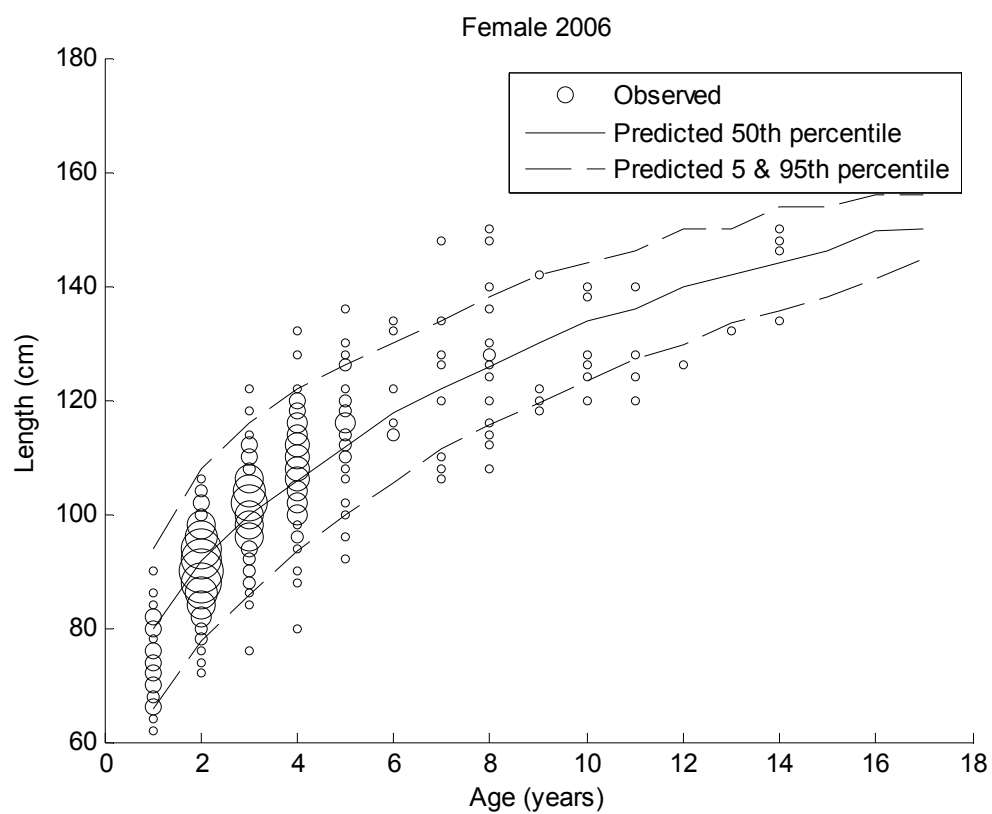
10.5 Scenario 26

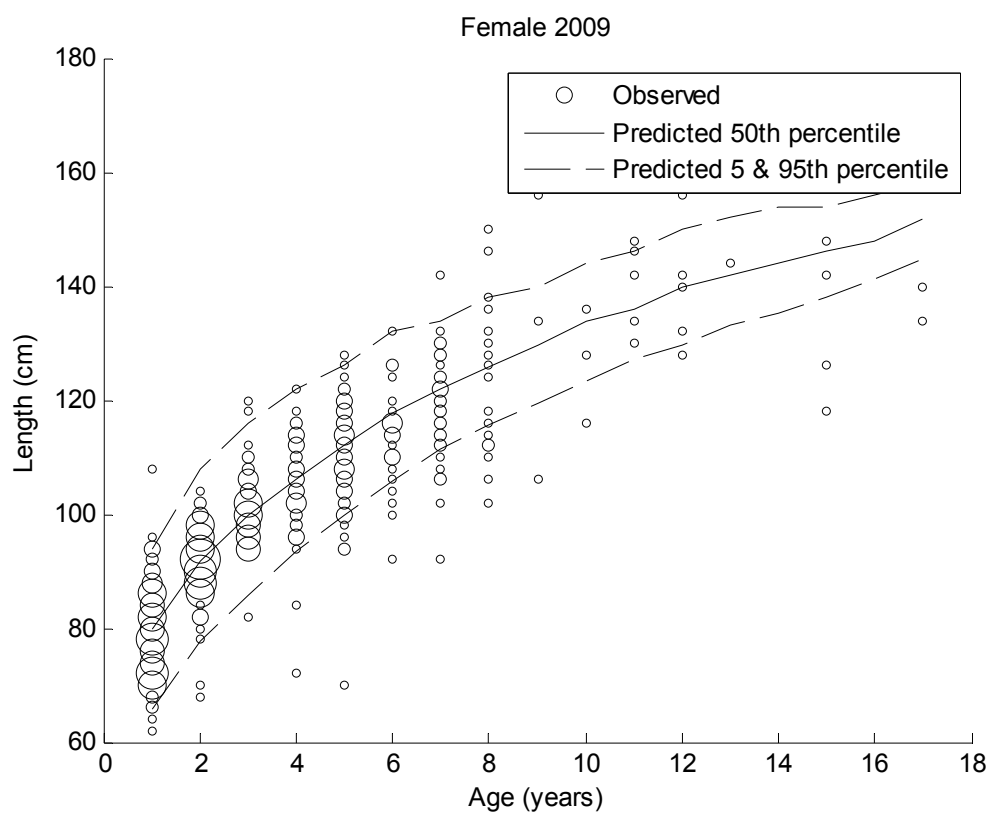
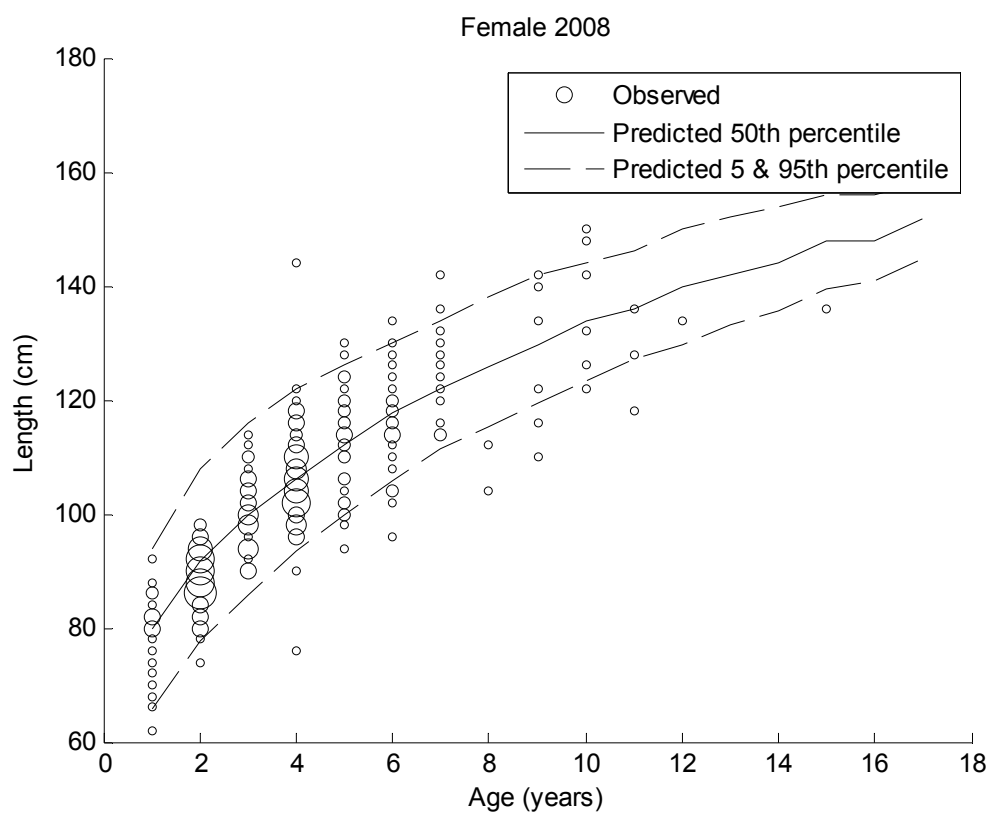


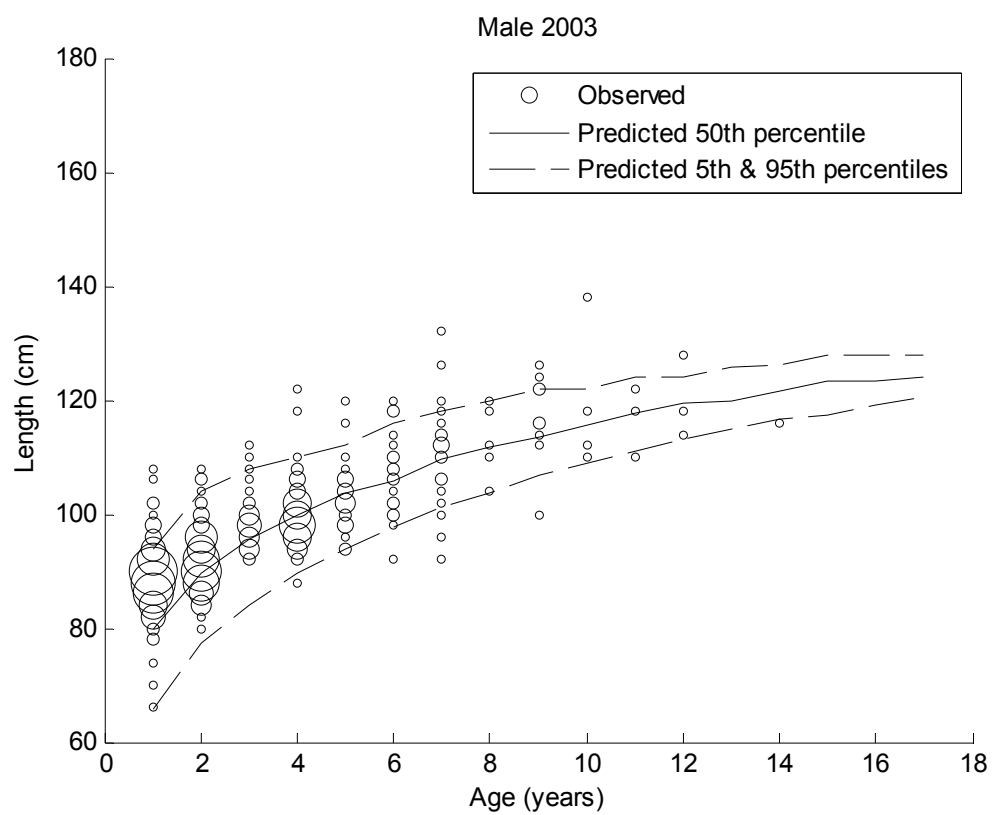
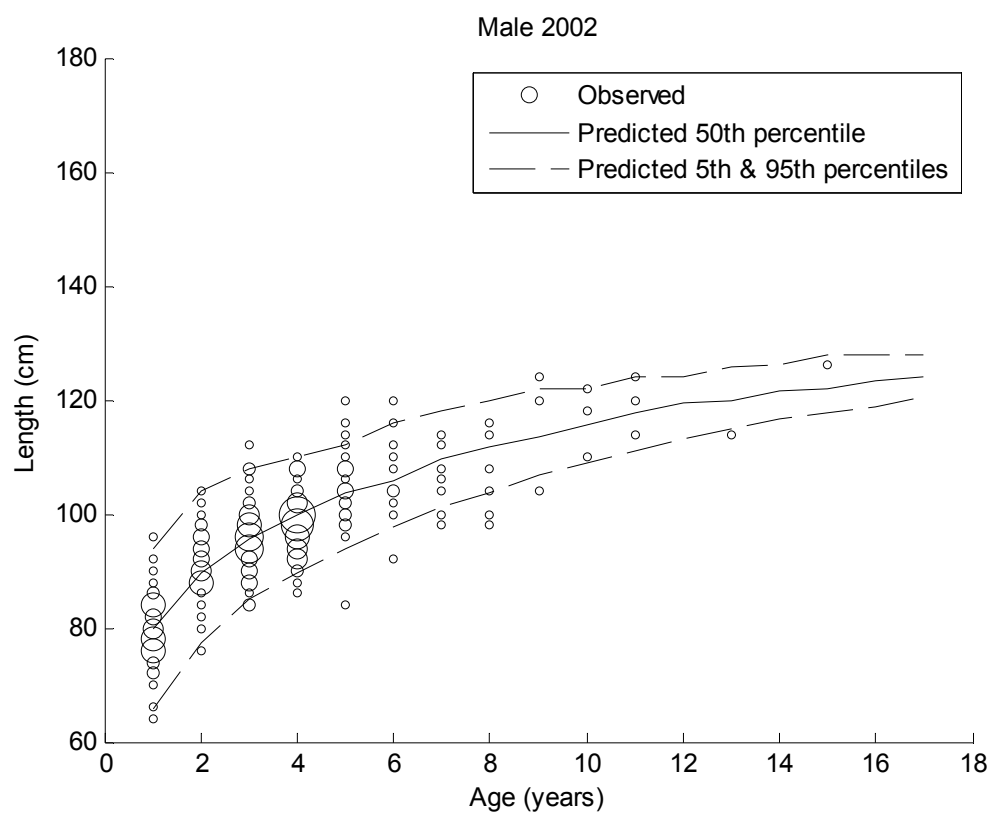


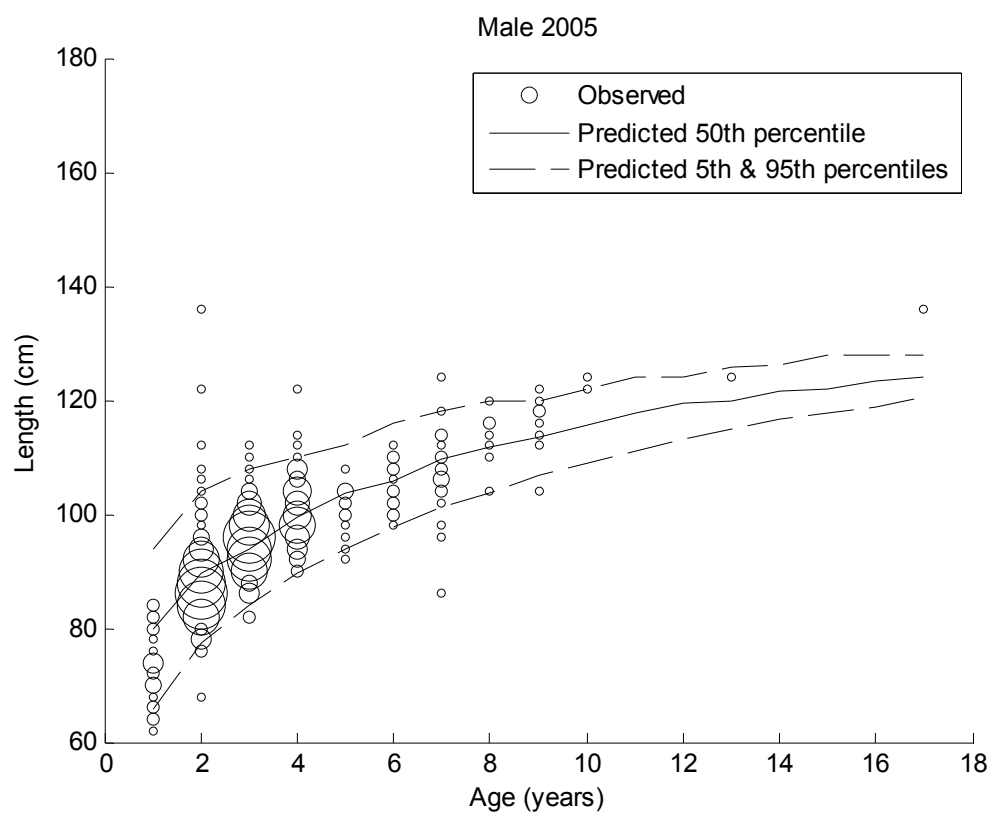
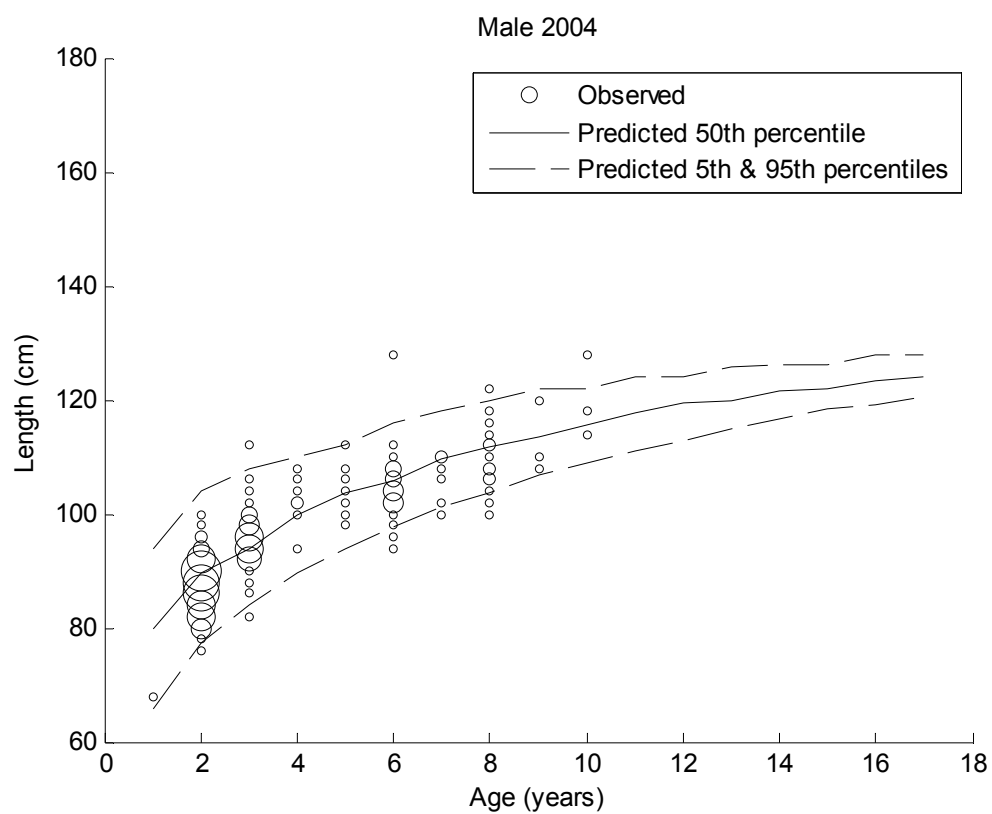


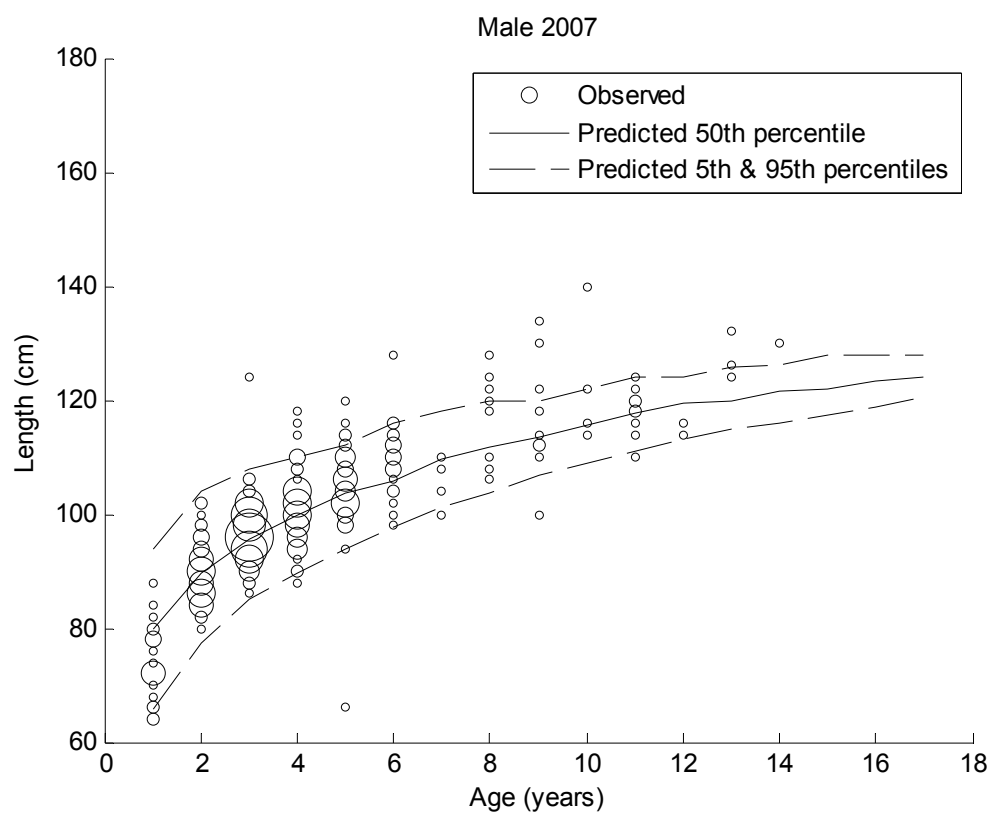
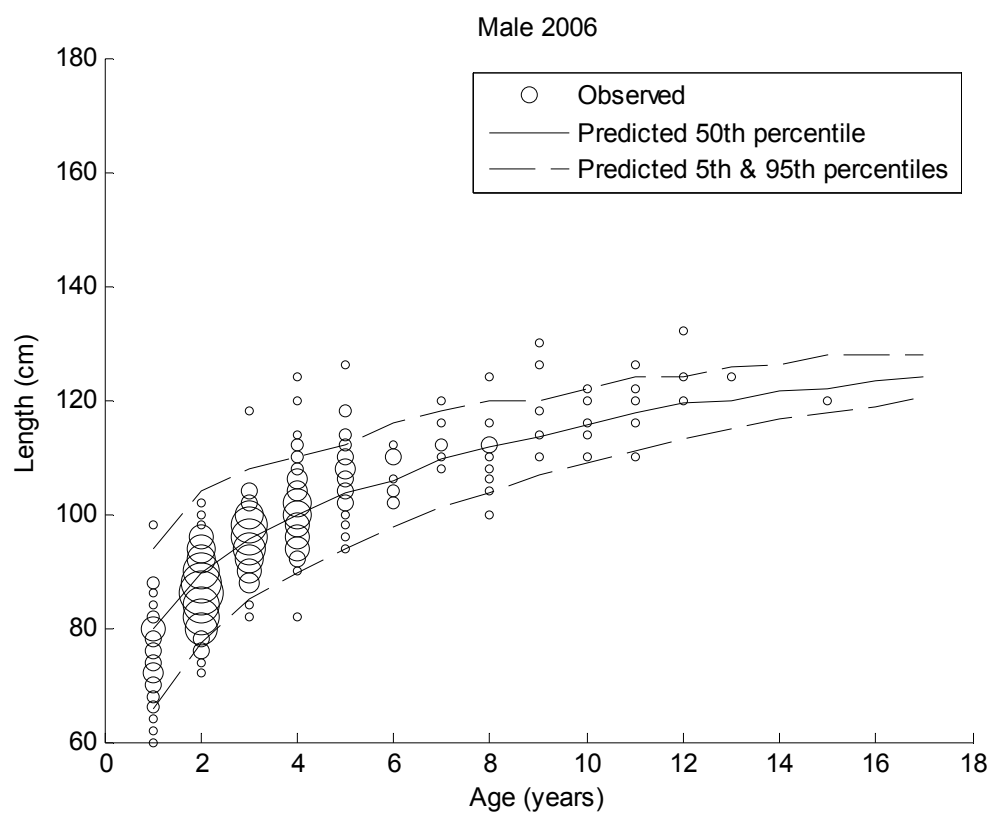


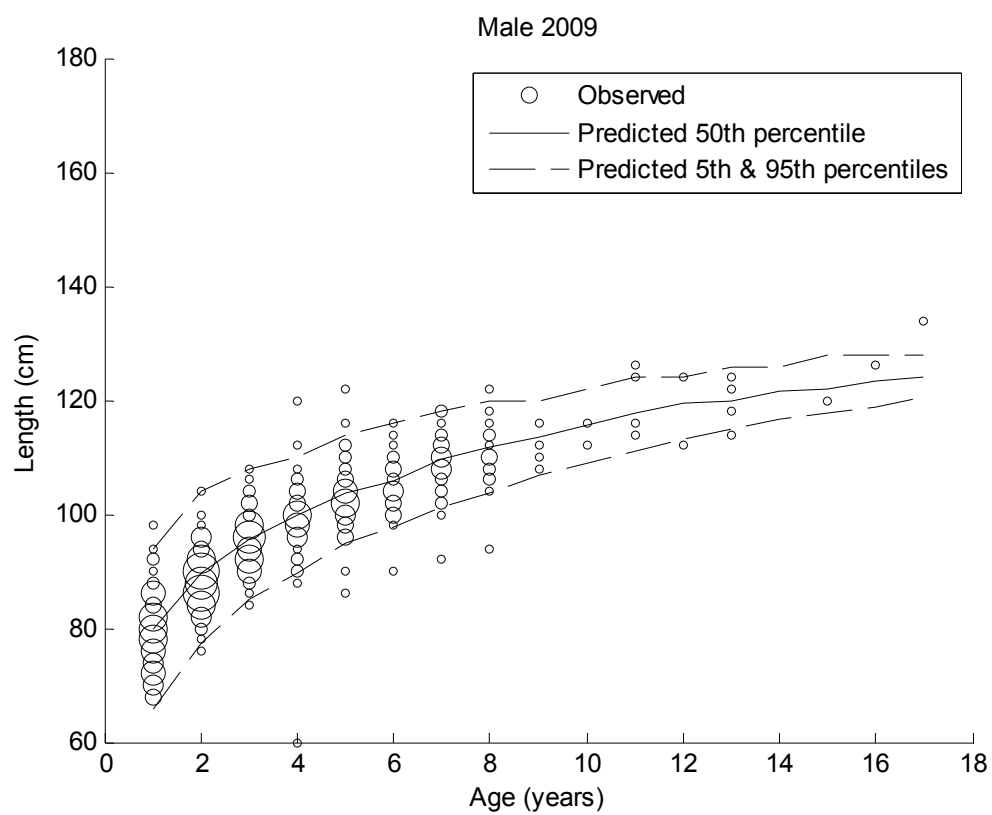
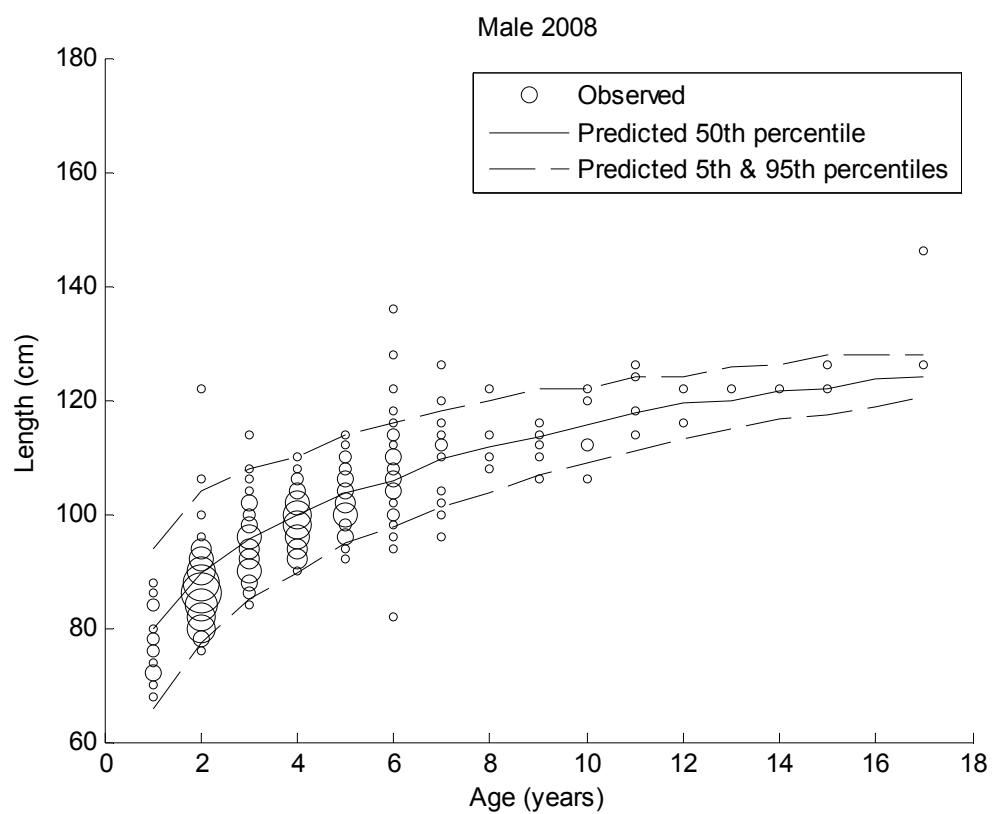




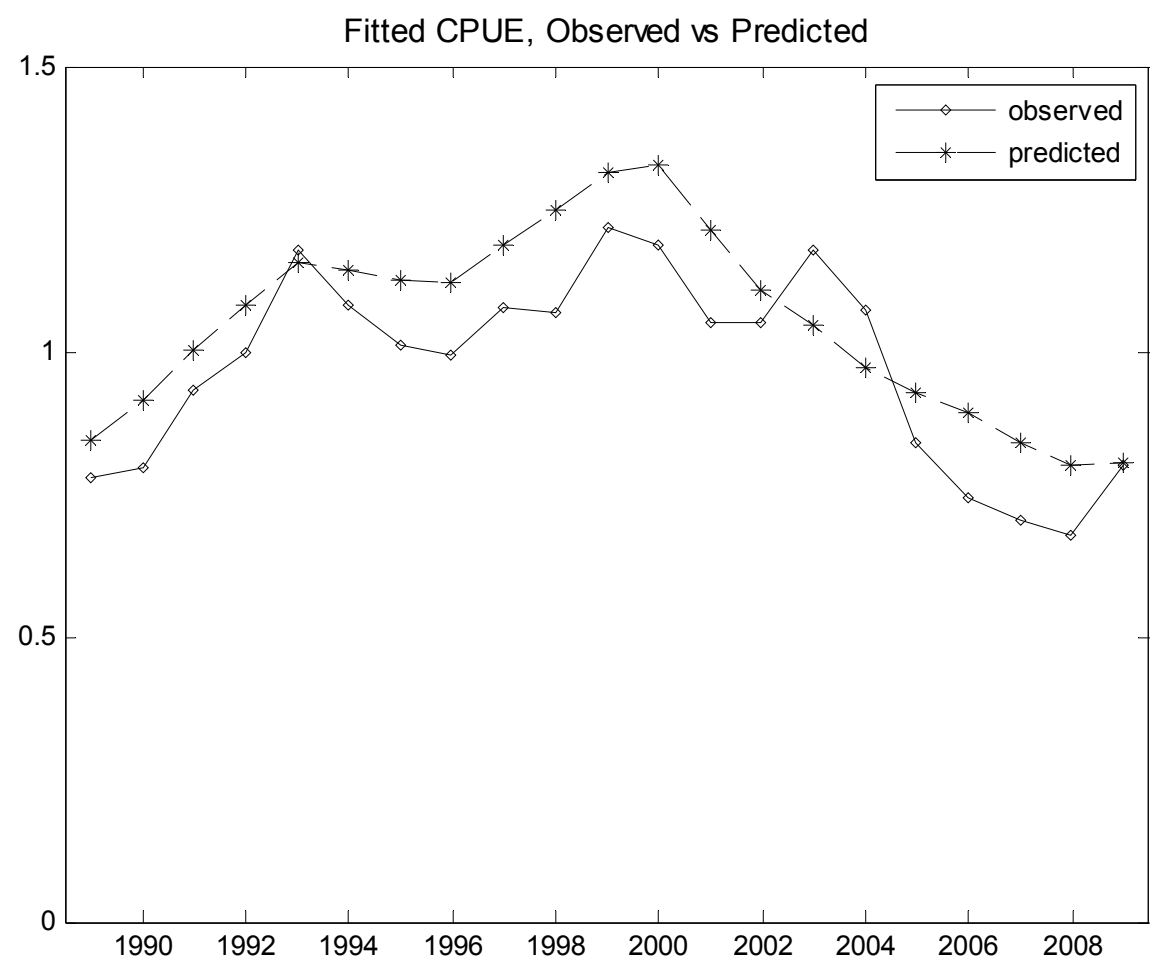


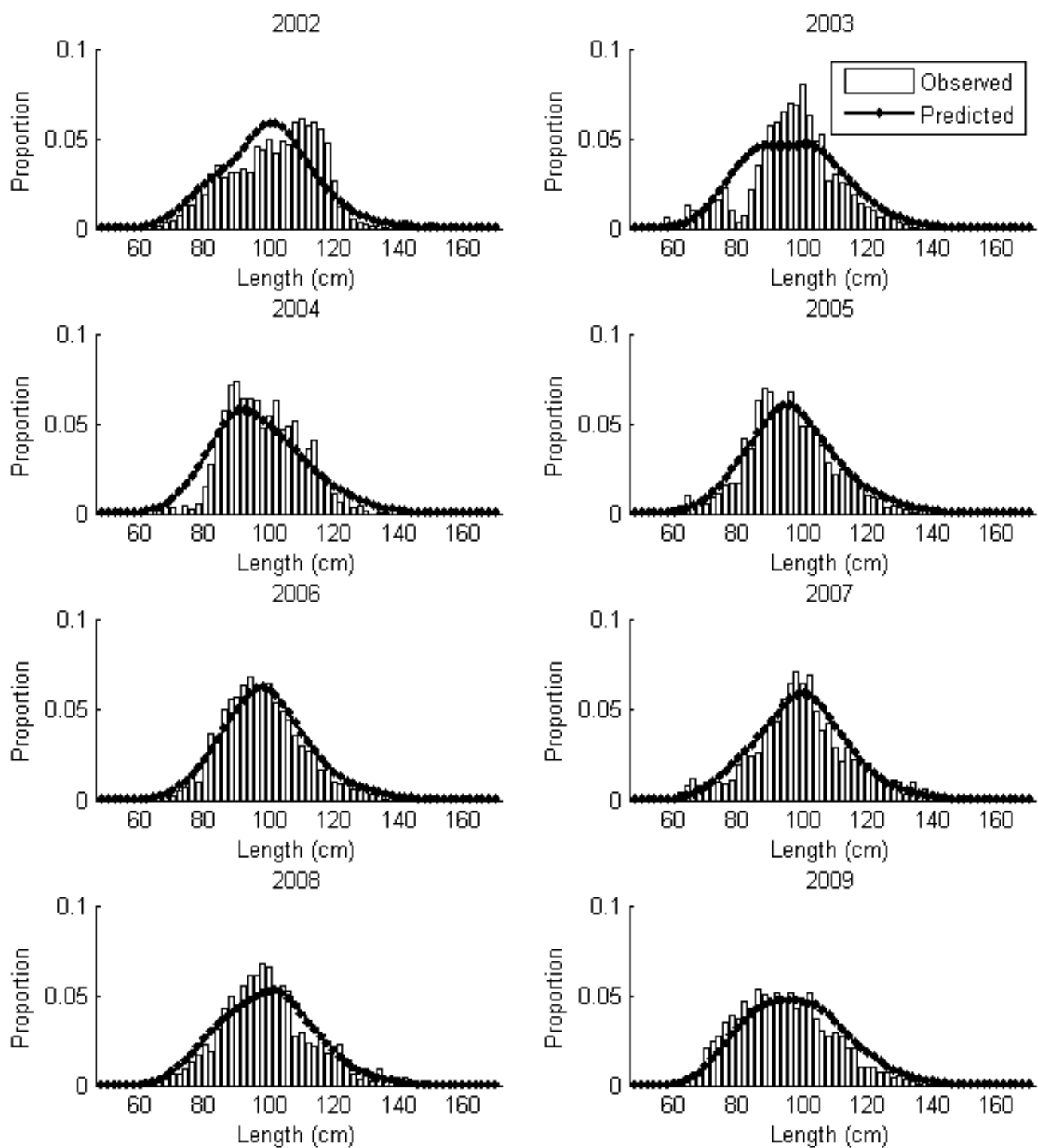


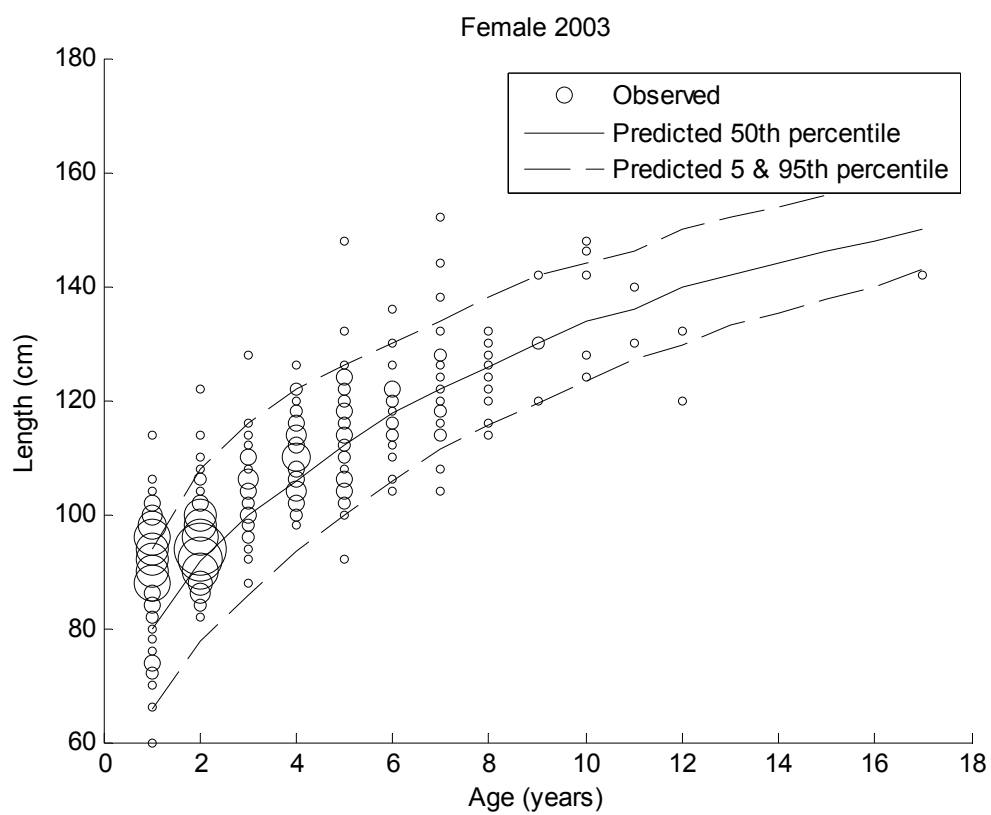
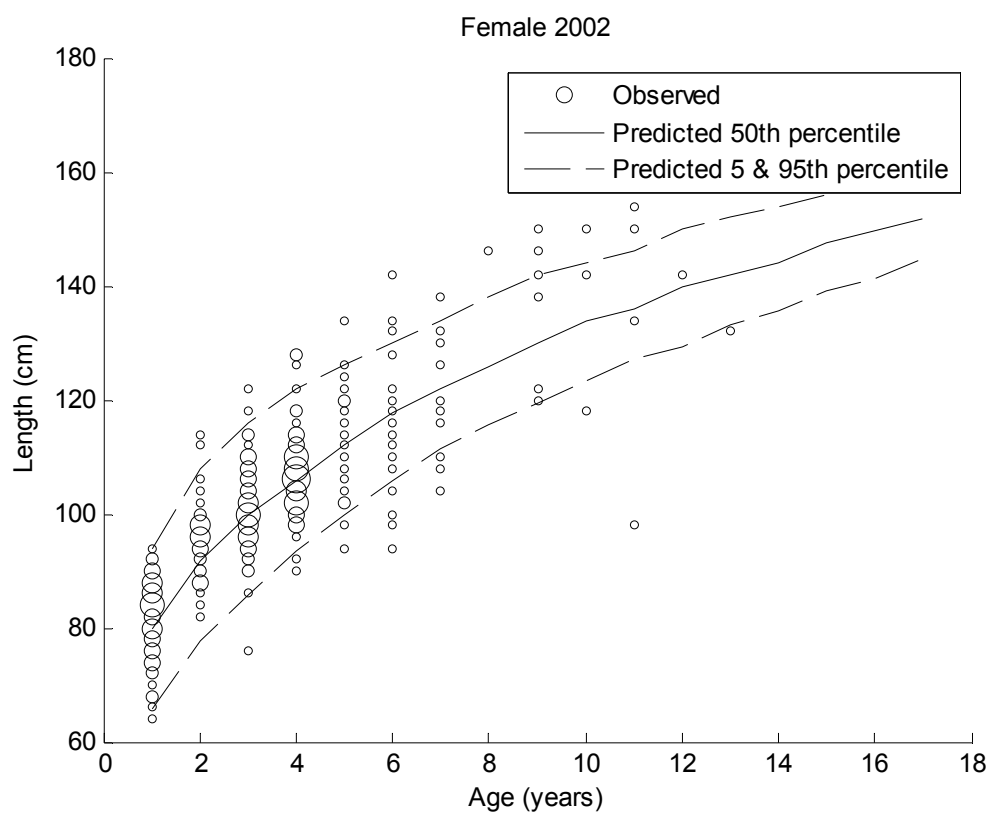


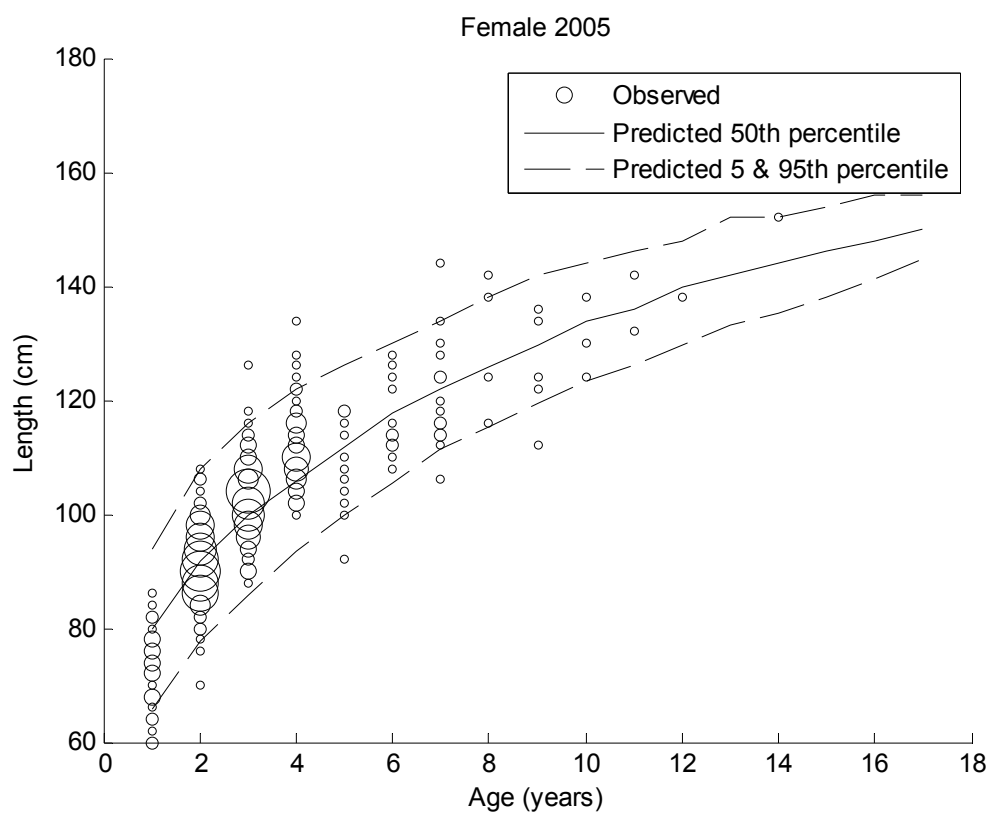
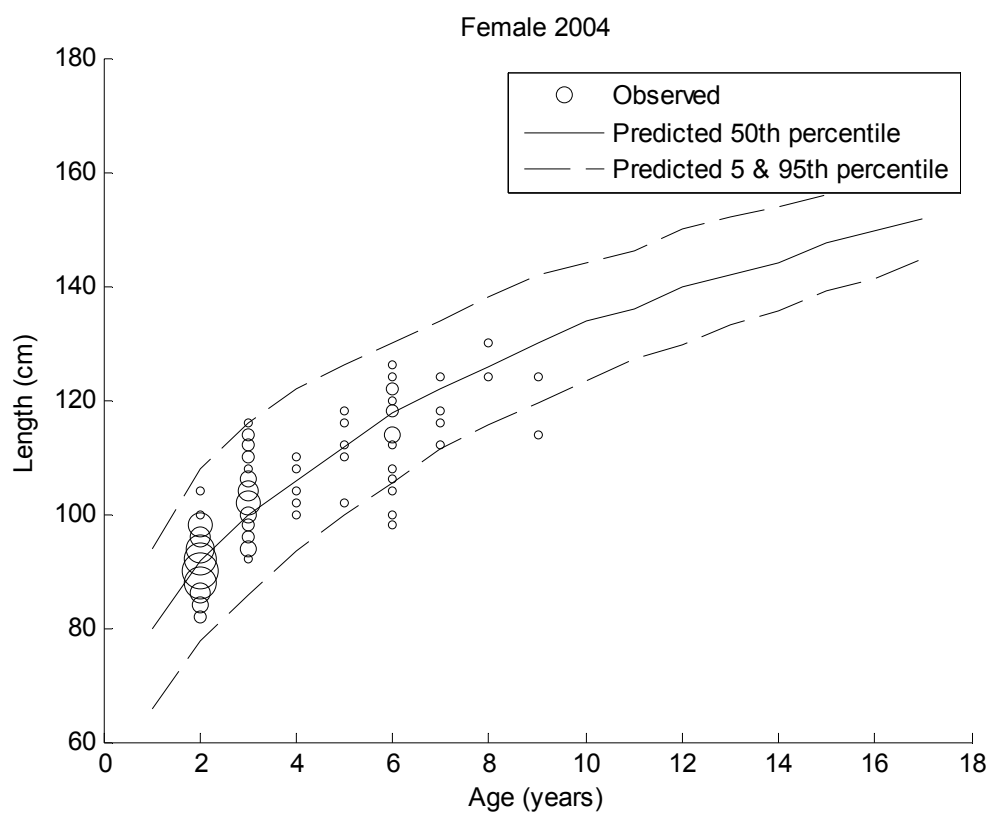


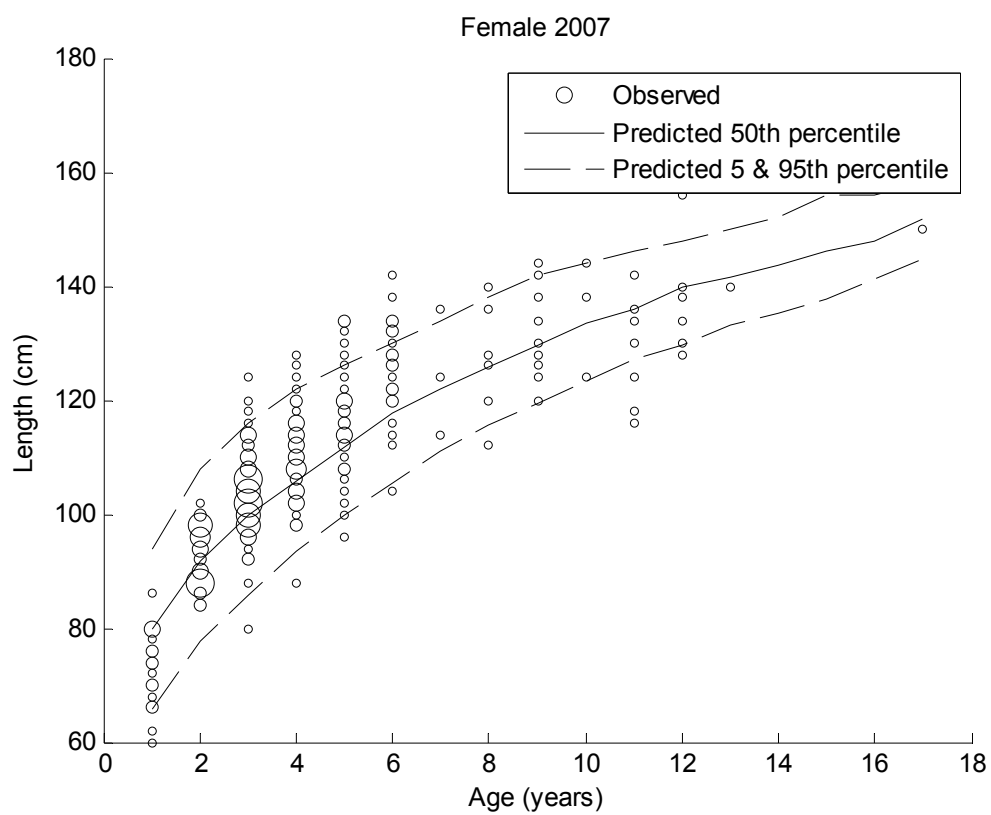
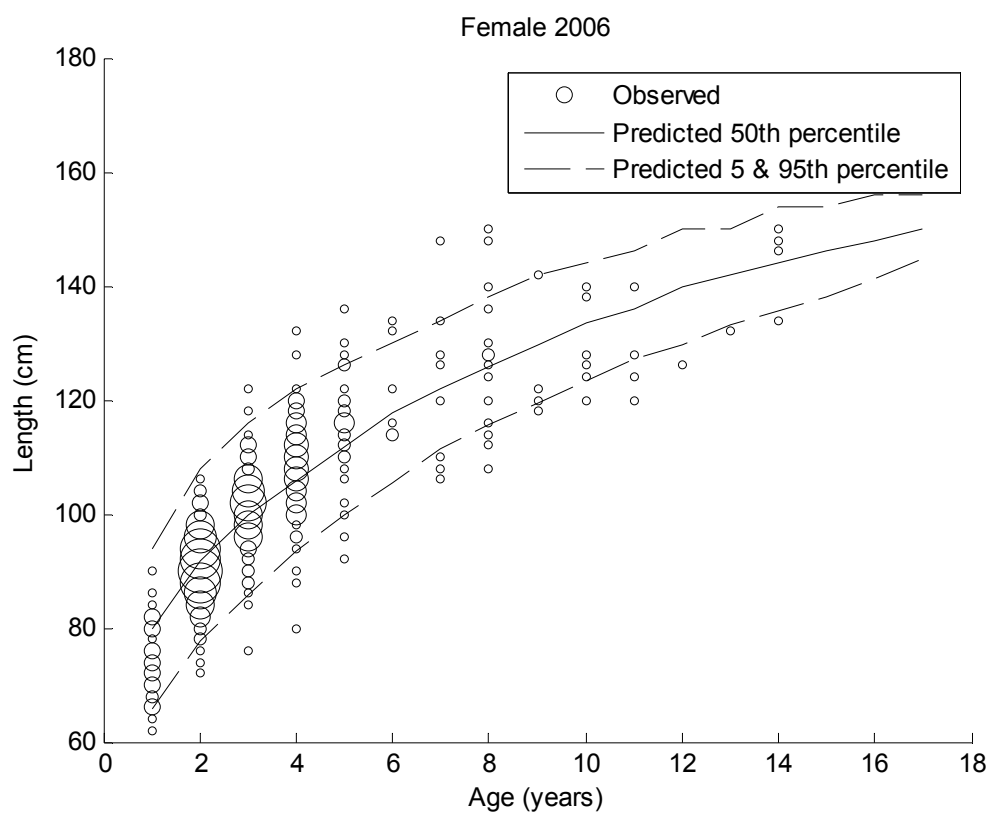
10.6 Scenario 26a

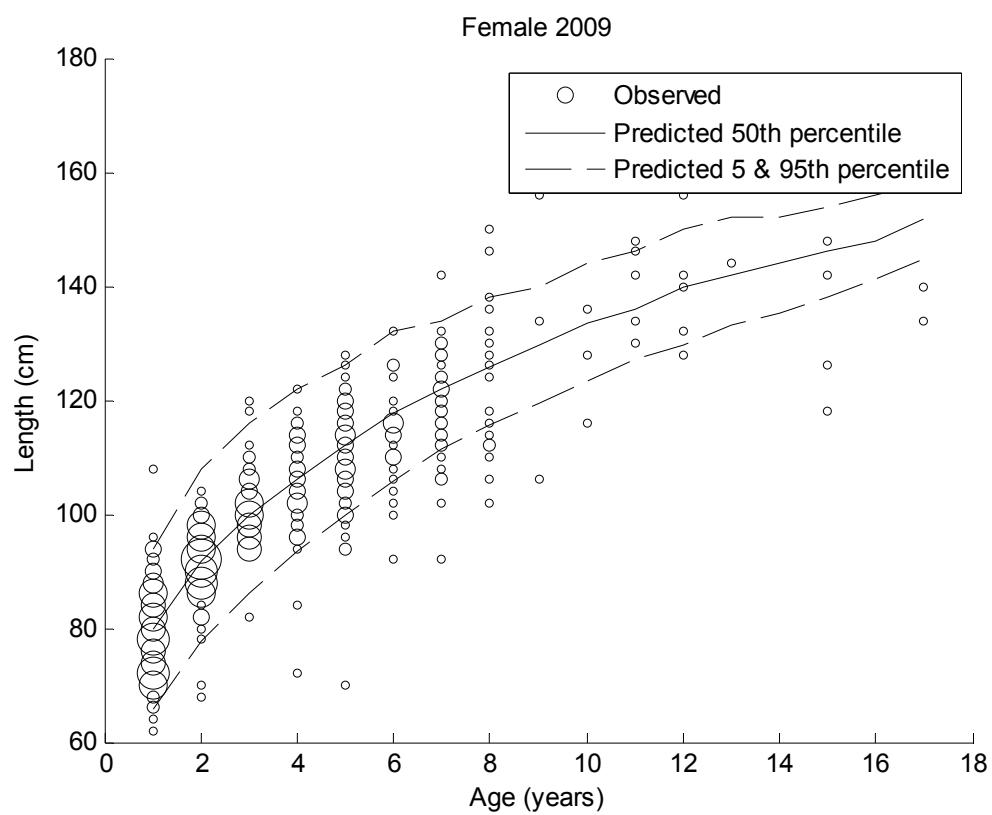
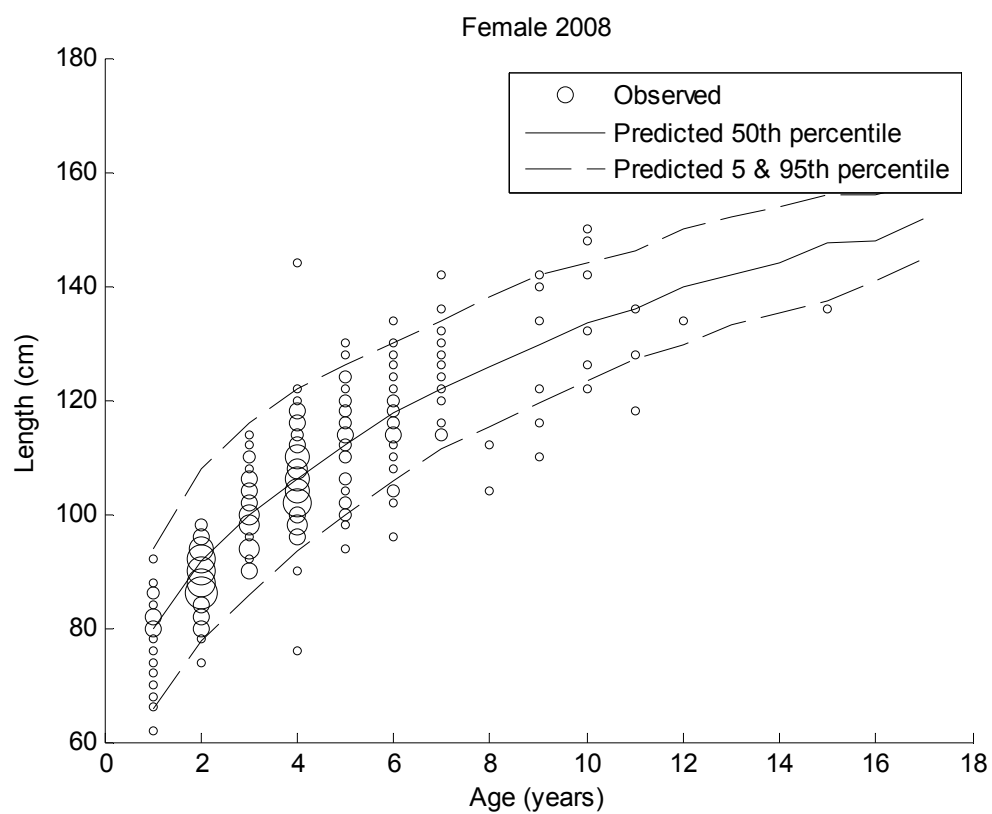


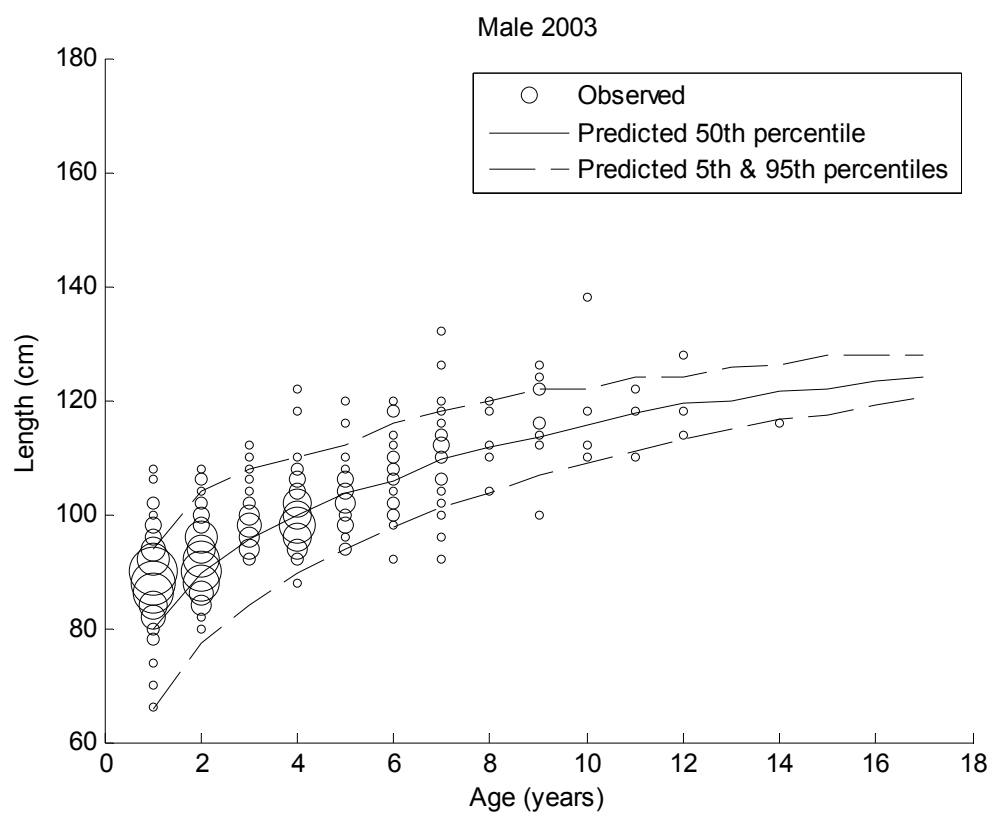
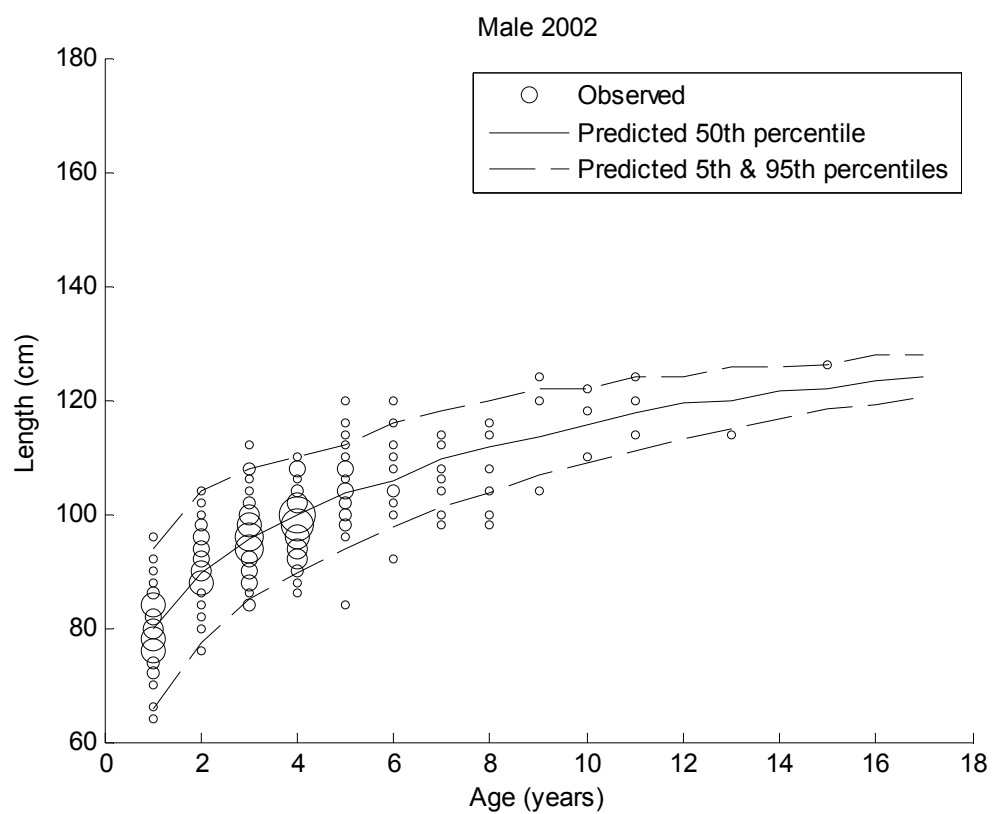


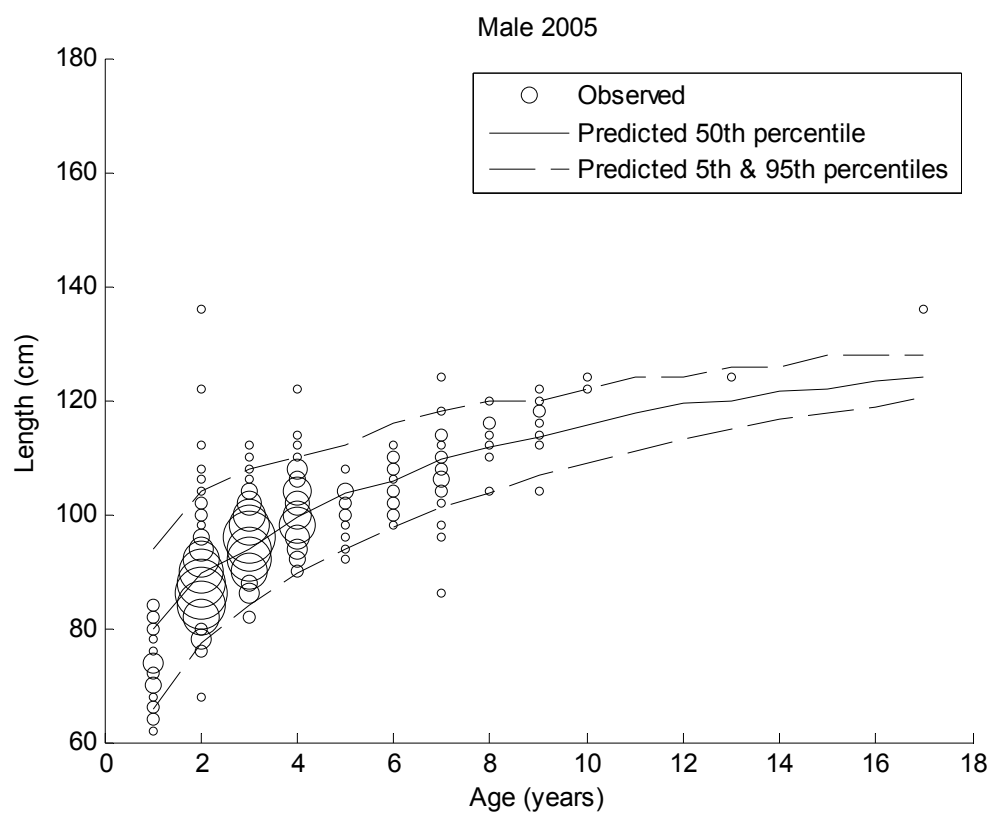
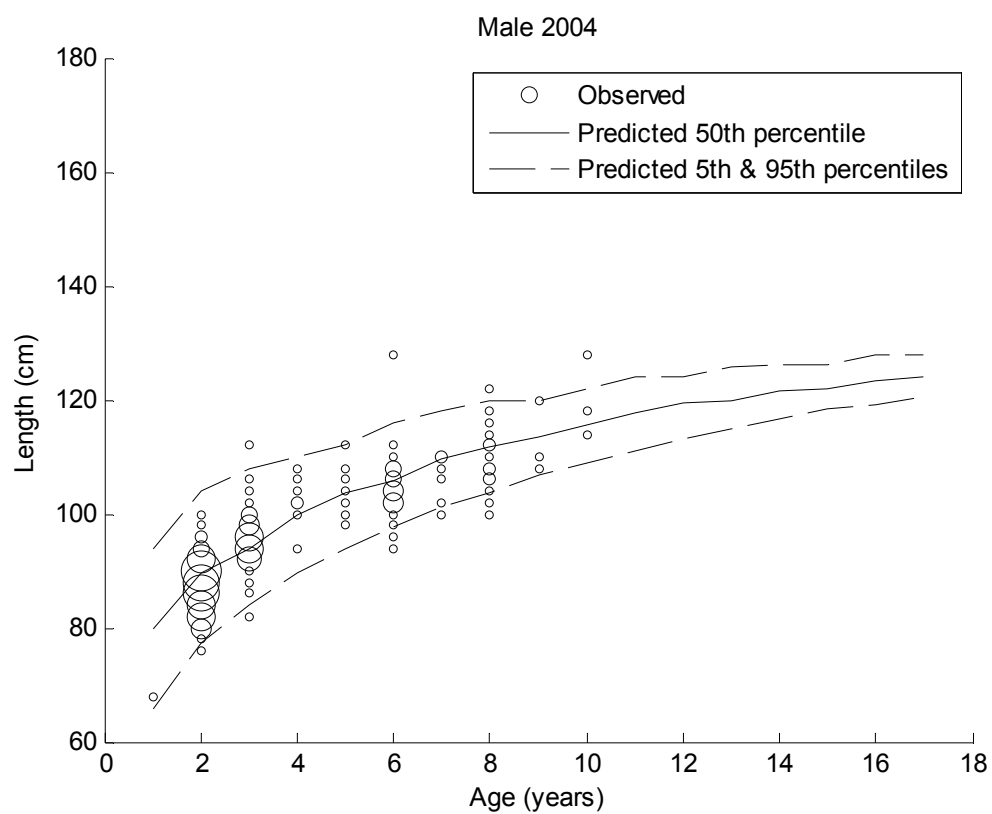


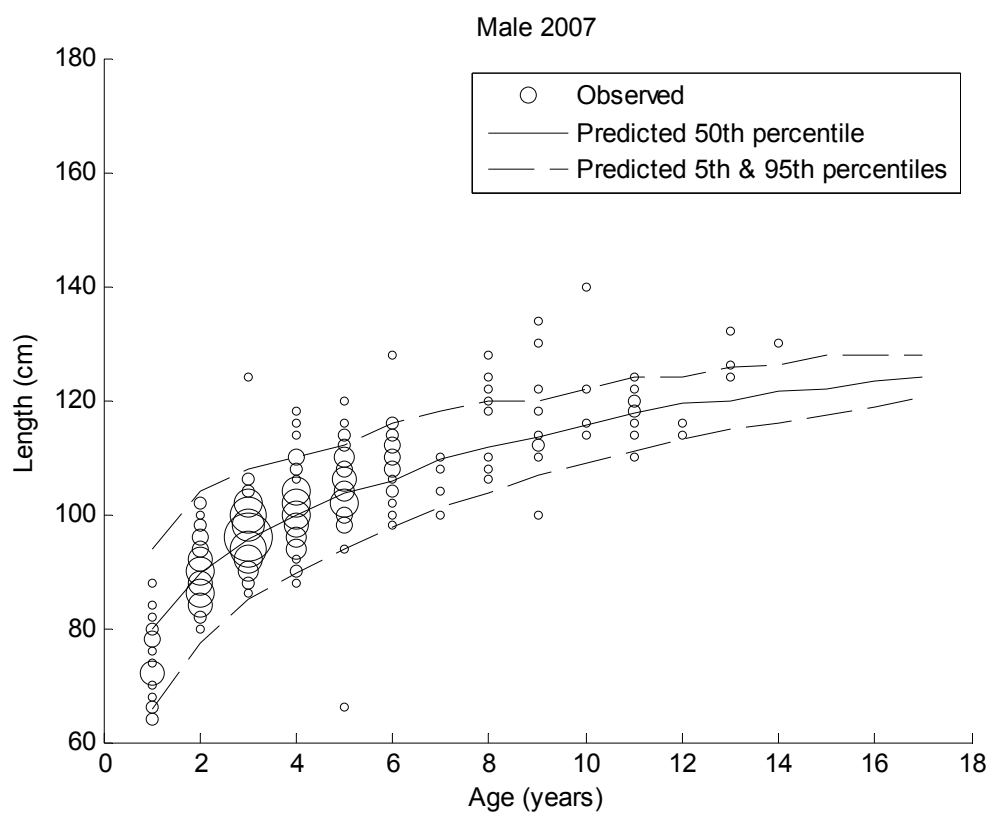
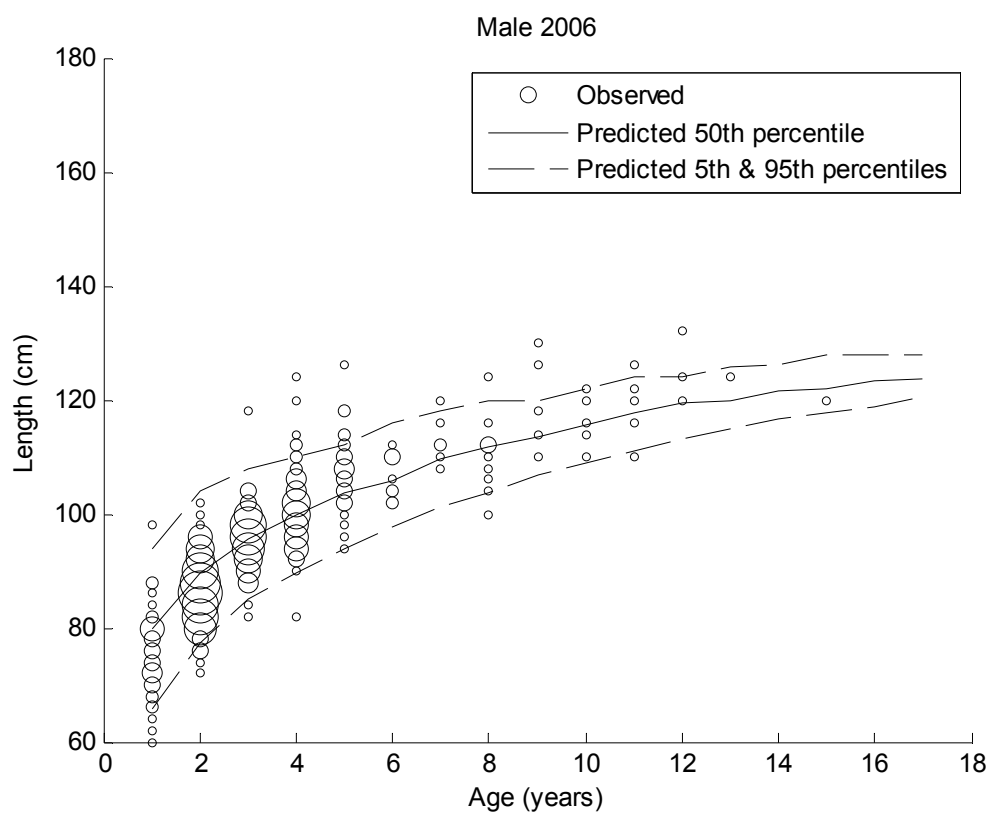


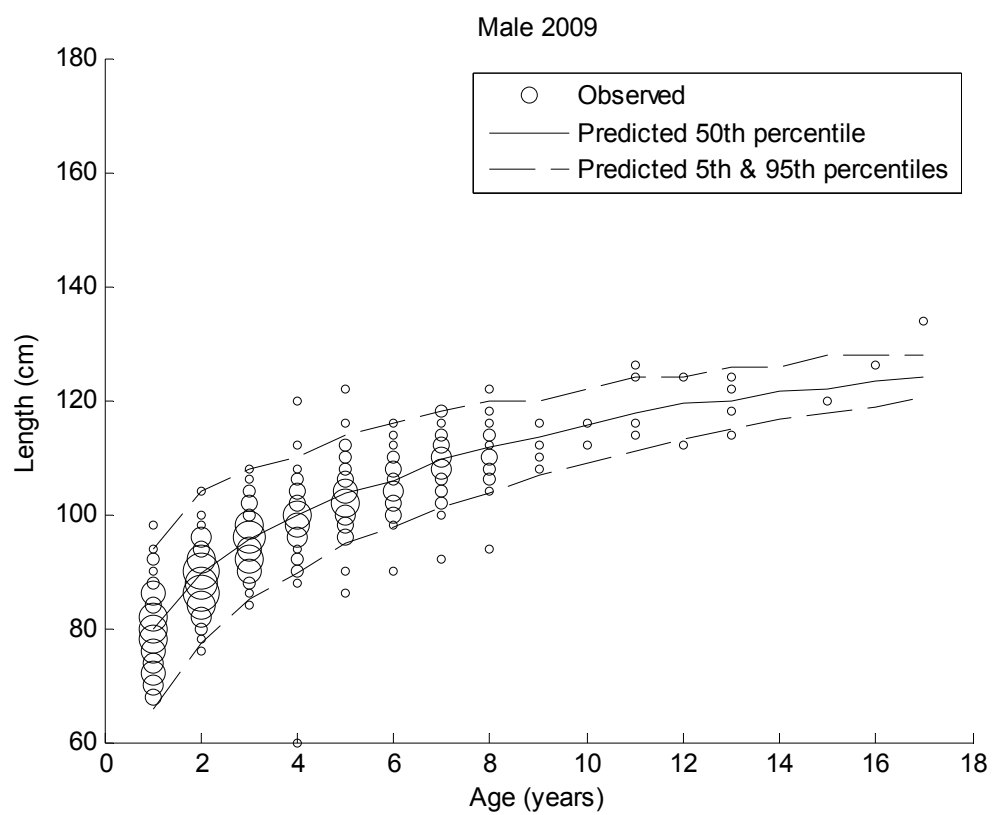
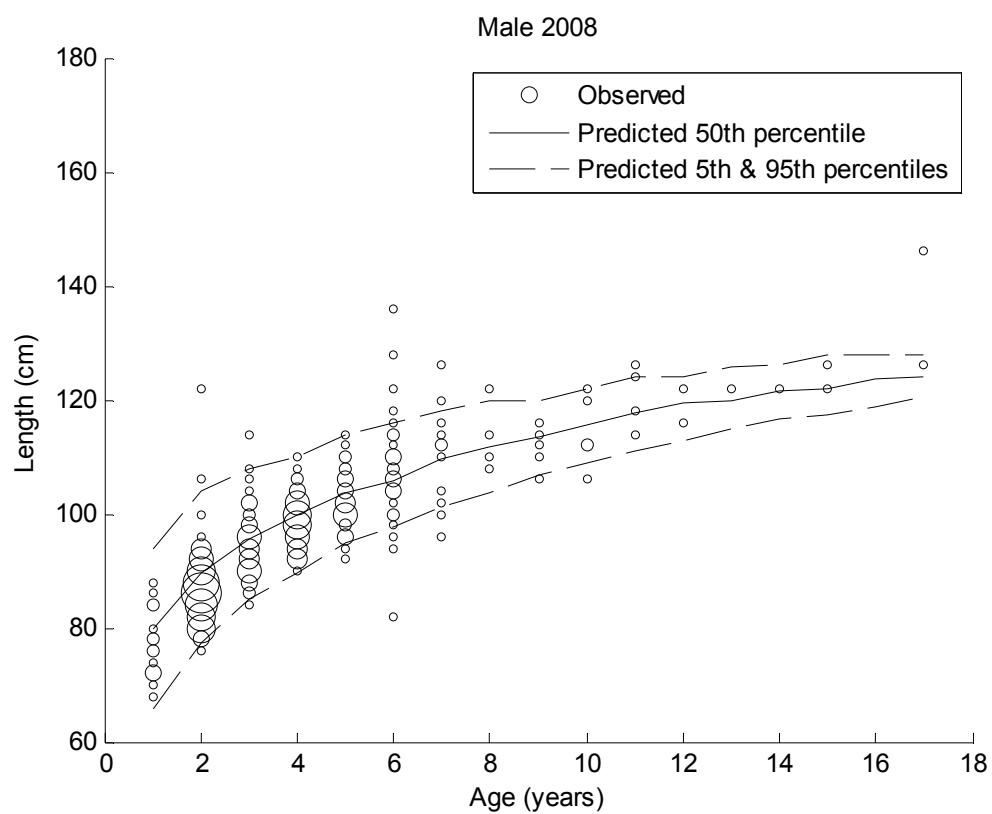








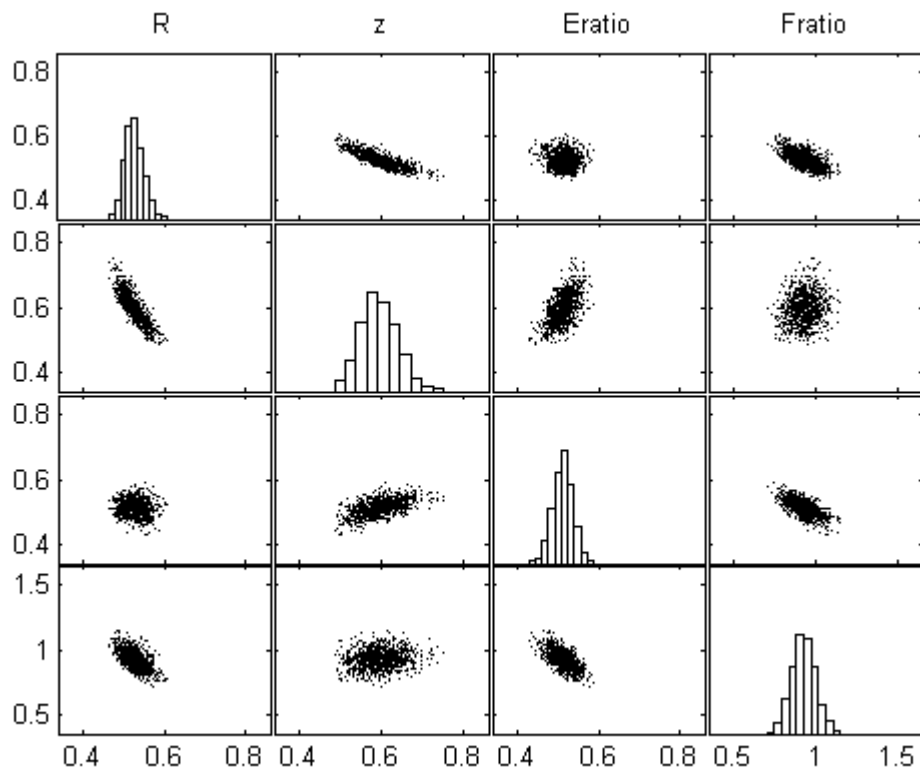




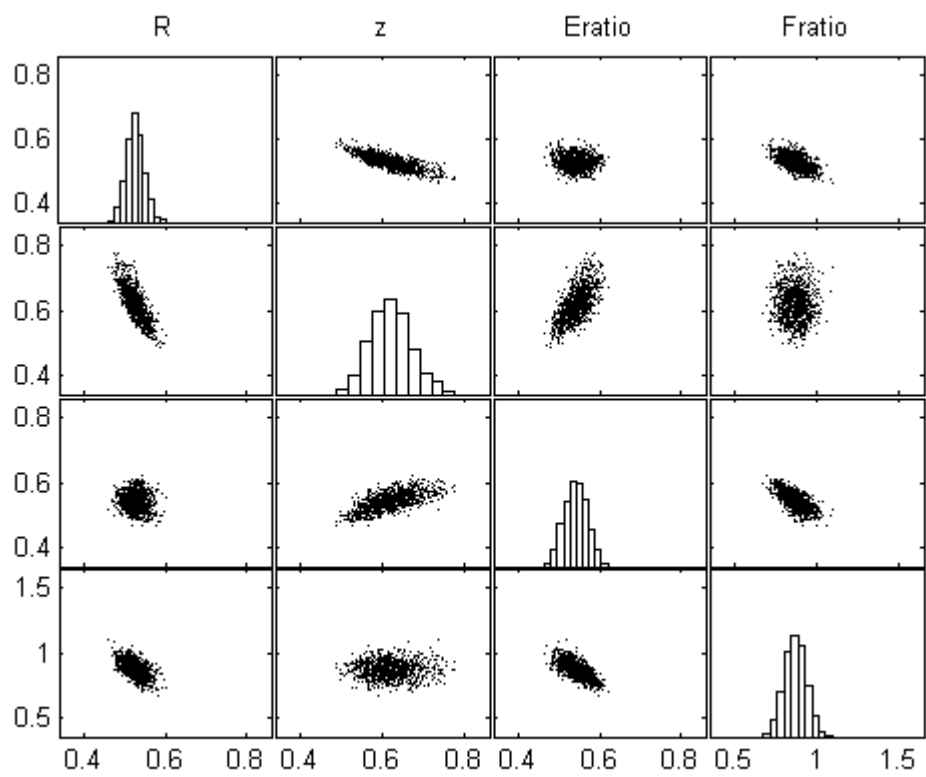
## 11 Appendix C – Posterior distributions of key parameters

In these plots, R (initial recruitment) is x 1e6.

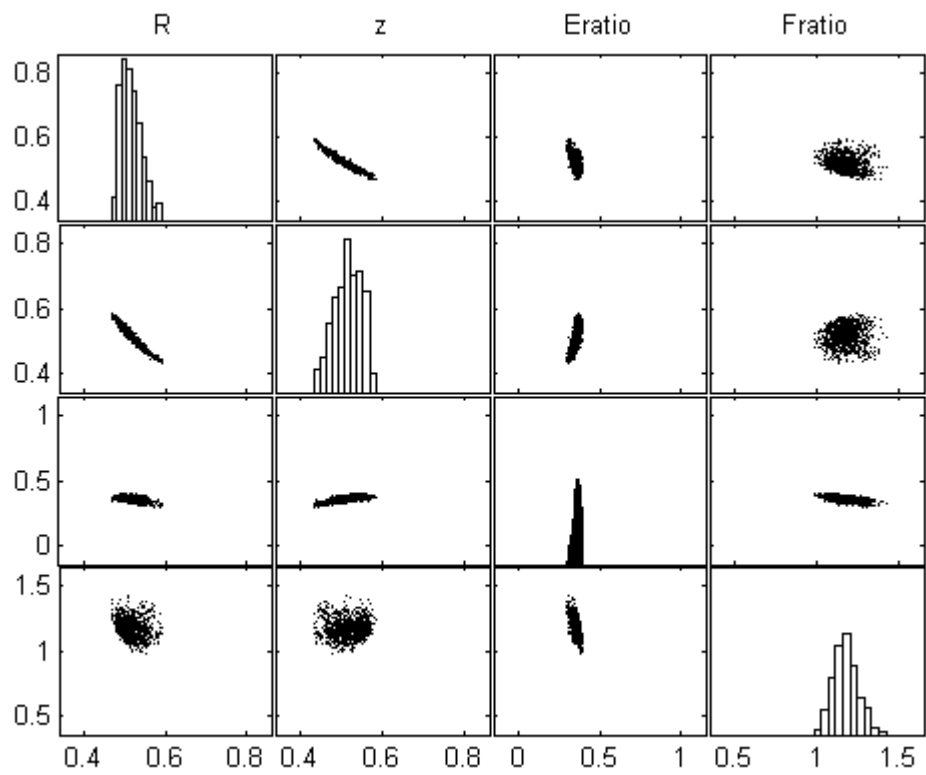
### 11.1 Scenario 24



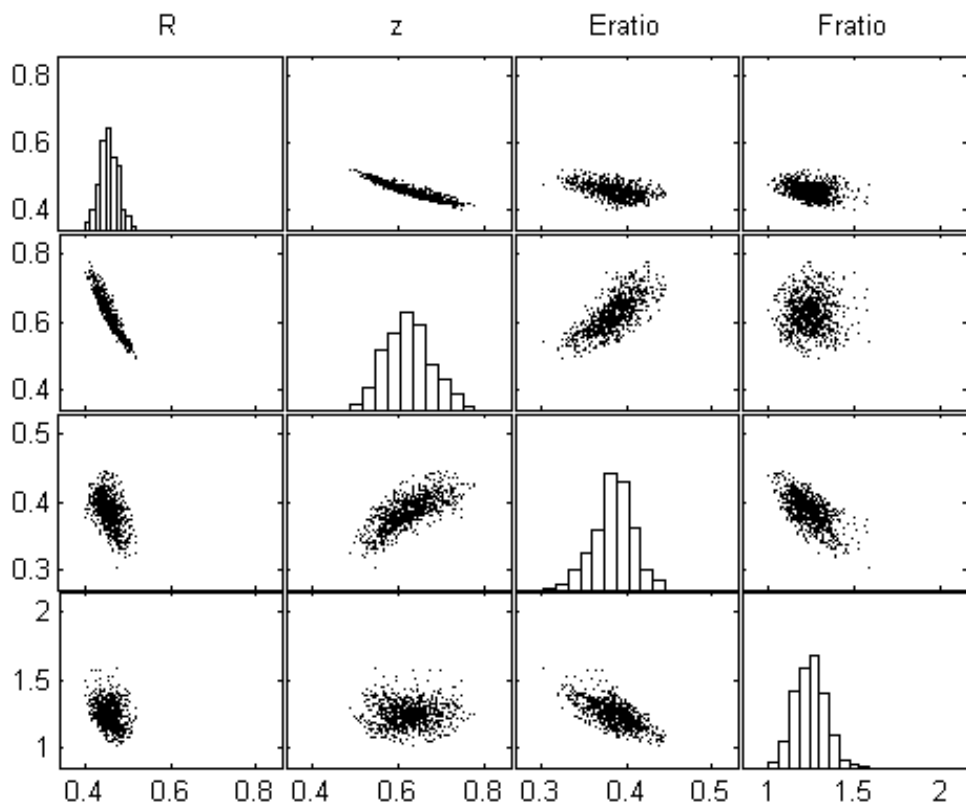
11.2 Scenario 24a



11.3 Scenario 26



11.4 Scenario 26a

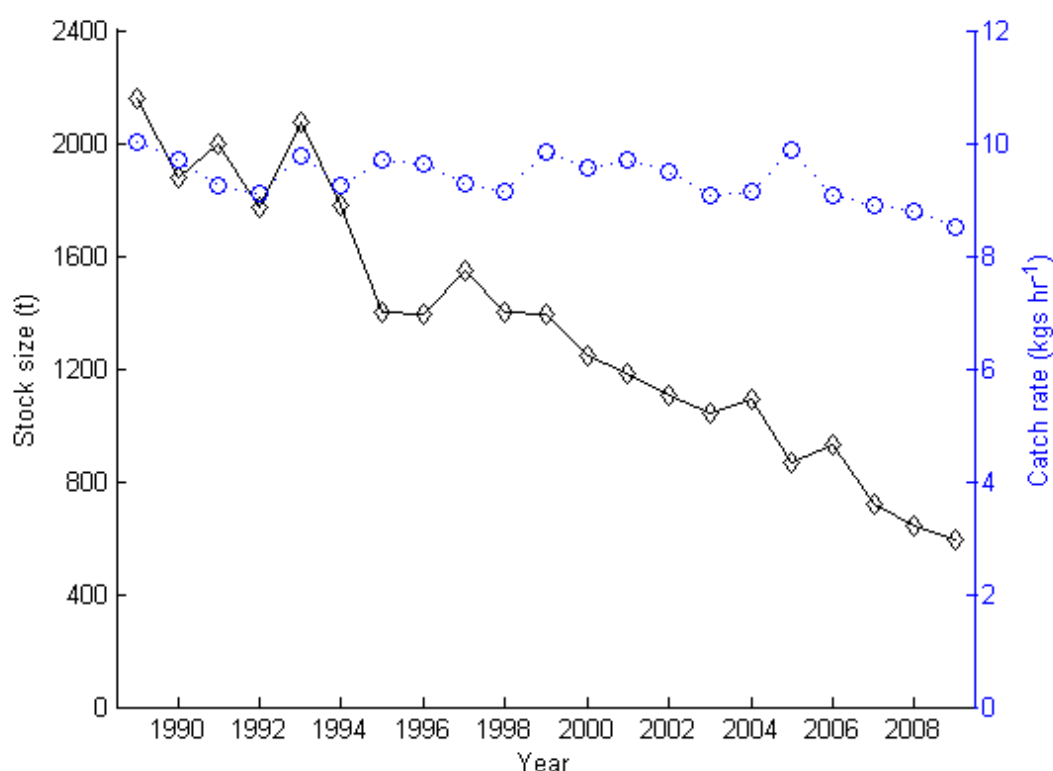


## 12 Appendix D – Hyperstability background and motivation

Two time series of annual catch rates (Figure 9) were considered in the stock assessment as advised by the Fisheries Queensland's REEFMAC SAG. The first series was derived from commercial line fishing on days when Spanish mackerel were caught (catches > 0). The second time series explored overcoming a degree of hyperstability by including all other additional days where no Spanish mackerel were caught (catches ≥ 0). The following paragraphs provide background to 1) what is hyperstability?, and 2) what were the reasons for considering hyperstability and the second catch rate time series?

What are hyperstable catch rates?

In simple terms hyperstability is when catch rates remain high and consistent as fish abundance declines (Hilborn and Walters 1992). Hyperstable catches can paint an optimistic picture of a fishery. On paper operators don't suffer dramatic changes in catches, but hidden in reality stock may have substantially declined (Figure 20).



**Figure 20** Example of a hyperstable relationship between population size (black) and catch rates (blue); as stock size declines catch rates remain steady

Why consider hyperstability?

Hyperstability has been credited as main data bias in many of Queensland's fisheries. Local examples include the target fishing of schooling ocean beach sea mullet and tailor, and historic ring netting of spotted mackerel (Begg, O'Neill *et al.* 2005; Bell, O'Neill *et al.* 2005; Leigh and O'Neill 2004). Internationally, a number of species of pelagic schooling fish have been overfished

with little indication of stock declines provided by fishery catch rates (Begg, O'Neill *et al.* 2005; Hilborn and Walters 1992). Typically the schooling behaviour of fish when catch rates are recorded will remain high and consistent even if fish abundance declines (Figure 20). This type of bias can be expected when fishing effort is focused on areas where schooling fish are abundant. Even if stock has declined, the schooling behaviour of pelagic fish can still result in commercially economic or recreationally quite good catch rates.

To further understand hyperstability the dynamics of schooling fish need to be compared against fisher behaviour and logbook catch reporting. Table 9 outlines the components that may have contributed to hyperstable catches of Spanish mackerel. The most serious concern was the lack of daily effort reporting in commercial logbooks. The base case catch rate standardisation (Figure 9) was quite restricted without appropriate daily effort information. Differences between fishing vessels and areas were modelled. However, resulting catch rates only indexed changing densities of Spanish mackerel schools when fish were found; not the frequency of schools or stock abundance.

In order for catch rates to be a reliable index of abundance, fishing effort should be distributed over a number of areas through time. This aspect was partially true for the commercial data given the wide expanse of mackerel fishing along Australia's East Coast. However, as wryly noted by Hilborn and Walters (1992) p.177, any fisher who regularly fished randomly over many sites would soon be out of business as they wouldn't catch many fish. Most commercial fishers know where fish can be found and that results in non random fishing typically concentrated on locations with higher numbers of fish. This is an accepted feature of fishery dependent data. However, catch rate indices would be far more accurate with daily data on each fishing operation's target species, vessels, gear, travel time, search time and efficiency, locations fished, active fishing time and zero catches (Table 9). Figure 21 illustrates the limitation of current logbook data and importance of recording daily fishing effort. The figure represents the difference between two fishing days by the same vessel. Many variants of this example are possible, which in reality would produce significant variance in daily catch.

Questions were raised by the ReefMAC SAG on whether the Spanish mackerel spawning fishery suffered from hyperstability or had the aggregation moved temporally and/or spatially? Commercial stakeholders had commented that in recent years more search time and area coverage was required to find Spanish mackerel schools in the Lucinda/Townsville region. No clear declines in regional commercial logbook catch rates were evident. This concern, together with the aspects noted in Table 9, was explored in the stock assessment through the second catch rate time series. The series was treated as biomass decline between 2005 and 2009. Together both the first (base case) and second catch rate time series provided important contrast to document hyperstability uncertainty in the stock assessment.

**Table 9** The contribution of different aspects of fisher behaviour, fish biology and commercial logbooks to Spanish mackerel hyperstable catch rates (base catch rate **Figure 9**).

---

**Fisher behaviour:**

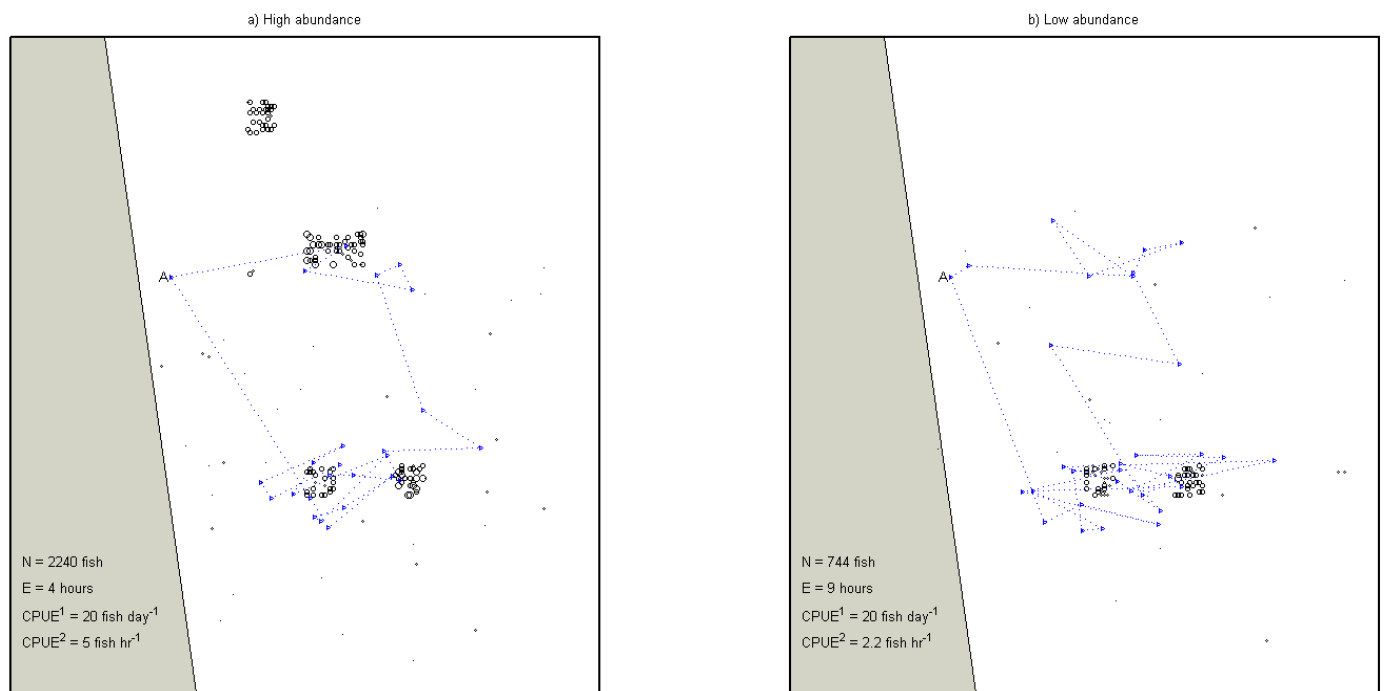
- Efficient at finding fish at local scale.
  - Vessels can travel large distances; at sea and from different ports.
  - Improved knowledge and information sharing that leads to non random spatial fishing.
  - Increased fishing power from using better vessels, gear, techniques and improved knowledge.
  - Aggregation of effort at higher catch times.
- 

**Fish biology:**

- The dynamics of schooling and movement of fish.
  - Type of concentration profile: the density of fish distributed spatially in time (Hilborn and Walters 1992).
- 

**Commercial logbooks:**

- Limited catch validation via linking catch, disposal and quota reporting systems.
  - No data codes to link fishing trips over multiple days.
  - No daily recording of each fishing operation's target species, vessels, gear, travel time, search time and efficiency, locations fished, active fishing time, zero catches and catchability.
  - Determinants of effort by fishers.
  - Determinants of area fished.
-



**Figure 21** Hypothetical comparison of how limited effort data can cloud catch rate (cpue) differences between a) high and b) low abundance. At high abundance the vessel searched and fished over a four hour day yielding 20 mackerel at a rate of 5 per hour. At low abundance the vessel had searched and fished over nine hours to yield the same catch at a rate of 2.2 per hour. The daily catch rate (CPUE<sup>1</sup>), as would be recorded in commercial logbook, indicated no change in abundance (hyperstable). In this hypothetical reality abundance had declined by 2/3 and catch rate per hour (CPUE<sup>2</sup>) declined by 56% (part-hyperstable). Here the drop in abundance and cpue were not 100% proportional as the fishing pattern was non random. Legend: N = exploitable population size, E = fishing effort, CPUE<sup>1</sup> = daily catch rate, CPUE<sup>2</sup> = catch per hour, vessel track = blue lines and symbols, fish = black circles and A = start of fishing track which progressed east and then south, before returning to A.

## 13 Appendix E – Fisheries Queensland Spanish mackerel monitoring program

Fisheries Queensland collects biological data annually from catches of Spanish mackerel along the East Coast of Queensland, between Cairns and the Queensland-New South Wales border. For reporting results, data are aggregated into four regions on the East Coast of Queensland (Townsville, Mackay, Rockhampton and South East Queensland; Figure 8).

Sampling occurs all year round, with most samples being collected during peak fishing periods in each region as these correspond to times of high abundance of this species. Samples are then assumed to be representative of what the fishery is catching within each season.

Prior to 2004, the monitoring of Spanish mackerel focused sampling on the major fishing grounds located between Cairns and Townsville (around Lucinda), and sampled primarily from the commercial sector during the peak season in October to December. In response to recommendations from a stock assessment (Welch, Hoyle *et al.* 2002) and various other recommendations (Hoyle 2002; Sumpton and O'Neill 2004; Tobin and Mapleston 2004), the Spanish mackerel monitoring program was expanded in 2004 to collect information that was more representative of the entire fishery.

From 2004, the monitoring of Spanish mackerel was expanded to include the recreational sector and a wider coverage of the East Coast of Queensland (Rose, Bailey *et al.* 2006) to include all coastal waters south of Cairns. The timing of sampling for each region was staggered throughout the year, so that numbers within each season were still representative of the numbers caught by the fishery. The program also increased the number of participating fishers in each sector to ensure that the samples were more representative across fishery participants and not just from a small number of operators.

Sampling effort is spatially-stratified where target numbers of commercial catches of Spanish mackerel to sample (measure) are set at the start of each sampling year. The total target number of fish to measure for the sampling season is stratified between regions based on historic logbook data. Target numbers for sampling each year originally set a number of fish lengths to measure (e.g. 2400 lengths) for the recreational and commercial sectors combined. In (approximately) 2007, this changed to setting annual targets of a number of catches to measure (e.g. 240 catches) for each sector separately. Currently, a target number of lengths to measure is also calculated and used as a guide, however more emphasis has been placed on measuring fish from the target number of catches so that fish measured are spread across a large number of catches, rather than a large number of fish measured from only a small number of catches. These targets are used as a guide (rather than a rule) for sampling, allowing for flexibility to adapt sampling when patterns in the catch are vastly different to the averaged historical catches.

From 2007, sampling effort for the recreational sector has targeted the same number of recreational catches to sample and fish to measure each season for all regions (e.g. 60 catches, 120 fish per region). This is mainly due to a lack of suitable historical data on which to base a regional stratification of sampling effort.

Each year, whole otoliths, used to estimate age (DPI&F 2008b; Fisheries Queensland 2009), have been collected from a subset of the total number of fish sampled. Only representative unbiased (and complete) catches are measured to collect length information; however biased catches (for example where larger or smaller fish may have been removed) may still be used for otolith collection. Otolith collection is stratified by 10 mm length classes. A maximum of 20 fish are collected in each length class from the North East Coast (Townsville and Mackay regions) and

from the South East Coast (Rockhampton and South East Queensland regions). During 2005-2007, collection of otoliths was length- and sex-stratified, where a cap of 10 otoliths for each sex and each length class was used. From 2007-08 otoliths have been collected randomly for sex and age, and therefore the sex and age structure of the otolith samples within the length class should be representative of what the fishery is catching.

Fisheries Queensland's monitoring of Spanish mackerel is described in more detail in (DPI&F 2005; DPI&F 2006; Fisheries Queensland 2009)

## **14 Appendix F – Preliminary stock assessment presentation**



## Stock Assessment of the East Coast Spanish Mackerel Fishery, Australia

Stock assessment preliminary results for review, 22<sup>nd</sup> April 2010

Alex Campbell and Michael O'Neill



### Summary

- **Aim:** to present the status of the east coast Spanish mackerel fishery and discuss model sensitivities.
- **Data:** CPUE and harvest @ age.
- **Result:** Exploitable biomass in 2009 was estimated between 30-60% of virgin; full range of uncertainty 25-80%.
- **Discussion points:**
  - Large uncertainty in recreational catch, but not high sensitivity.
  - High sensitivity to  $r_{\max}$  parameter.

## Harvest and monitoring data

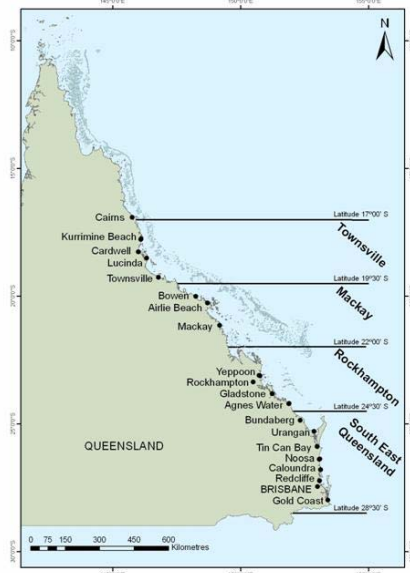
- Commercial
- Charter
- Recreational

QEC = Queensland east coast

NSW = New South Wales

t = tonnes

Fishing year = July – June; e.g. Sept 2008  
= 2009



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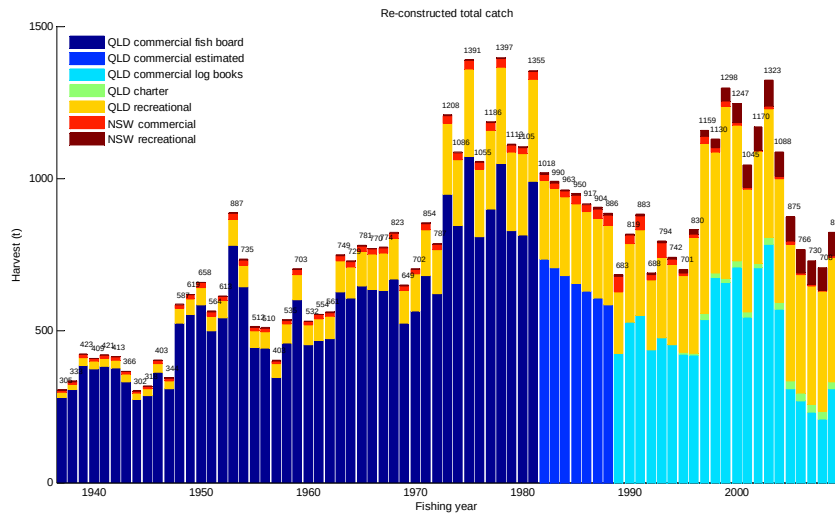
## Recreational catch (t; kept + released)

| Fishing year | Source                     | QEC (t) | NSW (t) |
|--------------|----------------------------|---------|---------|
| 1993         | Steffe, A. S. et al (1996) |         | 5       |
| 1994         | Steffe, A. S. et al (1996) |         | 7       |
| 1995         | Cameron and Begg (2002)    | 75      |         |
| 1997         | RFISH                      | 560     |         |
| 1999         | RFISH                      | 565     |         |
| 2001         | NFISH                      | 403     | 75      |
| 2002         | RFISH                      | 368     |         |
| 2005         | RFISH                      | 448     |         |

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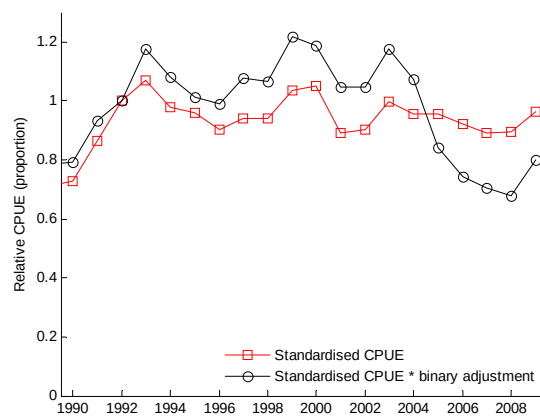
4

## Reconstructed catch history



5

## QLD commercial catch rates



REML:  $\log(wt) = \{ \text{fishyear} * \text{region} * \text{month} + \text{lunar} + \text{lunar\_adv}; \text{fixed effects} \} + [\text{boat}; \text{random effect}]$

Binary adjustment:  $\text{region} * \text{fishyear} + \text{region} * \text{month} + \text{region.lunar} + \text{region.lunar\_adv} + \text{region.pol}(\text{window}; 2) + \text{region.pol}(\text{windns}; 2)$

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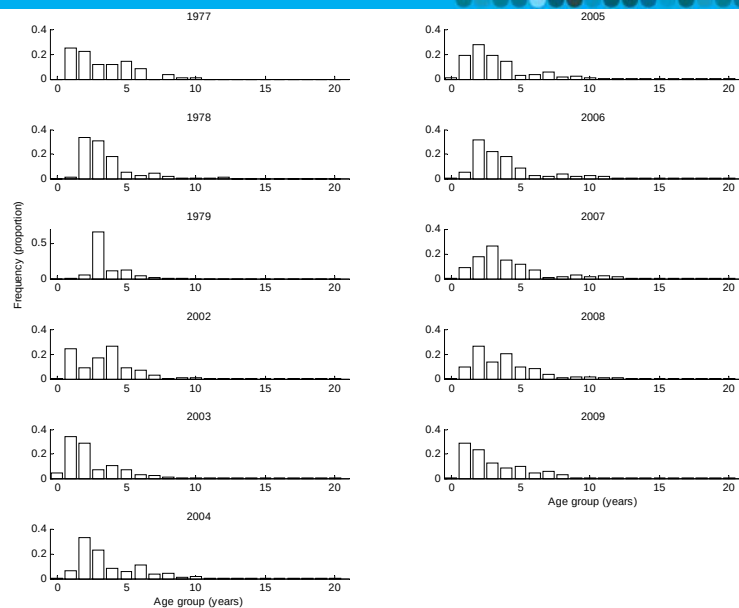
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## Age structures

- 1977-79, by McPherson, from the Tsv commercial sector.
- 2002-2003, by CRC and LTMP, from all regions and sectors.
- 2004, by LTMP, from the Tsv commercial sector.
- 2005 to 2009, by LTMP, from all regions and sectors.

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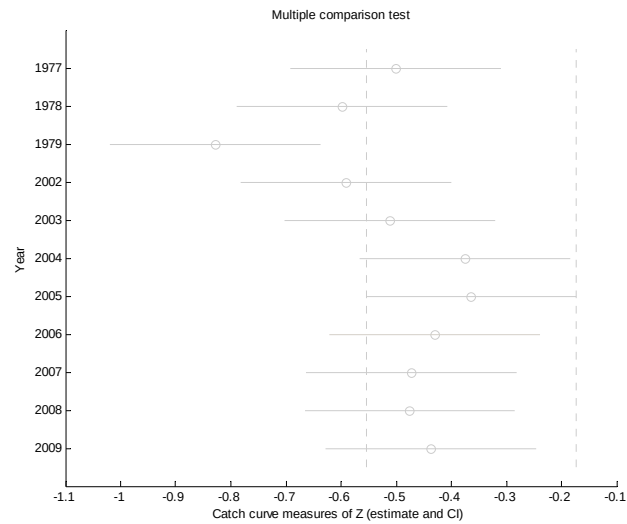
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## Catch curve measures of total mortality (Z)



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## Biology

| Parameter                                         | Estimate                                                                                                                                                                                   |
|---------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| M (instantaneous annual natural mortality)        | 0.34 (previous assessment)<br>0.3217 (F) & 0.3445 (M); Pauly schooling equation (1983)<br>0.26; Hoenig's 1983 equation, Maximum age = 17<br>0.32; Hoenig's 1983 equation, Maximum age = 14 |
| Age and length at maturity                        | 2+ years; 88cm TL                                                                                                                                                                          |
| Age at full recruitment to fishery                | 2+ years                                                                                                                                                                                   |
| Fecundity                                         | 76539 eggs/kg                                                                                                                                                                              |
| $r_{max}$ (max reproductive rate at low pop size) | 4.5 or weak prior ( $\sim U(.5, 10)$ ) or strong prior ( $h \sim N(.52, .24)$ )                                                                                                            |

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## Model runs

| Analysis | Model Type | Natural mortality | $r_{\max}$             | Tuning data | Harvest series | Recruitment variation $\sigma_r$ |
|----------|------------|-------------------|------------------------|-------------|----------------|----------------------------------|
| 1        | Age-Sex    | Pauly             | U(.5,10)               | Age 1       | Base           | 0                                |
| 2        | Age-Sex    | Hoenig            | U(.5,10)               | Age 1       | Base           | 0                                |
| 3        | Age-Sex    | Pauly             | U(.5,10)               | Age 2       | Base           | 0                                |
| 4        | Age-Sex    | Pauly             | U(.5,10)               | CPUE 1      | Base           | 0                                |
| 5        | Age-Sex    | Pauly             | U(.5,10)               | CPUE 2      | Base           | 0                                |
| 6        | Age-Sex    | Pauly             | $h \sim N(.52, .24)$   | Age 1       | Base           | 0.2                              |
| 7        | Age-Sex    | Pauly             | $h \sim N(.52, .24)$   | Age 1       | Base           | 0.4                              |
| 8        | Age-Sex    | Pauly             | $h \sim N(.52, .24)^*$ | Age 1       | Base           | 0.4                              |
| 9        | Age-Sex    | Pauly             | $h \sim N(.52, .24)^*$ | Age 1       | 75% Base       | 0.4                              |
| 10       | Age-Sex    | Pauly             | $h \sim N(.52, .24)^*$ | Age 1       | 125% Base      | 0.4                              |

Age 1: 2002-2009

Age 2: 1977,1978,2002-2009

CPUE 1: standardised CPUE

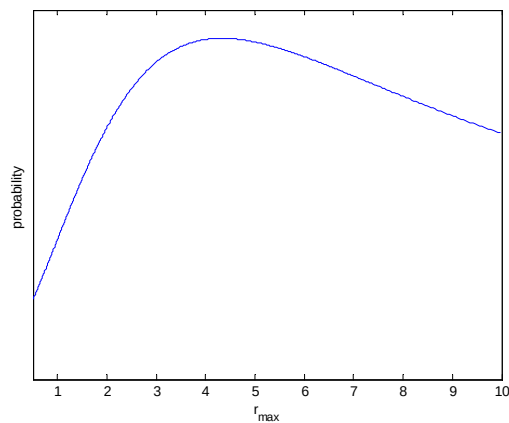
CPUE 2: standardised CPUE \* binary adjustment

\* Weighted strongly to force posterior

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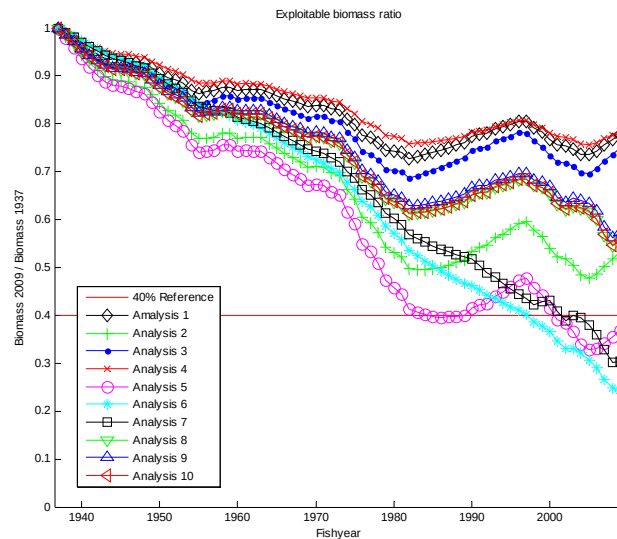
## $r_{\max}$ prior



$4 \cdot h / (1 - h)$ ,  $h \sim N(.52, .24)$  based on Scombridae family (Myers et al. 1999)

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## Outputs – 50<sup>th</sup> (5<sup>th</sup>; 95<sup>th</sup>) percentiles

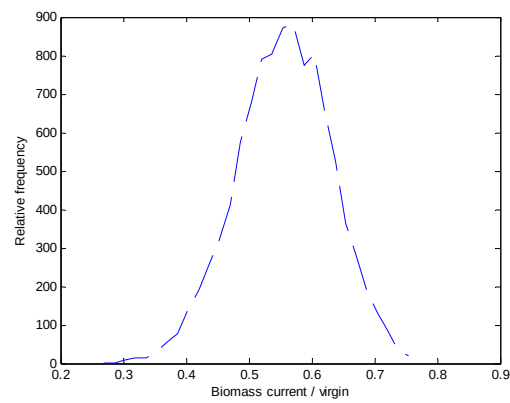
|    | R0                   | L50                     | Lsteep               | r <sub>max</sub>     | Bratio               | MSY                  |
|----|----------------------|-------------------------|----------------------|----------------------|----------------------|----------------------|
| 1  | 0.892 (0.654; 1.32)  | 80.43 (79.196; 84.126)  | 0.274 (0.116; 0.785) | 5.483 (1.679; 9.545) | 0.753 (0.48; 0.85)   | 1668.5 (862.1; 2742) |
| 2  | 0.441 (0.392; 0.551) | 80.303 (79.015; 83.514) | 0.255 (0.11; 0.743)  | 5.861 (2.628; 9.519) | 0.524 (0.349; 0.606) | 1047.2 (825.1; 1217) |
| 3  | 0.744 (0.595; 0.96)  | 81.18 (79.766; 84.383)  | 0.264 (0.133; 0.73)  | 7.445 (3.645; 9.752) | 0.74 (0.64; 0.812)   | 1913.6 (1518; 2413)  |
| 4  | 1.221 (1.197)*ns     | 75 (1.079)*ns           | 0.1 (0.440)*ns       | 2.931 (1.5529)*ns    | 0.784                | 1717.5               |
| 5  | 0.509 (3.906)*       | 75 (11.033)*            | 0.104 (-.496)*ns     | 4.28 (1.8993)*ns     | 0.369                | 920.68               |
| 6  | 1.3 (0.989; 1.799)   | 79.566 (78.065; 82.308) | 0.286 (0.103; 0.768) | 1.33 (1.037; 1.682)  | 0.258 (0.055; 0.481) | 693.52 (89.95; 2167) |
| 7  | 1.151 (0.925; 1.695) | 79.378 (77.836; 81.115) | 0.367 (0.127; 0.83)  | 1.552 (1.16; 1.736)  | 0.332 (0.079; 0.499) | 816.35 (25.90; 4084) |
| 8  | 0.72 (0.594; 0.905)  | 80.634 (79.143; 86.232) | 0.204 (0.086; 0.703) | 3.915 (3.345; 4.614) | 0.557 (0.425; 0.676) | 1189.3 (460.9; 2097) |
| 9  | 0.558 (0.455; 0.748) | 80.33 (78.978; 84.934)  | 0.239 (0.095; 0.778) | 3.913 (3.343; 4.601) | 0.575 (0.438; 0.705) | 963.72 (361.5; 1689) |
| 10 | 0.903 (0.745; 1.137) | 80.618 (79.126; 86.056) | 0.208 (0.087; 0.703) | 3.913 (3.346; 4.604) | 0.559 (0.425; 0.677) | 1545 (599.6; 2659)   |

\* Indicates estimate divided by estimated standard error (from hessian), ns indicates non-significant

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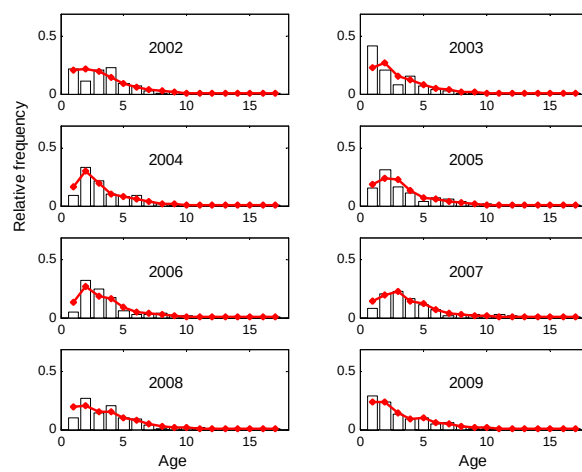
## Analysis 8 – posterior biomass ratio



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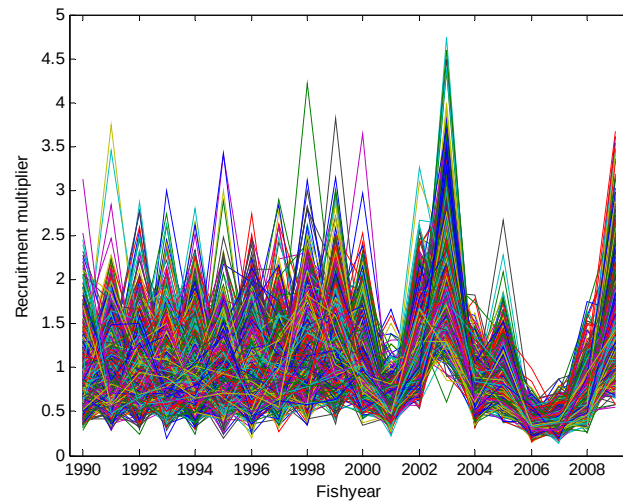
## Analysis 8 - goodness of fit



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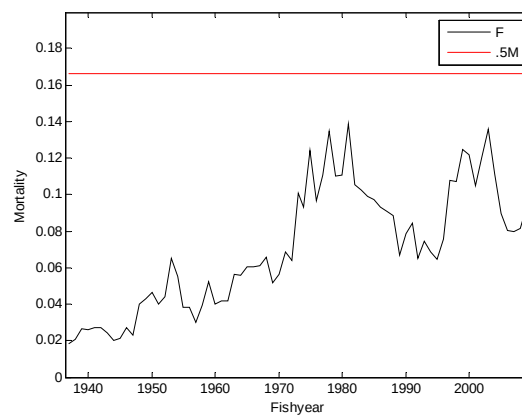
## Analysis 8 – recruitment deviations



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## Analysis 8 - mortality



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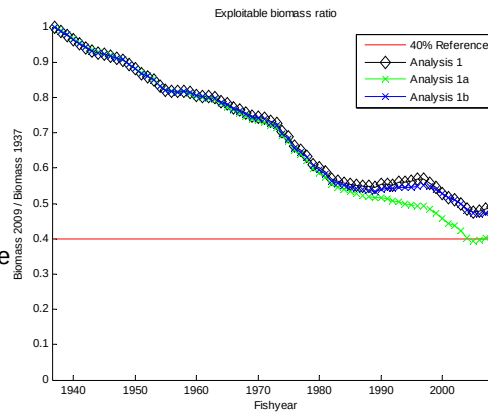
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## Recreational catch reconstruction sensitivity

- Variations in rec catch recon..
- Basic approach:

$$C_y = \text{effortproxy}_y * \text{cpue}_y$$

- Effort proxy is:
  - 1 - fixed avg effort based on known catch years & cpues
  - 1a - as above, adjusted cpue
  - 1b - vessel registrations



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## Conclusion / Discussion

- Large uncertainty regarding productivity,  $r_{max}$ 
  - If force to follow meta-analysis distribution, similar results to 2008 assessment
- Model not particularly sensitive to details of rec catch reconstruction
  - Next year rec survey will help
- How to get more information into models to pin down key parameters ( $r_{max}$  and natural mortality)?
  - Spatial?
  - Genetics?
  - Spawning aggregations?

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## **15 Appendix G – Minutes of Spanish mackerel meeting 22/04/2010**

**EAST COAST SPANISH MACKEREL FISHERY  
STOCK ASSESSMENT MEETING**

**Date: 22 April 2010  
Time: 10.30 am – 2:30pm**

**Level 5 PIB Building, 80 Ann St  
Brisbane**

**Meeting Minutes**

**1. Introductions**

**2. Stock assessment overview/results**

- Last model used was SALSA, incl. length. This new model does not include length, age & sex only.
- Overall results similar 30-60%, even more uncertainty in this assessment.
- Catch rates trending up in 2009 – weather was good, fishing was better
- Peaks in graph appear to indicate good pulses of recruitment
- Total mortality graph indicates increasing trend in better Z
- Use constant natural mortality in fish
- Small errors in accuracy in otolith reading no issues as model accounts for this
- Bias' in reading that change with age would be concerning in model
- Is catchability between ages equal? It is affected by catch of fish at diff ages – factor of size. We model how catchable fish are at each age, but we don't allow this to change systematically with time = av. Selectivity
- Recruitment = no. of 1 yr olds the next year.
- How long ago was fecundity est. calculated?
- Aim of model is to test diff assumptions
- Model runs 6-10 more realistic
- Exploitable biomass ratio graph in relation to virgin biomass – note that model runs most likely that inc recruit variation and have constraint on rmax parameter – middle of road
- 8,9,10 most likely. 8 is best base case run. 9, 10 test sensitivity to variation in catch history
- 9 = ttl catch history is only 3 quarters of base case
- B ratio = ttl exploitable biomass
- MSY not best place to set TAC at = no buffer against uncertainty nor best economic benefit
- MSY ranges are large = uncertain
- MSY is sensitive to ttl catch history
- Age data provides better contrast for model compared with CPUE = potentially hyperstable

- Andrew – there are better ways to estimate std catch rates = could result in better estimates in model for CPUE in the future
- Spikes in recruit deviation correspond with CPUE ests. Is rainfall, water temp etc. indicate better conditions for recruitment.
- Spawning temp ~26 degrees – Geoff Macpherson
- Lucinda is main spawning area, but there are other areas down coast – commercial. Recreational catch predominantly in SEQ.
- Rec catch reconstructed sensitivity
- More data collection proposed to reduce uncertainty
- Spatial, genetics, spawning aggs data to provide more information to pin down key parameters (rmax and nat. mortality).
- Note Bonnie – north/south rec catch issues with size estimates vs weight etc. potential for better ests. In ASR – or potential for development for PMS?

### *Lunch*

How to get more information for SA models?

- Looking at genetic variation in stock is indicator of how big stock was/is. Would help reduce uncertainty in rmax parameter. Could use this as another data source.
- Otoliths still available from Geoff's old collection available?
- Other sources of historical information – e.g. literature, old newspapers, fishing club records. Potential to incorp using a specified method into new SA.
- Haven't looked at other possible data sets for basic biology parameters e.g. eggs/kg, that go into the assessment.
- Reef fish assessment = more eggs produced from larger animals – Andrew T
- In this model no. of eggs not impt, rather no. that survives to recruitment.
- Spawning aggs – disruptions?
- Andrew T – new FRDC project. Are aggregations in green zones bigger? Uncertainty in the status of protection afforded. How SM distribute them selves over the green zones. Deploying listening stations in green and non green zones. 50 fish/year tagged and will ping each time they go past stations = amount of times in each of the diff. zones. Will provide info to feed into any future issues with sustainability for SM, will actually have movement data. Reduces some uncertainty with SA too.
- Data collection for the future – phone applications, automated/electronic catch reporting
- Check – NSW catch. Sydney fish markets - reported increase in SM.