

Introduction

Early work on age length keys (ALKs) for the 2022 bluefish research track assessment began with data that had been compiled and used in conjunction with the 2015 bluefish assessment. Concurrent with this work, the bluefish working group (WG) worked with east coast states and agencies to re-request all biological data (ages, maturity, fork and total lengths, sampling information, etc) for as many years as were available.

Multinomial ALKs

Very early in the 2022 assessment process, WG members discussed exploration of multinomial ALKs, especially in light of how much interpolation and extrapolation might be required to develop traditional ALKs at a regional-seasonal level. Early in the bluefish data time series, age data can be sparse (Tables 1-2), particularly, at the season-region level. The model-based multinomial approach was viewed as an objective, repeatable, and efficient way to develop ALKs. The multinomial approach to developing age-length keys (Gerritsen et al. 2006) is used across a number of stocks assessed by ASMFC and NOAA Fisheries, and available in modelling software [e.g., weakfish (ASMFC 2019), Stock Synthesis (Methot and Wetzel 2013)]. Given this exploration, the WG also wanted to explore a comparison of traditional, season-only ALKs vs multinomial, season-only ALKs.

The 2015 WG expended a lot of effort to find new sources of age data and validate data (WG2015, 2015). A short time after the assessment, some additional adjustments were deemed necessary (Celestino 2016).

As noted above, early exploration of ALKs was conducted on the legacy data set (i.e., data used for the 2015 assessment, with subsequent annual additions). For development of multinomial ALKs, a variety of modelling approaches and data borrowing strategies were considered. For example, we compared deriving ALKs from various levels of data aggregation (e.g., either a subset of year-season-specific data, or year-season-region-specific data) in multiple multinomial models, versus including data for all years, seasons, and regions in a single model from which predictions were subsequently made. In terms of data borrowing requirements, for the single model approach, there must be at least one fish in every age class (0-6+) in each year (regardless of season or region), whereas for the alternative approach, at least one fish must be present in every age class (for each season and region). Where borrowing was necessary to meet these minimum requirements, the WG explored borrowing fish from both adjacent years (the year before and after the year in question) and from just the adjacent year with the most fish; the reasoning behind the latter approach was that it would allow us to capture the most fish using the least amount of borrowing. The WG discussed, but did not pursue, borrowing from regions within the same year because our hypothesis is that there are differences in size at age by region and season (Figure 1). In the end, the WG decided to use the borrowing approach that used both adjacent years, reasoning that it allows us to average across uncertainty. The potential consequence of borrowing across years is the depression of the individual year class signals, but the working group believed it more important to preserve regional growth patterns.

To facilitate converting bluefish catch and survey length composition data to age compositions, the WG designed all ALKs to extend from 1-100 cm. The model-based (multinomial) approach interpolated all lengths between the maximum and minimum in the entire dataset, requiring us to add one fish at 1cm to either age 1 (in spring), or age 0 (in fall), and at 100 cm to age 6.

We ultimately explored 3 model-based approaches:

- A. Make predictions from a single model in which we pooled all years, both seasons, and both regions: $Age \sim FL + Year + Season + Region$, $data = all\ age\ data$
- B. Make predictions from a single model in which we pooled all years and both regions, but ran separate multinomial models for each season (this helped the model predict that there should be few, if any, spring age 0 fish in the ALK, consistent with the biology of bluefish): $Age \sim FL + Year + Season + Region$, $data = all\ spring\ age\ data$; $Age \sim FL + Year + Season + Region$, $data = all\ fall\ age\ data$
- C. Make predictions from year-season-region-specific multinomials: $Age \sim FL$, $data = e.g., all\ spring\ age\ data\ in\ southern\ region, in\ 1985$

In general, when comparing the performance of the three approaches (methods A, B, C) in years, seasons, regions where data are sparse, performance (as defined by fit to observed data) appeared notably different among the methods, with Method A performing worst, Method C performing best, and Method B intermediate. In years, seasons, and regions where data were abundant, performance was very similar among all of the methods (excepting spring age 0s and 1s, where Method C performed best). Example performance of the three approaches is provided in Figure 2. The WG initially reasoned that poor fits to the data observed in Methods A and B were akin to fitting to an average condition (generalized over year classes), and so tended to support Method C.

With respect to performance of fitting spring age 0 fish, the WG noted that most of these fish tend to be collected in late June. The WG considered re-defining 'spring' to accommodate this, but quickly realized that one large obstacle to doing this is the availability of recreational catch data which is reported in 2-month waves. The WG was concerned that these few aberrant fish would affect the ageing of all spring collected fish. So, for biological reasons, data reasons (MRIP wave 3), timing reasons (largely, but not exclusively, collected in late June), their low number, and concerns related to age validation (are the fish true age 0s), the WG simply removed spring age 0 fish from the data prior to fitting multinomial ALKs (as was done in 2015). Spring age 0 fish were retained in an alternate set of traditional ALKs (discussed below).

The WG also considered a hybrid approach where we would use different methods in data-poor years than in data-rich years, but the WG was concerned with subjectivity associated with determining and defining a data-poor year.

In order to keep the ASAP modelling runs nested, the WG endeavored to nest the ALKs as well. To achieve this, the same data are used for season-only and season-region ALKs.

As noted above, initial analyses were conducted on legacy data. The WG discussed which source of data should be used for the final ALKs. On the one hand, the legacy data set had been vetted, audited and carefully curated over time, and used in the 2015 benchmark assessment. On the other hand, over time, ancillary data (e.g., maturity, FL/TL, etc) had become disassociated with the age data, limiting its utility

to just ALKs (and not biological analyses). After successive refinement of the 2021 data call, sample sizes by dataset (legacy vs new) became increasingly comparable (Tables 1-4), as were the distribution of size at age by region and season (Truesdell et al. 2022). Given the comparable sample sizes, and the ability to maintain all associated biological data with the age data, the WG agreed to use the newly collected data for ALKs.¹

Nevertheless, the legacy data were used to inform screening of the new data collection:

- there were a few age-season-region combinations in which the 2021 collected dataset had zero fish while the legacy dataset had > 0 fish – in those cases, legacy data were merged with the new data set.
- the legacy dataset was used to screen for outliers in the new dataset (i.e., within an age, season, and region, samples were removed if their fork length was outside of the bounds observed in the legacy dataset).
- spring North Carolina (NC) ages between 1985-20000 in the new dataset were ‘bumped’ based on the legacy upper confidence limit of all reliable data (WG2015, 2015).

The WG observed bimodality in size and weight at age for ages 3-4 (this was observed in both the legacy and new database). Between approximately 2006 and 2012, NC bluefish collected during the first quarter of the year were larger than fish collected later in the year. The ASMFC’s NC Technical Committee member indicated the difference was related to whether the fish was captured in the ocean or the bay, and further plotting validated this observation (Figure 3; also Truesdell et al. 2022). To account for this in our ALKs we would need two spring-south ALKs to accommodate the NC age 3s and 4s (2006-2012):

- A spring south ALK without inshore NC age 3-4 fish to age catch
- A spring south ALK with offshore NC age 3-4 fish to age PSIGNS (the Pamlico Sound North Carolina inshore gillnet survey)

This complicated ALK construction and data borrowing, led to an unwieldy number of ALKs, and became unduly complex, and so was abandoned. This was a level of nuance that was difficult to implement in practice.

The working group also discussed whether to exclude scale samples (for example, those collected in association with NMFS port samples) – the WG didn’t observe any substantive differences in size at age by structure (otolith vs scale) to warrant excluding scales, and so all were retained in the ALKs. See Truesdell et al. 2022 for an annual age structure summary.

In light of the discussion and results discussed above, the WG initially decided to produce multinomial ALKs via these rules:

1. Method C (described above)

¹ In mid-September 2022 the WG became aware that SEAMAP samples prior to 2021 were inadvertently omitted from the ALKs. Since this was an inadvertent omission, and not an error, the WG was concerned with revising the age data at this late date, reasoning that an actual error could arise as the ALK change cascades through the assessment (re-age indices, re-age catch, etc.). Moreover, SEAMAP samples are largely age 1 spring samples and age 0 fall samples, where our ALKs are already sufficiently robust. Therefore, the WG made the decision to keep the ALKs unaltered, and incorporate the omitted SEAMAP samples through subsequent management track assessments (i.e., next scheduled for summer 2023).

2. For situations where the largest age 5 was larger than the largest age 6, we added one age 6 fish with a length equal to the max length of age 5, + 1 cm, to ensure the multinomial model gave reasonable predictions.
3. To ensure ALK predictions between 1 and 100 cm, we inserted 1 fish at 1cm for age 1 (spring) or age 0 (fall), and 1 fish at 100 cm for age 6.

These steps sometimes resulted in nonsensical ALKs (Figure 4). The methods above were subsequently modified such that rule 2 was generalized to apply to all ages; in addition, 1 age 6 fish was added at all lengths greater than the largest observed age 6 fish. These modifications stabilized the predictions in a number of cases, but not all, and there appeared to be some ‘unfixable’ ALKs. To remedy these problems, the WG reconsidered their interpretation of Figure 2 now viewing close fits to sparse data as a negative attribute rather than a positive one.

In light of this additional exploration, the WG reasoned that the single model approach (Method A, above) had the advantage of having to borrow less data relative to other alternatives considered, as well as allowing us to use AIC to support decisions about ALK resolution. Method A was used for development of final model-based multinomial ALKs. All spring age 0 fish were removed from the dataset prior to running multinomial models, which helped the performance of model predictions relative to biological expectations (e.g., minimized the probabilities of spring age 0 fish in ALKs).

Using method A, in addition to the steps above related to extending the ALKs from 0-100 cm, we only needed to borrow data for age 4 fish in 2004. For this year, fish were borrowed from both adjacent years within each season and region (a total of 16 fish in spring north, 23 fish in spring south, 15 fish in fall north, and 9 fish in fall south). No additional borrowing was needed.

Lastly, the WG discussed whether there was any information that could be gleaned from the multinomial models that would help with effective sample size determination. Such information could be considered along with information on length sampling to quantitatively or qualitatively adjust the effective sample size initial values. The multinomial models provide parameter estimates and their associated standard errors, from which CVs were calculated. The WG looked at a number of metrics, by year from the year-season multinomial model:

- Inverse of the average CV across all ages
- Inverse of the maximum CV
- Inverse of CV on ‘important’ ages (arbitrarily selected as age 2 for exploratory purposes)
- The average and total sample size of age data

The results of this preliminary exploration are provided in Figure 5.

Traditional ALKs

Traditional ALKs (i.e., non-model based ALKs such as those used in the 2015 assessment) were only constructed at the year-season level due to concerns related to the sparse nature of data at the year-season-region level of resolution that would require a large number of decisions related to data borrowing.

Each length category observed in the size data must have a corresponding probability distribution at age. To interpolate and extrapolate proportions the following protocol was implemented:

- For any year-season combination in which there was no data for an entire age, we borrowed fish from the year before and after (from within the same season; details below). Although the presence of each age is not necessary for computing proportions-at-age, the working group felt that zero observations at age was a sampling issue, and the model was likely to behave better if all age categories were represented. All subsequent borrowing was derived from averaging proportions (not raw number of fish).
 - For spring, fish only needed to be borrowed in 3 instances: 35 age-3 fish were borrowed for 1995, and 16 age-4 fish were borrowed for 2000 and again for 2004.
 - For fall, fish only needed to be borrowed in 6 instances: 25 age-4 fish were borrowed for 1997, 20 age-5 fish were borrowed for the same year, 14 age-3 fish were borrowed for 2001, and for 2004, 16 age-4 fish, 51 age-5 fish, and 87 age-6 fish were borrowed.
- After filling missing ages, for any remaining missing length bins, we averaged from both adjacent length bins (the next available largest and smallest length bin, within the same age) by taking the average proportion at length and age; the exceptions to this were cases in which borrowing from adjacent length bins resulted in no fish (proportion = 0) between two ages (Figure 6).
- The final step implemented was to simply fill in 1s (proportion = 100%) from 1 cm (at either age 1 for spring, or age 0 for fall) to the smallest observed fish, and for age 6, from the largest observed to 100 cm. This assumes that all individuals smaller than the smallest individual observed in the age-length data set were age-1 or age-0 and that all individuals larger than the largest individual observed in the age-length data set were age-6+.

A visual comparison of traditional and multinomial ALKs is presented in Appendix 1, and some diagnostic plots for the multinomial ALKs is presented in Appendix 2.

Literature Cited

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Table 1. Age sample sizes from 2021/2022 data collection - spring.

| Year | Age 0 | Age 1 | Age 2 | Age 3 | Age 4 | Age 5 | Age 6+ |
|------|-------|-------|-------|-------|-------|-------|--------|
| 1985 | 0 | 123 | 99 | 38 | 27 | 54 | 21 |
| 1986 | 0 | 99 | 68 | 23 | 48 | 44 | 42 |
| 1987 | 0 | 117 | 62 | 14 | 12 | 27 | 16 |
| 1988 | 0 | 51 | 99 | 49 | 32 | 7 | 18 |
| 1989 | 0 | 47 | 32 | 8 | 40 | 25 | 15 |
| 1990 | 0 | 12 | 48 | 36 | 24 | 32 | 7 |
| 1991 | 0 | 88 | 57 | 10 | 25 | 13 | 10 |
| 1992 | 0 | 225 | 63 | 75 | 11 | 16 | 16 |
| 1993 | 1 | 97 | 156 | 16 | 19 | 23 | 24 |
| 1994 | 0 | 117 | 39 | 10 | 60 | 37 | 19 |
| 1995 | 0 | 120 | 86 | 0 | 9 | 44 | 26 |
| 1996 | 0 | 133 | 73 | 25 | 4 | 9 | 10 |
| 1997 | 0 | 99 | 72 | 23 | 10 | 6 | 6 |
| 1998 | 0 | 124 | 152 | 35 | 16 | 13 | 20 |
| 1999 | 0 | 100 | 155 | 7 | 15 | 17 | 22 |
| 2000 | 0 | 134 | 37 | 1 | 0 | 1 | 2 |
| 2001 | 0 | 12 | 126 | 10 | 1 | 1 | 5 |
| 2002 | 0 | 223 | 87 | 6 | 8 | 42 | 38 |
| 2003 | 0 | 76 | 158 | 4 | 13 | 17 | 45 |
| 2004 | 14 | 483 | 188 | 23 | 0 | 3 | 2 |
| 2005 | 0 | 205 | 98 | 8 | 3 | 2 | 1 |
| 2006 | 0 | 144 | 79 | 28 | 4 | 6 | 39 |
| 2007 | 0 | 253 | 230 | 30 | 12 | 15 | 76 |
| 2008 | 3 | 292 | 281 | 57 | 11 | 19 | 42 |
| 2009 | 0 | 177 | 117 | 67 | 20 | 26 | 73 |
| 2010 | 2 | 140 | 147 | 157 | 81 | 30 | 56 |
| 2011 | 4 | 95 | 154 | 181 | 91 | 21 | 82 |
| 2012 | 2 | 247 | 271 | 190 | 110 | 40 | 127 |
| 2013 | 8 | 106 | 503 | 353 | 188 | 45 | 63 |
| 2014 | 1 | 133 | 225 | 120 | 163 | 99 | 151 |
| 2015 | 23 | 141 | 303 | 157 | 126 | 144 | 224 |
| 2016 | 3 | 244 | 470 | 294 | 99 | 102 | 202 |
| 2017 | 19 | 105 | 364 | 125 | 81 | 31 | 199 |
| 2018 | 10 | 313 | 204 | 177 | 70 | 64 | 109 |
| 2019 | 12 | 313 | 449 | 89 | 103 | 61 | 95 |
| 2020 | 1 | 39 | 133 | 173 | 76 | 46 | 36 |
| 2021 | | 90 | 125 | 281 | 182 | 44 | 32 |

Table 2. Age sample sizes from 2021/2022 data collection - fall.

| Year | Age 0 | Age 1 | Age 2 | Age 3 | Age 4 | Age 5 | Age 6+ |
|------|-------|-------|-------|-------|-------|-------|--------|
| 1985 | 321 | 646 | 309 | 117 | 67 | 14 | 58 |
| 1986 | 206 | 355 | 326 | 122 | 80 | 67 | 82 |
| 1987 | 143 | 267 | 177 | 180 | 77 | 37 | 60 |
| 1988 | 143 | 127 | 94 | 66 | 123 | 100 | 122 |
| 1989 | 322 | 103 | 10 | 10 | 8 | 25 | 23 |
| 1990 | 125 | 263 | 15 | 10 | 10 | 21 | 46 |
| 1991 | 132 | 57 | 30 | 18 | 5 | 2 | 62 |
| 1992 | 179 | 266 | 22 | 47 | 18 | 5 | 31 |
| 1993 | 186 | 178 | 25 | 13 | 27 | 5 | 60 |
| 1994 | 339 | 218 | 7 | 13 | 22 | 23 | 20 |
| 1995 | 258 | 333 | 36 | 5 | 14 | 30 | 27 |
| 1996 | 239 | 222 | 56 | 27 | 16 | 14 | 61 |
| 1997 | 65 | 128 | 14 | 1 | 0 | 0 | 9 |
| 1998 | 185 | 246 | 106 | 13 | 9 | 6 | 20 |
| 1999 | 91 | 196 | 75 | 7 | 1 | 2 | 49 |
| 2000 | 43 | 298 | 24 | 9 | 3 | 2 | 4 |
| 2001 | 1 | 117 | 111 | 0 | 2 | 5 | 40 |
| 2002 | 197 | 363 | 60 | 5 | 1 | 3 | 5 |
| 2003 | 276 | 88 | 23 | 1 | 7 | 41 | 70 |
| 2004 | 121 | 114 | 16 | 5 | 0 | 0 | 0 |
| 2005 | 341 | 112 | 57 | 9 | 9 | 10 | 17 |
| 2006 | 91 | 103 | 69 | 10 | 10 | 3 | 26 |
| 2007 | 545 | 264 | 172 | 64 | 13 | 8 | 13 |
| 2008 | 671 | 251 | 131 | 31 | 8 | 6 | 26 |
| 2009 | 646 | 263 | 152 | 151 | 39 | 10 | 18 |
| 2010 | 540 | 266 | 119 | 137 | 58 | 31 | 51 |
| 2011 | 458 | 267 | 123 | 125 | 51 | 49 | 76 |
| 2012 | 588 | 263 | 246 | 193 | 118 | 28 | 73 |
| 2013 | 787 | 303 | 356 | 238 | 136 | 106 | 97 |
| 2014 | 677 | 527 | 308 | 235 | 193 | 153 | 182 |
| 2015 | 731 | 412 | 290 | 90 | 111 | 128 | 244 |
| 2016 | 575 | 640 | 358 | 254 | 114 | 109 | 206 |
| 2017 | 677 | 329 | 362 | 134 | 67 | 24 | 114 |
| 2018 | 734 | 556 | 288 | 206 | 98 | 72 | 48 |
| 2019 | 474 | 614 | 380 | 100 | 74 | 13 | 13 |
| 2020 | 452 | 181 | 406 | 310 | 57 | 44 | 35 |
| 2021 | 671 | 381 | 266 | 268 | 129 | 23 | 17 |

Table 3. Difference in sample size between legacy dataset and 2021/2022 data call: spring.

| Year | Age 0 | Age 1 | Age 2 | Age 3 | Age 4 | Age 5 | Age 6+ |
|------|-------|-------|-------|-------|-------|-------|--------|
| 1985 | 0 | 2 | -9 | -5 | -2 | -1 | -22 |
| 1986 | 0 | -2 | -23 | 0 | 0 | 0 | -12 |
| 1987 | 0 | 1 | 0 | -1 | 0 | -1 | -15 |
| 1988 | 0 | 1 | -15 | -6 | -7 | -7 | -26 |
| 1989 | 0 | 0 | 0 | -7 | -5 | 0 | -19 |
| 1990 | 0 | 0 | 0 | -1 | 0 | 0 | -11 |
| 1991 | 0 | 2 | -1 | 0 | 0 | 0 | -11 |
| 1992 | 0 | 1 | 2 | -3 | 0 | 0 | -20 |
| 1993 | 0 | 7 | -5 | -1 | 0 | 0 | -44 |
| 1994 | 0 | 0 | 3 | 0 | 0 | 0 | -37 |
| 1995 | 0 | 9 | -10 | 0 | 1 | 1 | -27 |
| 1996 | 0 | 76 | 23 | 1 | 1 | 1 | -1 |
| 1997 | 0 | 1 | -3 | 0 | 0 | 0 | -11 |
| 1998 | 0 | 2 | -35 | -2 | -2 | -3 | -23 |
| 1999 | 0 | 7 | 21 | 1 | 2 | 2 | -6 |
| 2000 | 0 | 8 | 14 | 1 | 0 | 1 | 0 |
| 2001 | 0 | 12 | 126 | 10 | 1 | 1 | 5 |
| 2002 | 0 | 32 | -276 | -27 | -13 | -20 | -47 |
| 2003 | 0 | 72 | 157 | 4 | 13 | 17 | 45 |
| 2004 | 14 | 483 | 187 | 23 | 0 | 3 | 2 |
| 2005 | 0 | 185 | 11 | 0 | 0 | 0 | 0 |
| 2006 | 0 | 105 | 6 | 2 | 2 | 1 | -2 |
| 2007 | 0 | 171 | 13 | 1 | 2 | 0 | -6 |
| 2008 | 3 | 95 | 14 | 6 | 0 | -1 | -3 |
| 2009 | 0 | 78 | 11 | 4 | 2 | 6 | 7 |
| 2010 | 2 | 35 | 5 | -8 | -4 | -8 | -12 |
| 2011 | 4 | -114 | -12 | 0 | 0 | -1 | 10 |
| 2012 | 0 | -97 | -6 | -15 | -14 | -3 | -6 |
| 2013 | 4 | -195 | 36 | 18 | 11 | 1 | 0 |
| 2014 | 0 | -158 | 20 | 5 | 33 | 31 | 26 |
| 2015 | 0 | -128 | 25 | 3 | -6 | -9 | -3 |
| 2016 | -2 | -96 | 10 | 5 | 10 | 6 | 2 |
| 2017 | -1 | -39 | 27 | 6 | 0 | 1 | 1 |
| 2018 | 0 | -39 | 15 | 12 | 1 | 0 | 0 |
| 2019 | 11 | -96 | 20 | 7 | -1 | 1 | 0 |
| 2020 | 0 | 0 | 6 | 7 | 0 | 3 | 2 |
| 2021 | 0 | 2 | -9 | -5 | -2 | -1 | -22 |

Table 4. Difference in sample size between legacy dataset and 2021/2022 data call: fall.

| Year | Age 0 | Age 1 | Age 2 | Age 3 | Age 4 | Age 5 | Age 6+ |
|------|-------|-------|-------|-------|-------|-------|--------|
| 1985 | -1 | -17 | -6 | -3 | 0 | -1 | -1 |
| 1986 | -10 | -38 | -28 | -5 | 0 | -1 | 0 |
| 1987 | 0 | -7 | -29 | -17 | -2 | -3 | 0 |
| 1988 | 0 | -2 | -4 | -8 | -4 | -3 | -1 |
| 1989 | 0 | -8 | 0 | 0 | 0 | -1 | 0 |
| 1990 | 0 | 0 | -10 | -3 | 0 | 0 | 0 |
| 1991 | -1 | 0 | -1 | -7 | -6 | -5 | -8 |
| 1992 | -1 | -10 | -1 | 14 | 2 | 1 | 0 |
| 1993 | -2 | -1 | -9 | 0 | 0 | 0 | 0 |
| 1994 | 0 | -1 | 0 | 0 | 0 | -13 | -21 |
| 1995 | -3 | -2 | -1 | 0 | 0 | -1 | 0 |
| 1996 | 48 | 26 | -2 | -8 | -1 | 0 | 8 |
| 1997 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1998 | 0 | 0 | 0 | 0 | 0 | 0 | -49 |
| 1999 | 10 | 143 | 63 | 7 | 1 | 2 | 42 |
| 2000 | 1 | -34 | -105 | 9 | 1 | -3 | -38 |
| 2001 | 1 | 117 | 111 | 0 | 2 | 5 | 40 |
| 2002 | 141 | -86 | -22 | -3 | -6 | -41 | -70 |
| 2003 | 218 | 82 | 18 | 1 | 7 | 41 | 70 |
| 2004 | 103 | 108 | 15 | 5 | 0 | 0 | 0 |
| 2005 | 252 | 19 | 3 | 0 | 0 | 0 | 0 |
| 2006 | 51 | 9 | 4 | -1 | 0 | 0 | -3 |
| 2007 | 51 | 11 | 10 | 1 | 0 | 0 | -8 |
| 2008 | 153 | 7 | -1 | 0 | 0 | 0 | -3 |
| 2009 | 66 | 58 | 10 | 1 | 0 | 0 | 0 |
| 2010 | 69 | 16 | 3 | -1 | 0 | -1 | 2 |
| 2011 | -131 | -33 | 0 | -1 | 0 | 0 | 0 |
| 2012 | -85 | -25 | -27 | -8 | -1 | -1 | -5 |
| 2013 | -60 | 22 | 112 | 90 | 70 | 57 | 56 |
| 2014 | 3 | 65 | 49 | 45 | 61 | 50 | 58 |
| 2015 | -106 | -2 | 42 | -2 | 3 | -20 | -21 |
| 2016 | 1 | 34 | 5 | -1 | 1 | 0 | 2 |
| 2017 | -82 | -11 | -2 | 5 | 0 | -2 | 1 |
| 2018 | 63 | 22 | 10 | 1 | 3 | 0 | 0 |
| 2019 | -68 | 20 | 6 | 4 | -1 | 0 | 1 |
| 2020 | -3 | 7 | -3 | -2 | 1 | 0 | 0 |
| 2021 | -1 | -17 | -6 | -3 | 0 | -1 | -1 |

Figure 1. Bar plot of mean size at age by region. Black bars depict the north region, whereas grey bars depict the south region. In general, for a given age, size at age is greater in the north than south, with the exception of fall age 0; all comparisons significant when accounting for multiple comparisons (Holm's test, alpha = 0.05), except for fall age 5 and fall age 6.

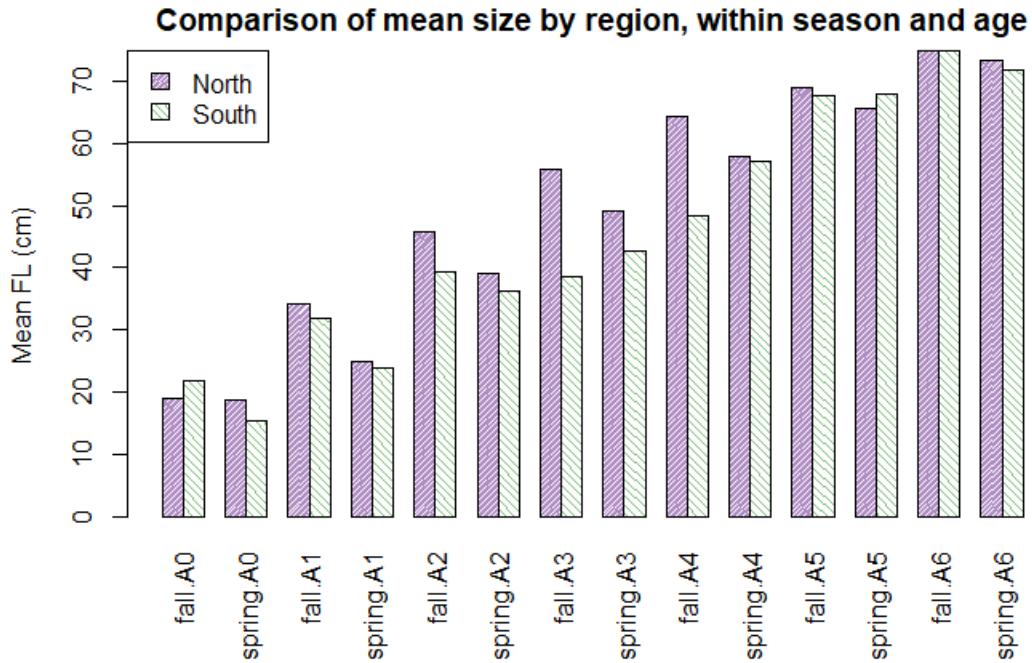
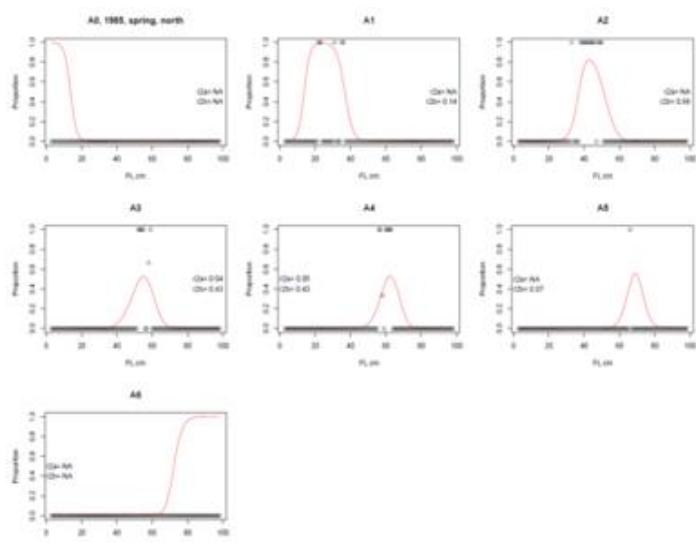
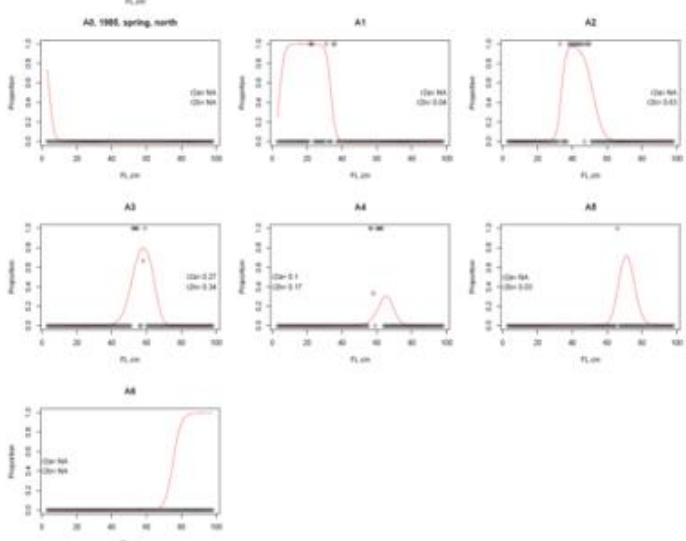


Figure 2. Comparison of observed and predicted age proportions (y-axis) by length (x-axis), by Methods A, B, and C. Red lines depict multinomial prediction, whereas open circles depict observed data. Methods A and B tend to fit observed data in spring 1985, poorly, whereas Method C fits observed data from spring 1985 reasonably well.

Method A



Method B



Method C

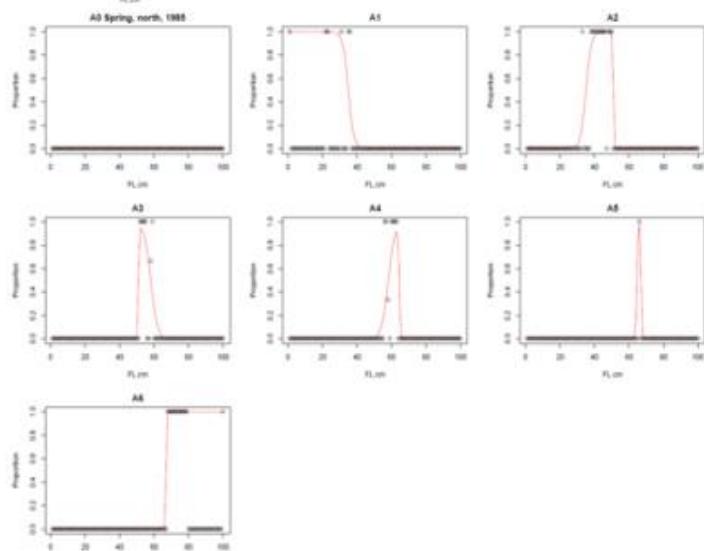


Figure 3. Stacked bar plot of number of fish by age, size, quarter of year, region (inshore vs offshore) in NC. Numbers on right edge of the figure indicate age (e.g., 1 = age 1, ..., 5 = age 5).

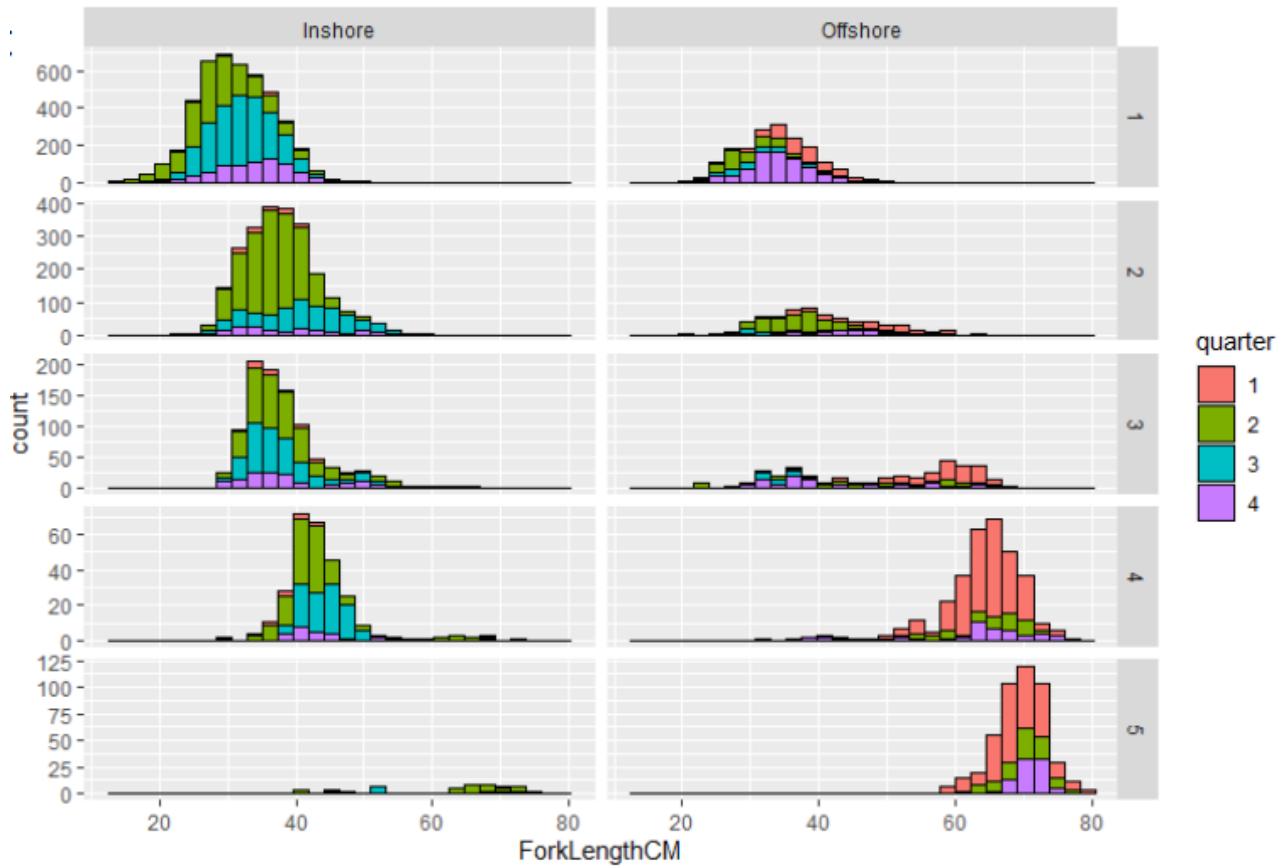


Figure 4. Multinomial predictions for a 2001 fall-south age length key, showing unintuitive and biologically unlikely predictions from original data rules, suggesting age 1 fish that are larger than age 2 fish, and that approximately 20% of 100 cm fish are ages 4 and 5. Modified original rules performed only modestly better, while the new final approach produced intuitive, sensible ALKs where the mode of ages increases with increasing size.

Fall south 2001 (note ages 1-2 and 4-5)

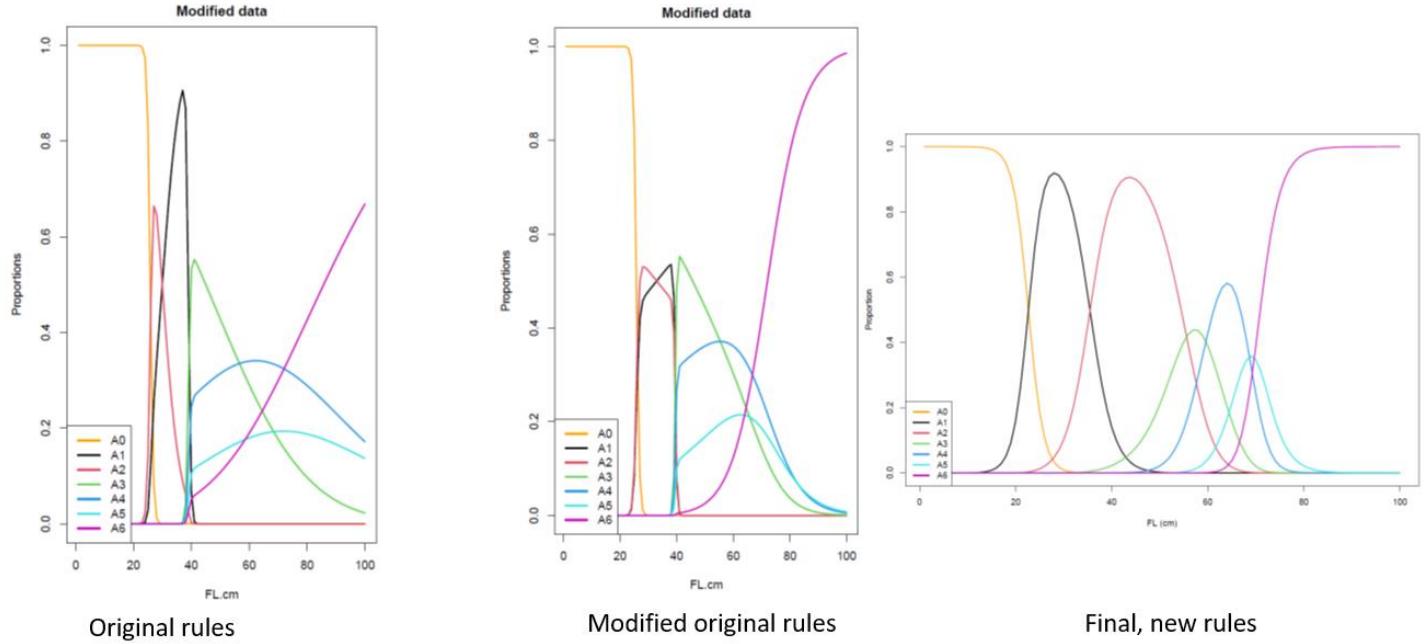


Figure 5. Preliminary relative estimates to scale effective sample size.

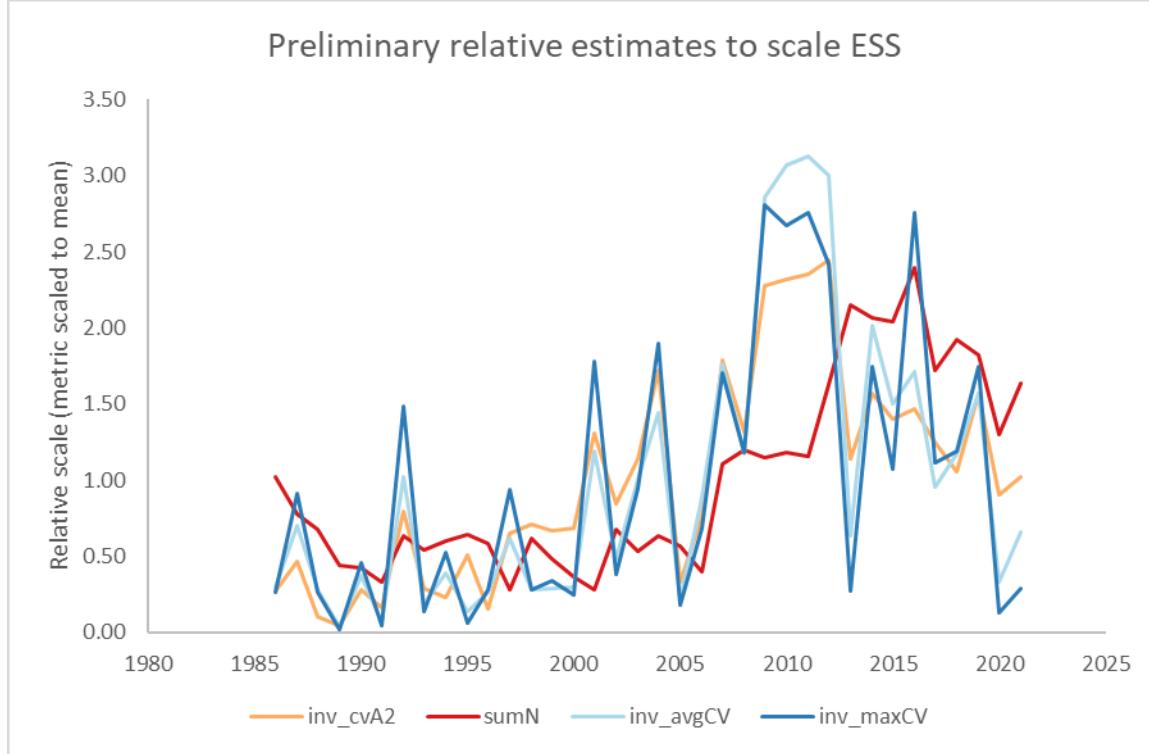
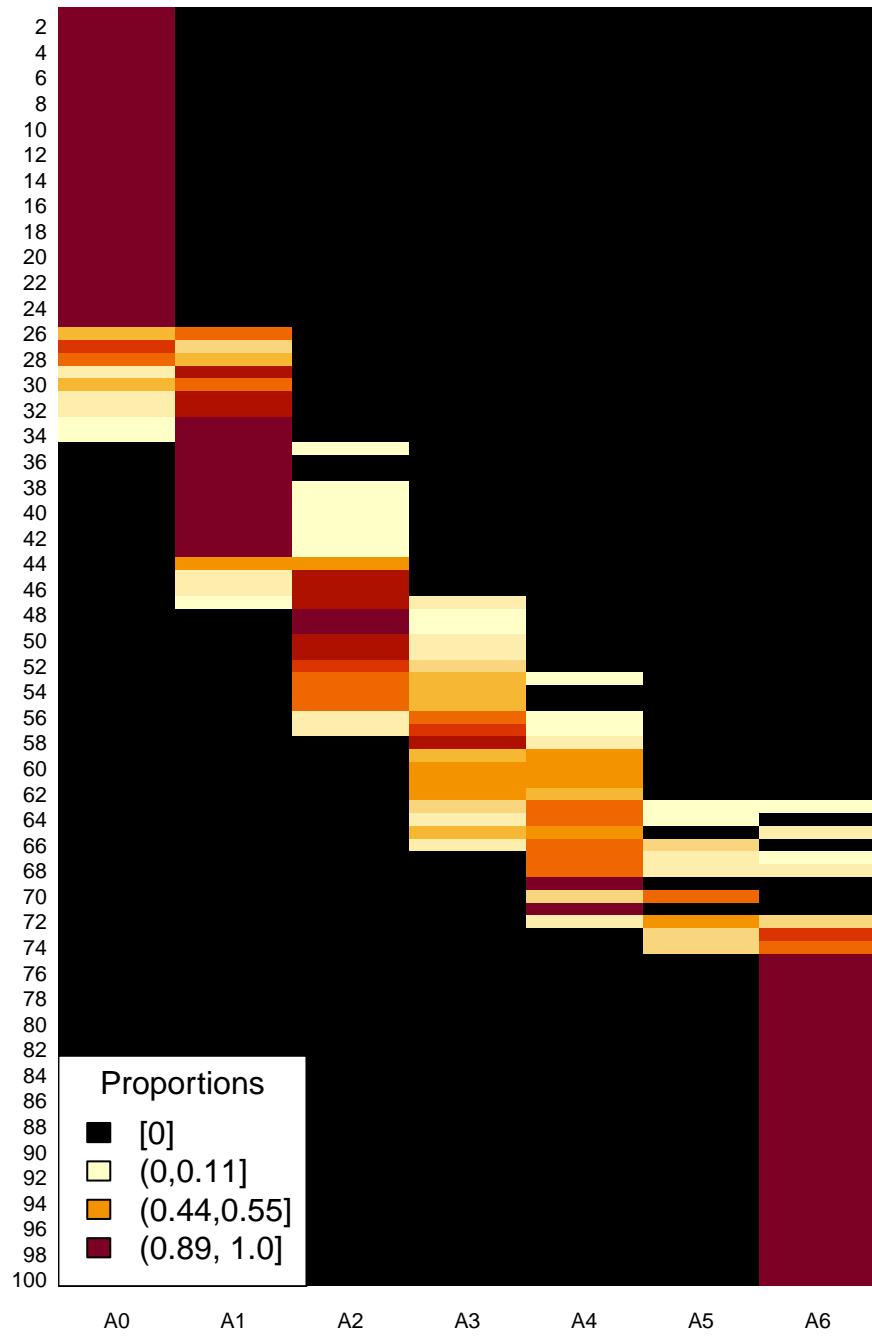


Figure 6. An excerpt of the spring 2005 ALK depicting an exception to the interpolation rule where, in this case, averaging between the proportions starting at length 66 and larger would have resulted in a series of lengths in which proportions would be non-zero for ages 4 and 6, but zero for age 5. An additional exception that is depicted relates to the rule related to filling in 1s for age 6. Under the usual protocol, 1s would have been filled in below the largest age 6 fish (at 66 cm). Interpolated and extrapolated cells are highlighted in yellow.

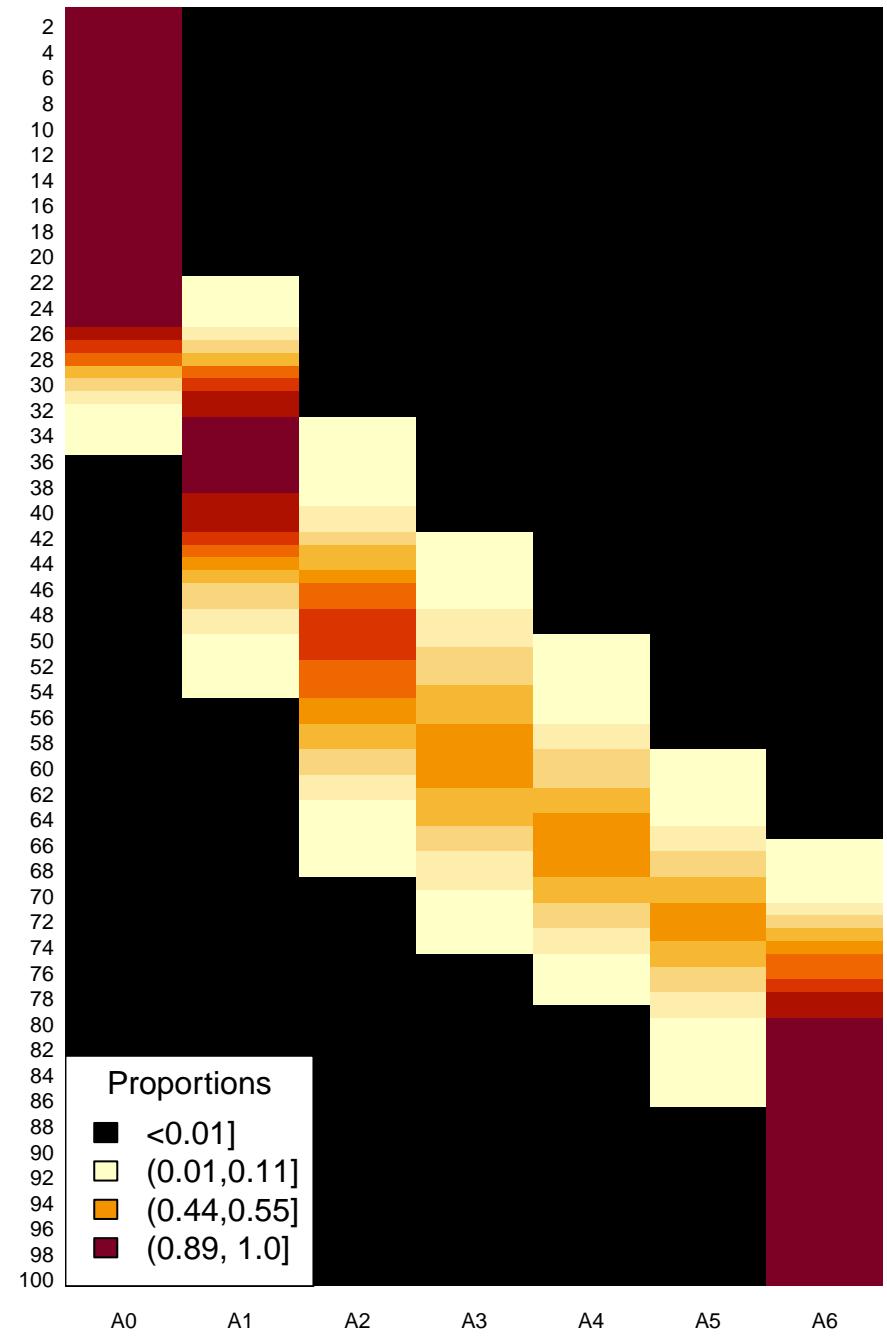
| FL (cm) | A0 | A1 | A2 | A3 | A4 | A5 | A6 |
|---------|----|----|----|----|-----|------|------|
| 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| ... | | | | | | | |
| 63 | 0 | 0 | 0 | 0 | 0.5 | 0.5 | 0 |
| 64 | 0 | 0 | 0 | 0 | 0.5 | 0.25 | 0.25 |
| 65 | 0 | 0 | 0 | 0 | 0.5 | 0.25 | 0.25 |
| 66 | 0 | 0 | 0 | 0 | 0.5 | 0 | 0.5 |
| 67 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 68 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 69 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 70 | 0 | 0 | 0 | 0 | 0.5 | 0.5 | 0 |
| 71 | 0 | 0 | 0 | 0 | 0.5 | 0.5 | 0 |
| 72 | 0 | 0 | 0 | 0 | 0.5 | 0.5 | 0 |
| 73 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 74 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 75 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| ... | | | | | | | |
| 99 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 100 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

Appendix I

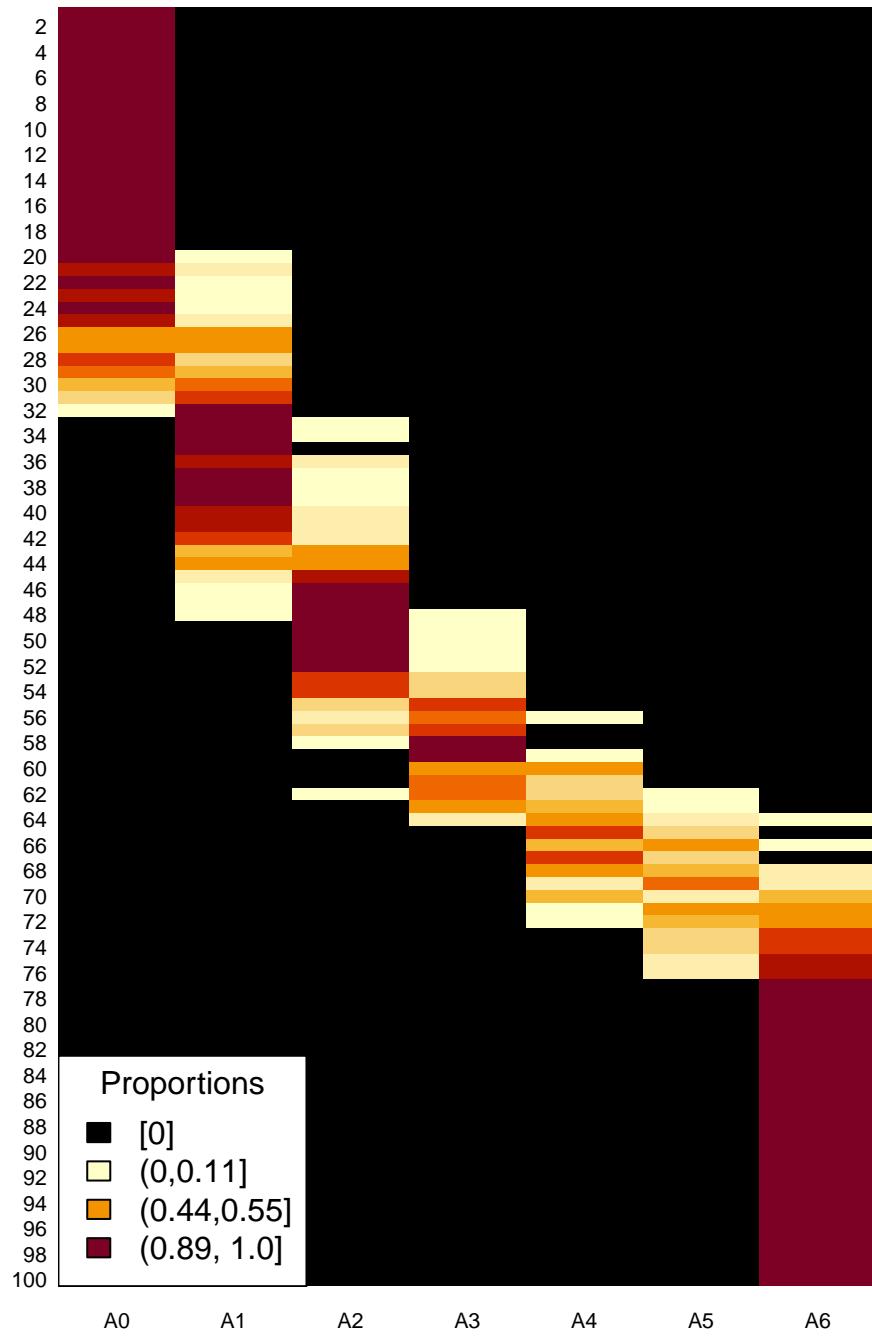
Traditional ALK, fall 1985



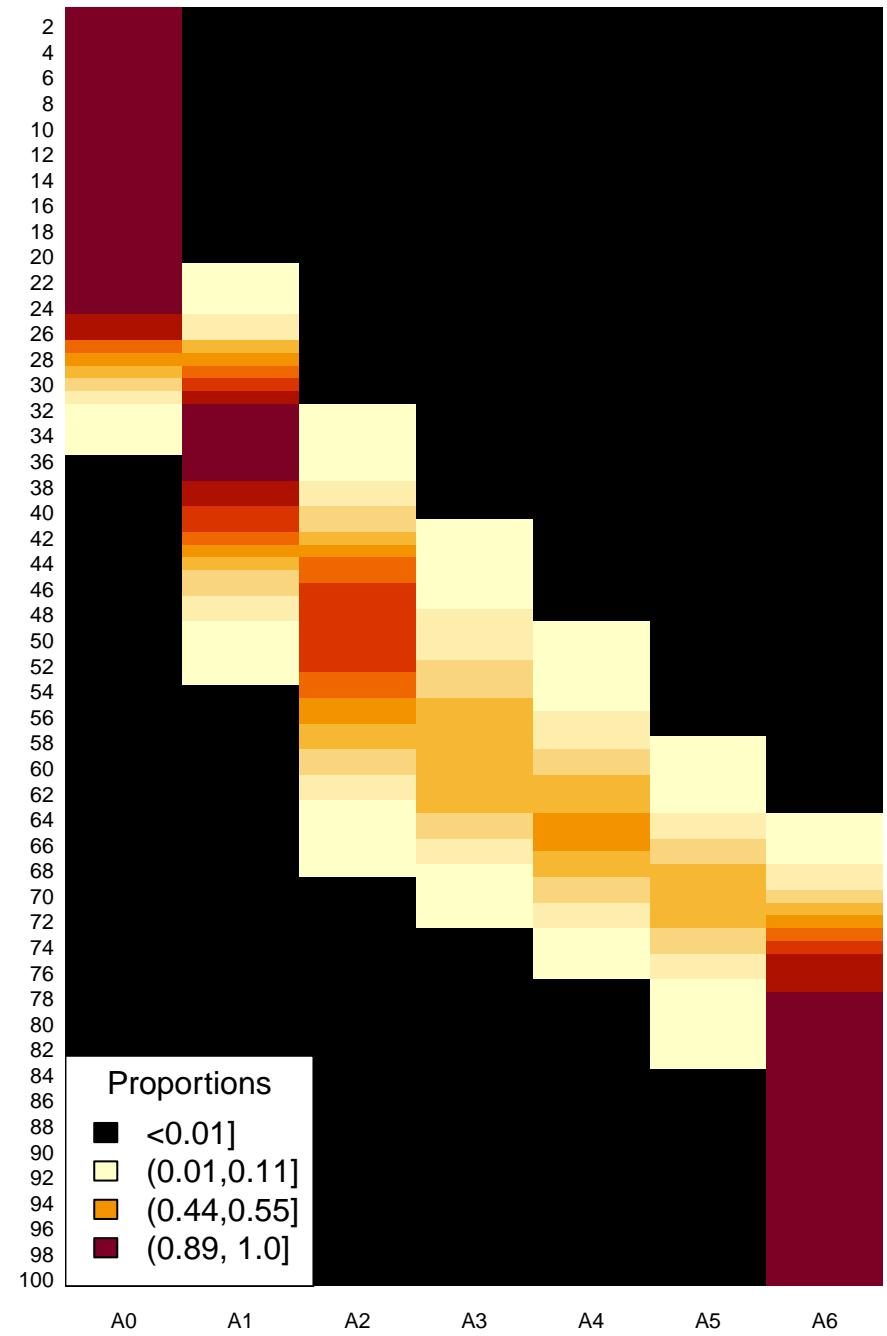
Multinomial ALK, fall 1985



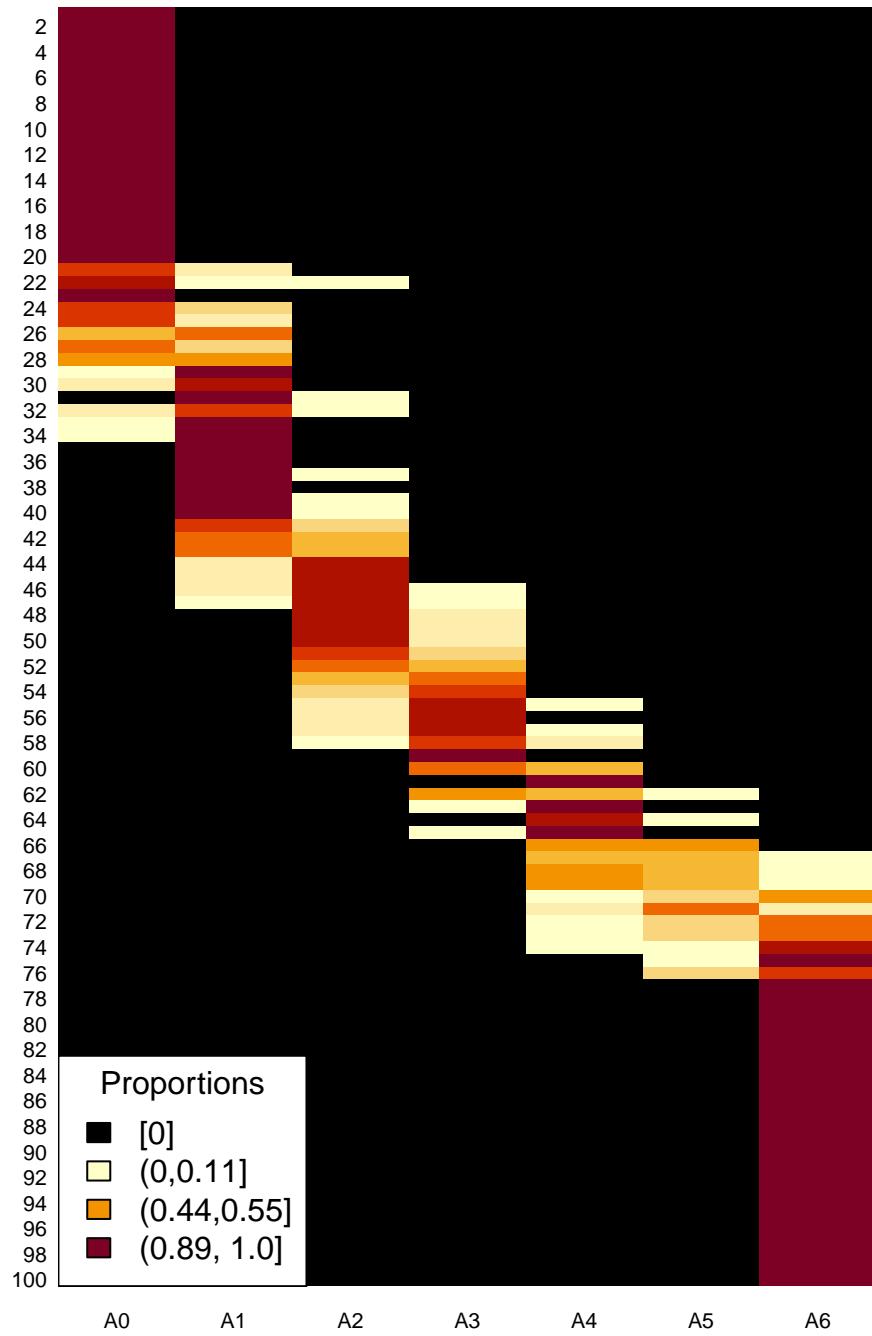
Traditional ALK, fall 1986



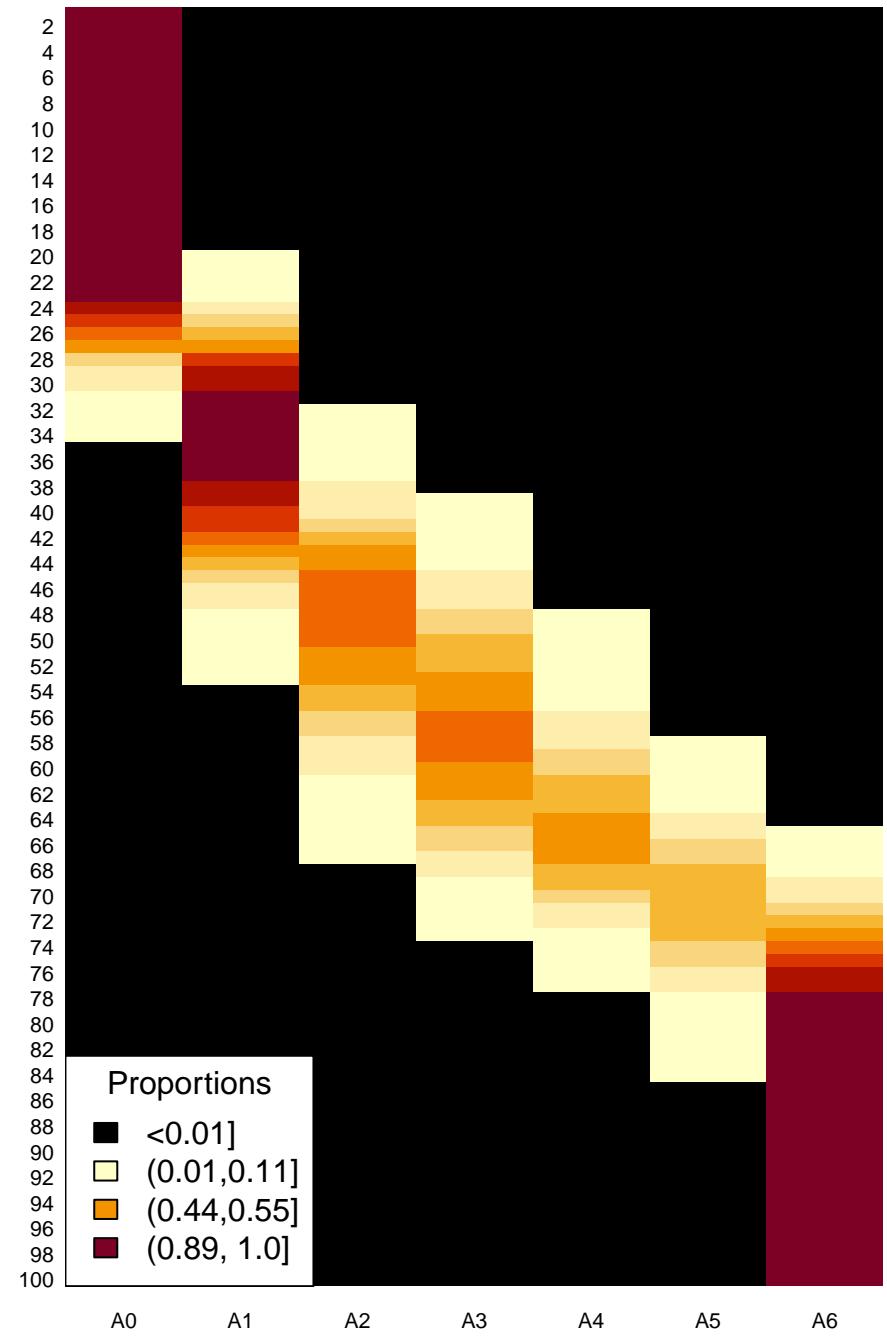
Multinomial ALK, fall 1986



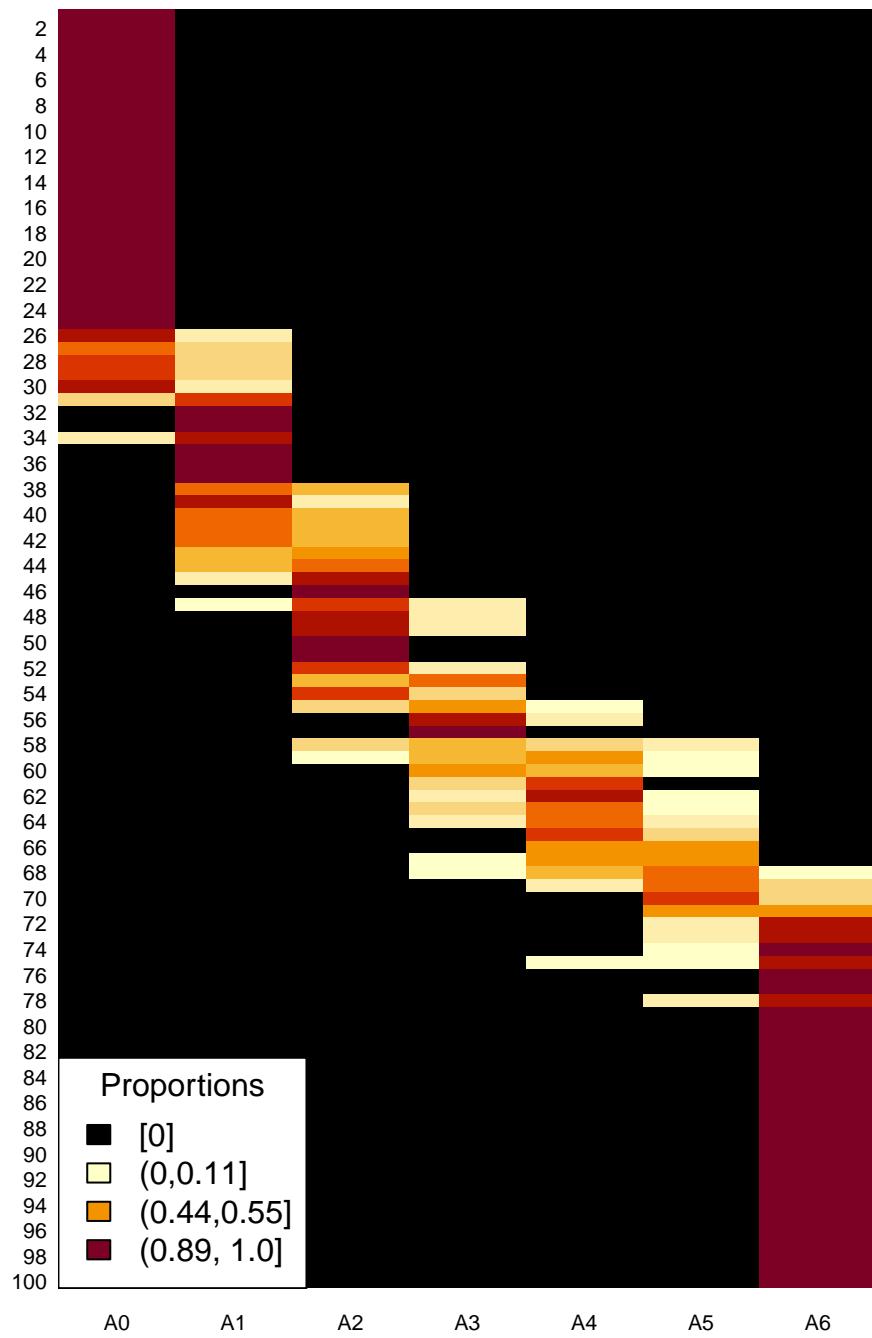
Traditional ALK, fall 1987



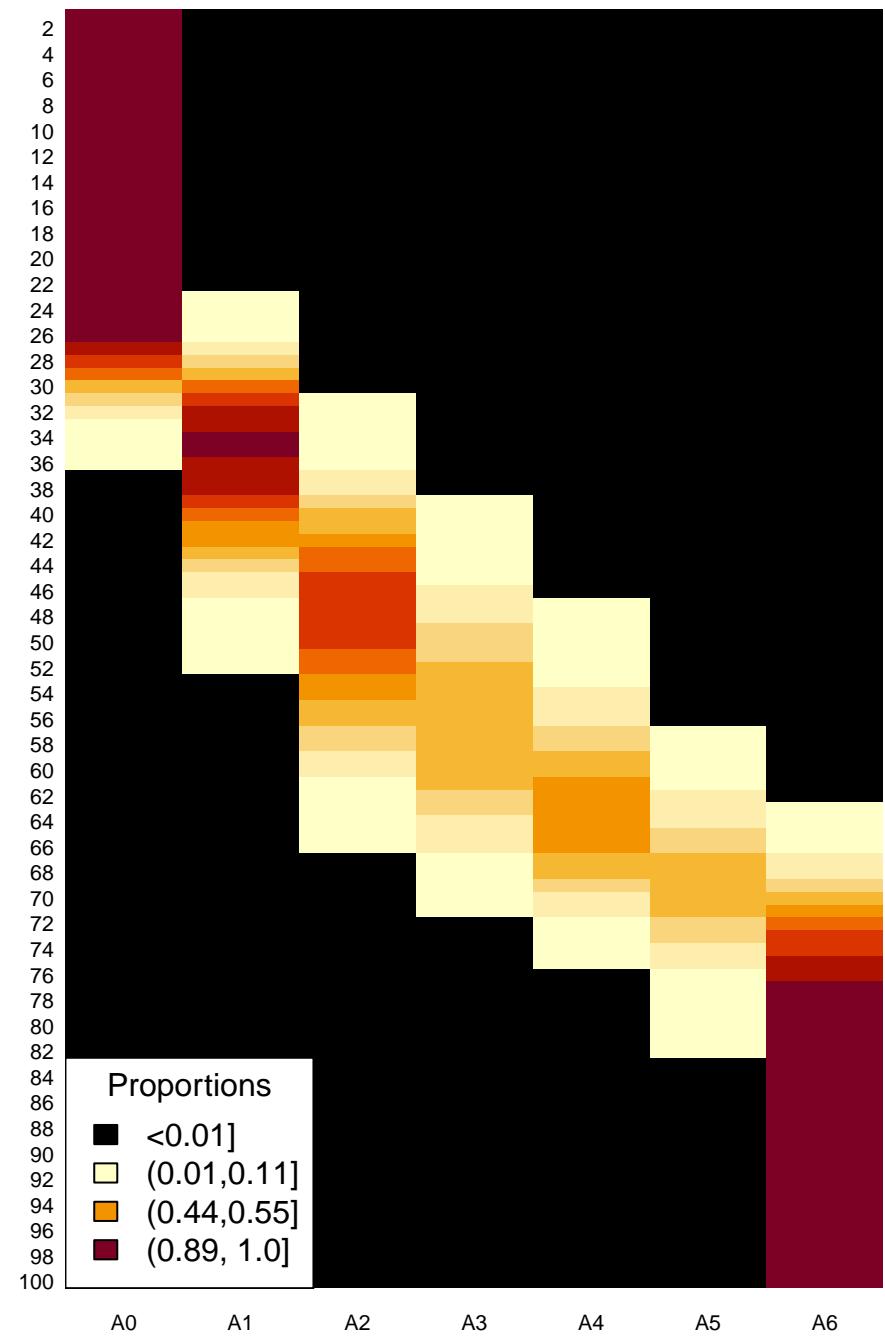
Multinomial ALK, fall 1987



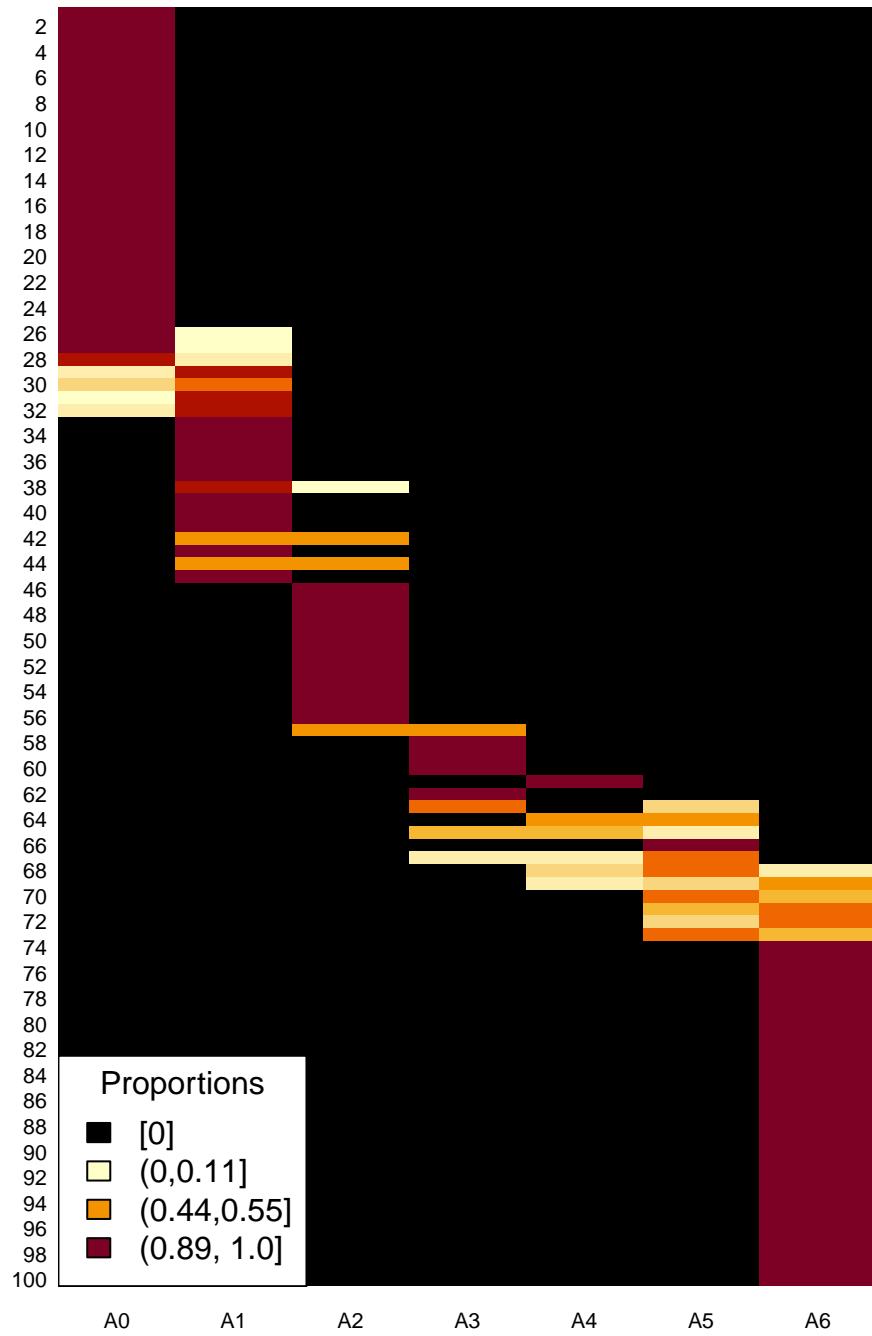
Traditional ALK, fall 1988



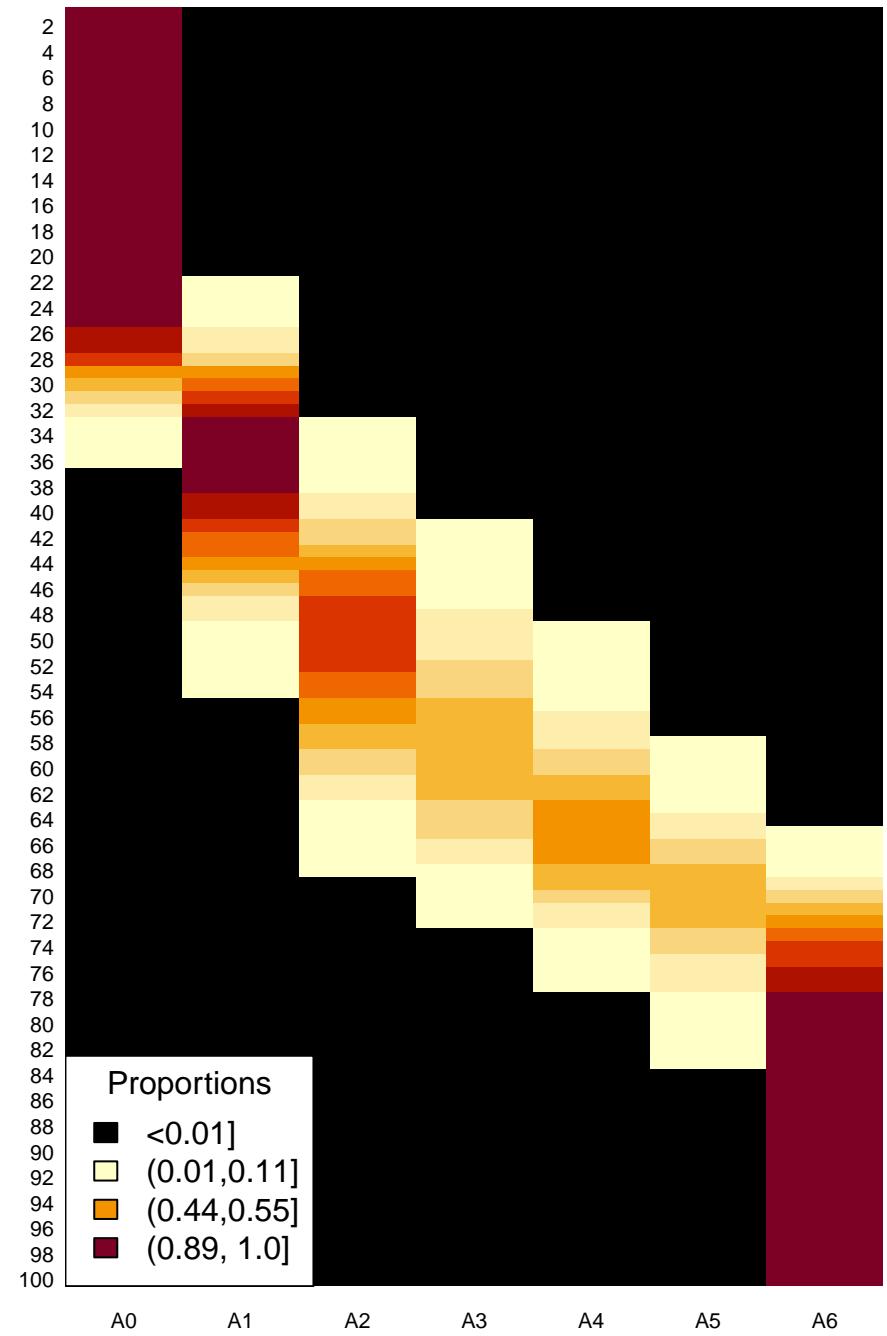
Multinomial ALK, fall 1988



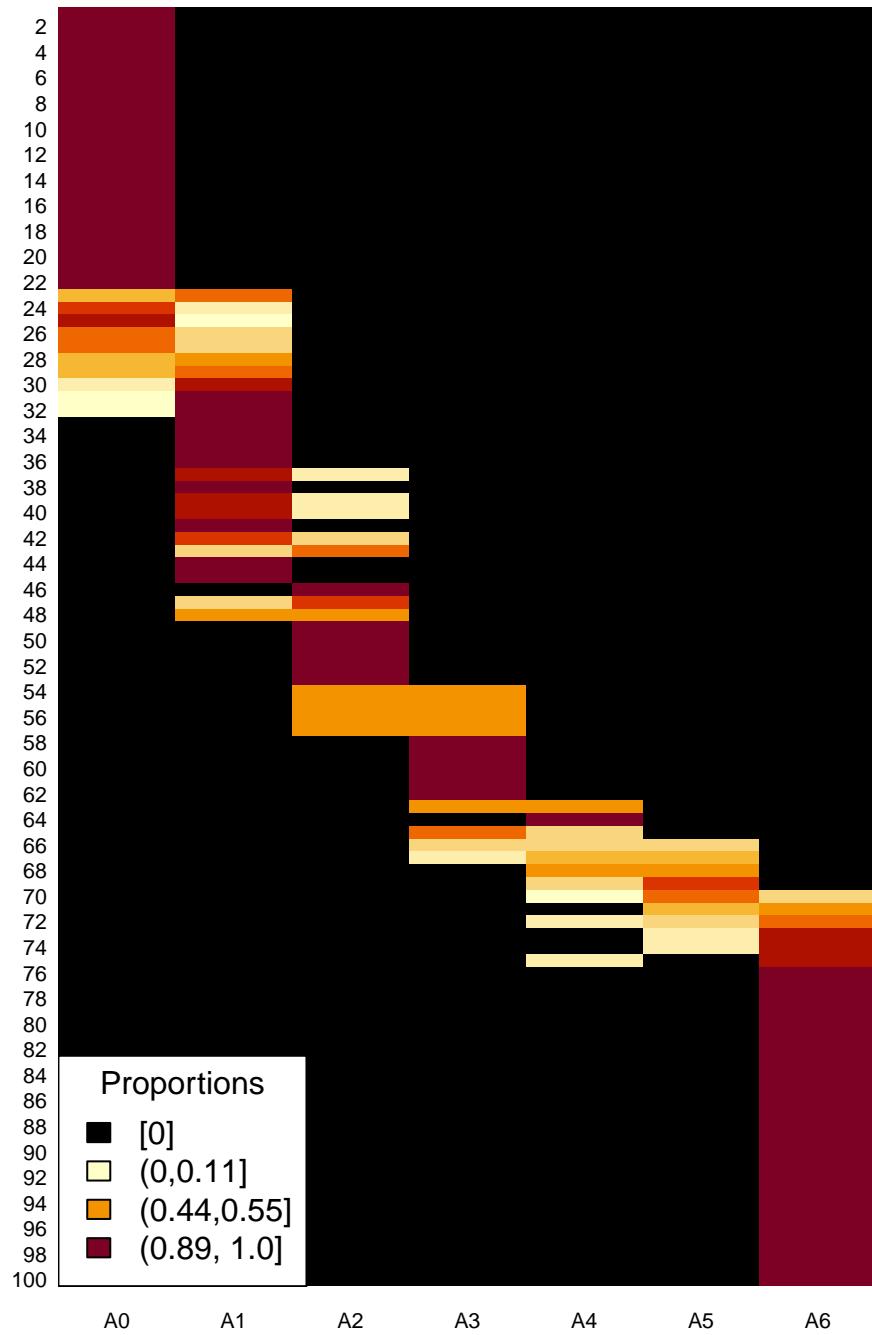
Traditional ALK, fall 1989



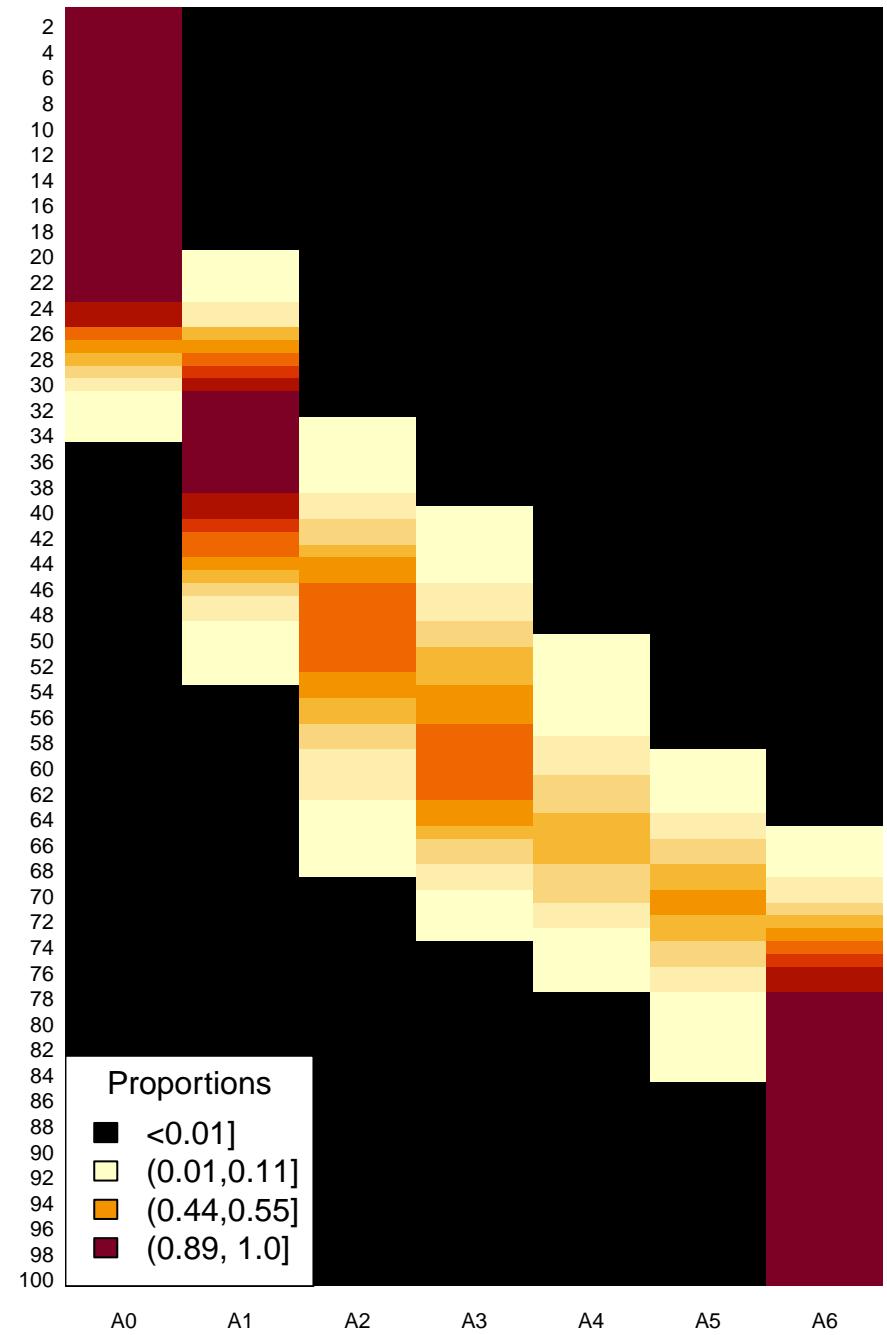
Multinomial ALK, fall 1989



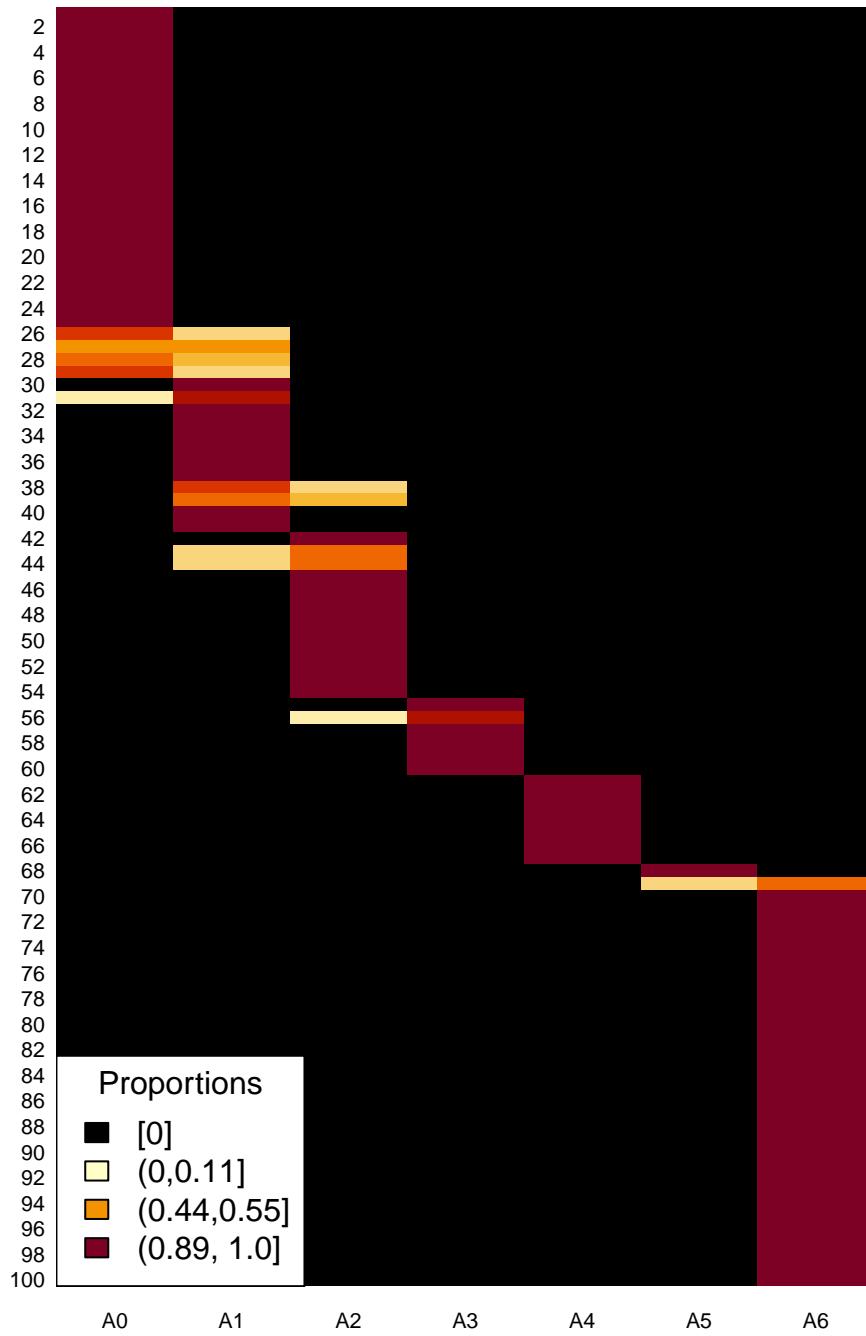
Traditional ALK, fall 1990



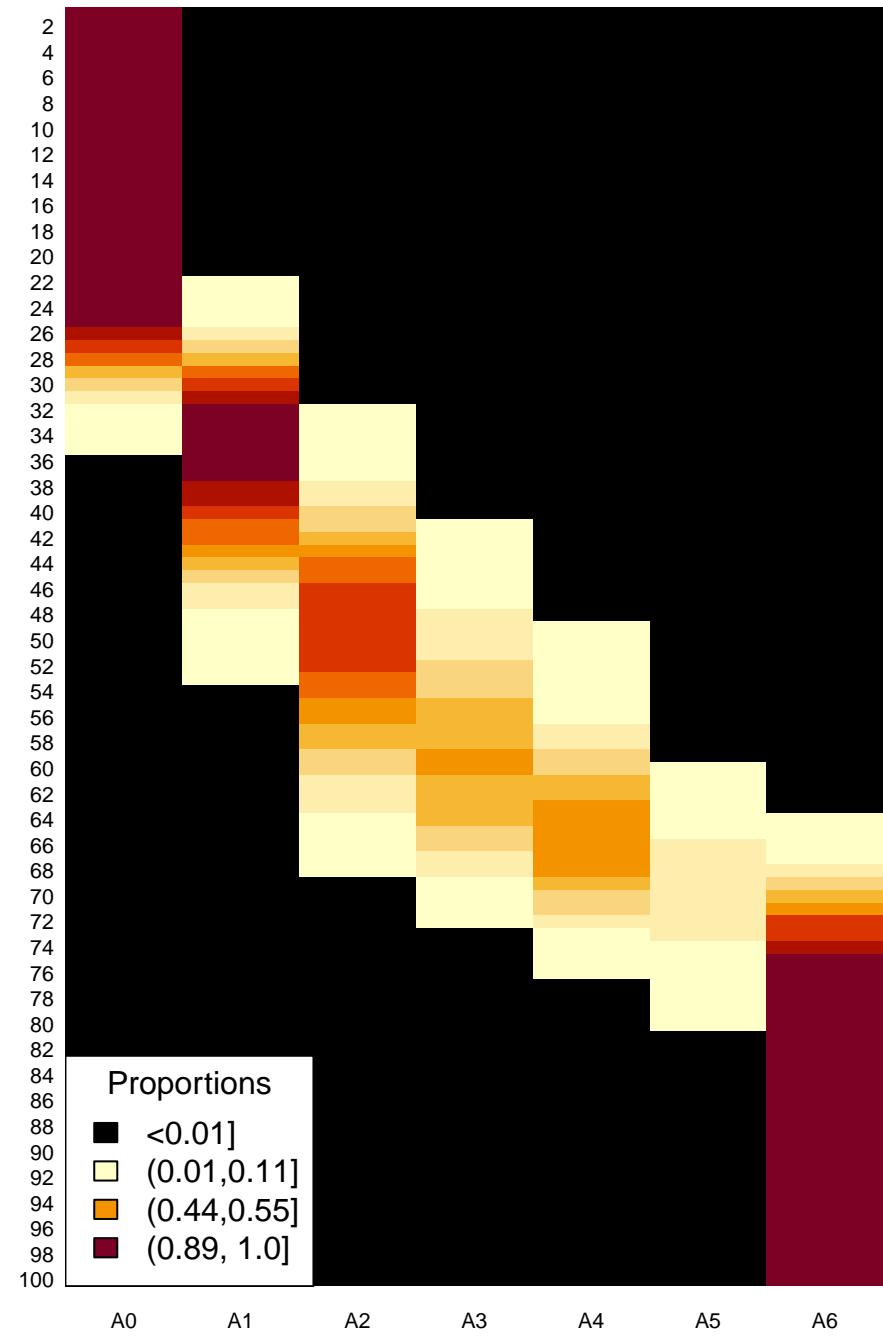
Multinomial ALK, fall 1990



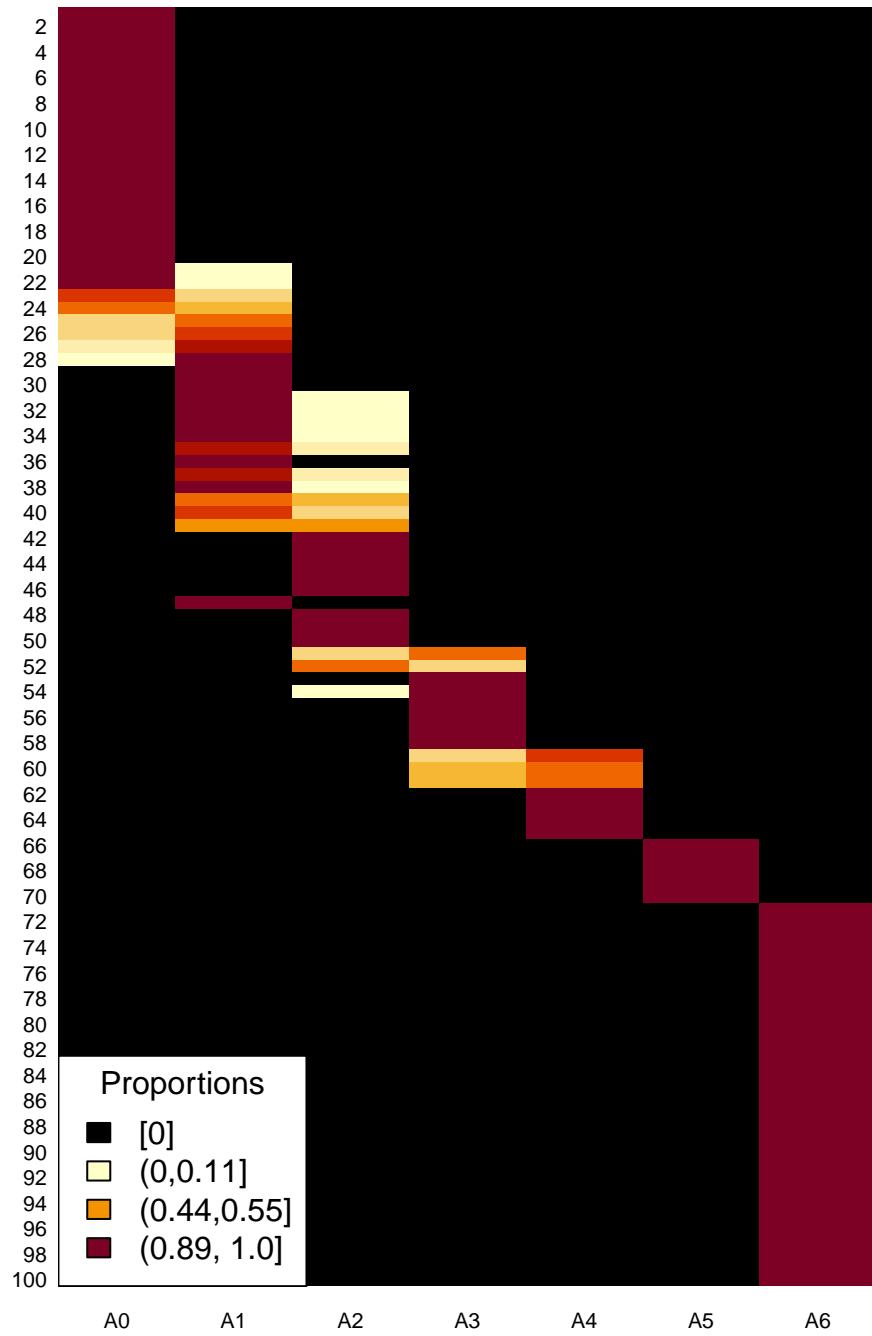
Traditional ALK, fall 1991



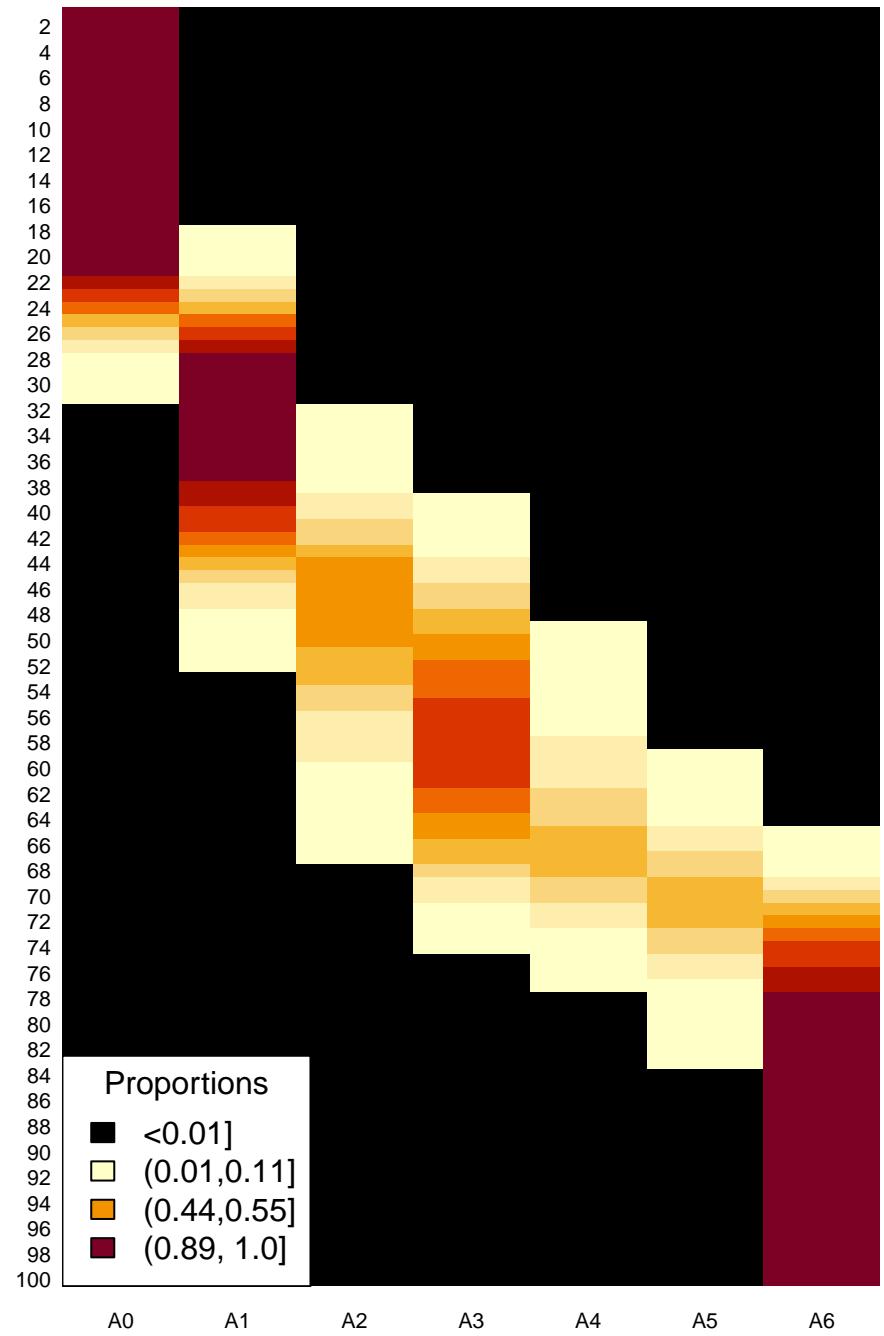
Multinomial ALK, fall 1991



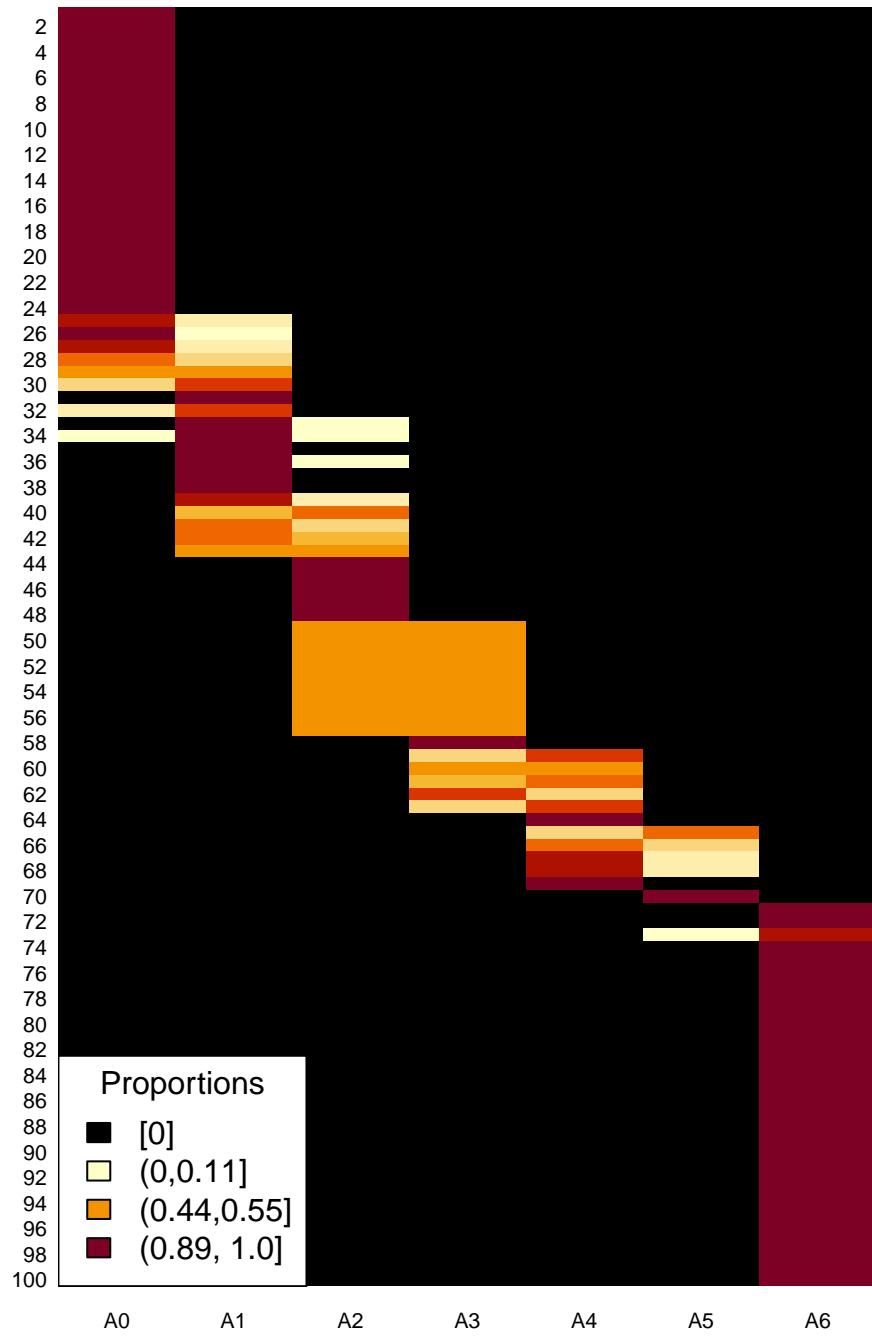
Traditional ALK, fall 1992



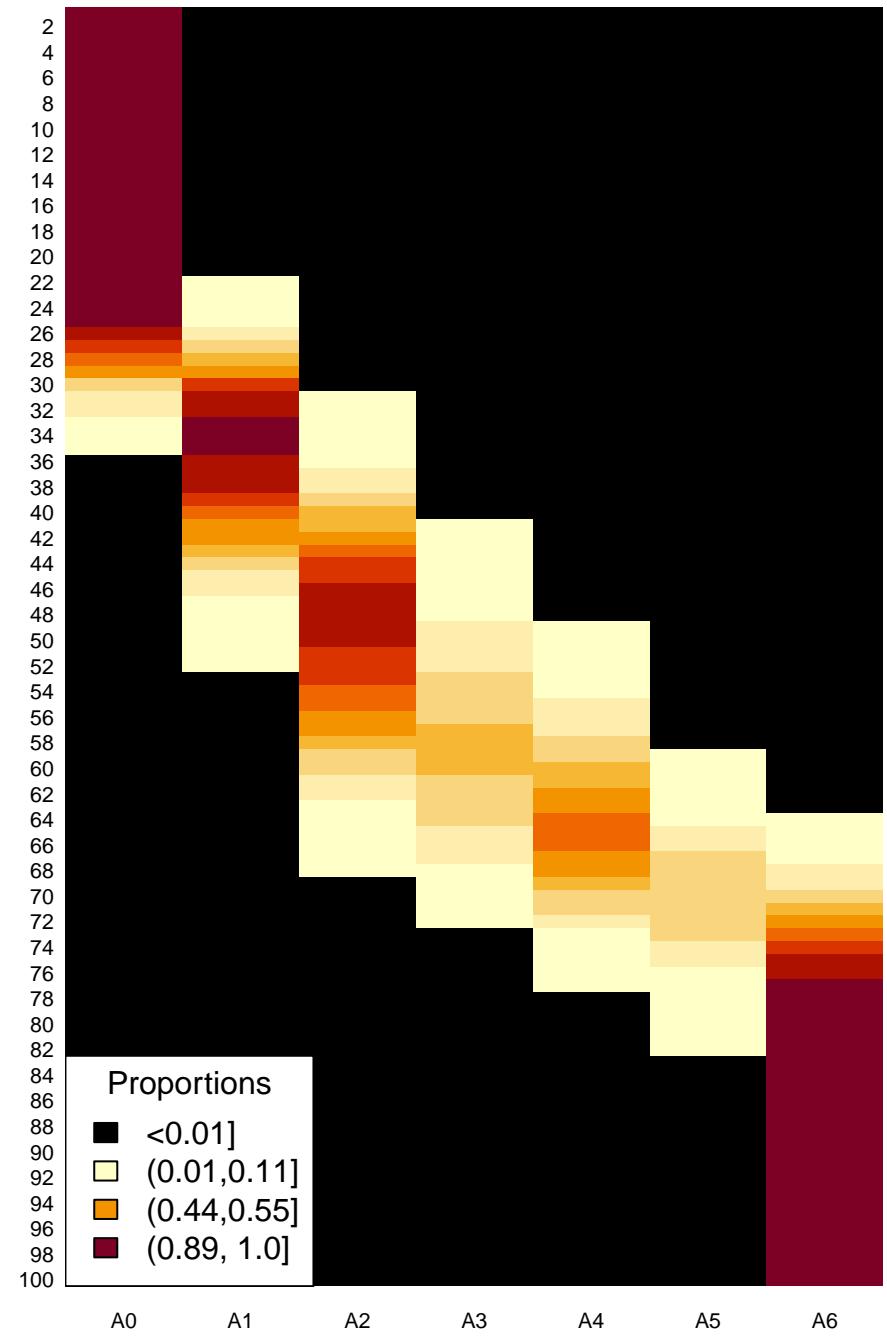
Multinomial ALK, fall 1992



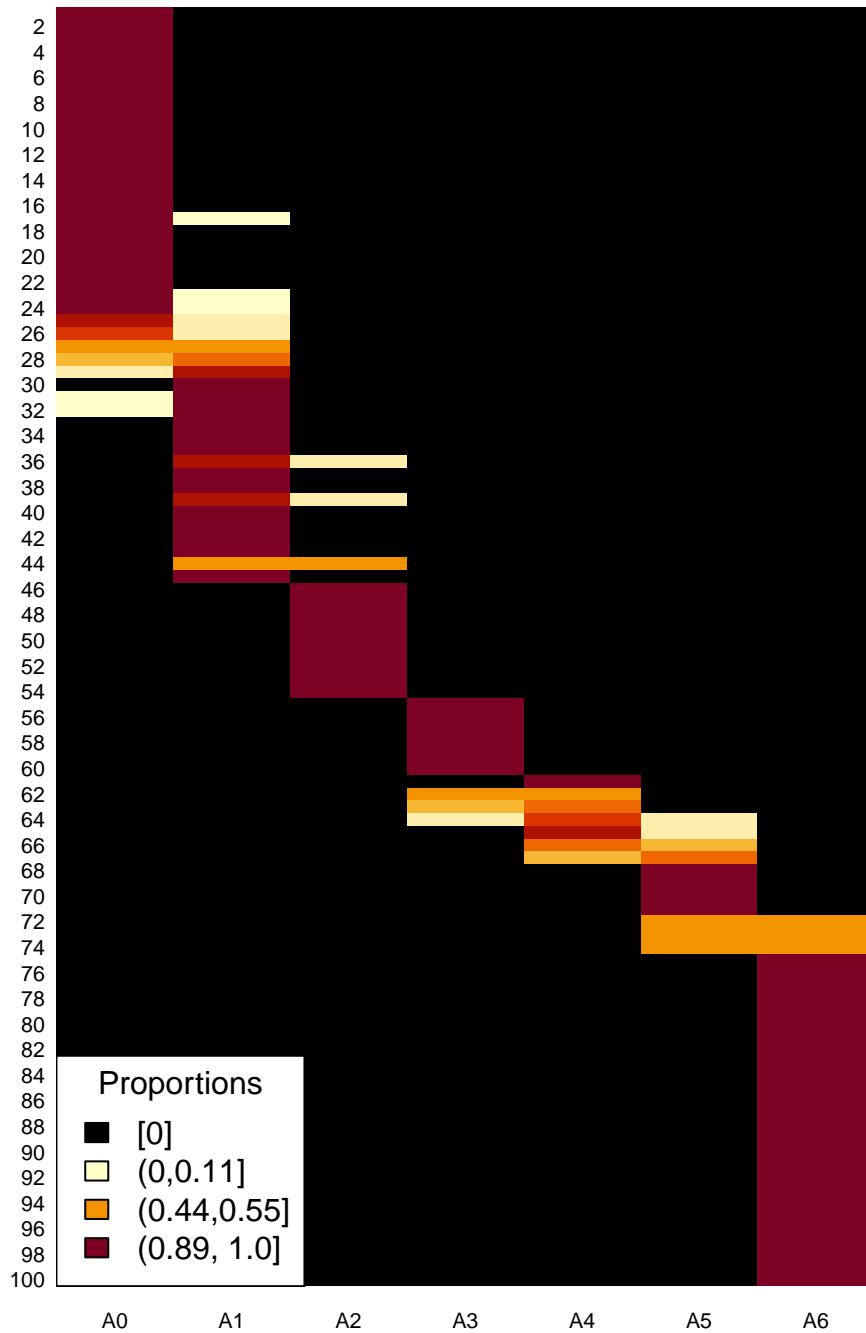
Traditional ALK, fall 1993



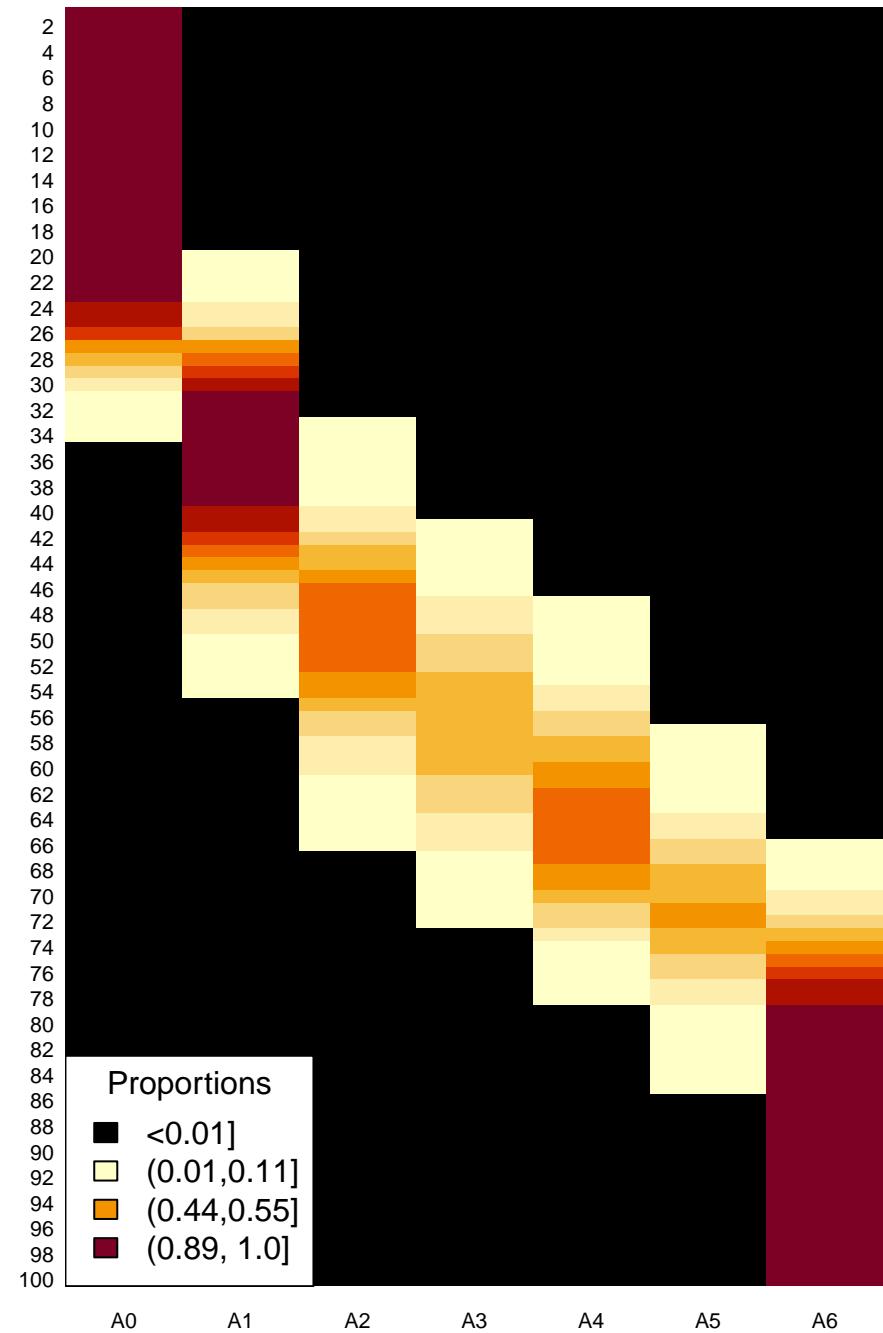
Multinomial ALK, fall 1993



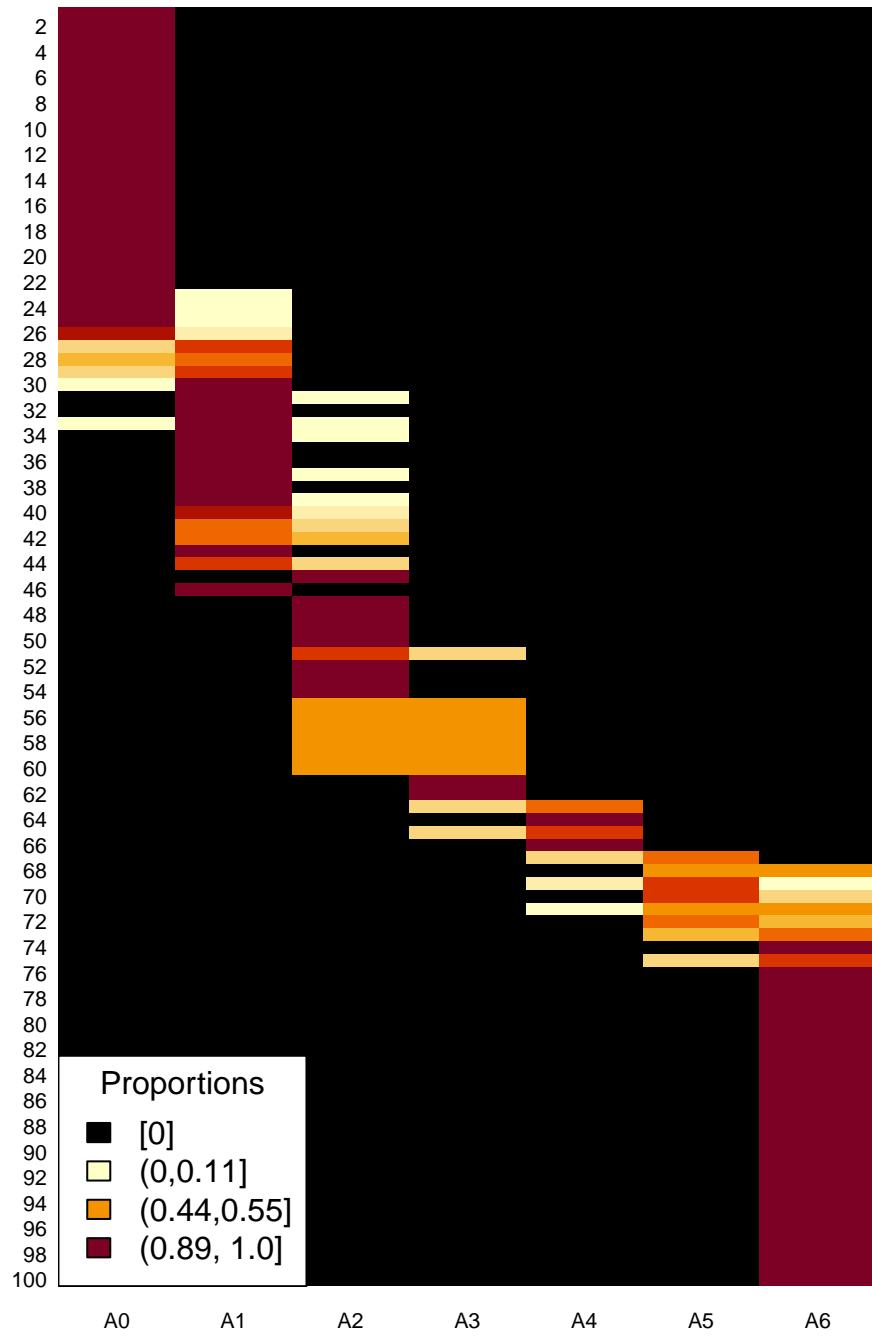
Traditional ALK, fall 1994



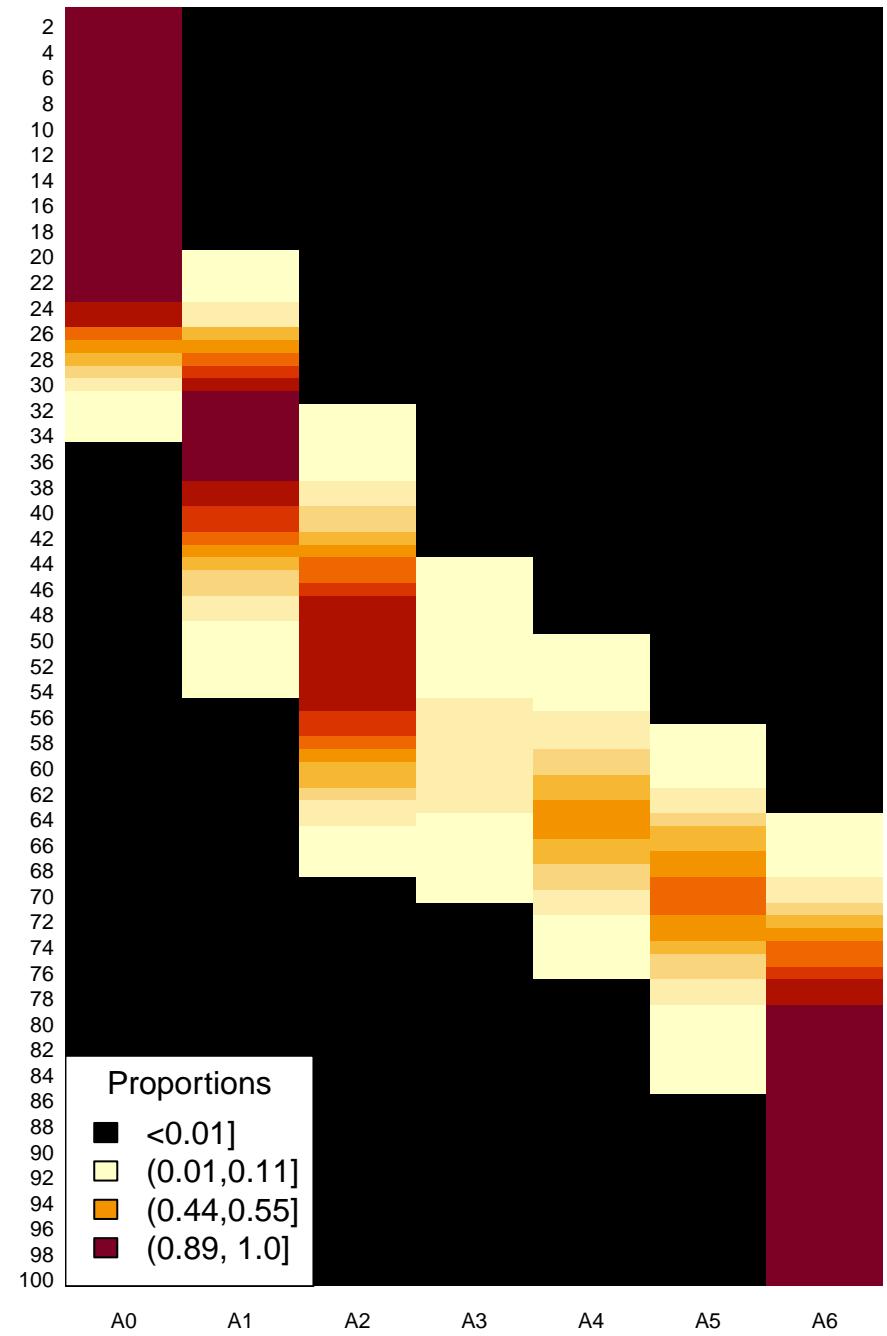
Multinomial ALK, fall 1994



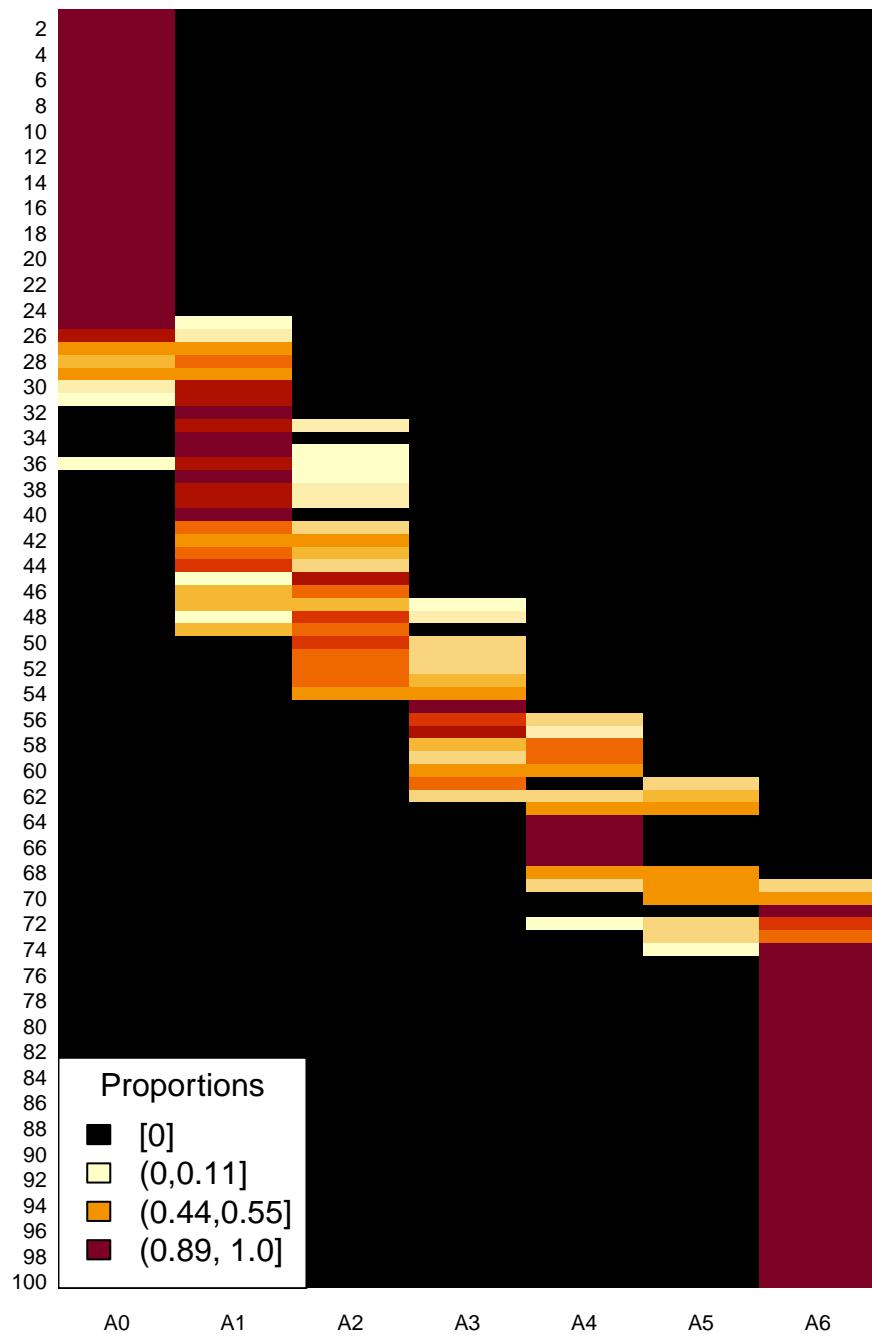
Traditional ALK, fall 1995



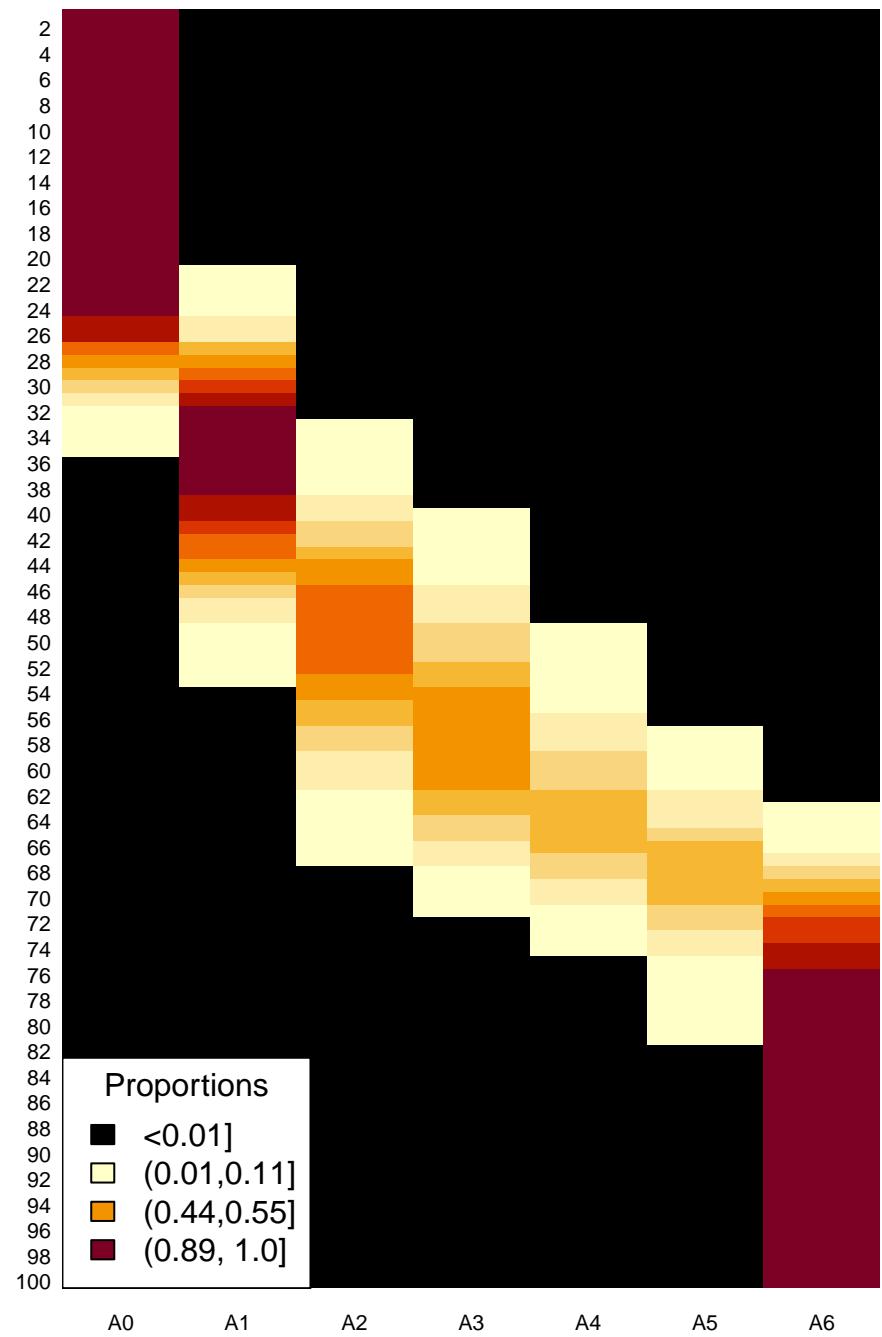
Multinomial ALK, fall 1995



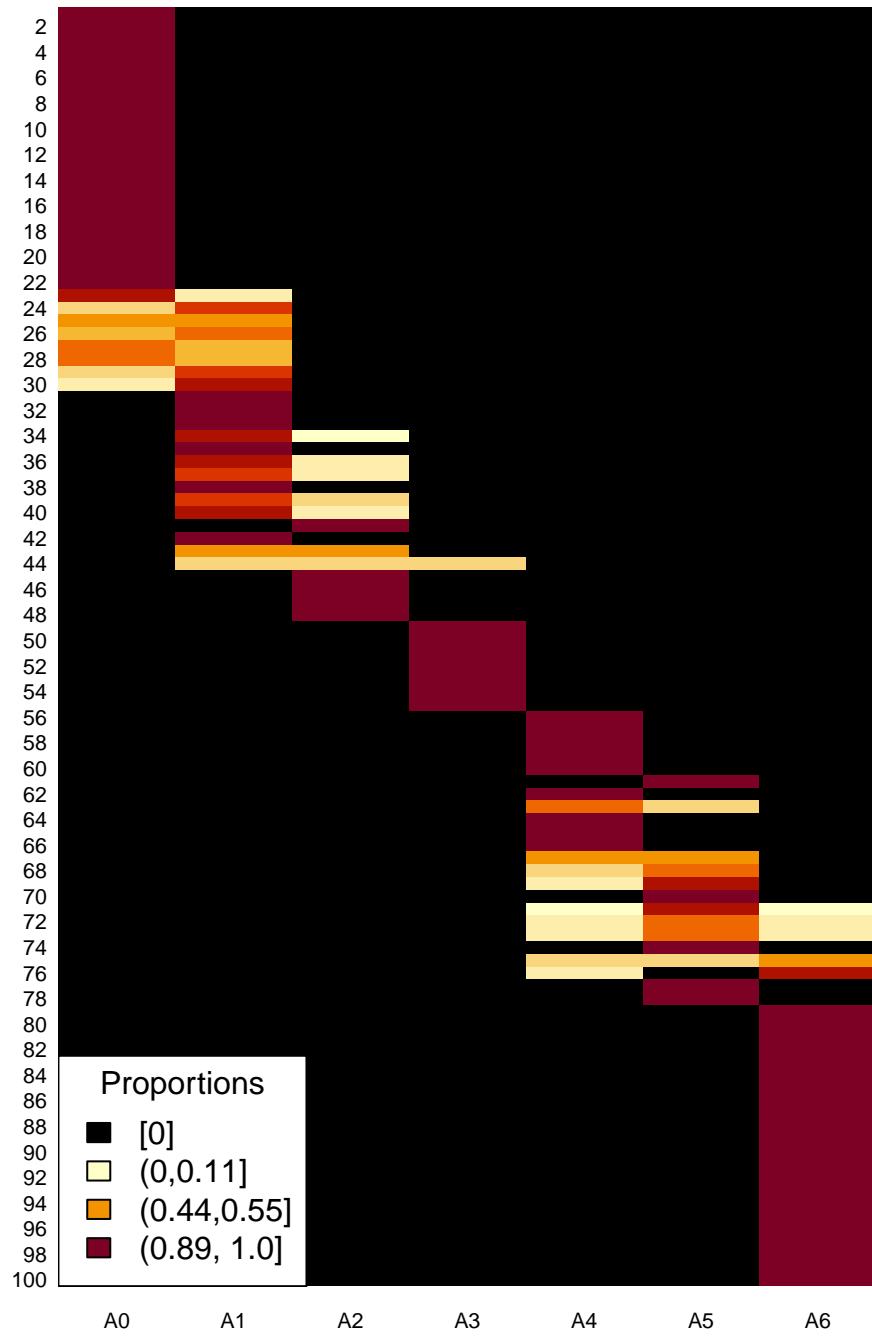
Traditional ALK, fall 1996



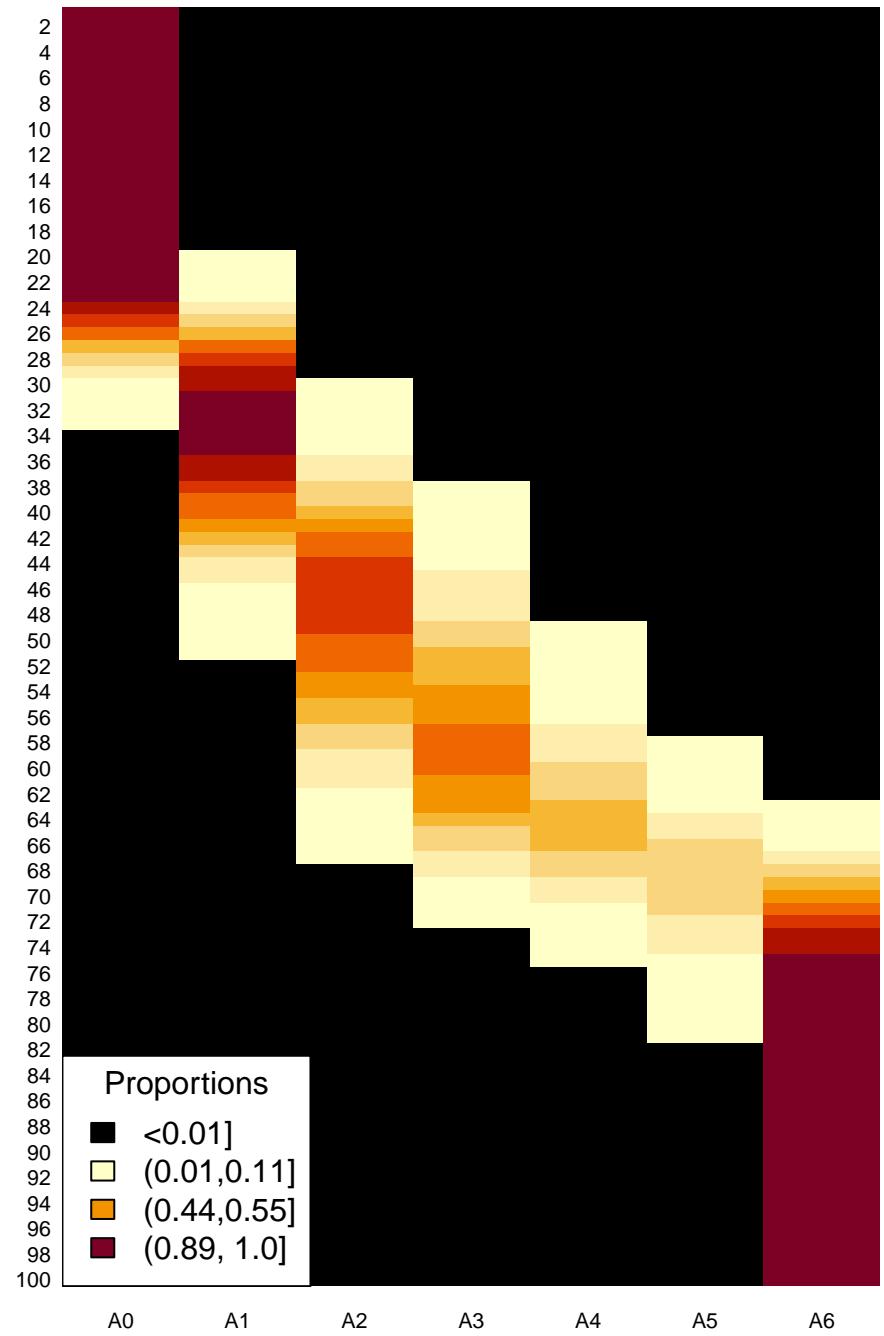
Multinomial ALK, fall 1996



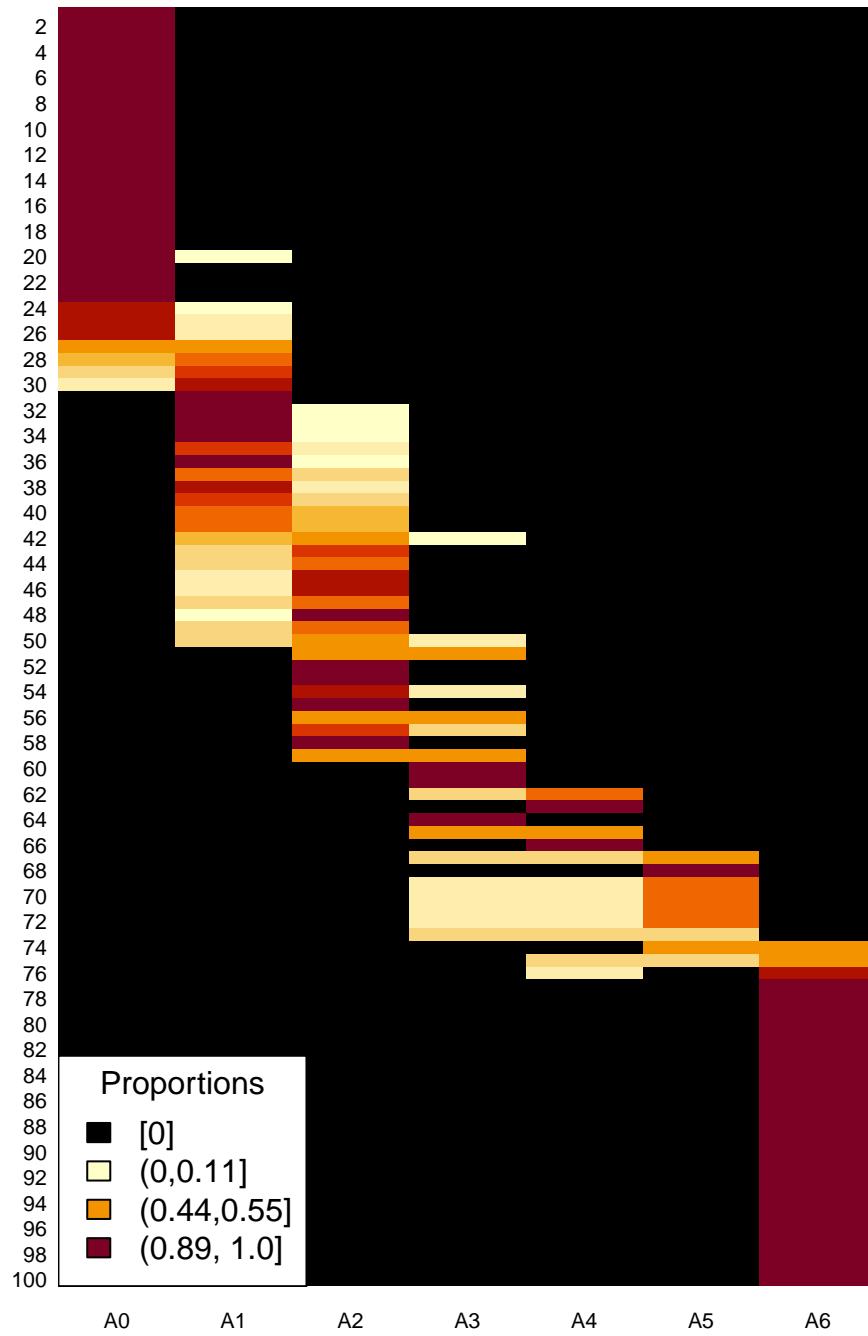
Traditional ALK, fall 1997



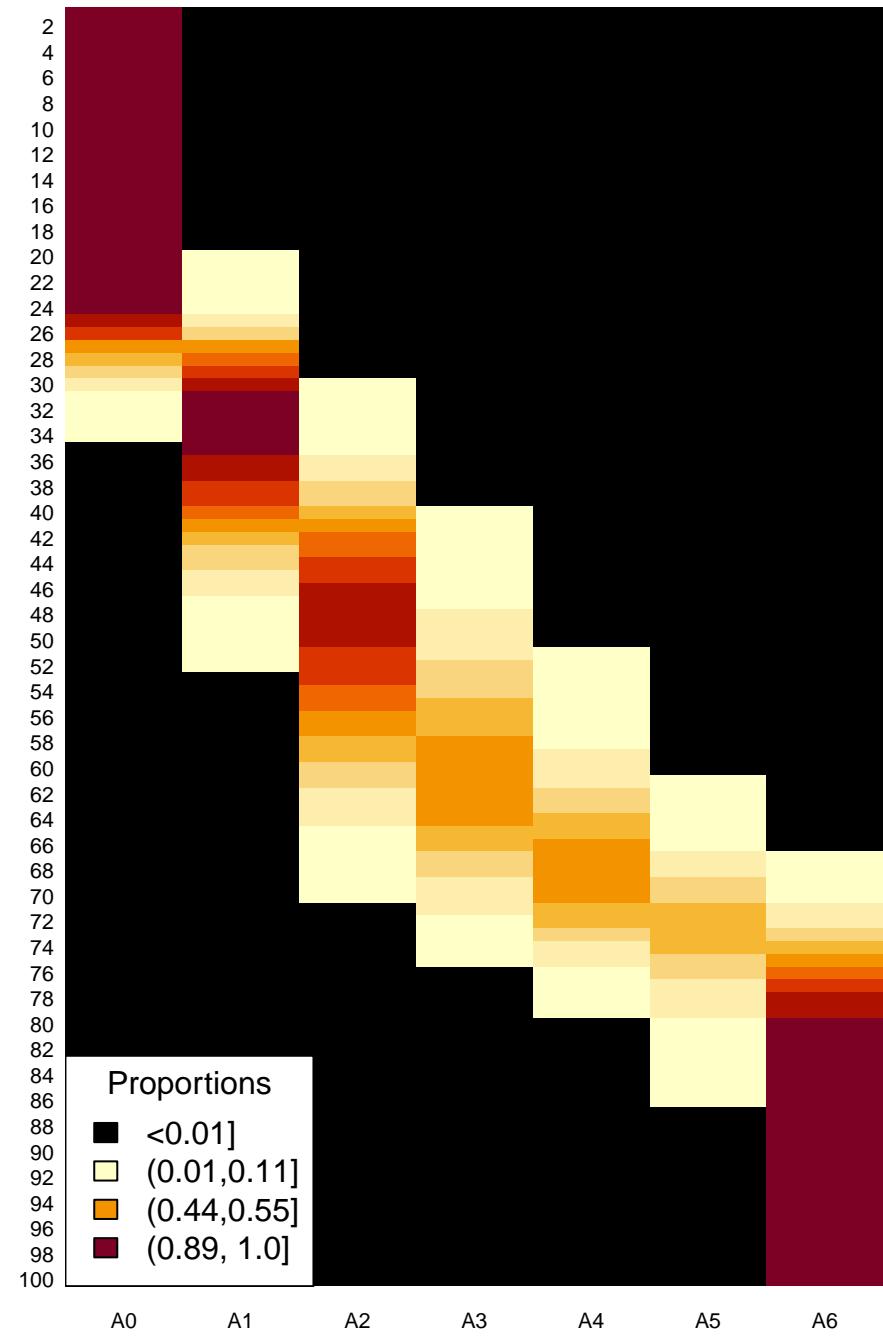
Multinomial ALK, fall 1997



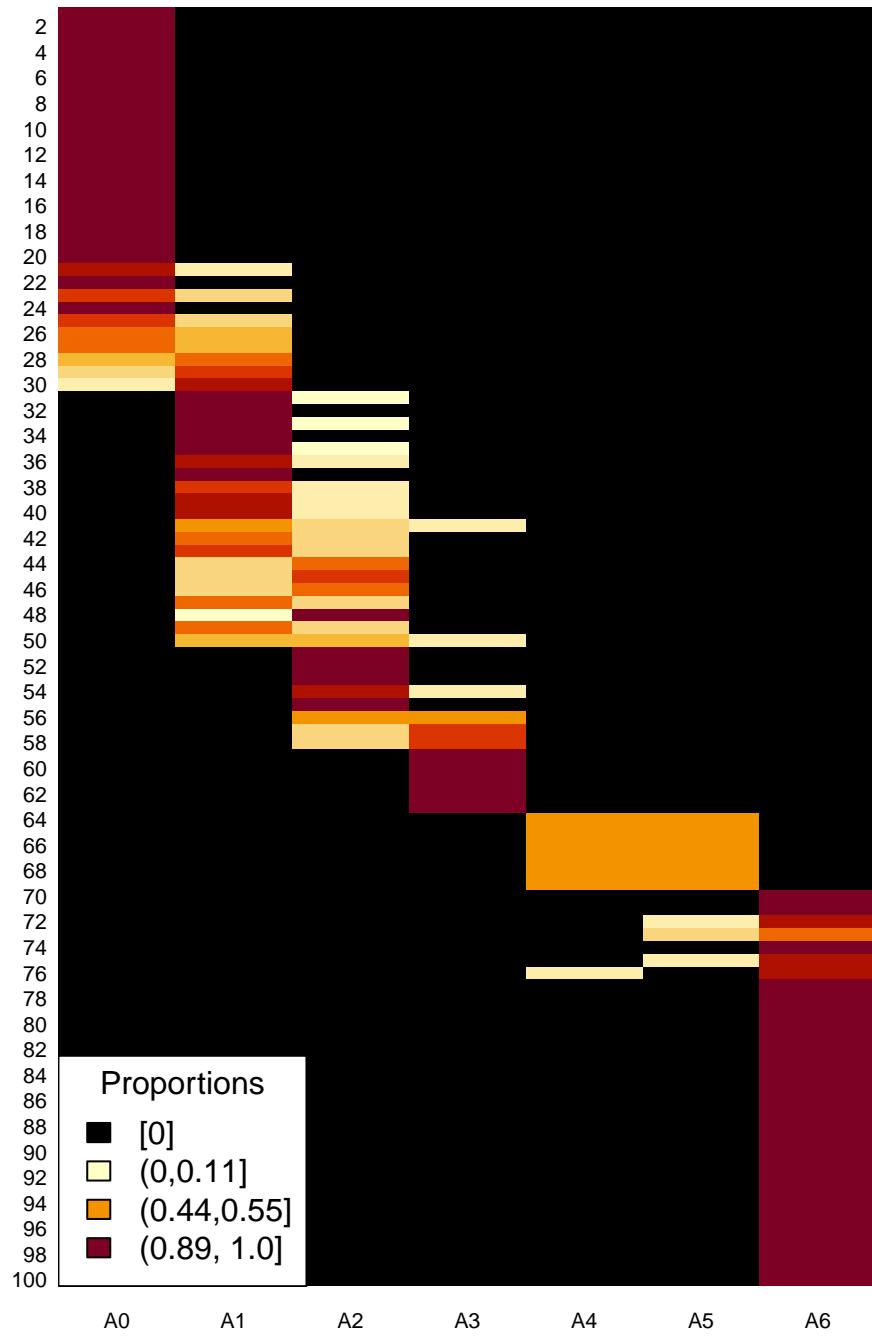
Traditional ALK, fall 1998



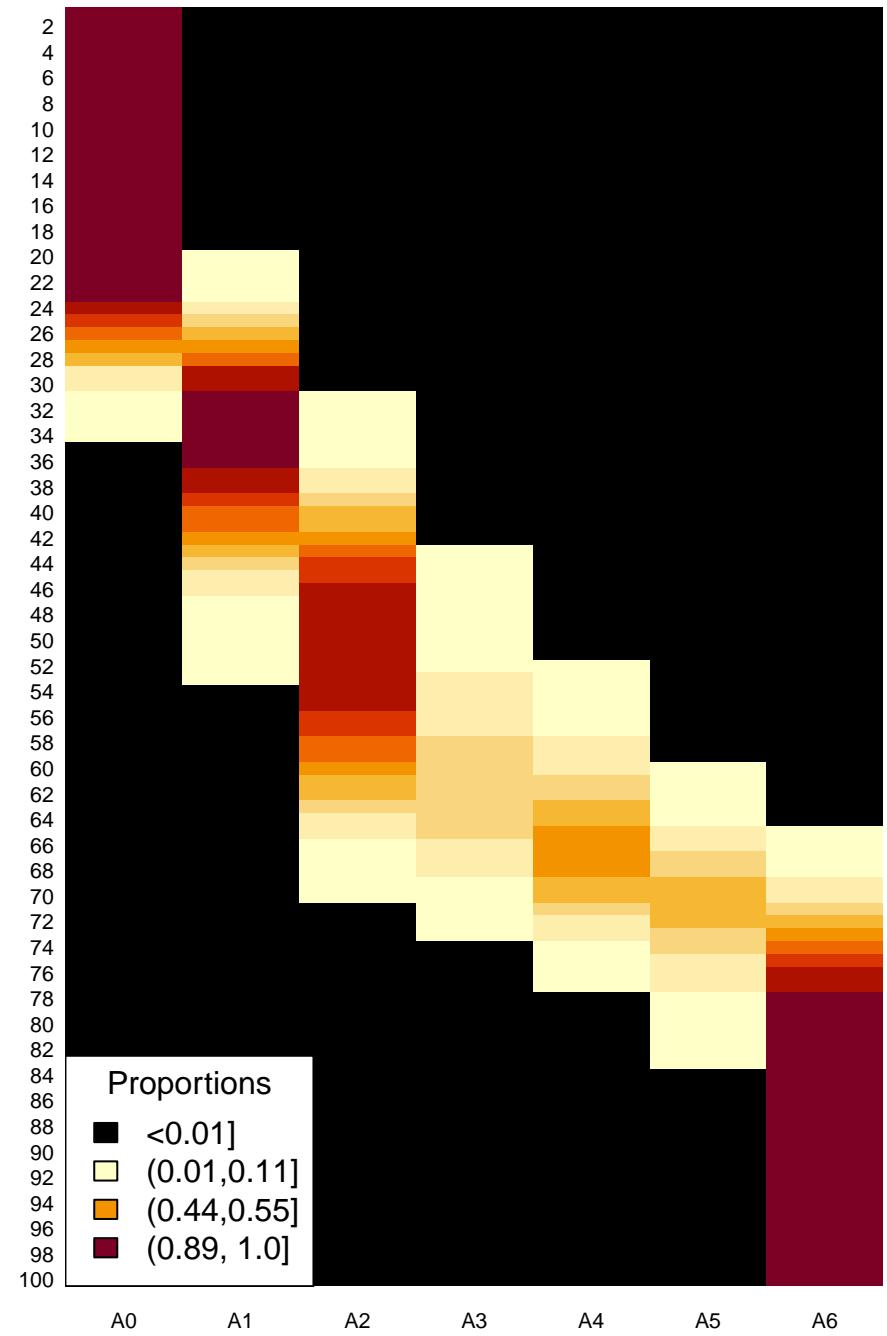
Multinomial ALK, fall 1998



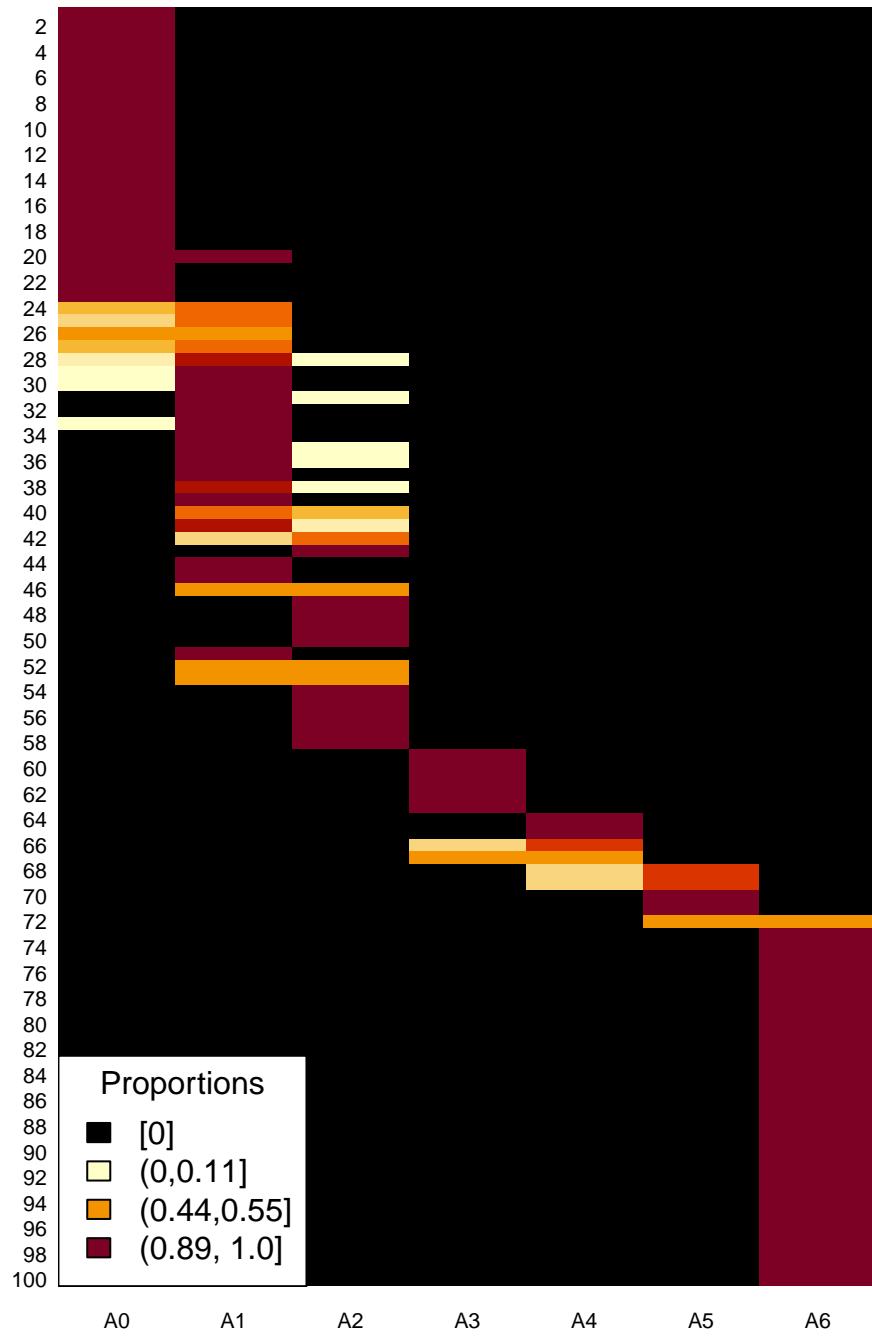
Traditional ALK, fall 1999



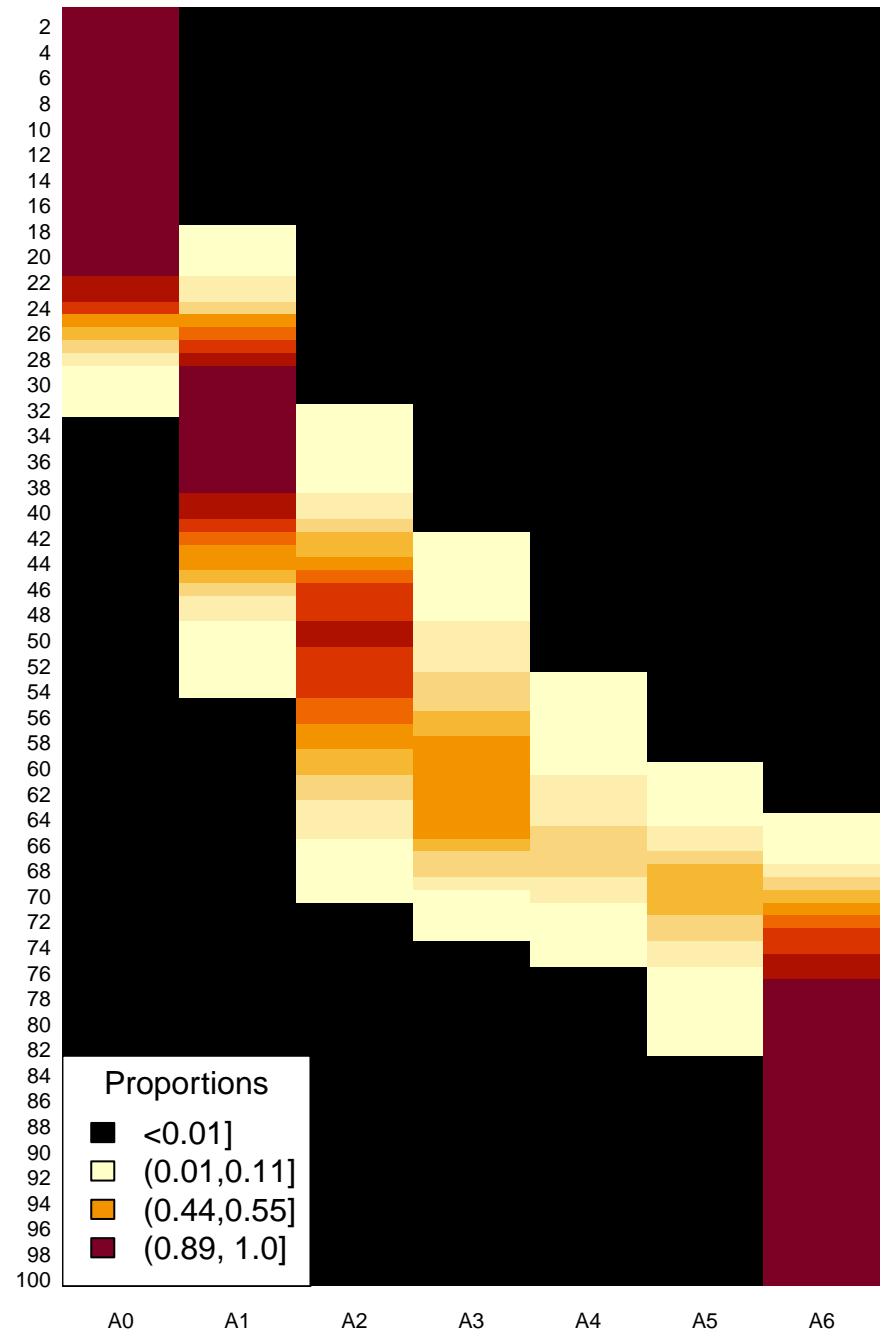
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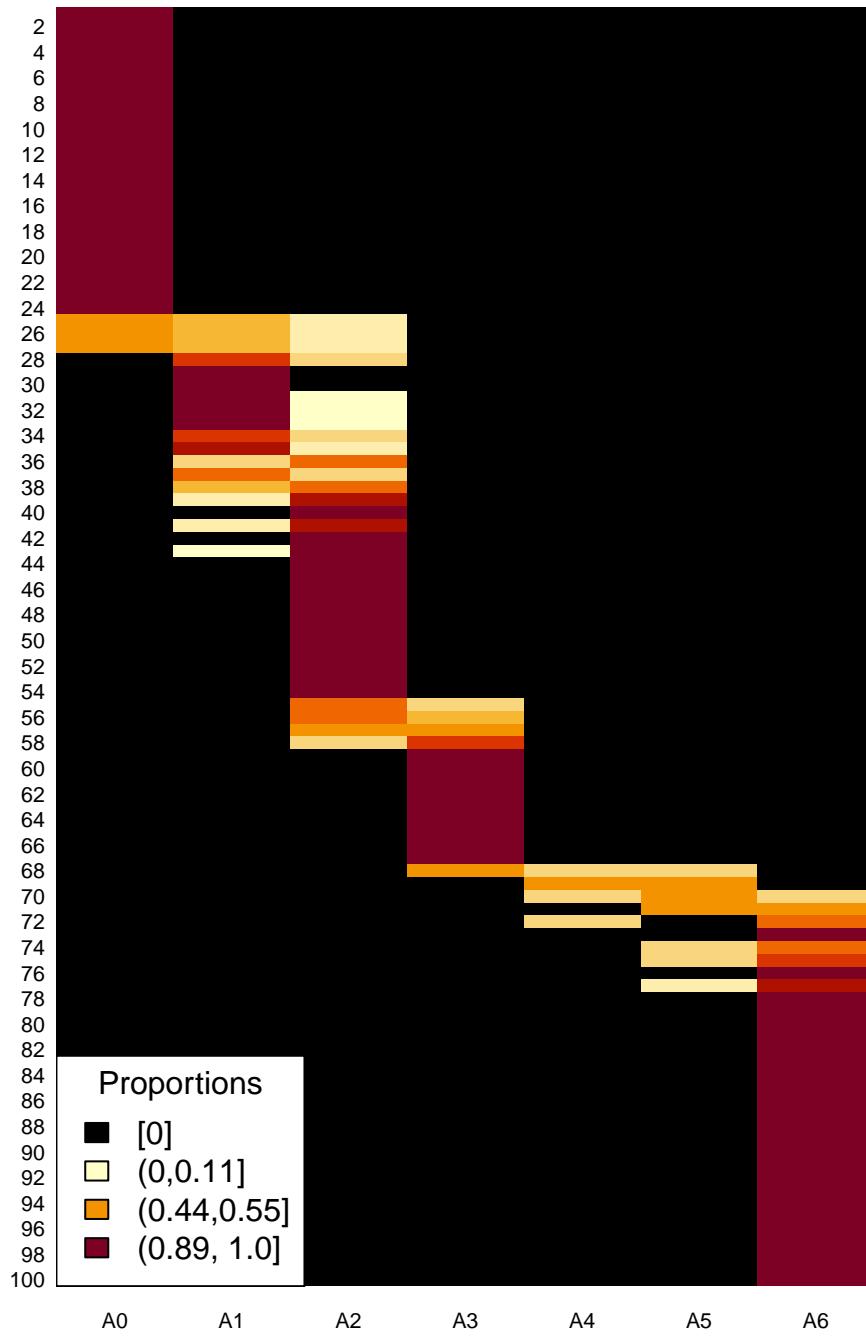
Traditional ALK, fall 2000



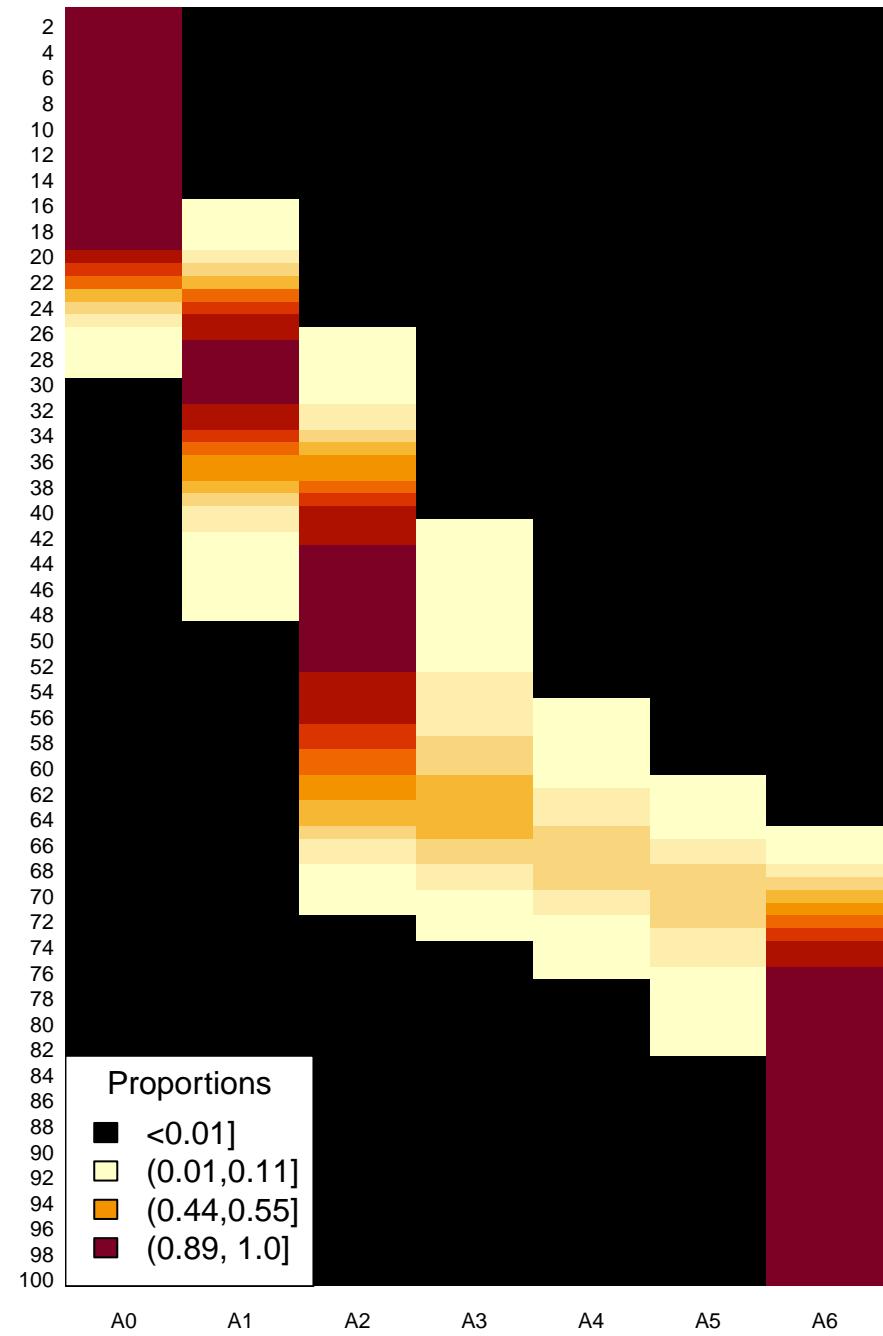
Multinomial ALK, fall 2000



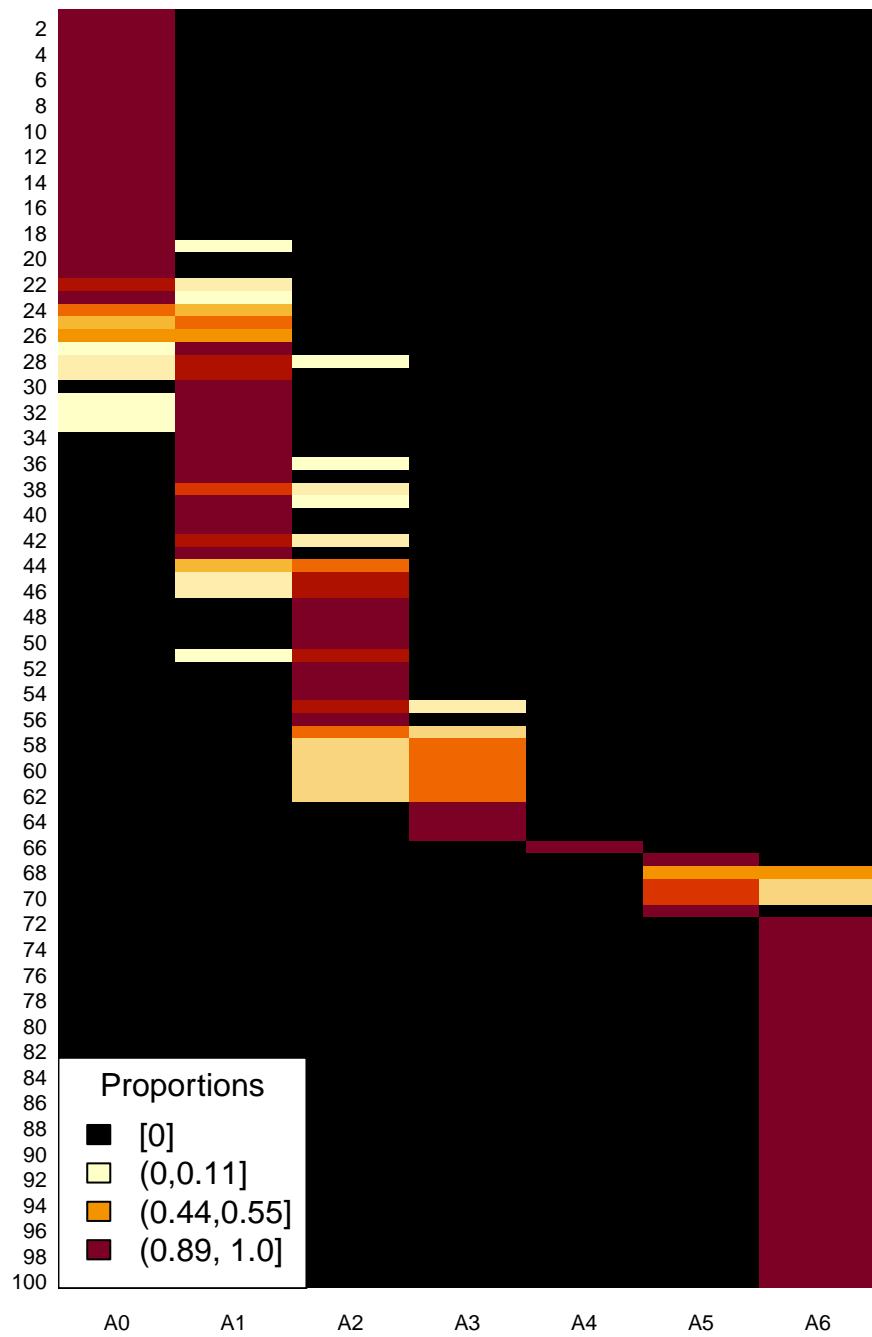
Traditional ALK, fall 2001



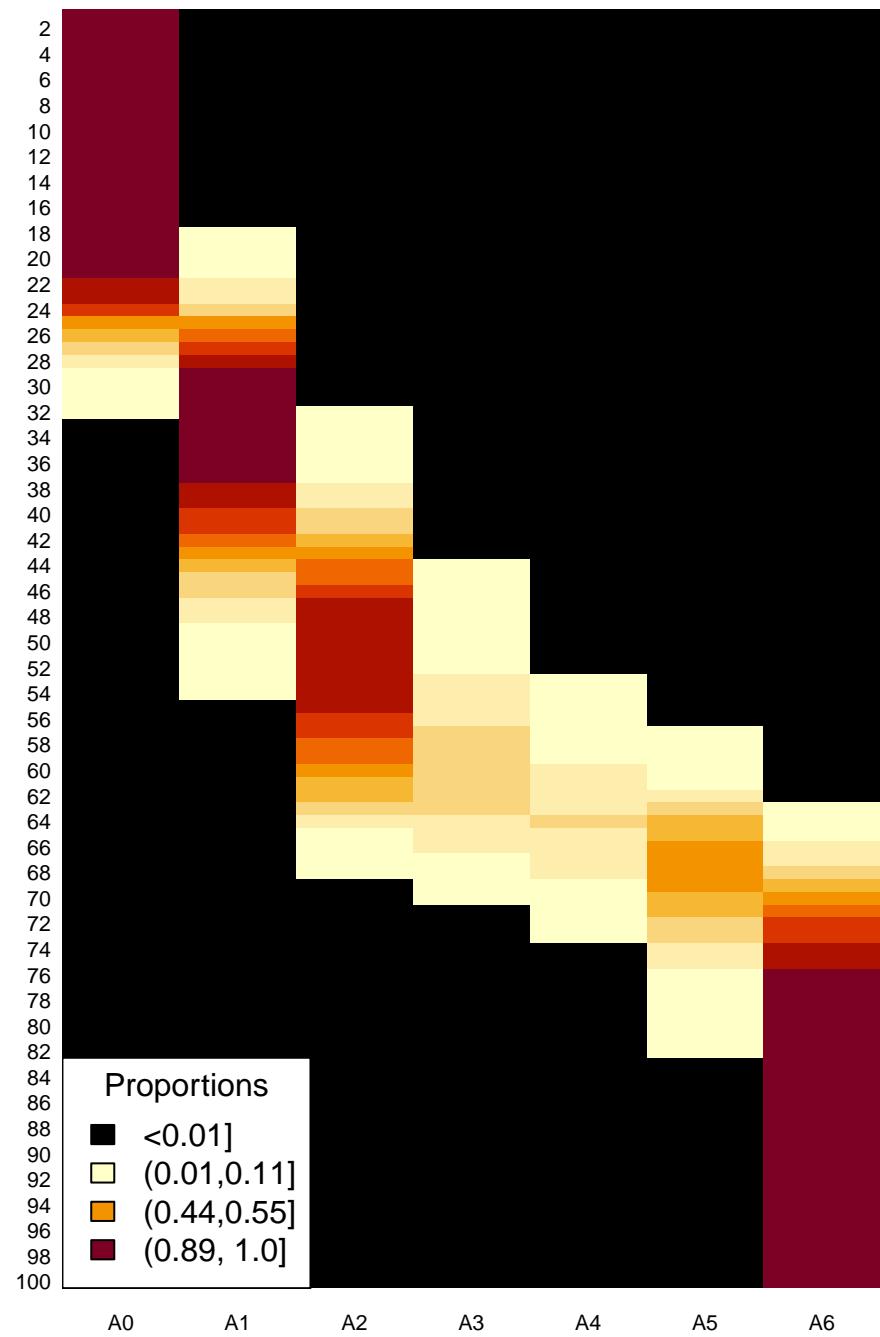
Multinomial ALK, fall 2001



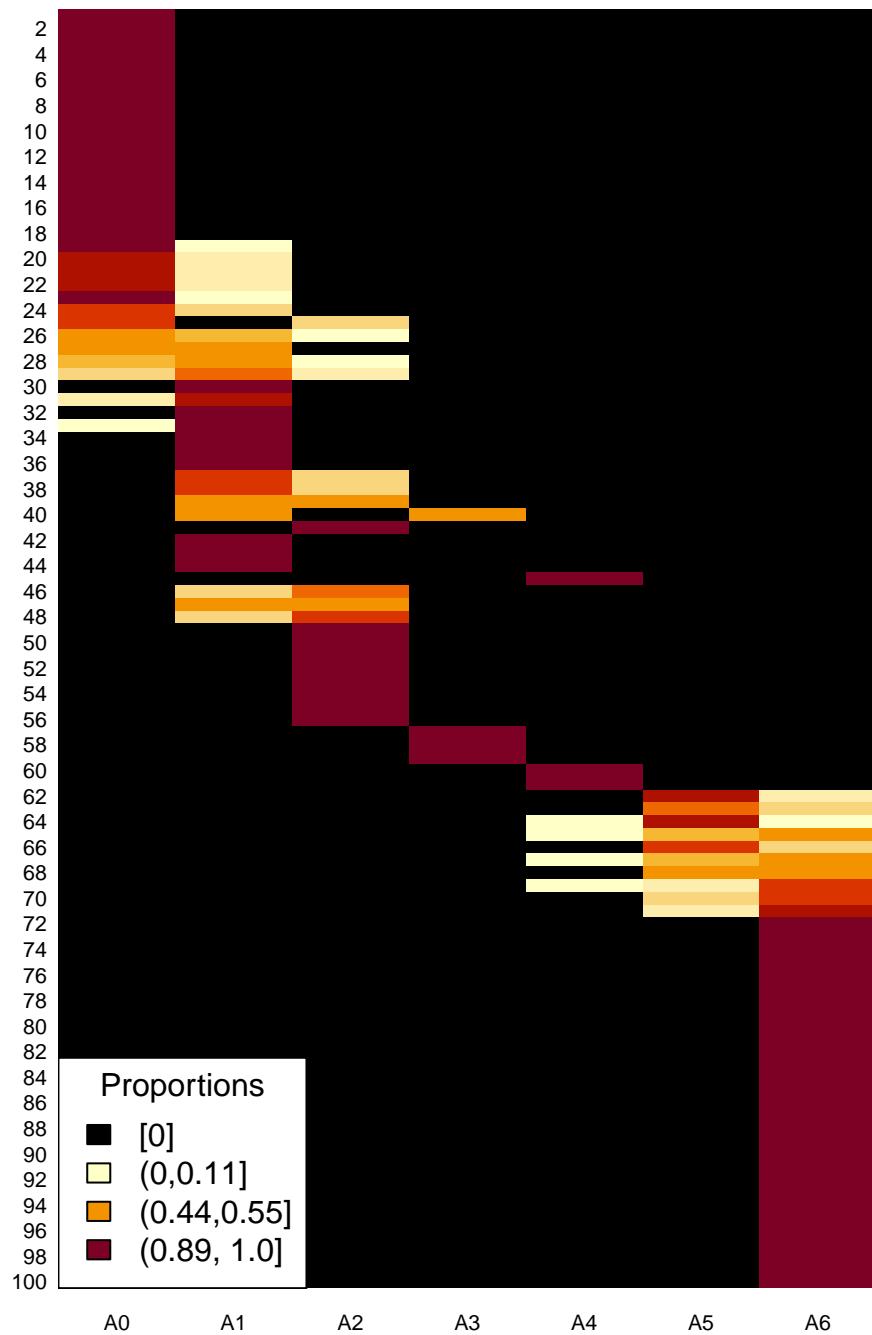
Traditional ALK, fall 2002



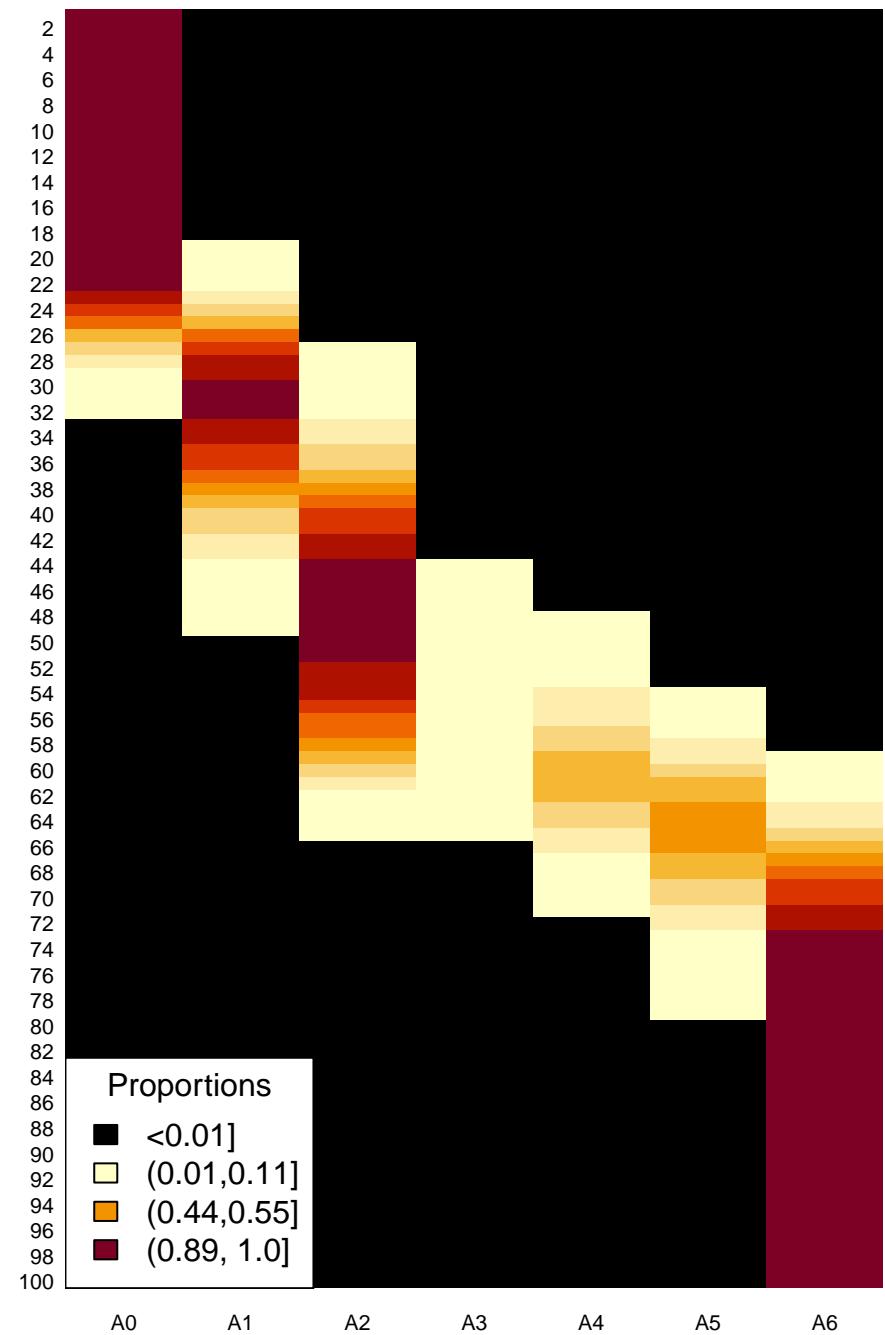
Multinomial ALK, fall 2002



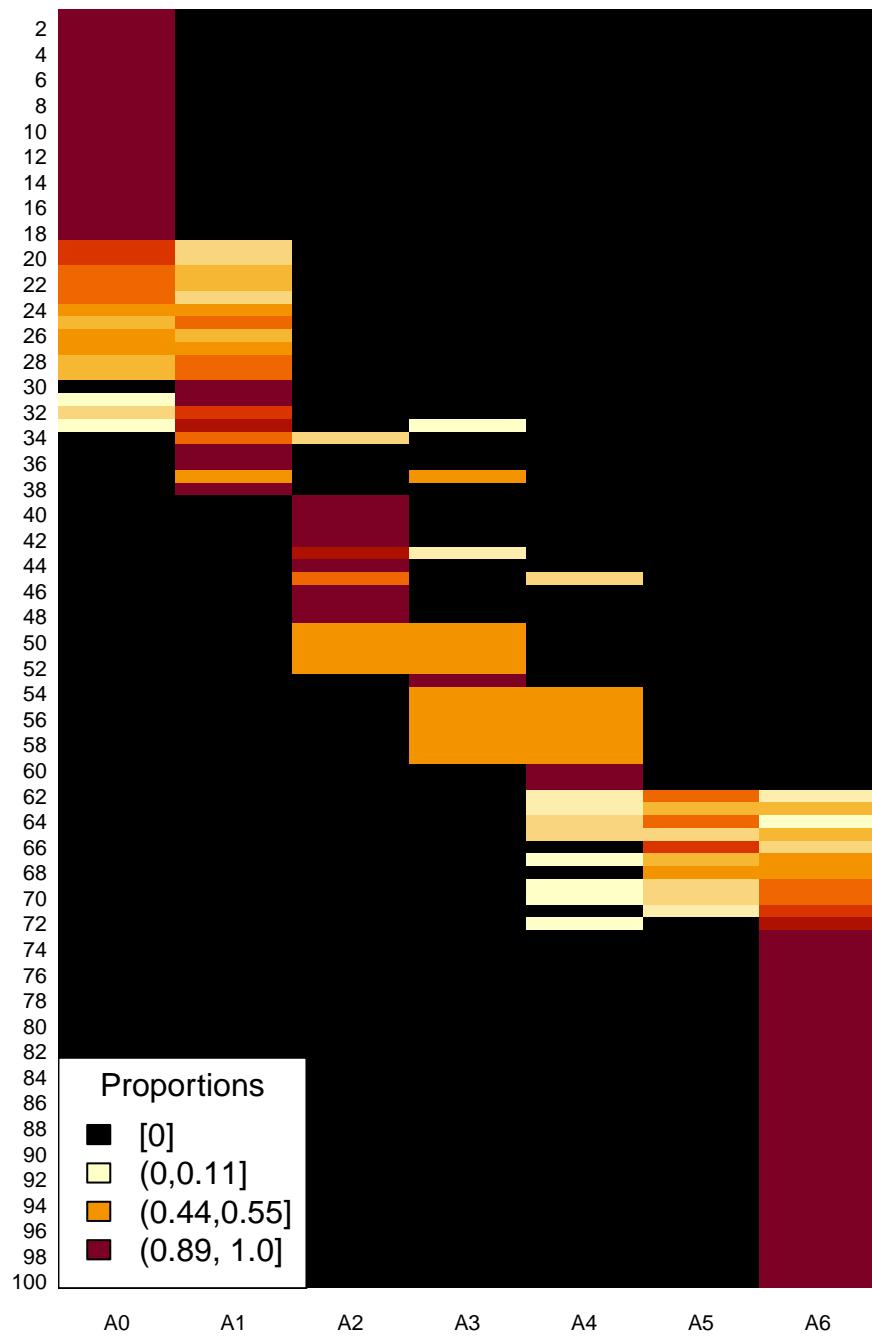
Traditional ALK, fall 2003



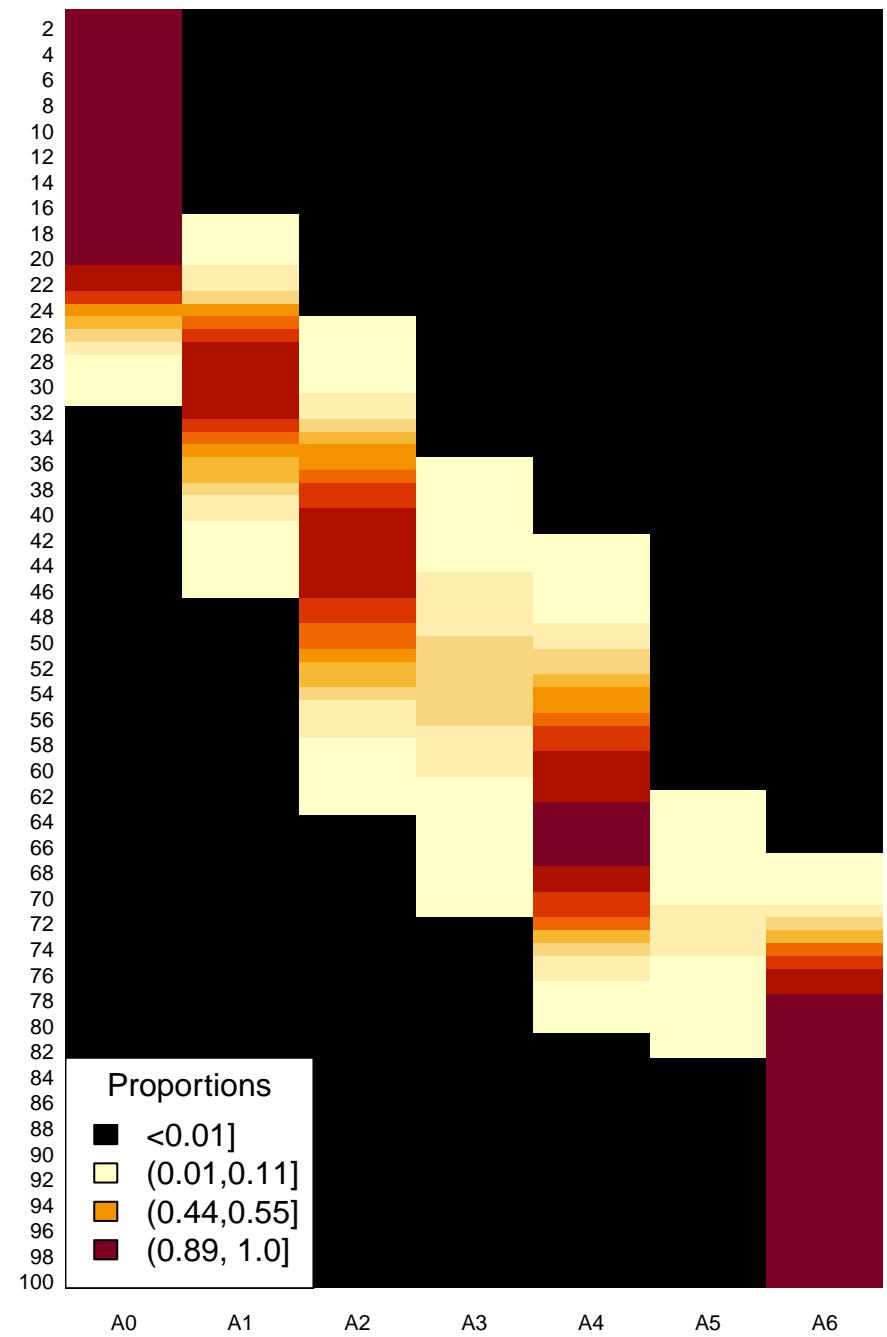
Multinomial ALK, fall 2003



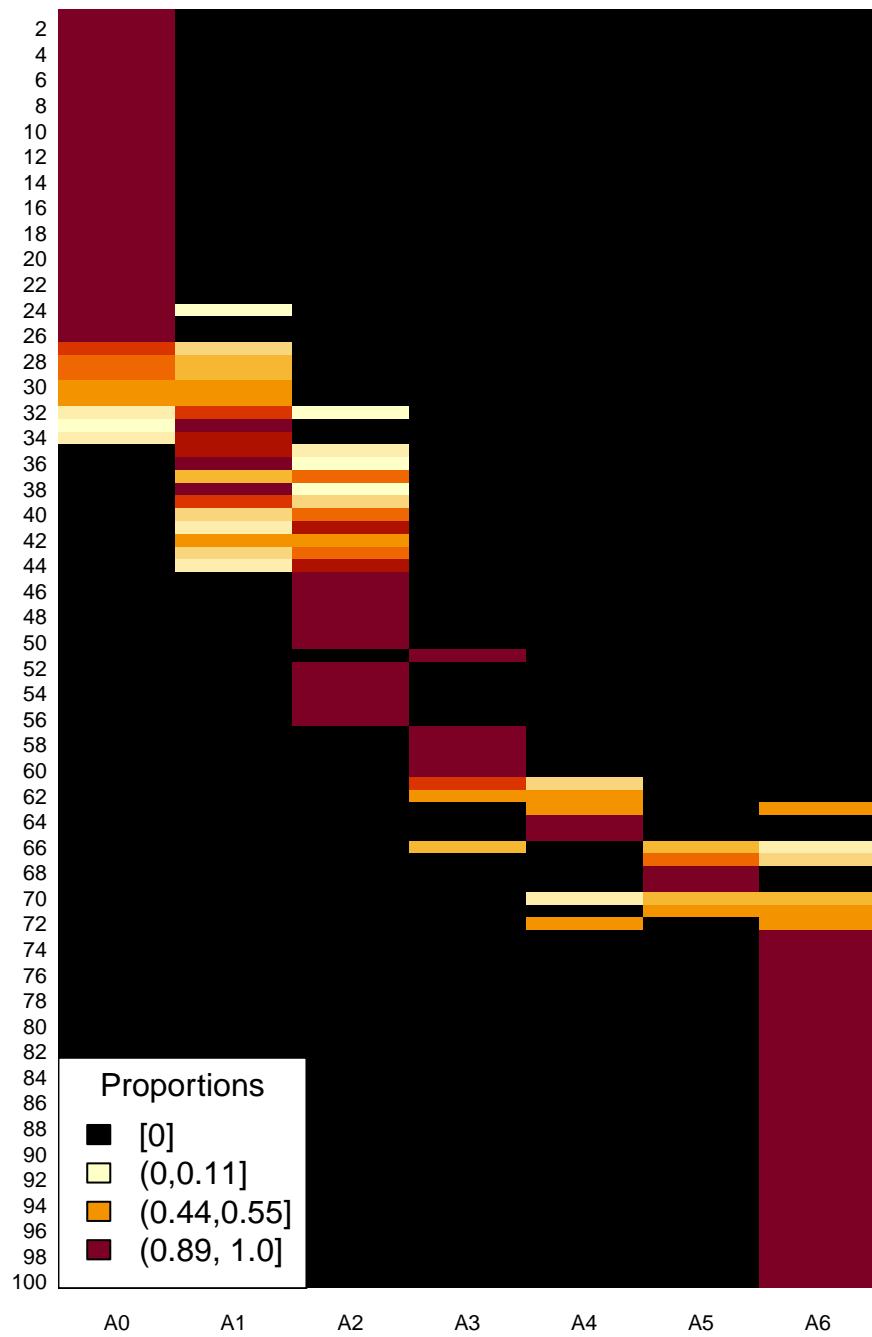
Traditional ALK, fall 2004



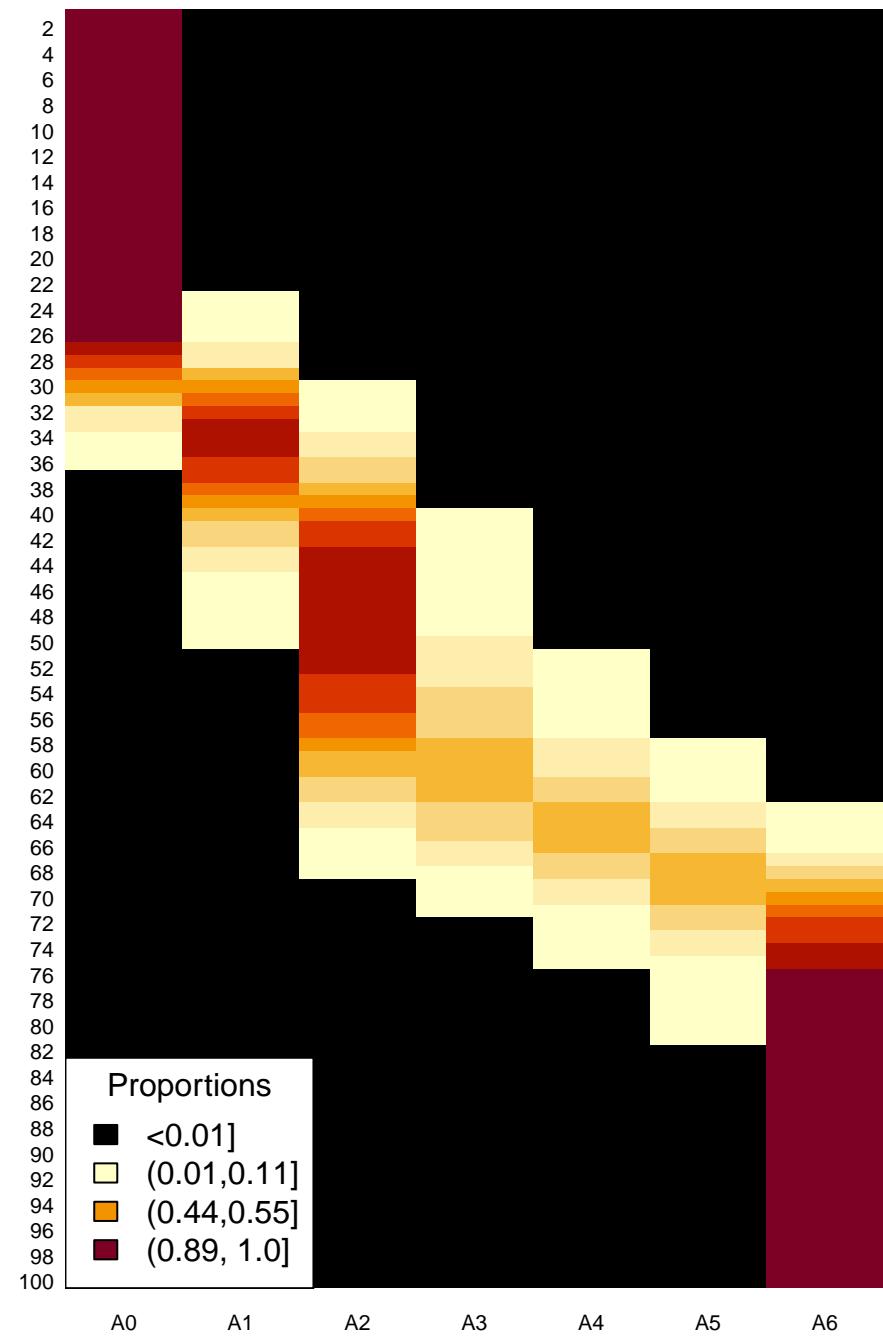
Multinomial ALK, fall 2004



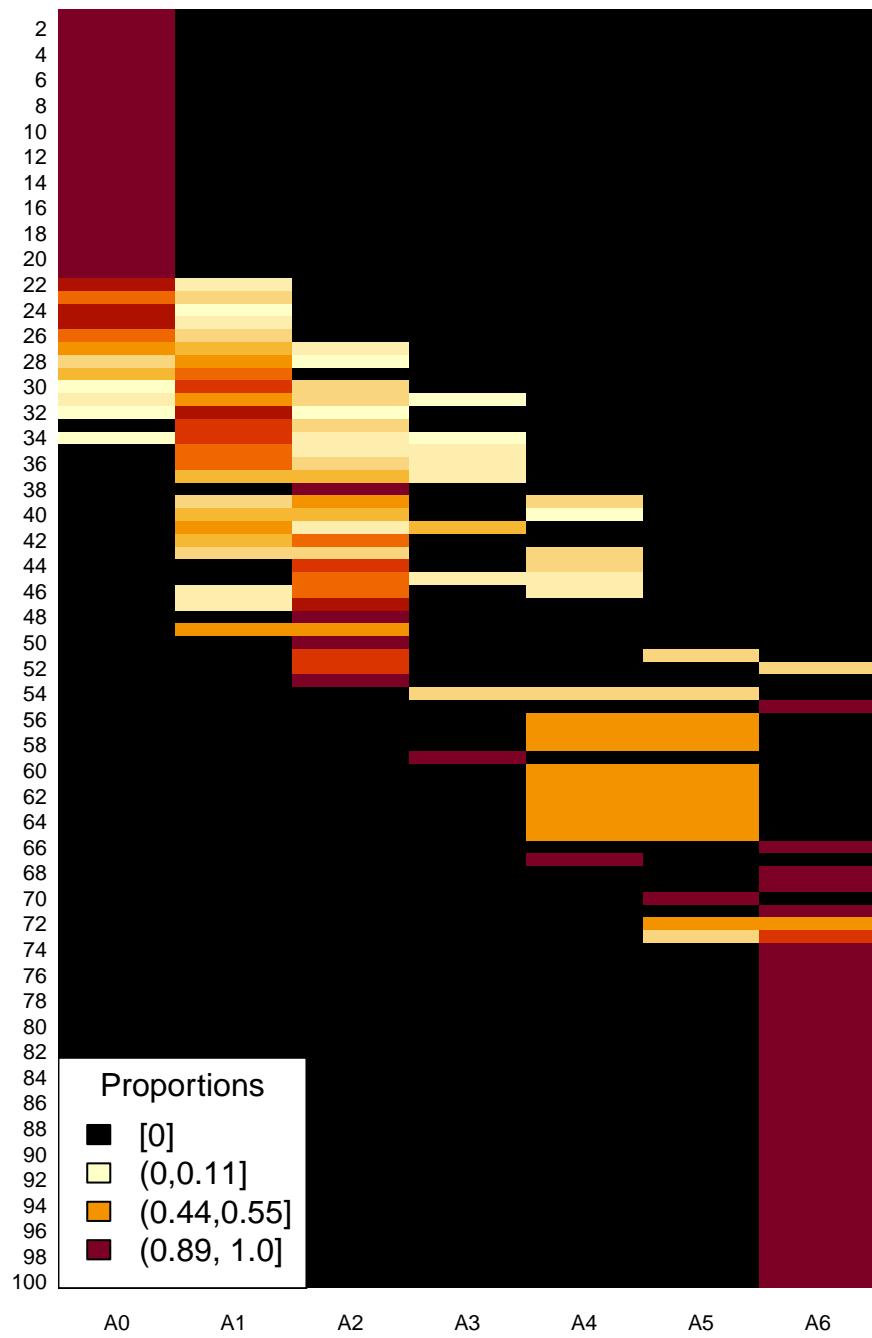
Traditional ALK, fall 2005



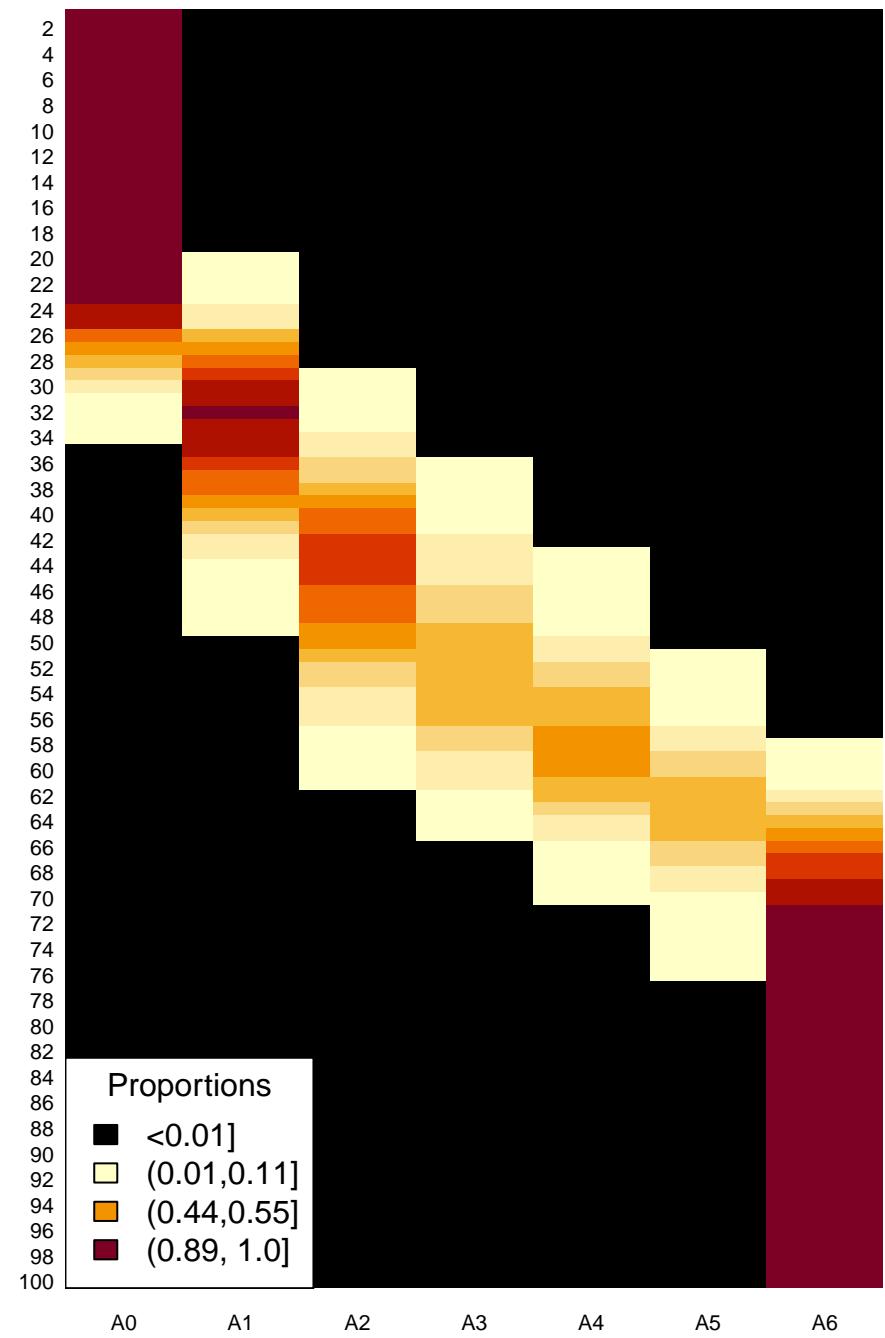
Multinomial ALK, fall 2005



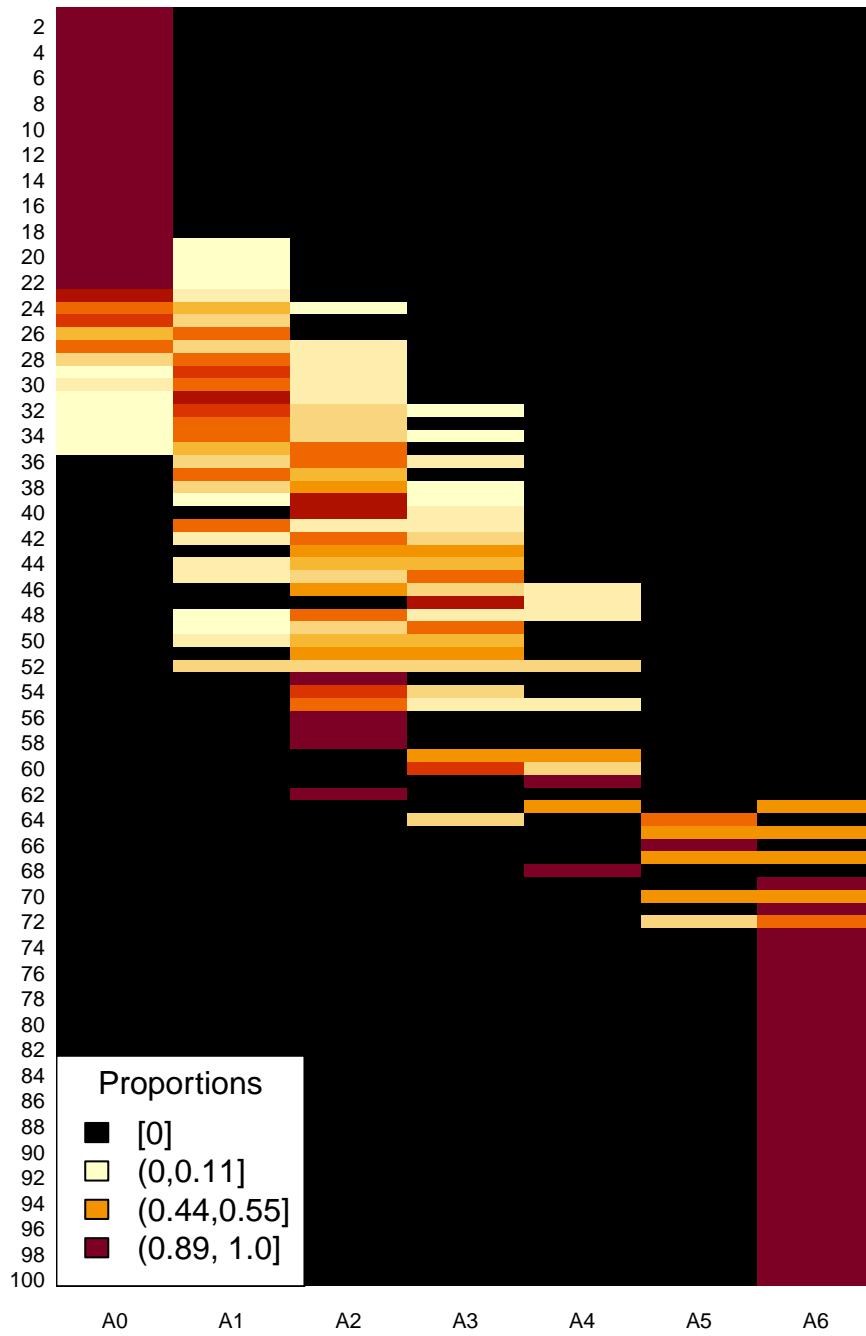
Traditional ALK, fall 2006



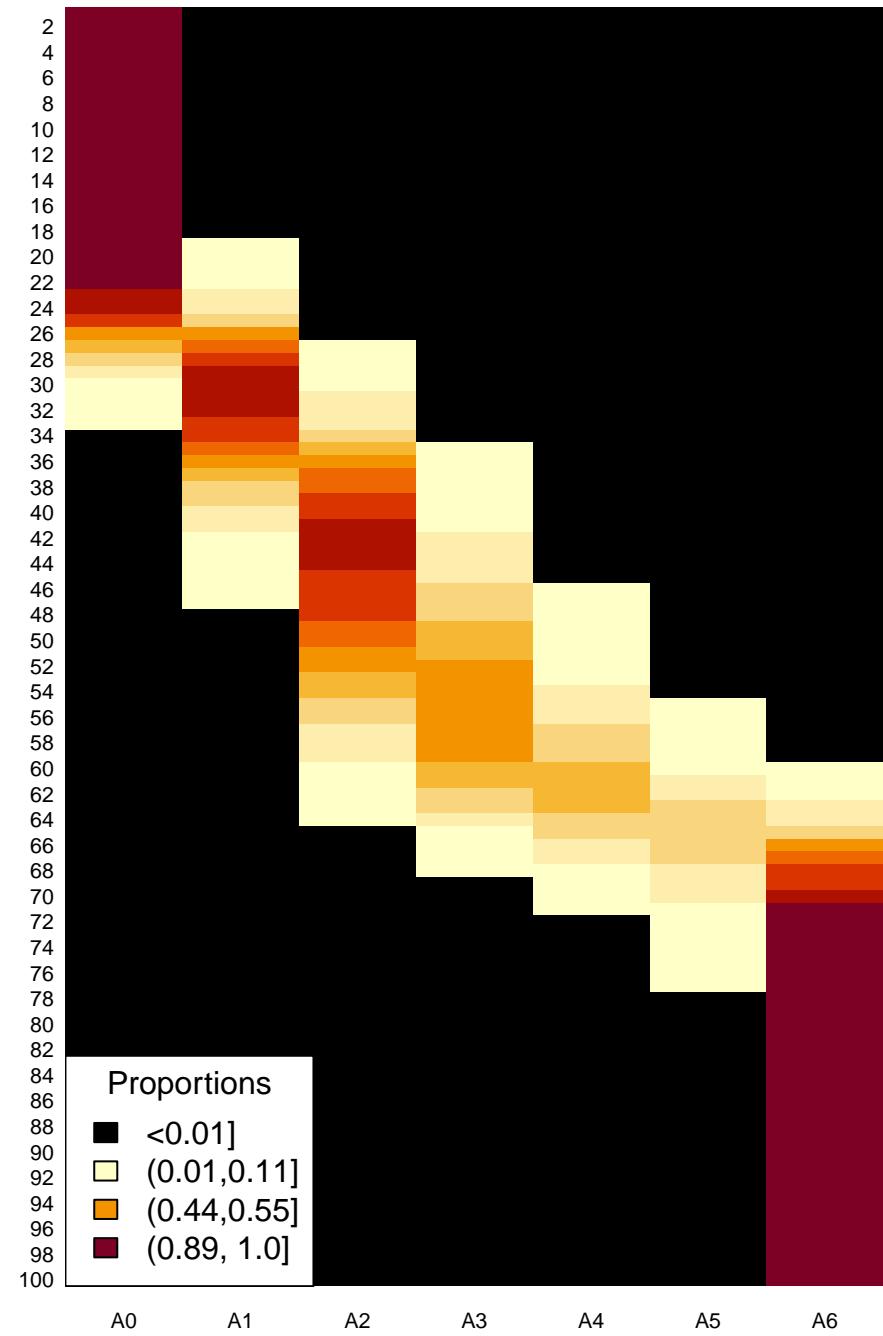
Multinomial ALK, fall 2006



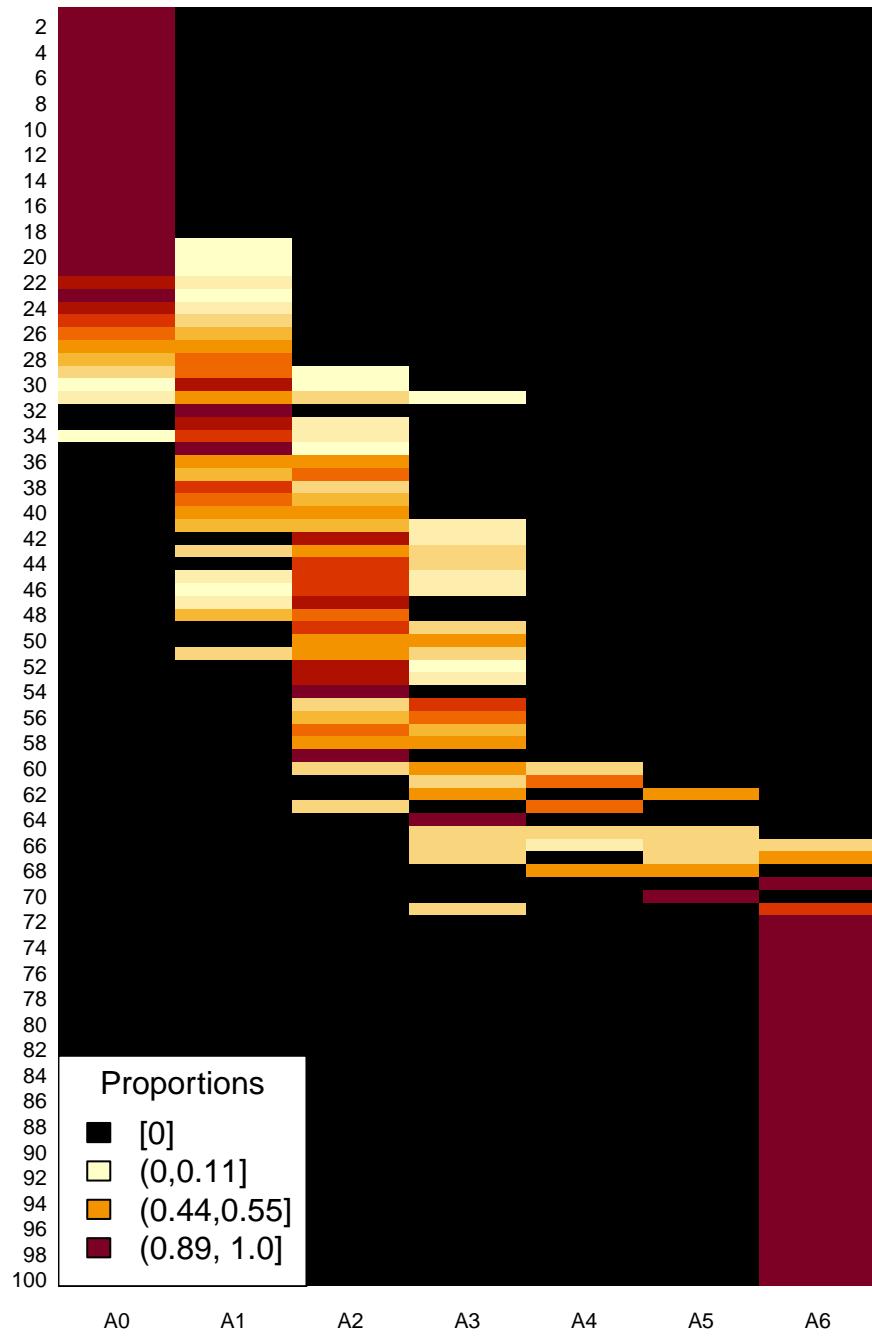
Traditional ALK, fall 2007



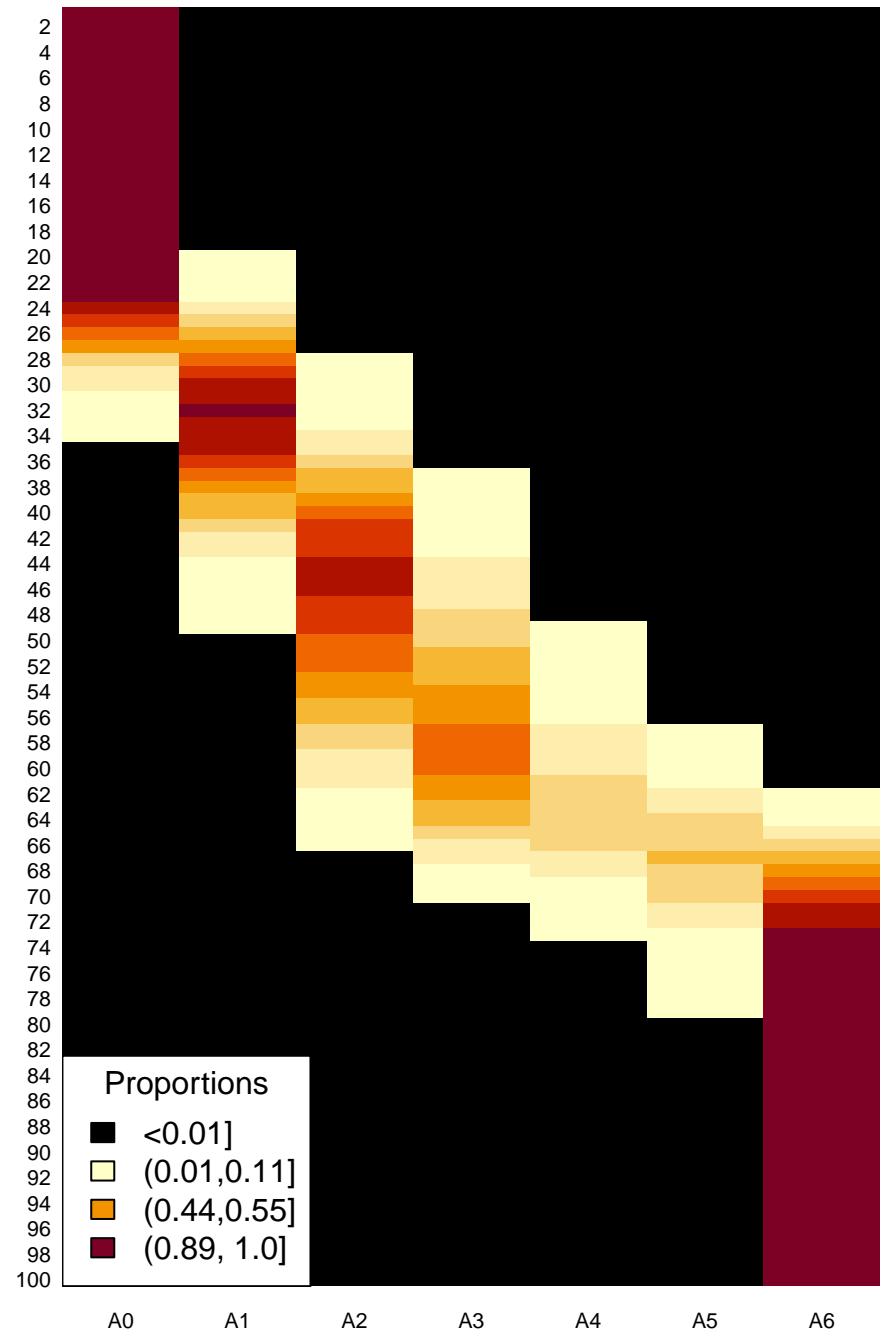
Multinomial ALK, fall 2007



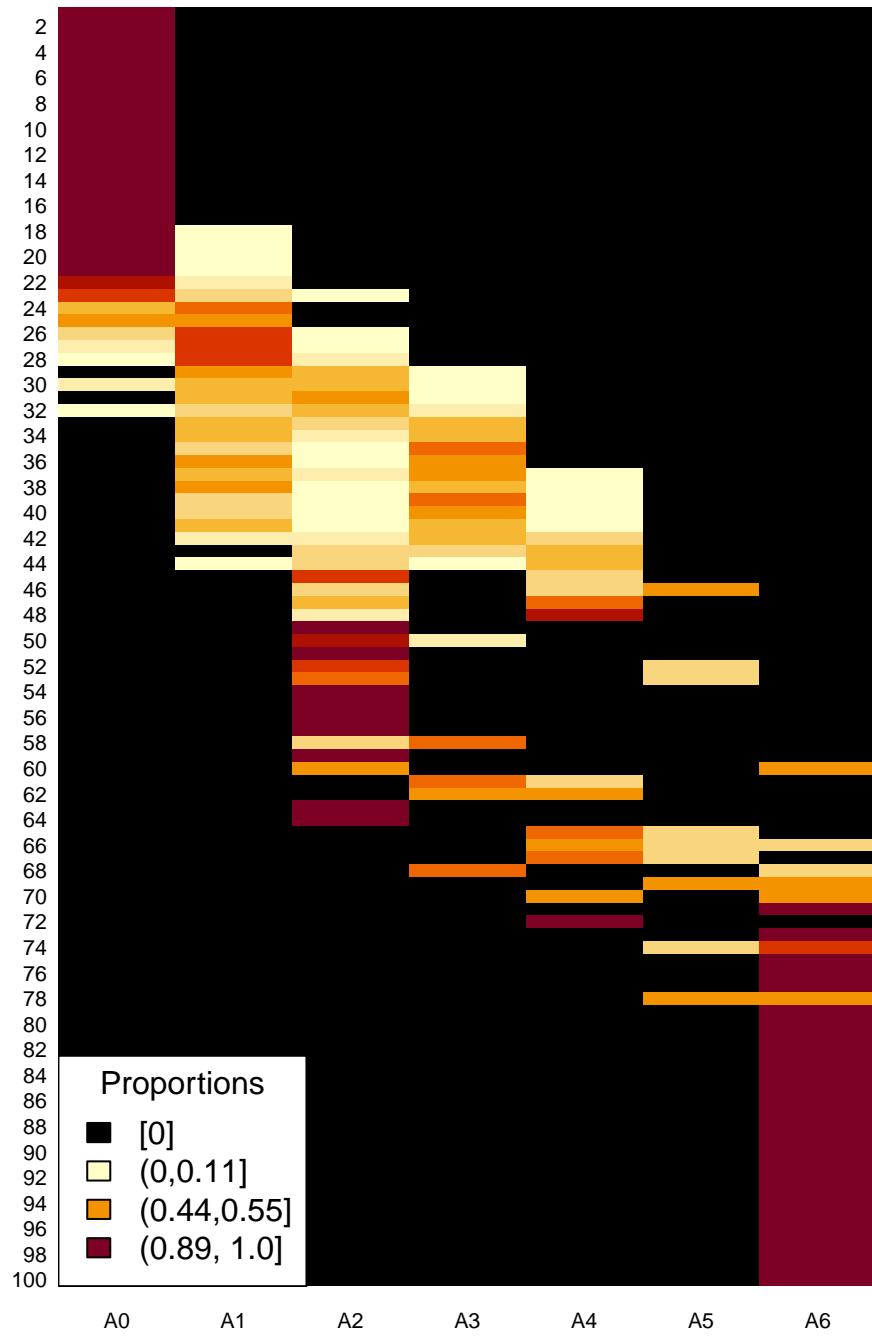
Traditional ALK, fall 2008



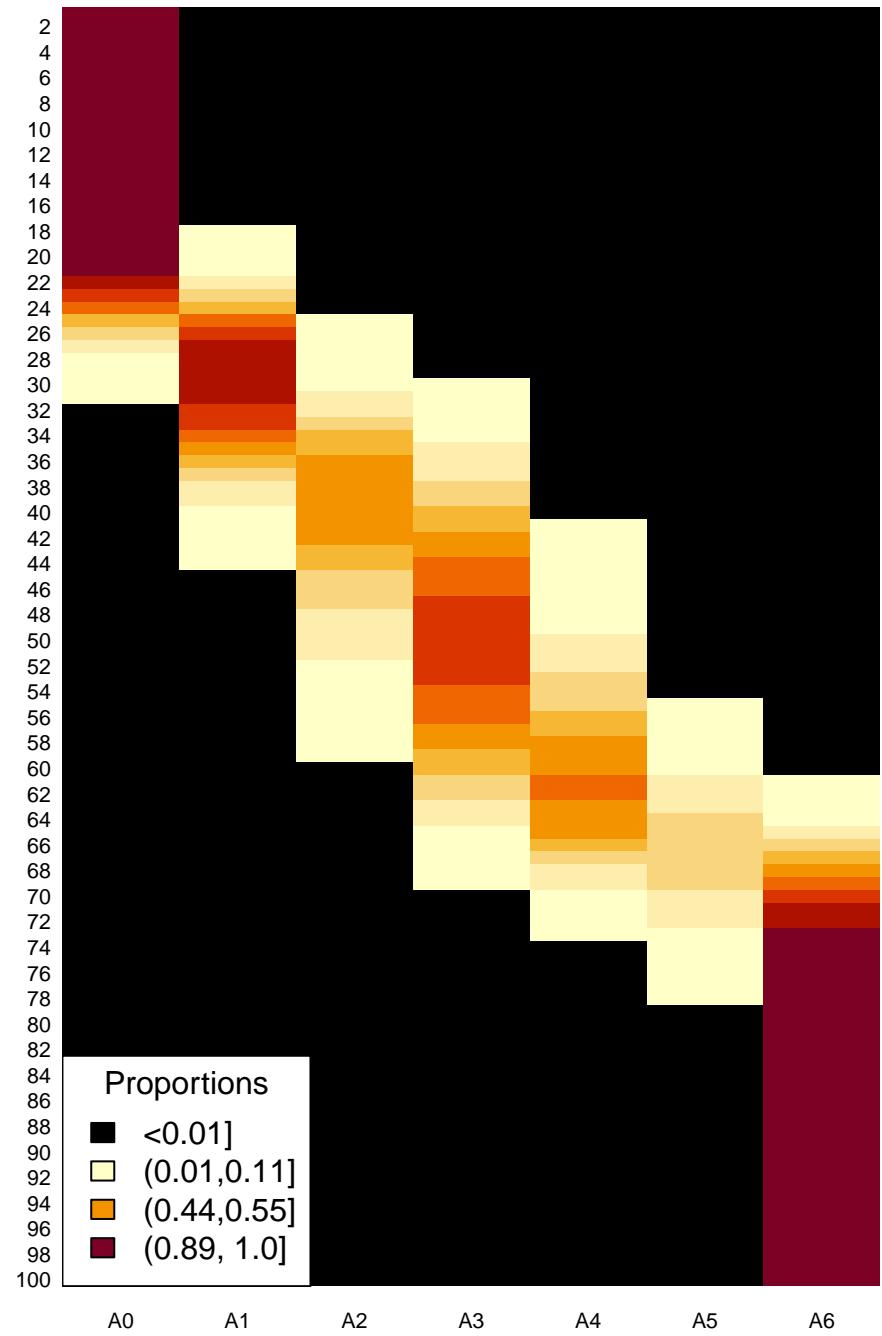
Multinomial ALK, fall 2008



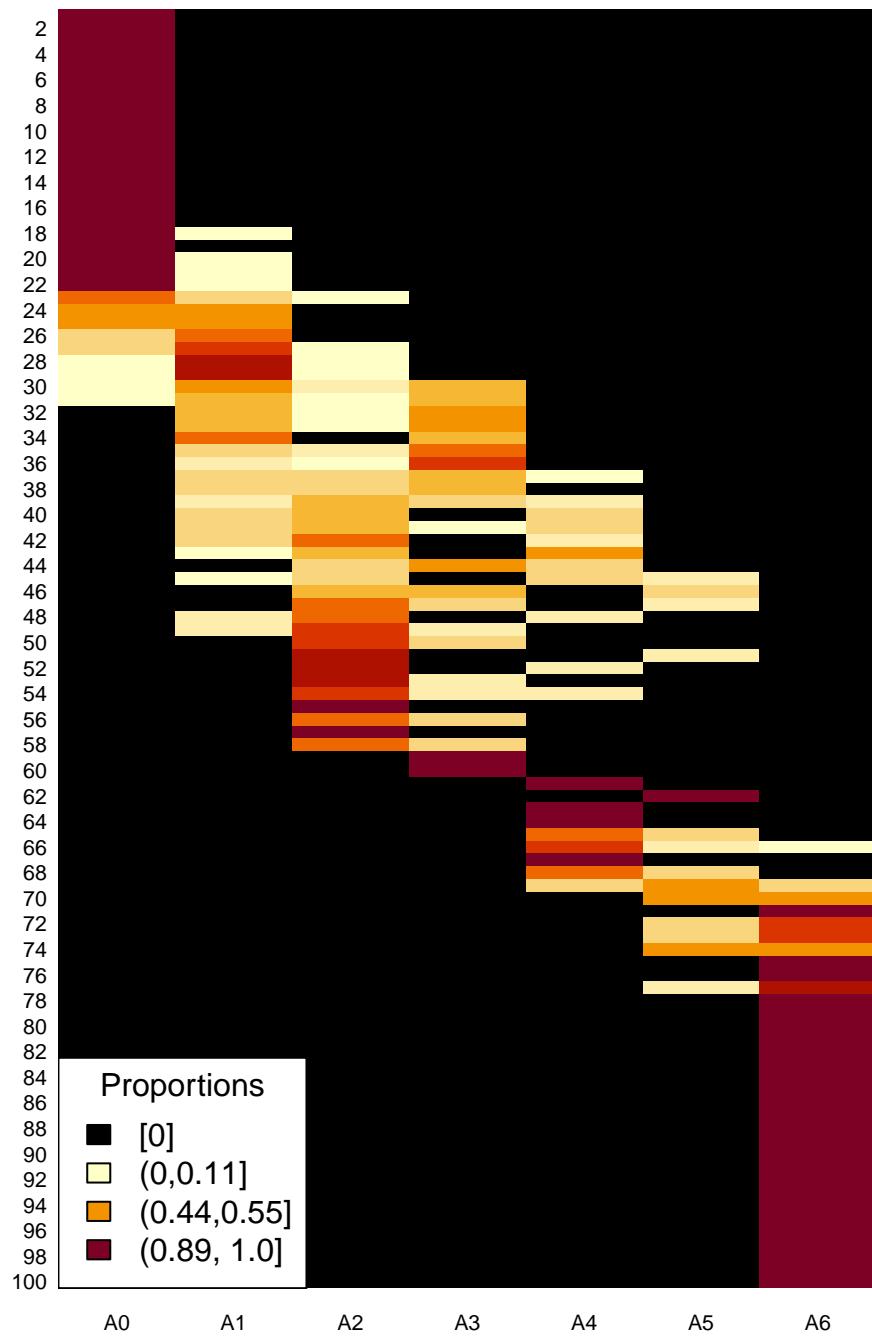
Traditional ALK, fall 2009



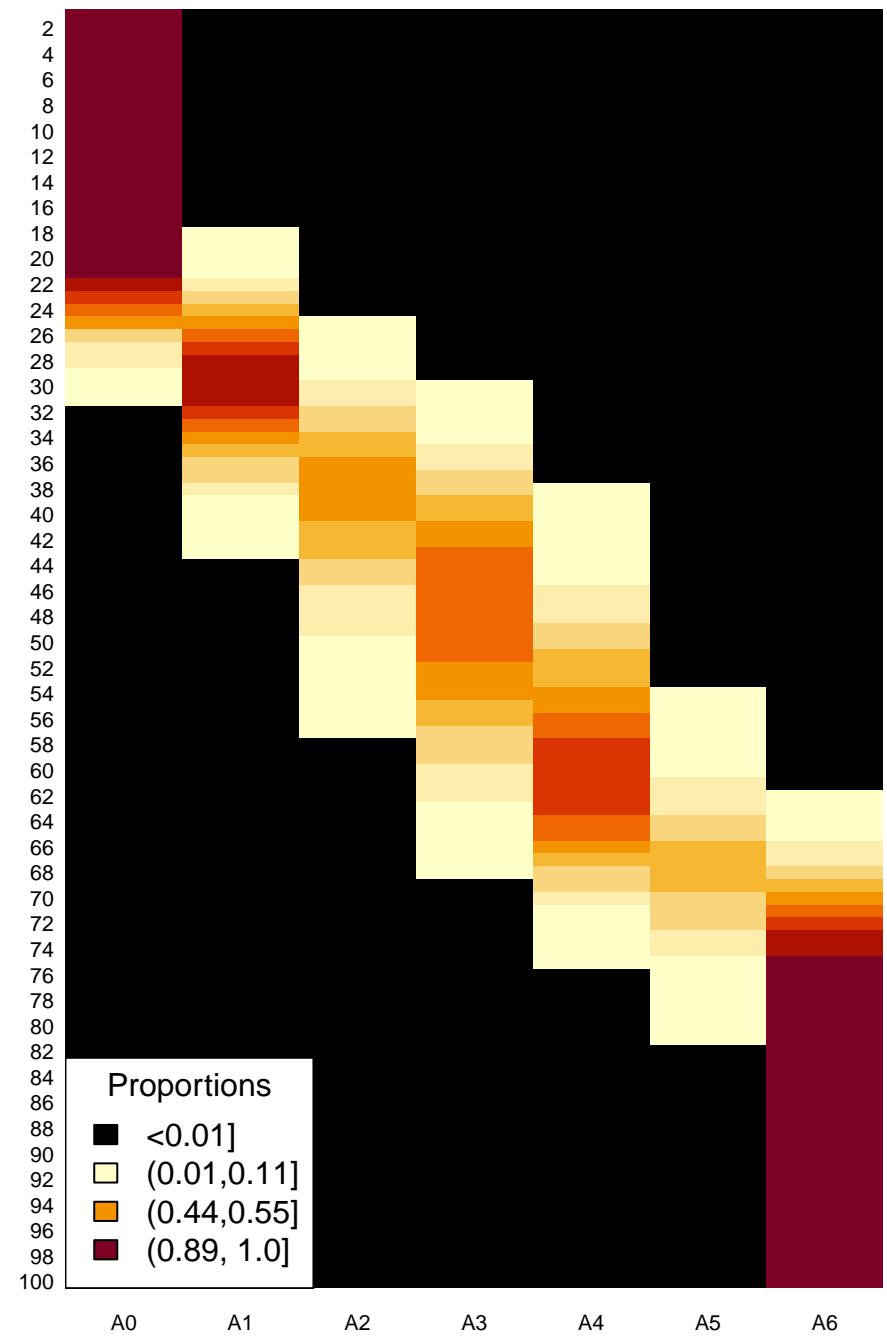
Multinomial ALK, fall 2009



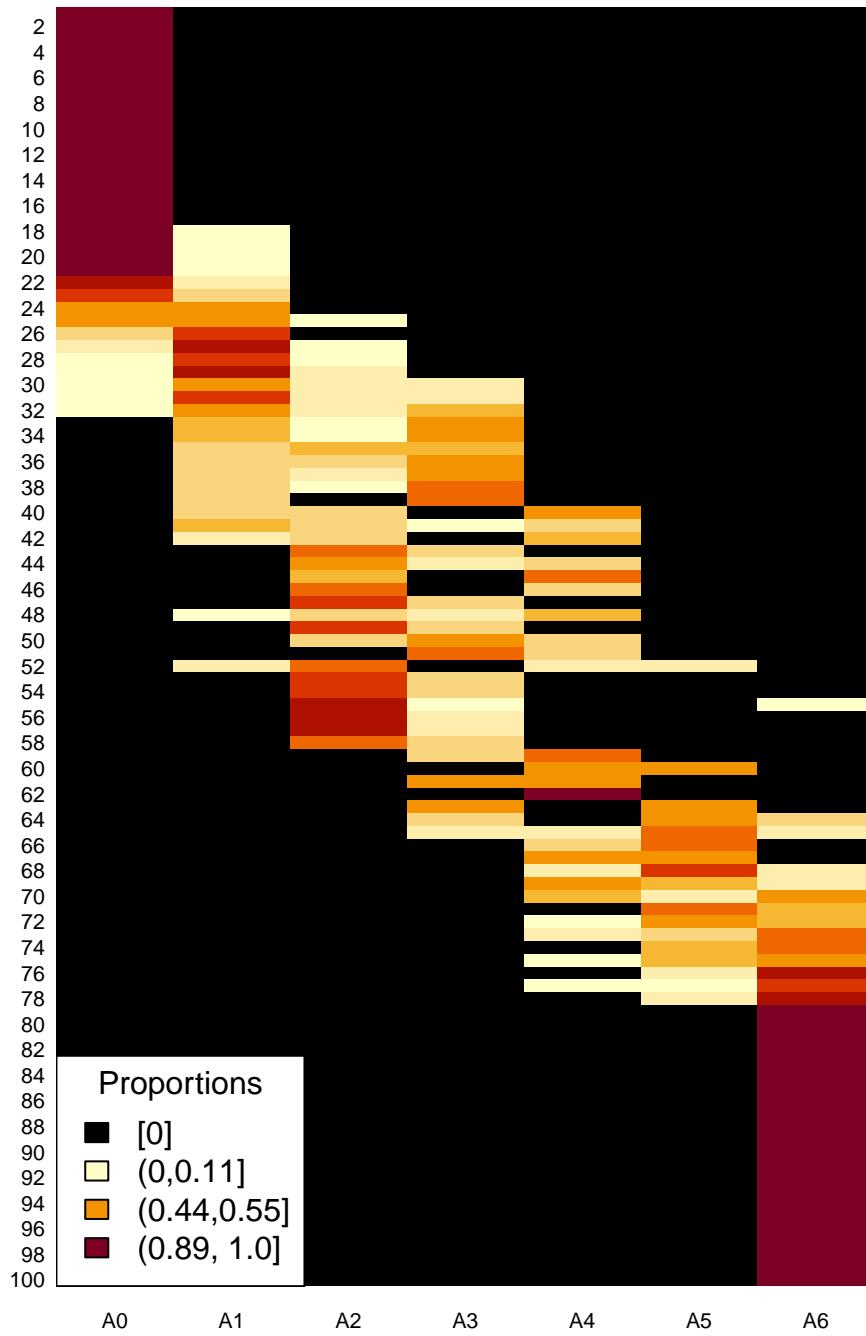
Traditional ALK, fall 2010



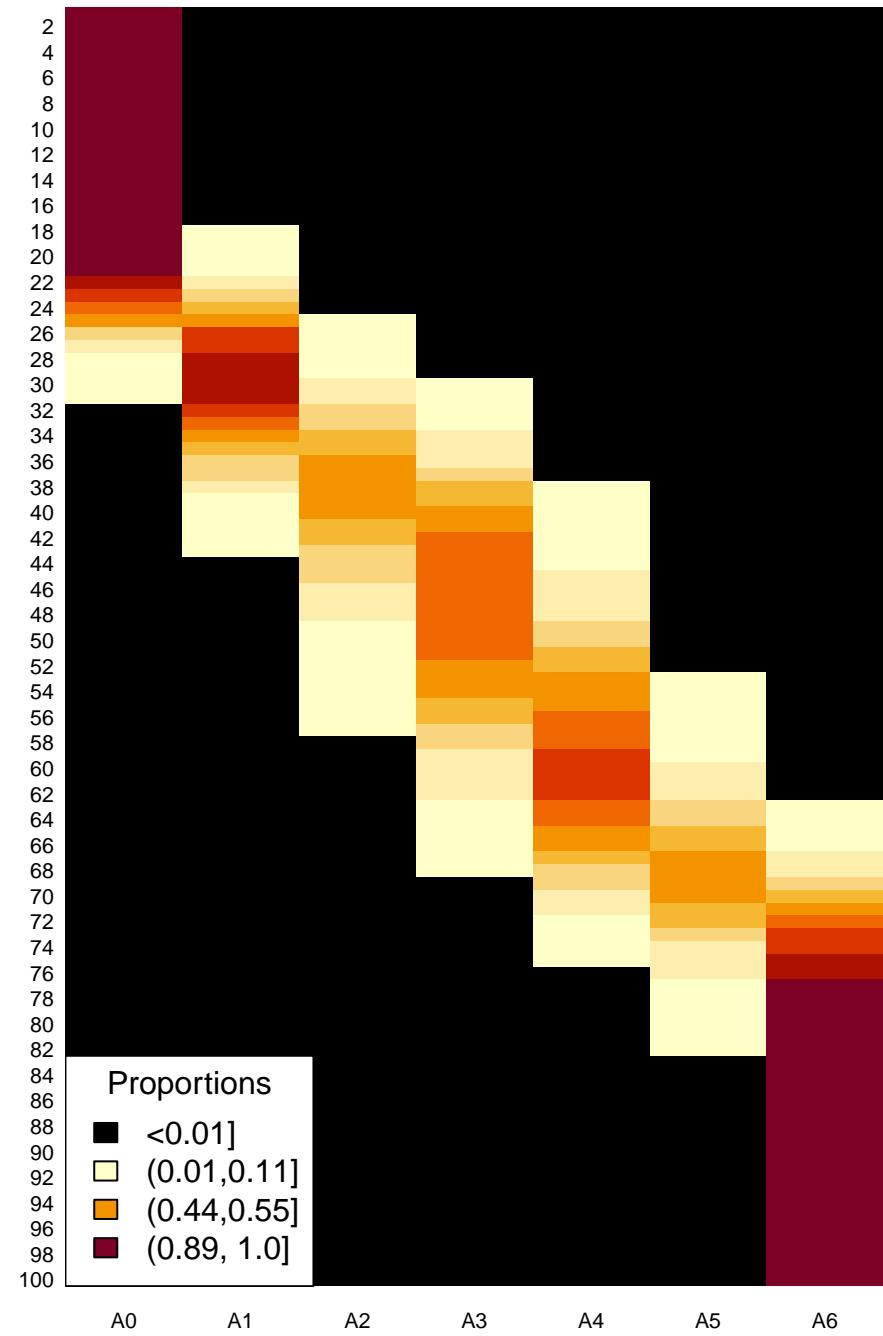
Multinomial ALK, fall 2010



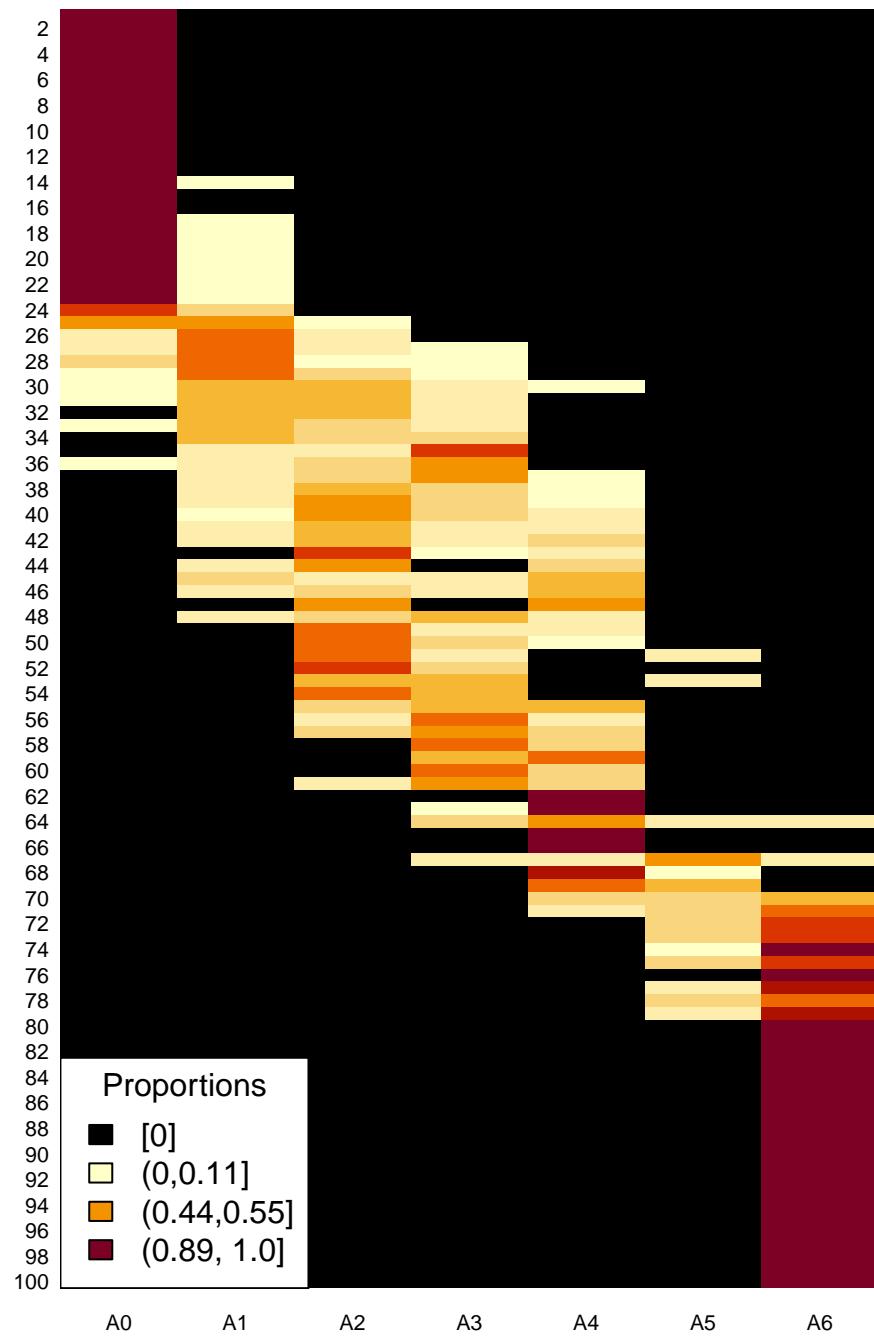
Traditional ALK, fall 2011



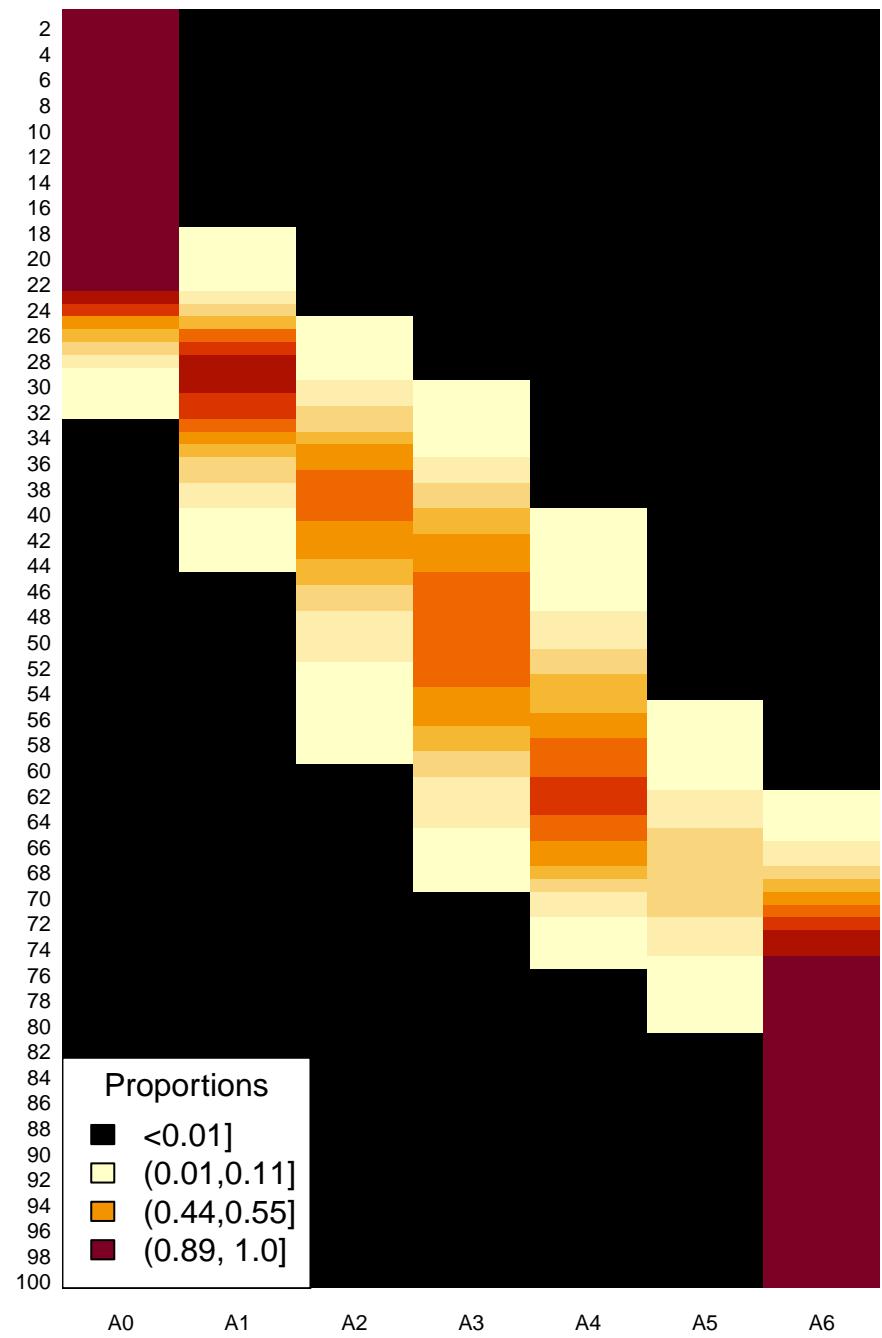
Multinomial ALK, fall 2011



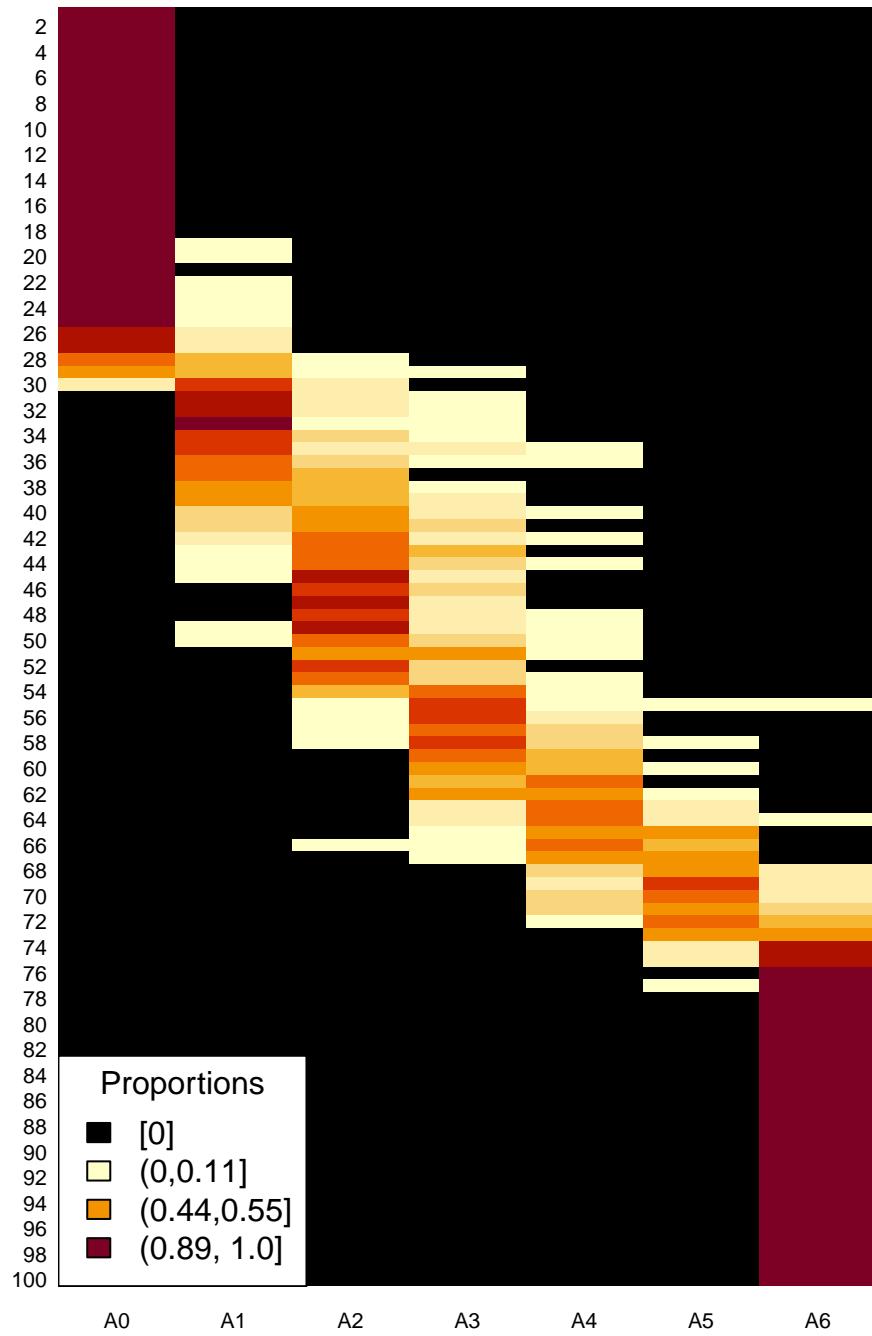
Traditional ALK, fall 2012



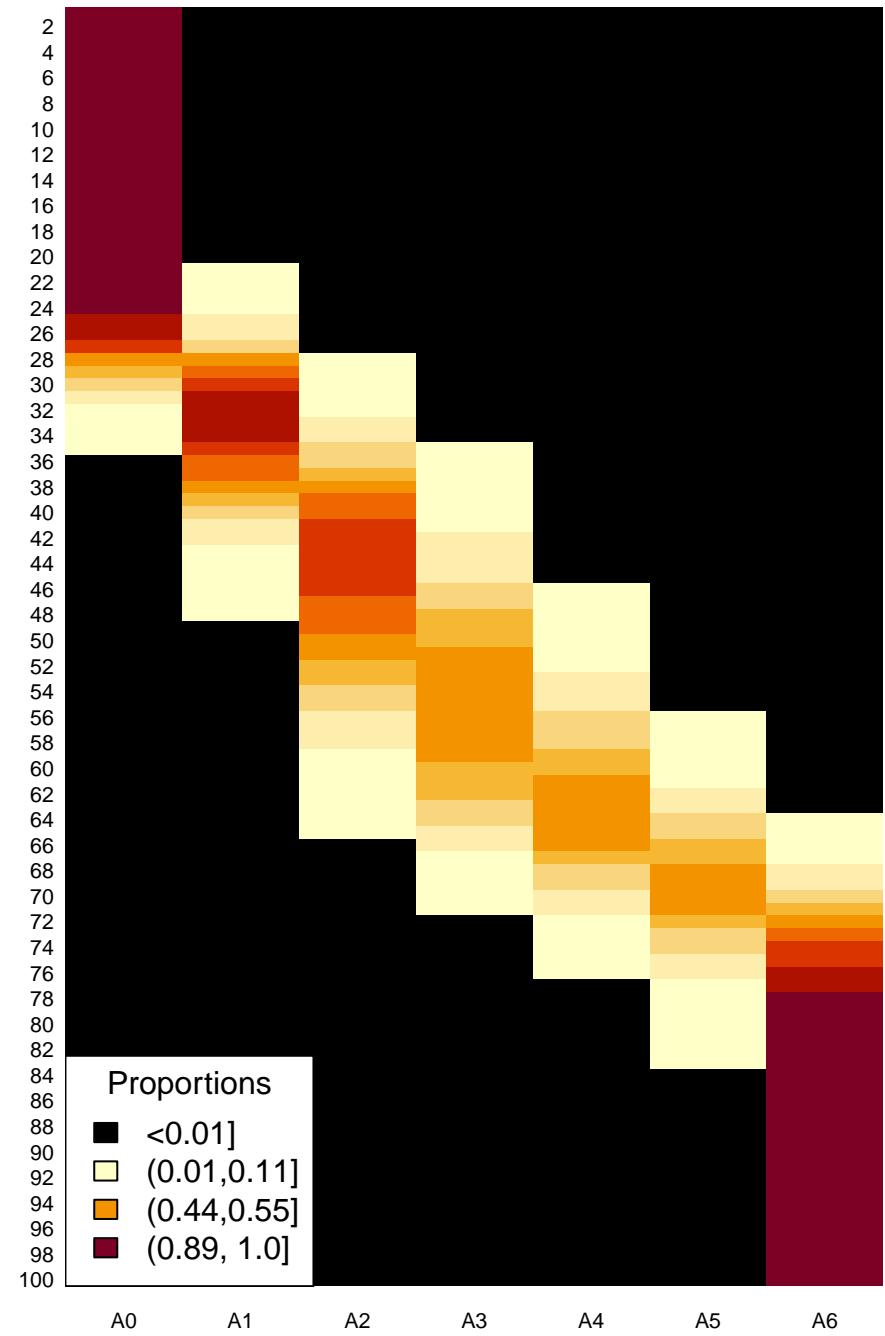
Multinomial ALK, fall 2012



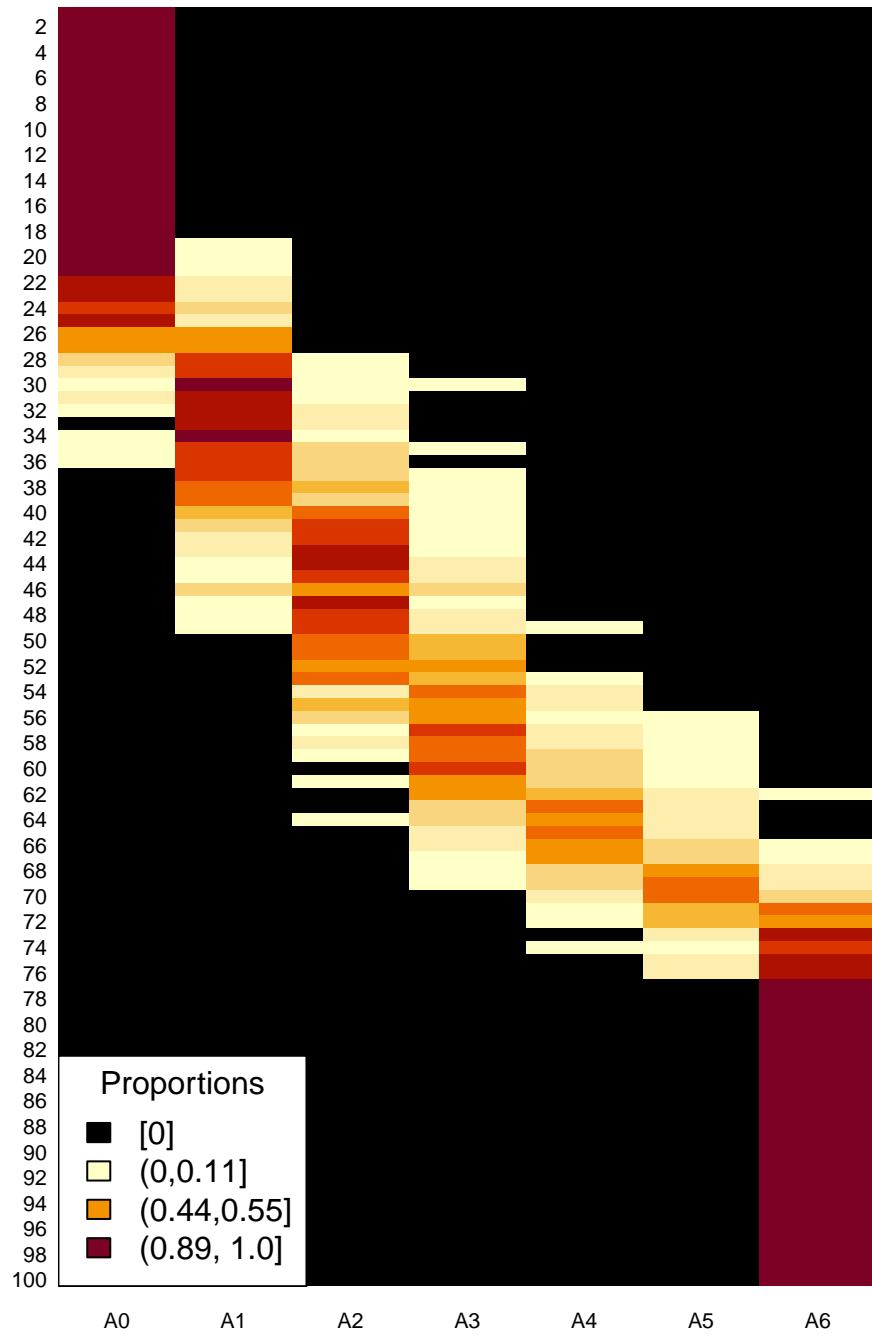
Traditional ALK, fall 2013



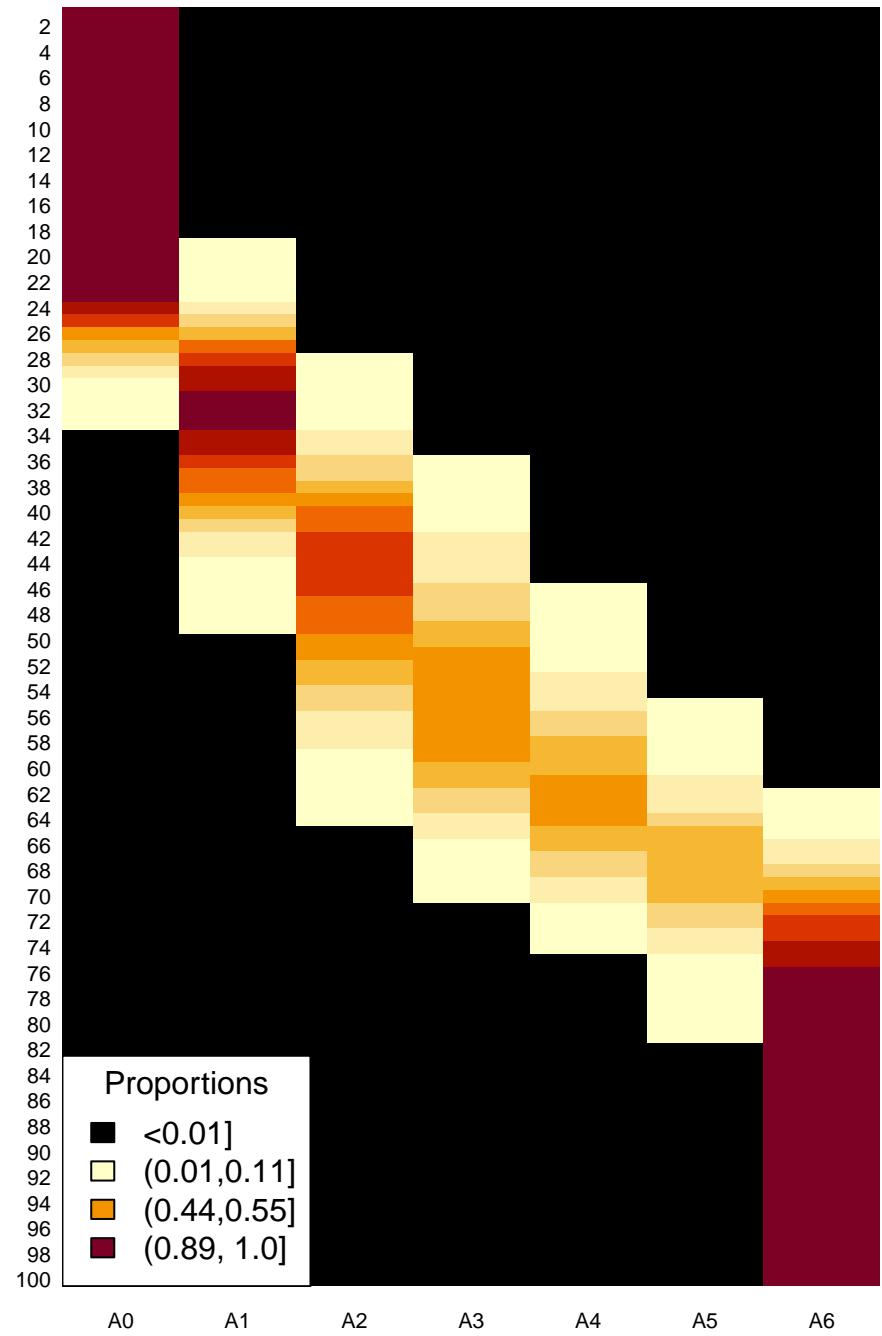
Multinomial ALK, fall 2013



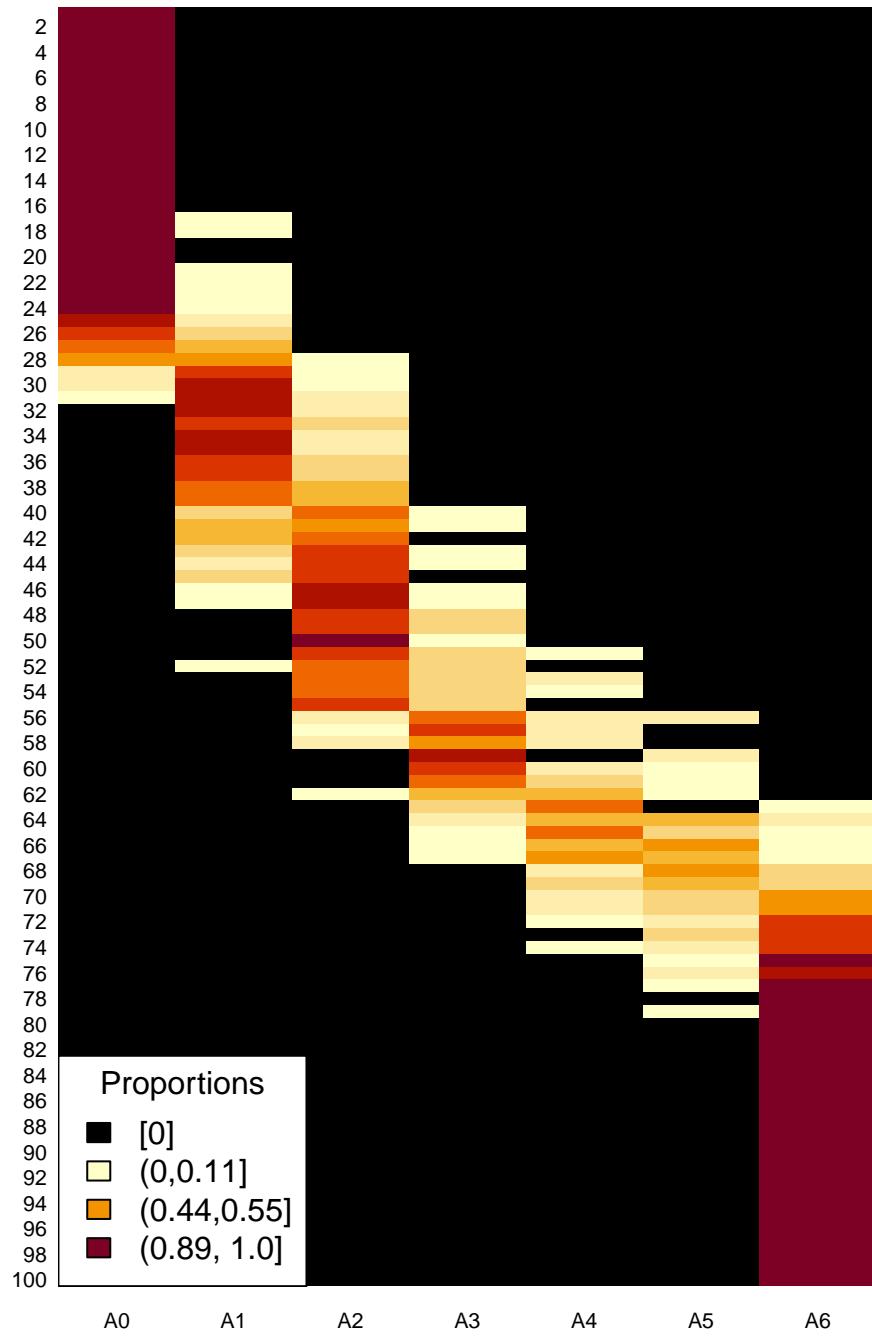
Traditional ALK, fall 2014



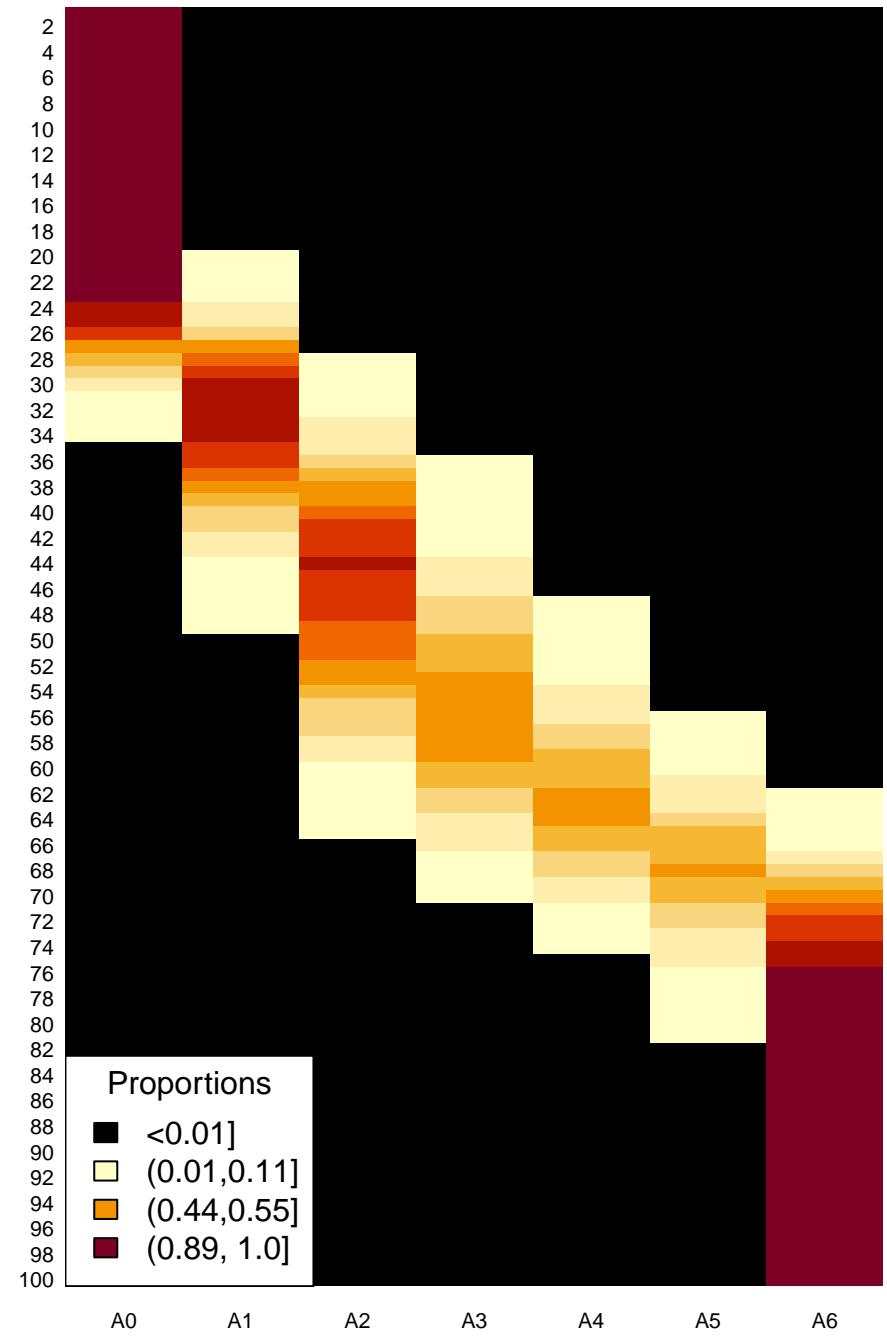
Multinomial ALK, fall 2014



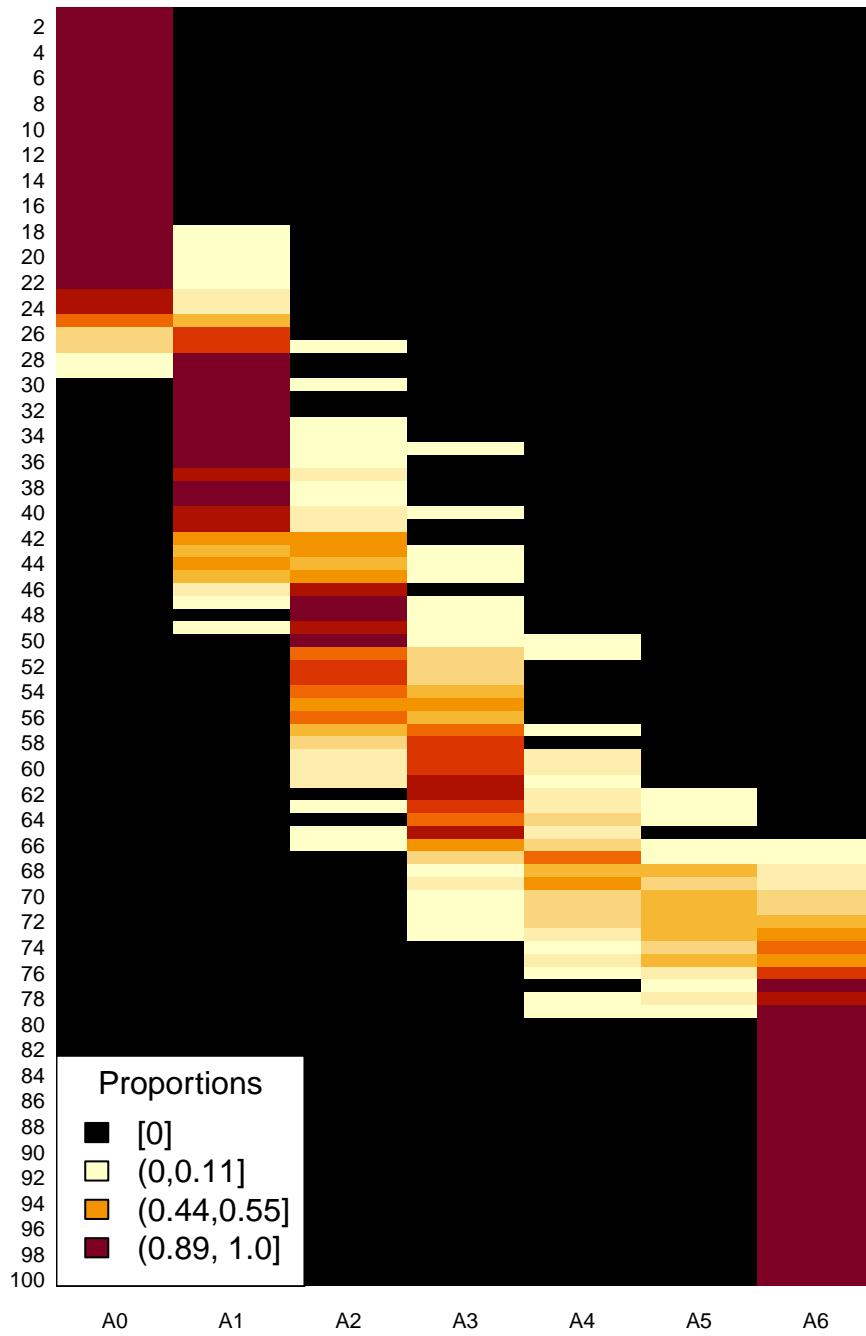
Traditional ALK, fall 2015



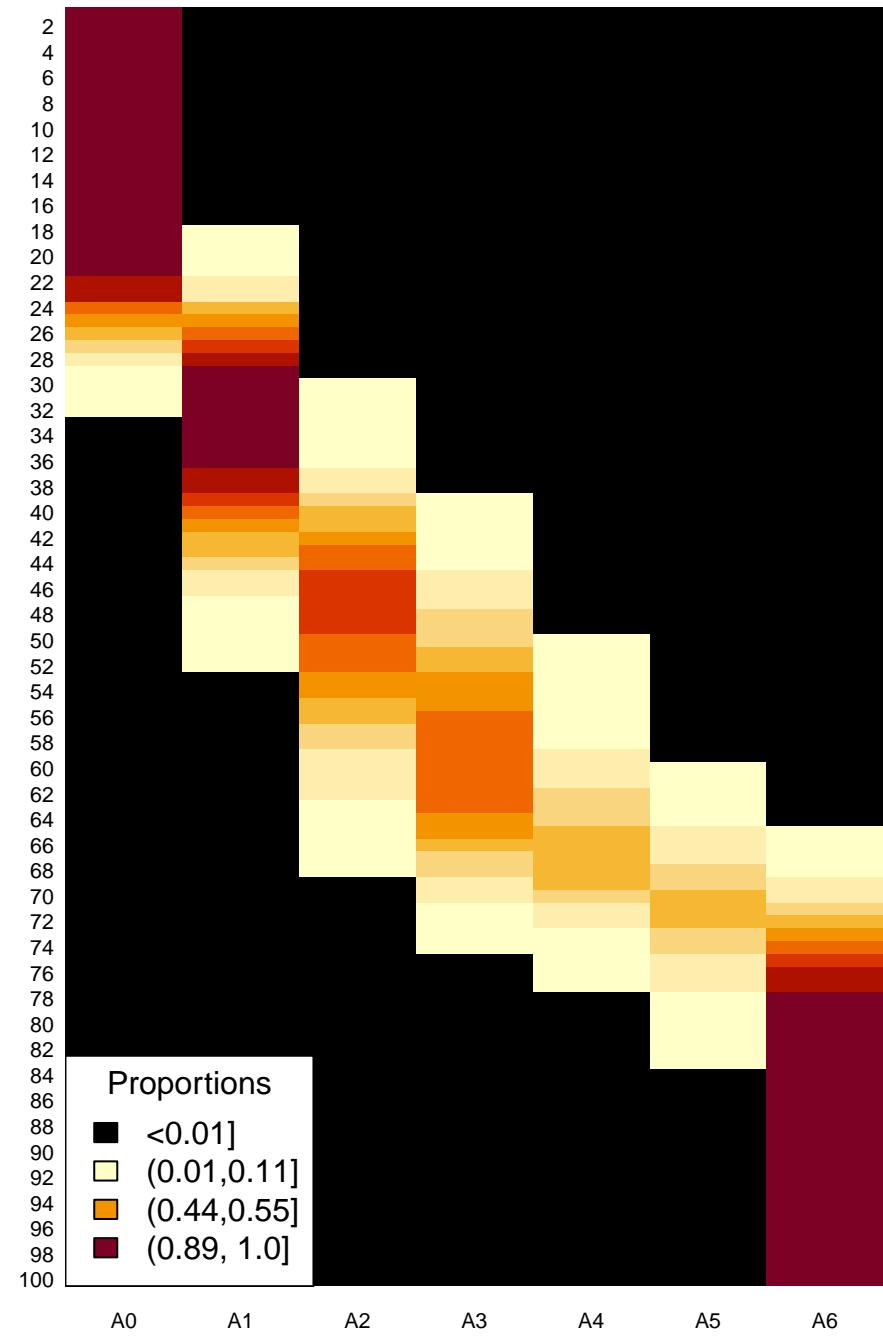
Multinomial ALK, fall 2015



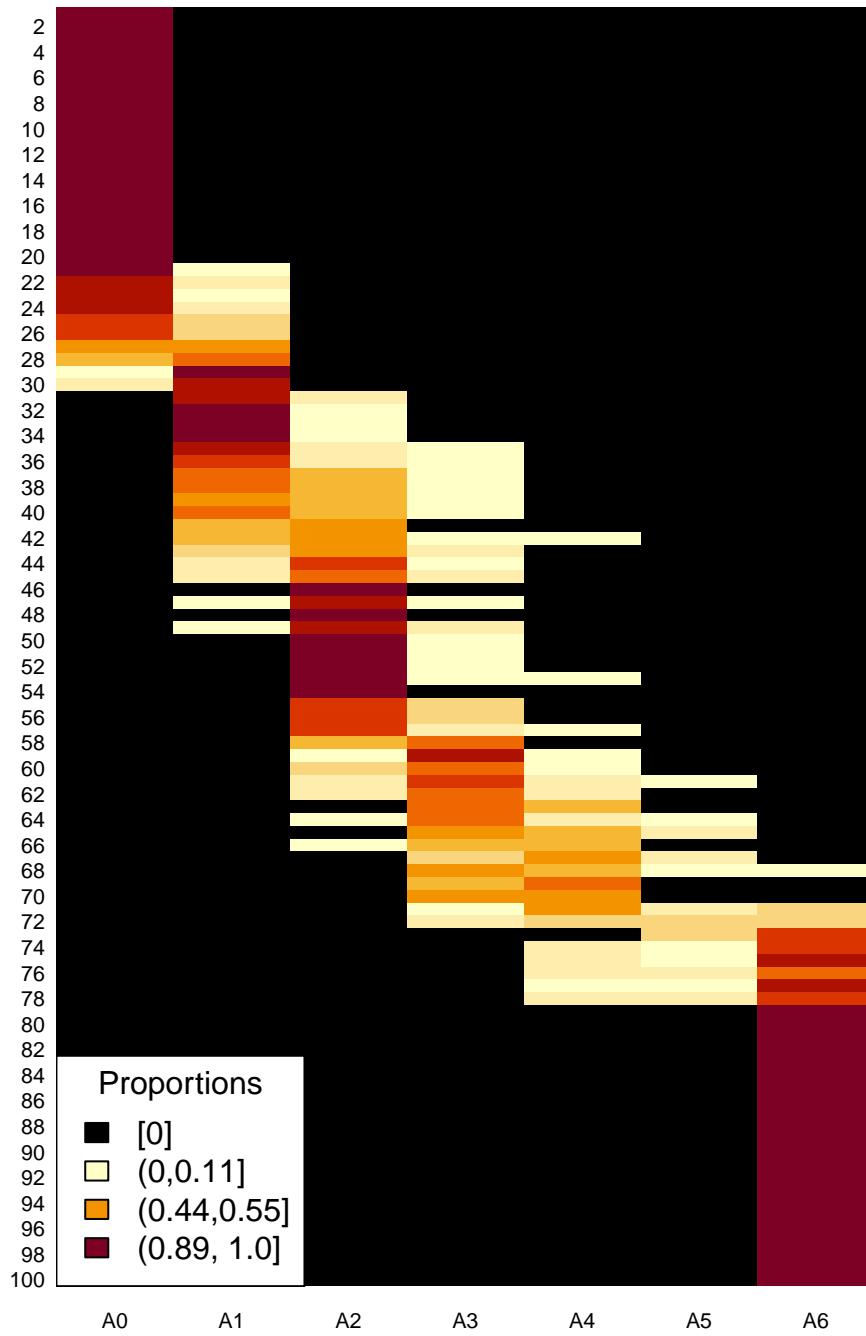
Traditional ALK, fall 2016



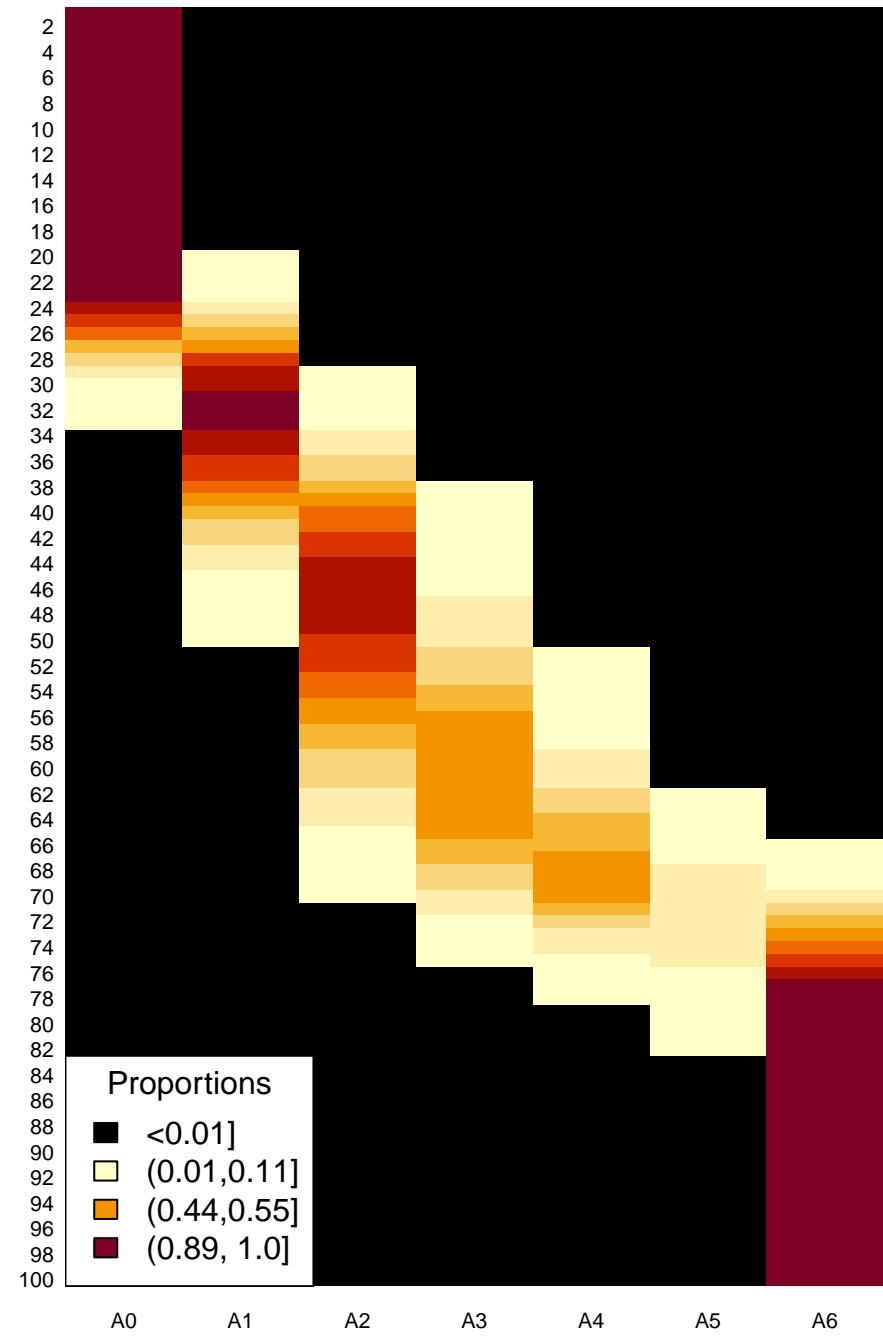
Multinomial ALK, fall 2016



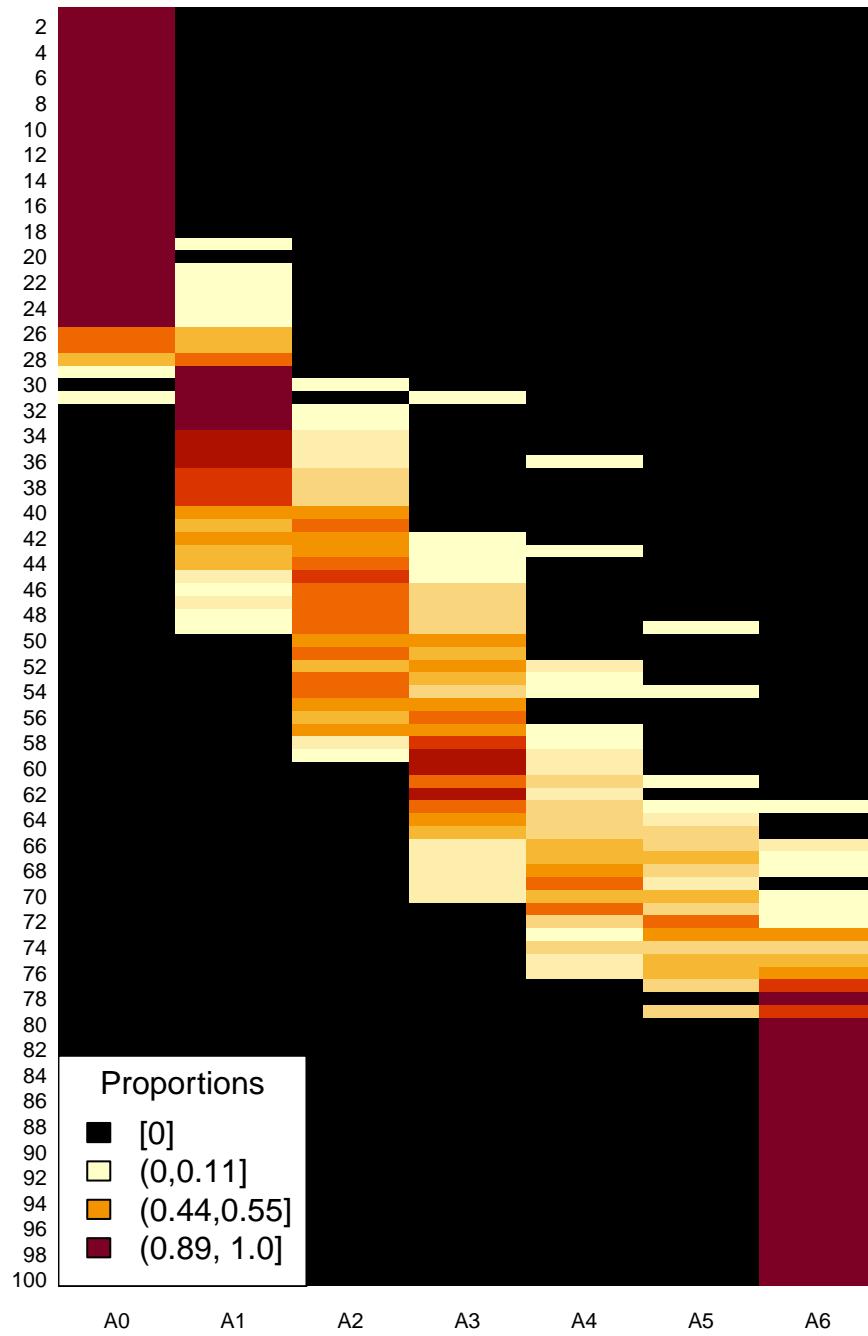
Traditional ALK, fall 2017



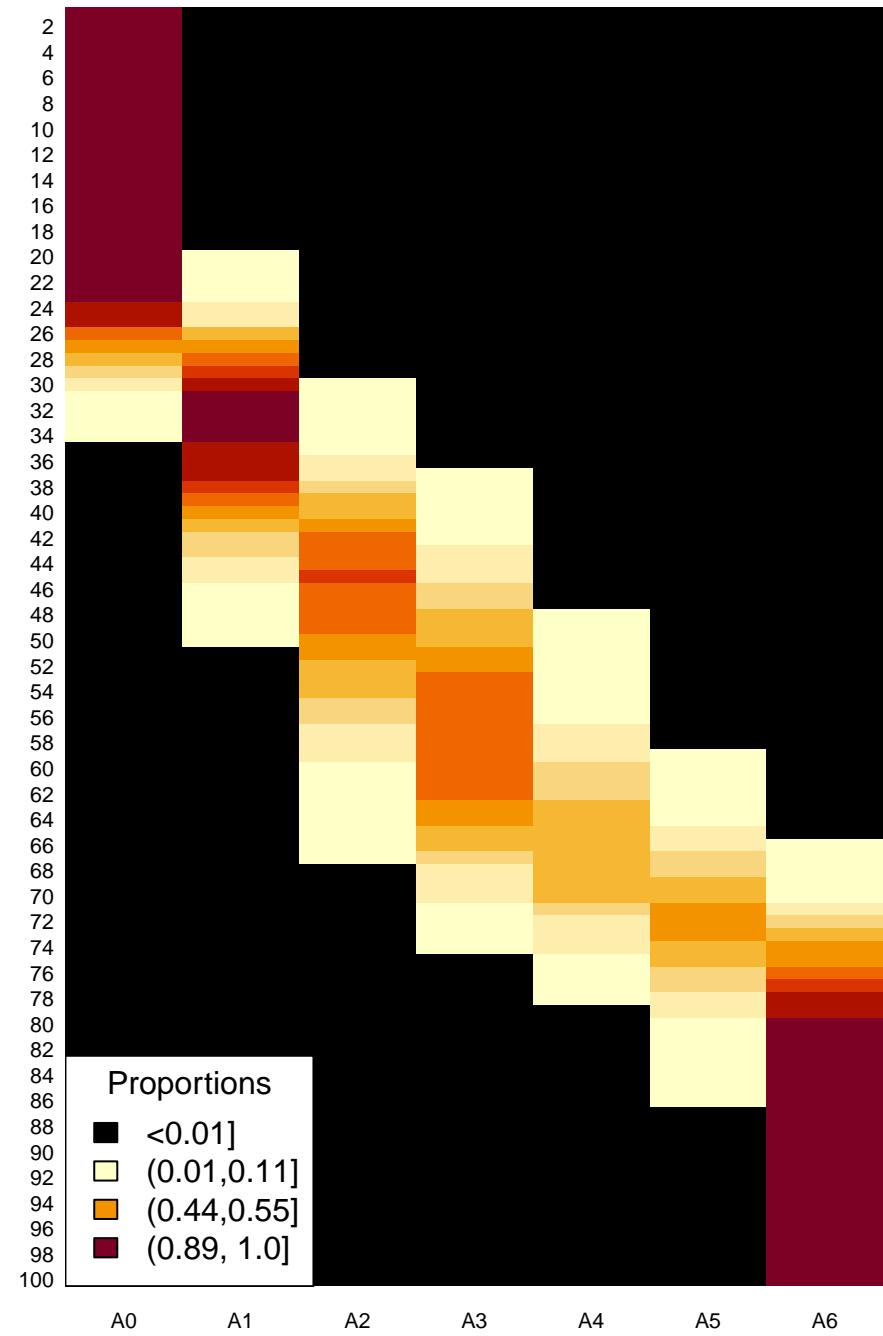
Multinomial ALK, fall 2017



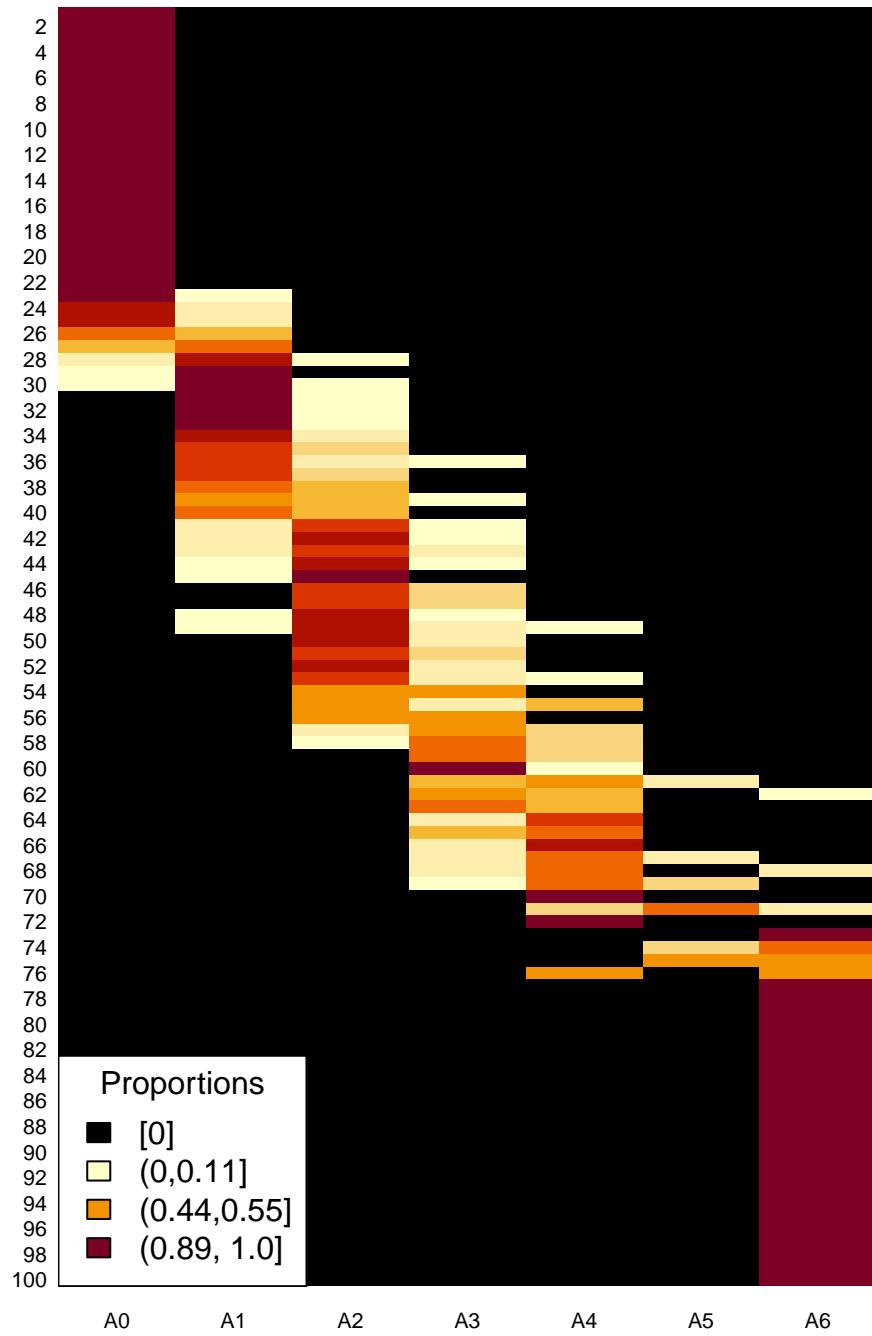
Traditional ALK, fall 2018



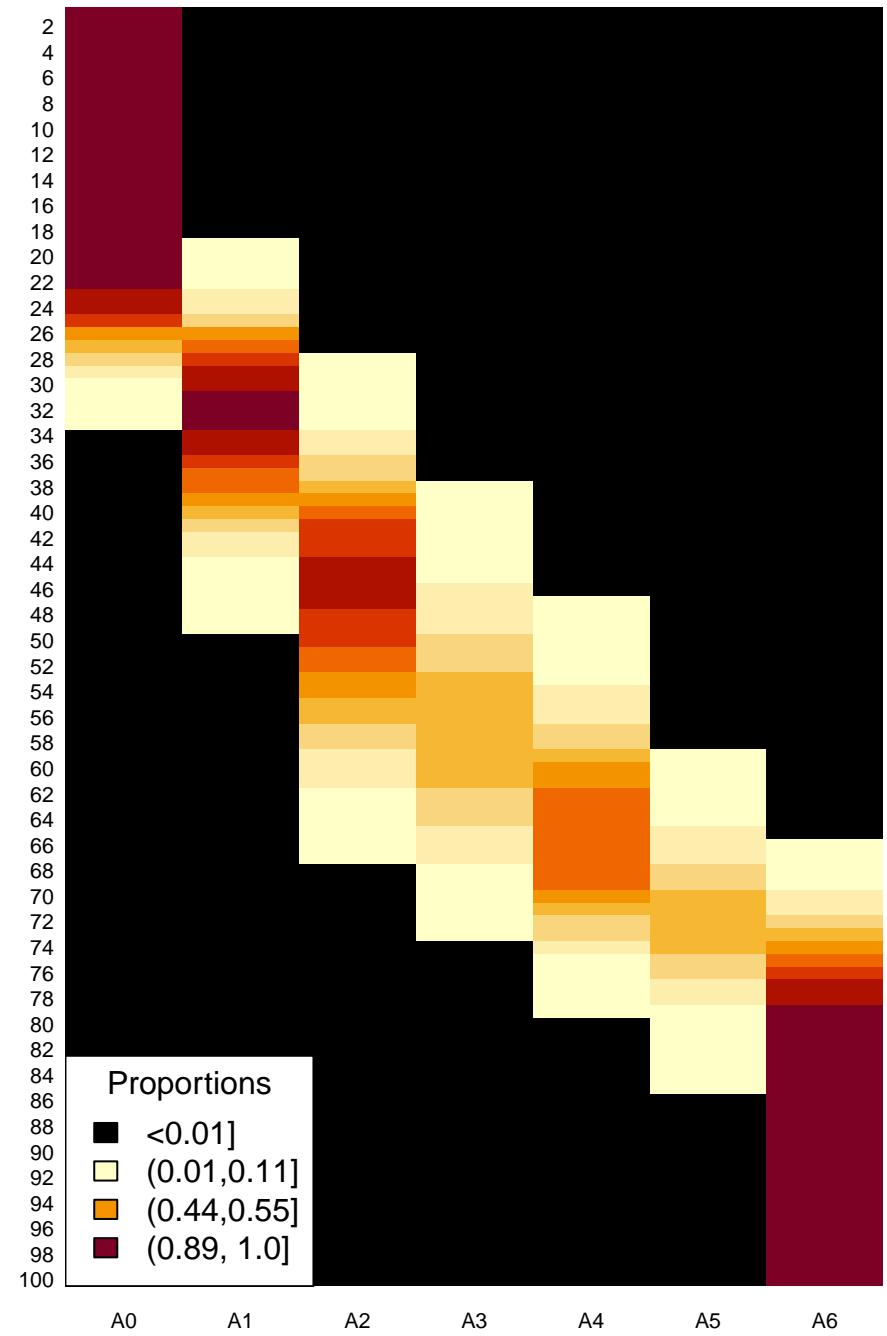
Multinomial ALK, fall 2018



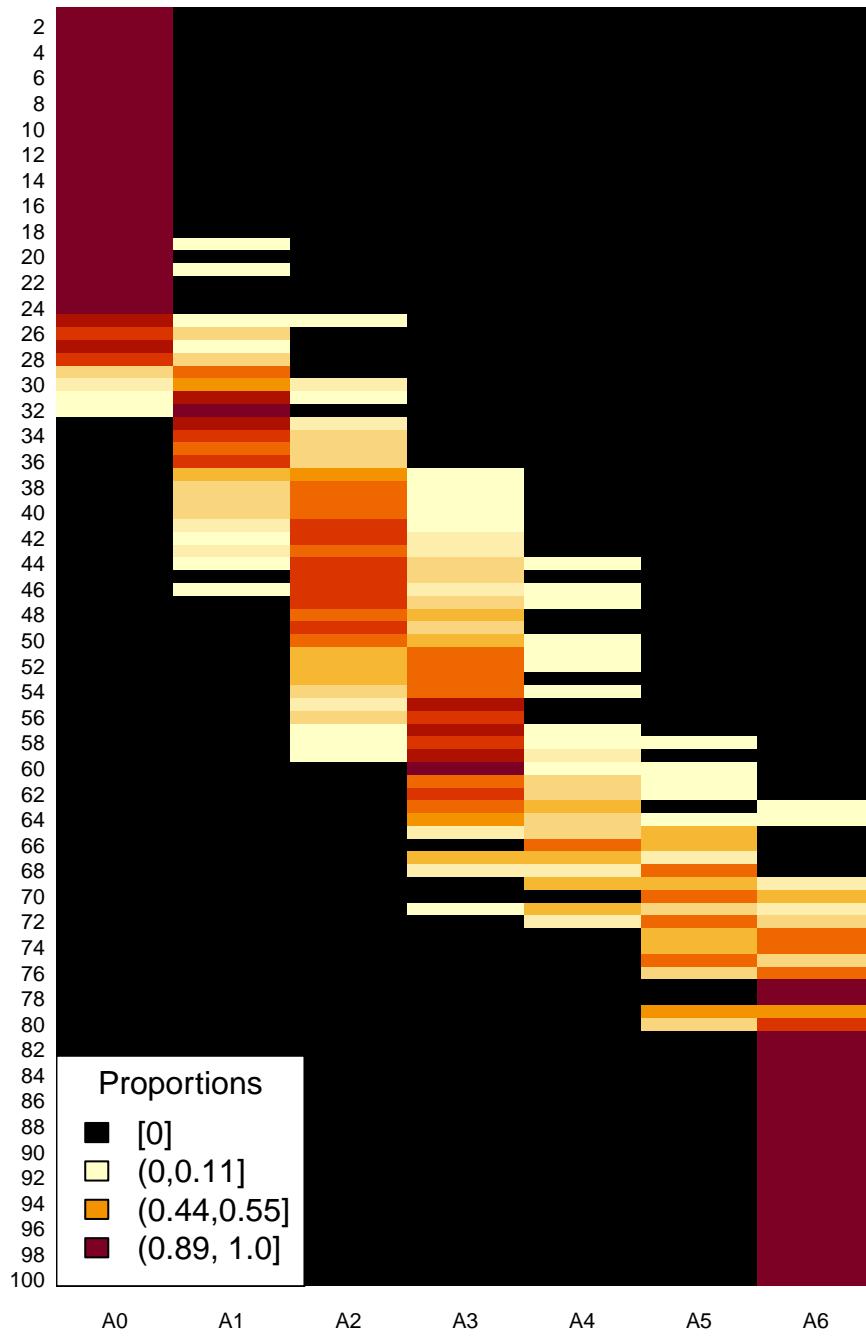
Traditional ALK, fall 2019



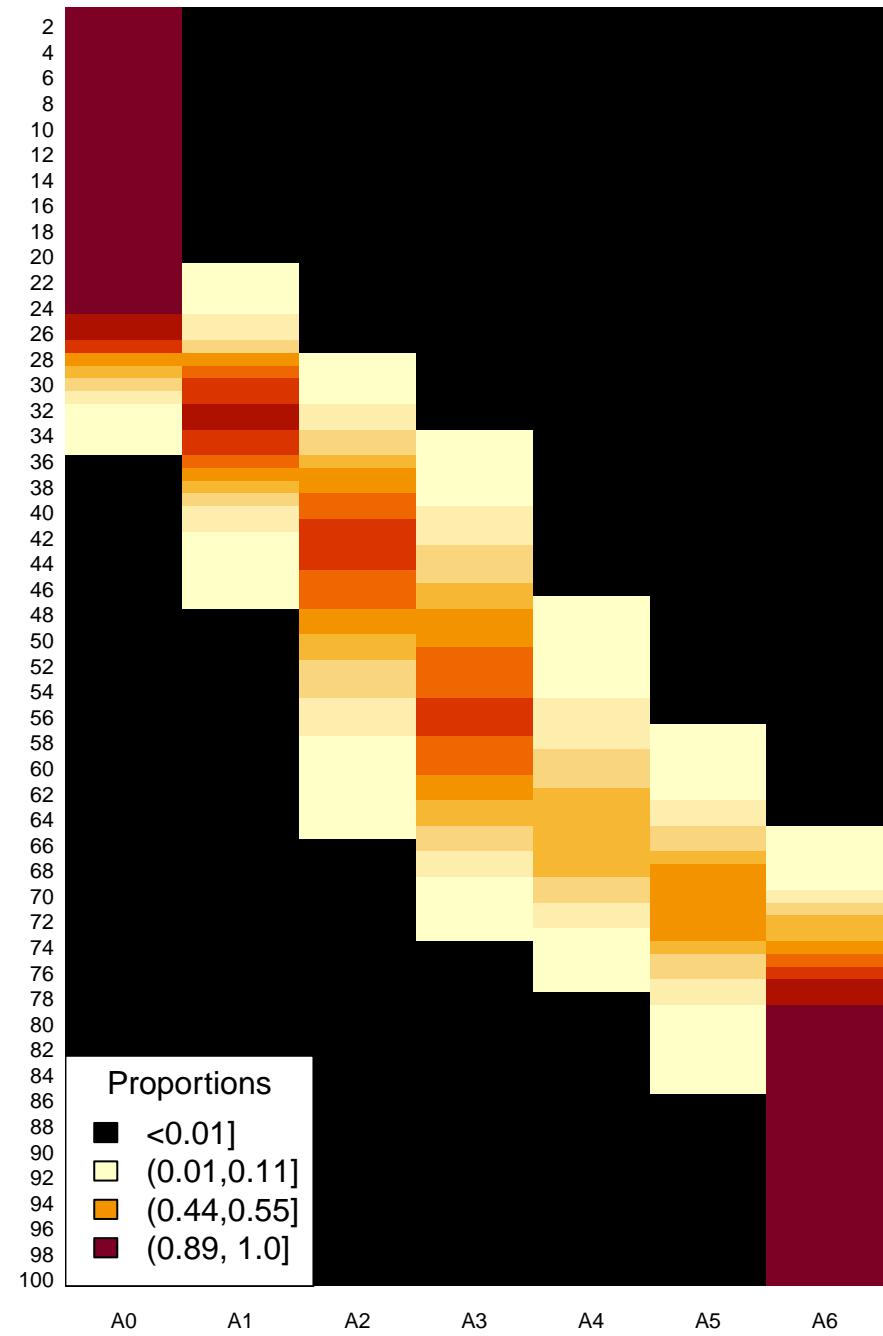
Multinomial ALK, fall 2019



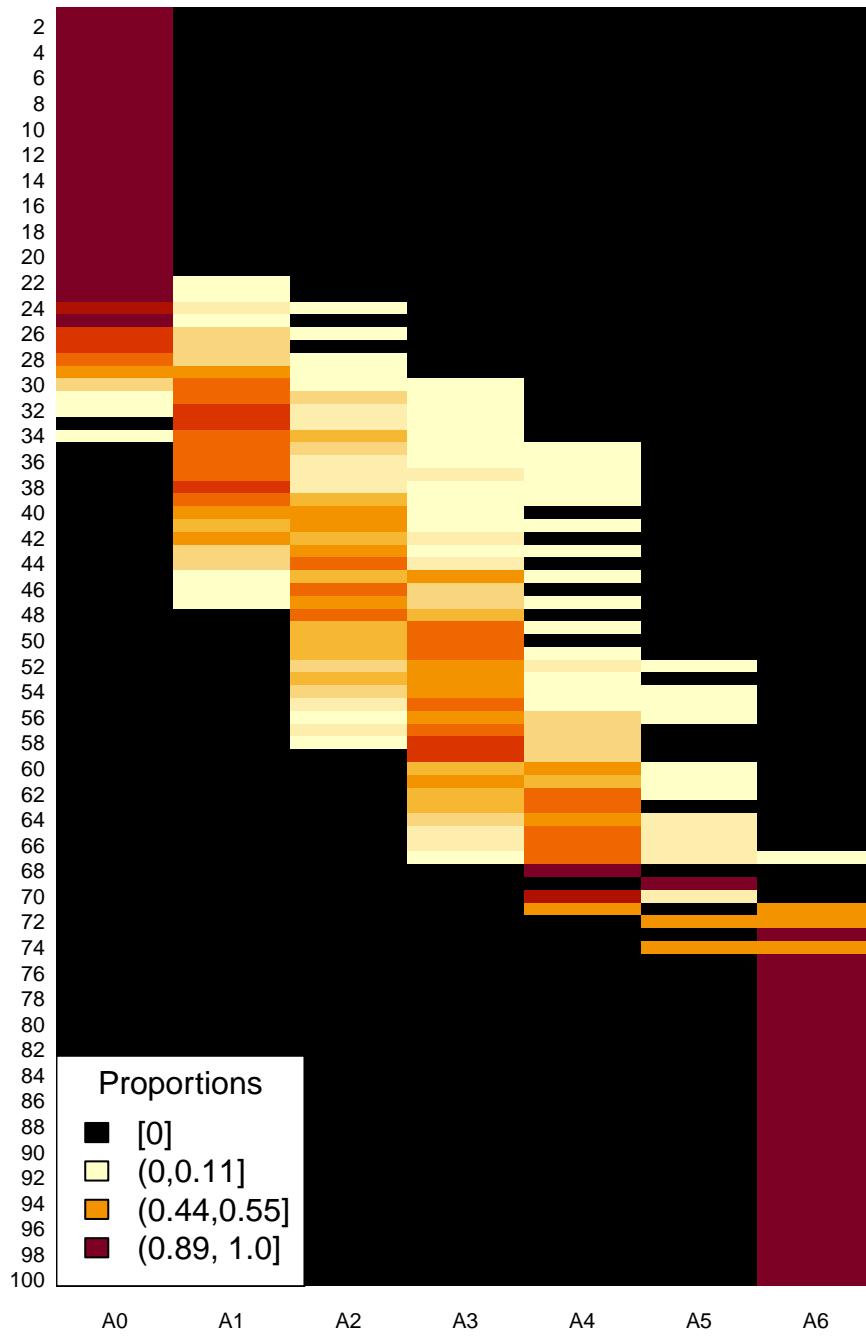
Traditional ALK, fall 2020



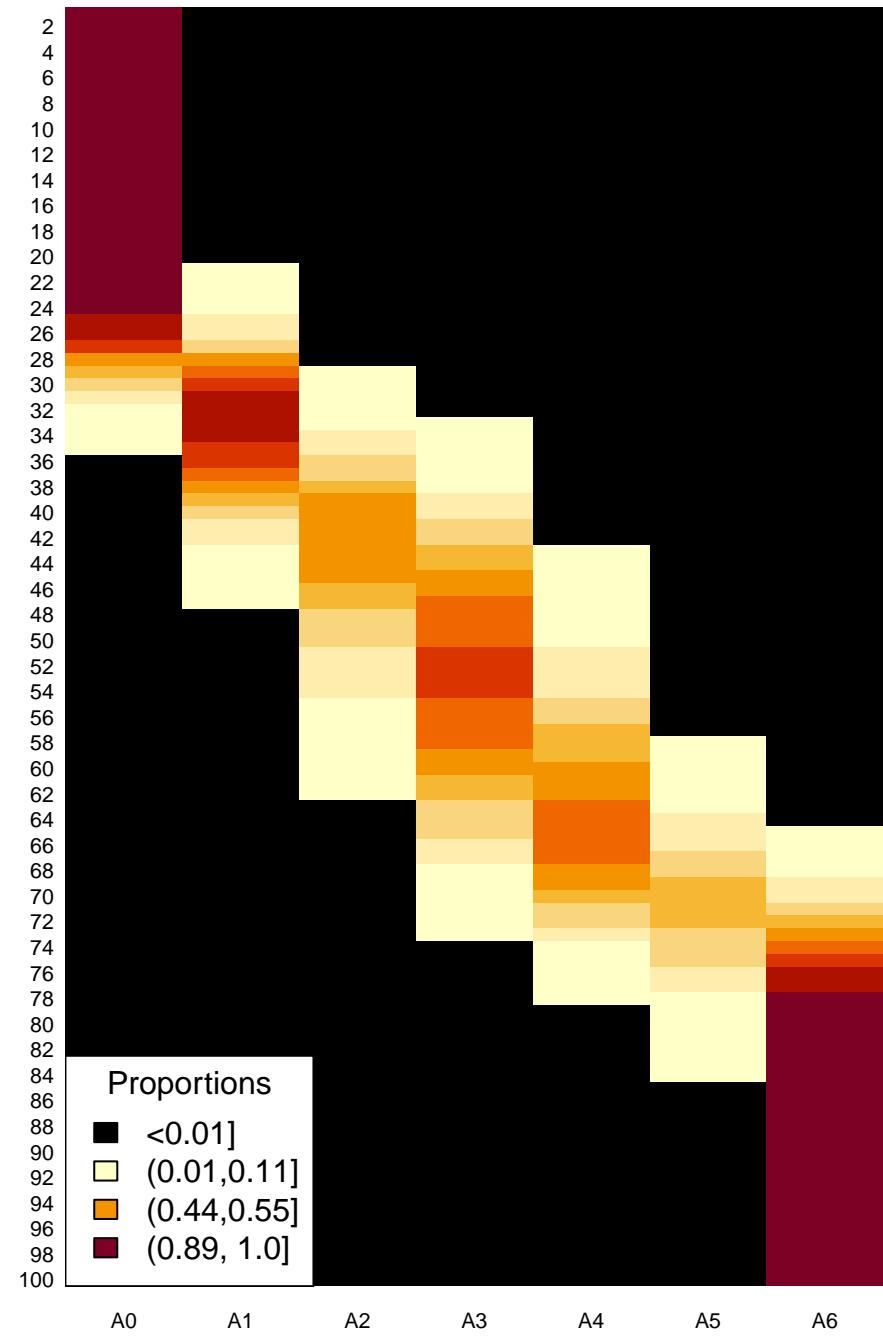
Multinomial ALK, fall 2020



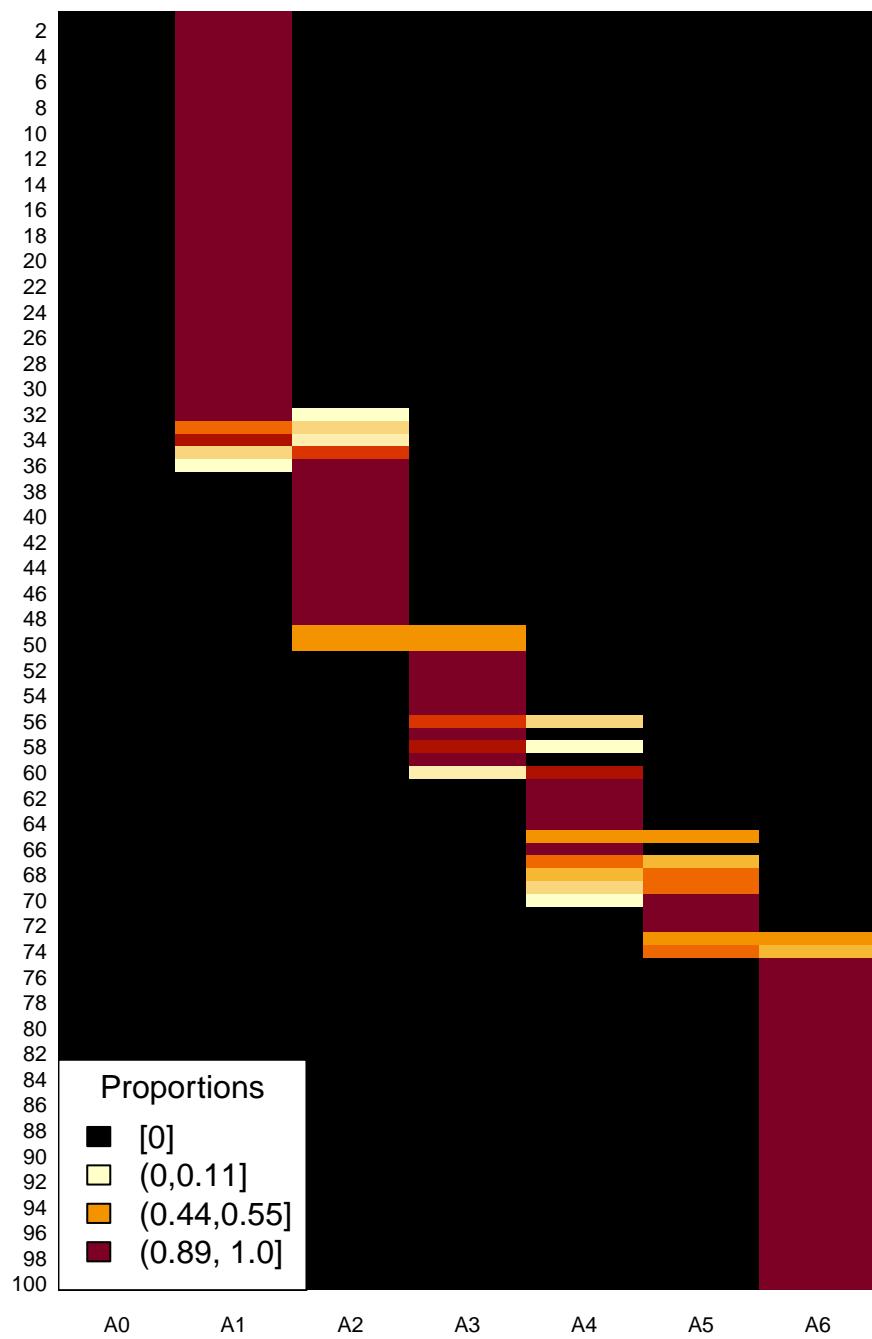
Traditional ALK, fall 2021



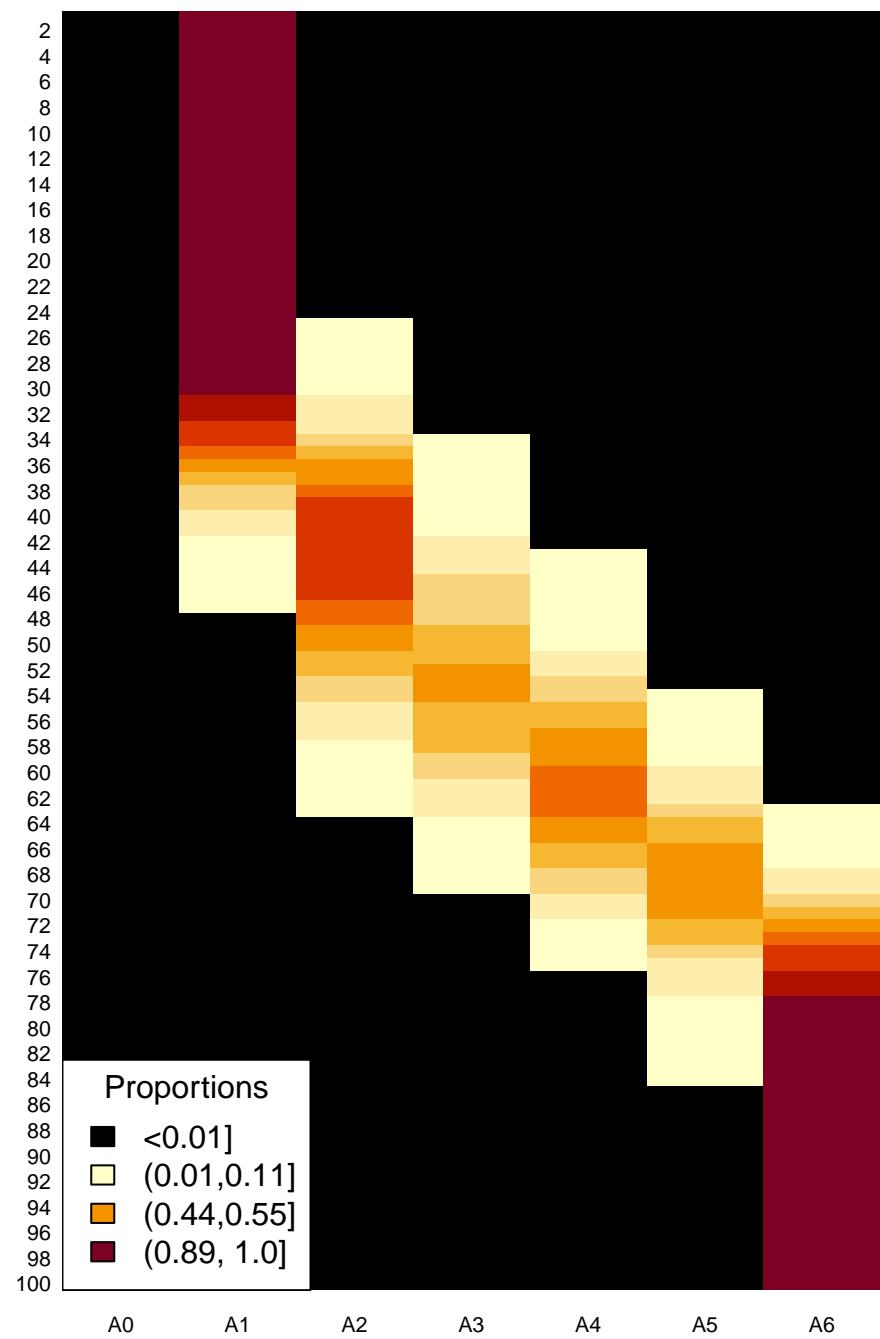
Multinomial ALK, fall 2021



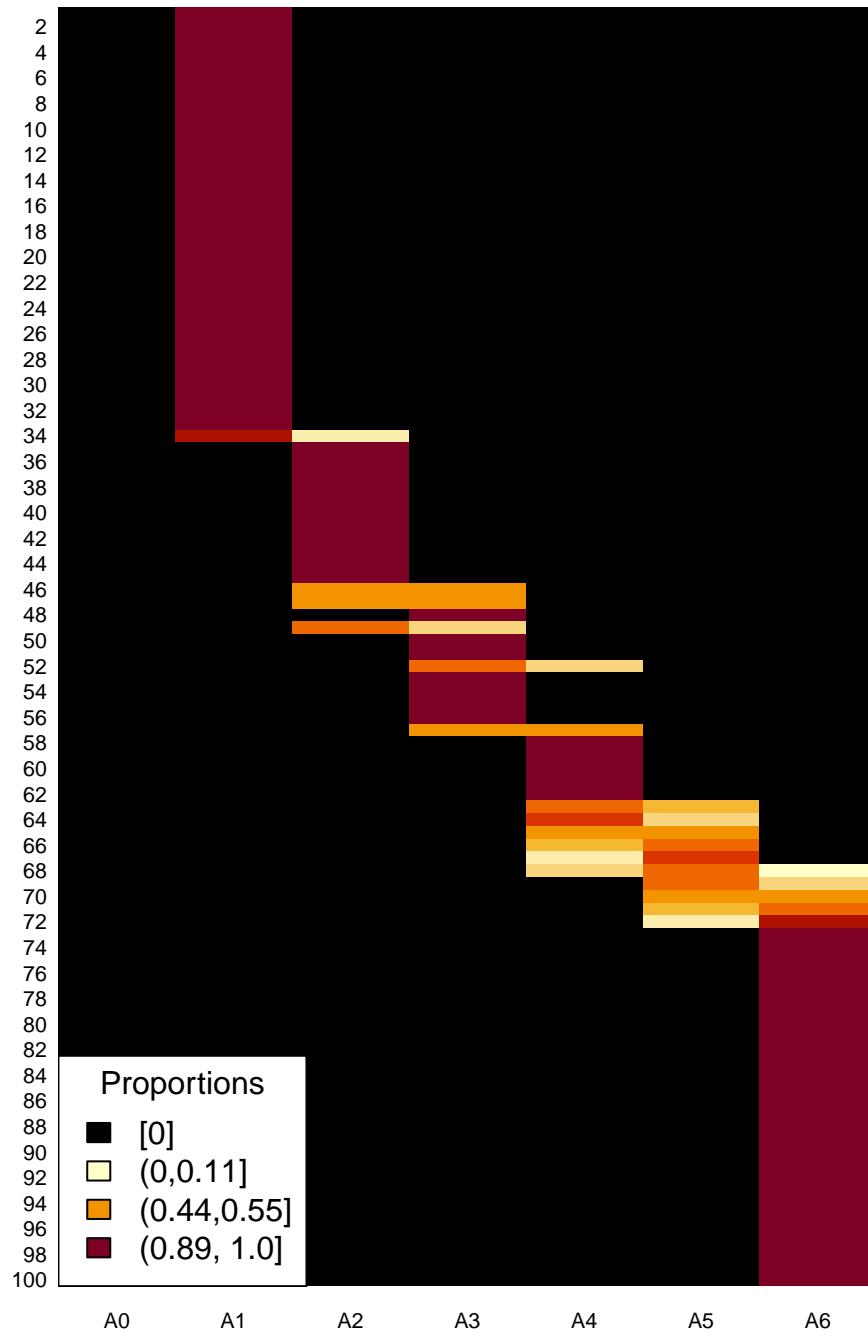
Traditional ALK, spring 1985



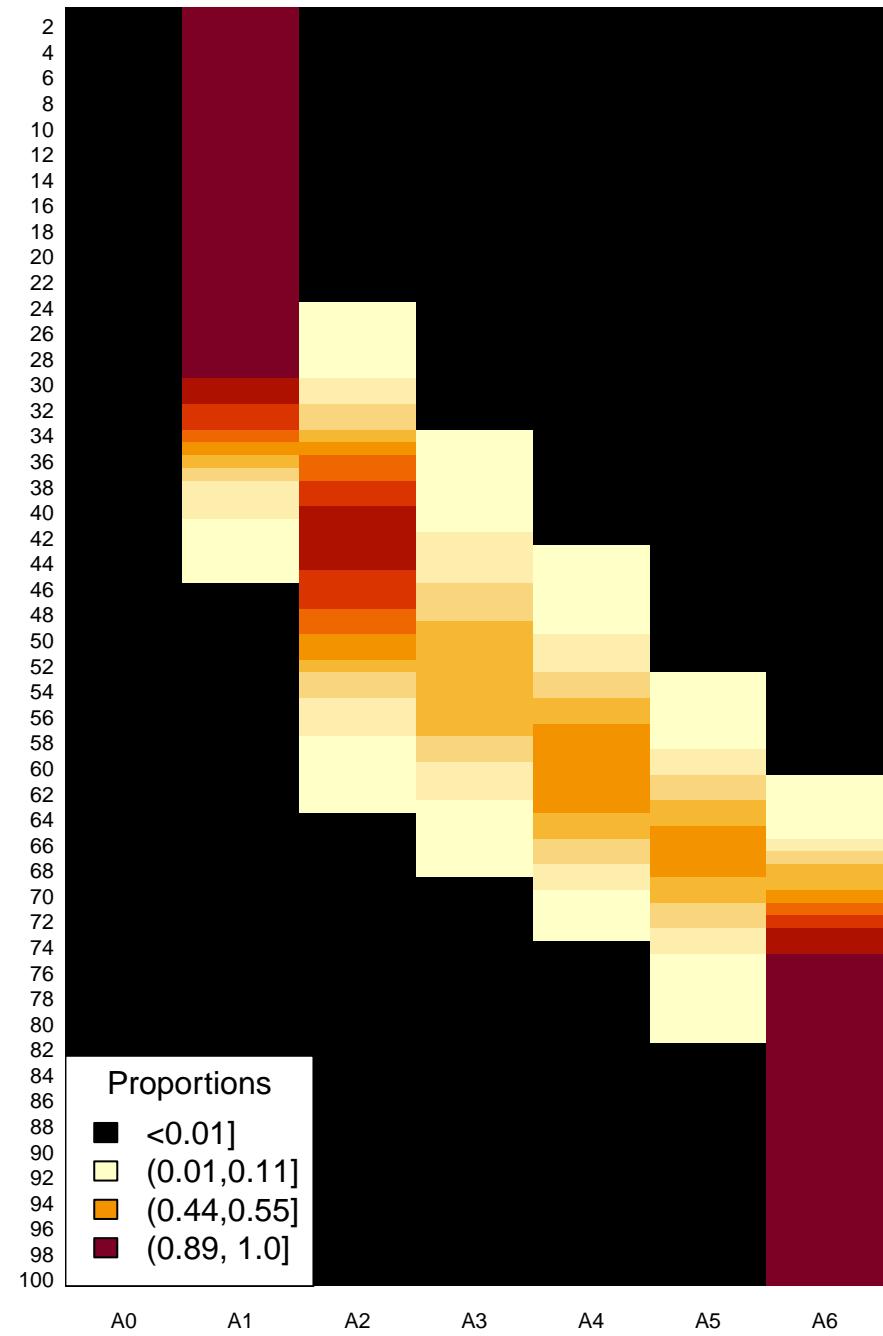
Multinomial ALK, spring 1985



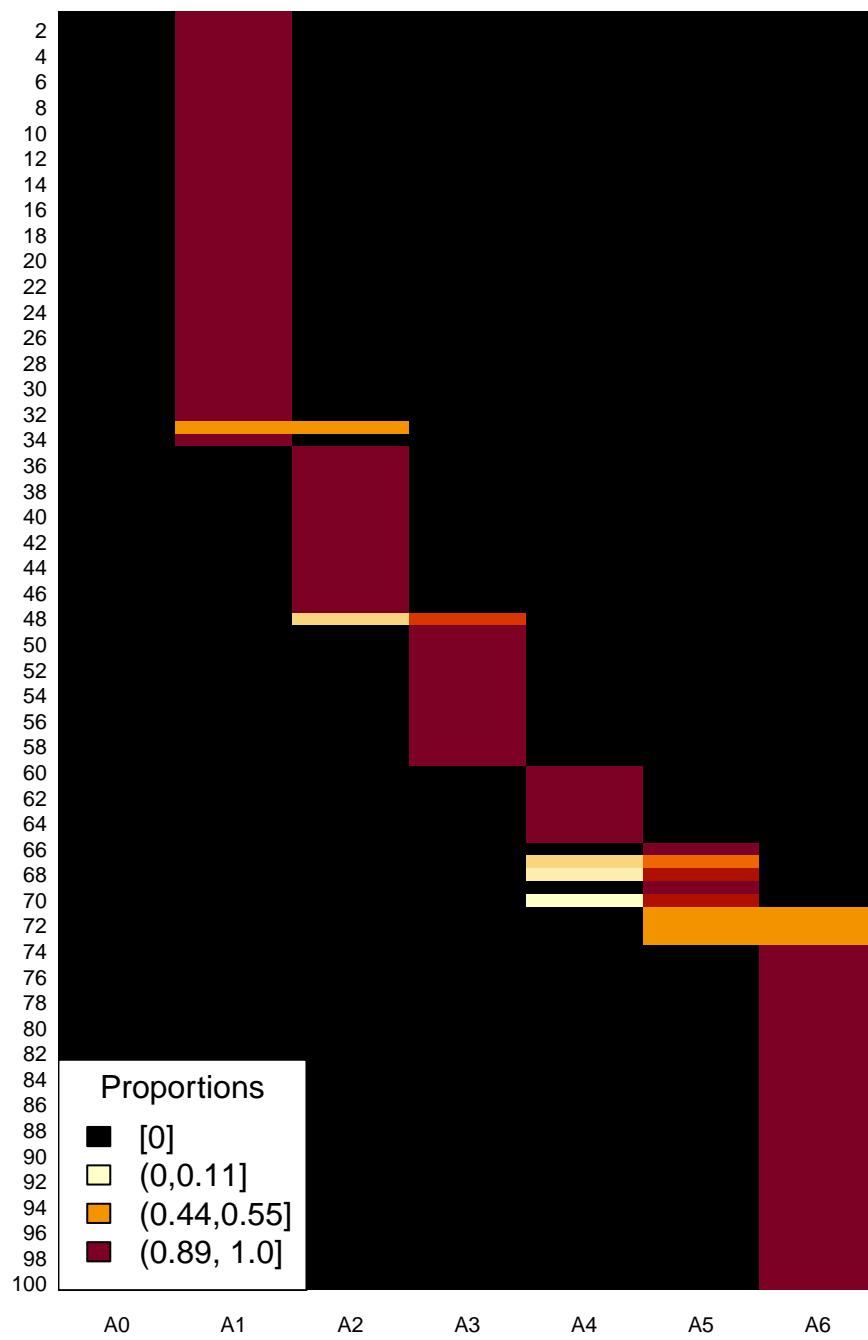
Traditional ALK, spring 1986



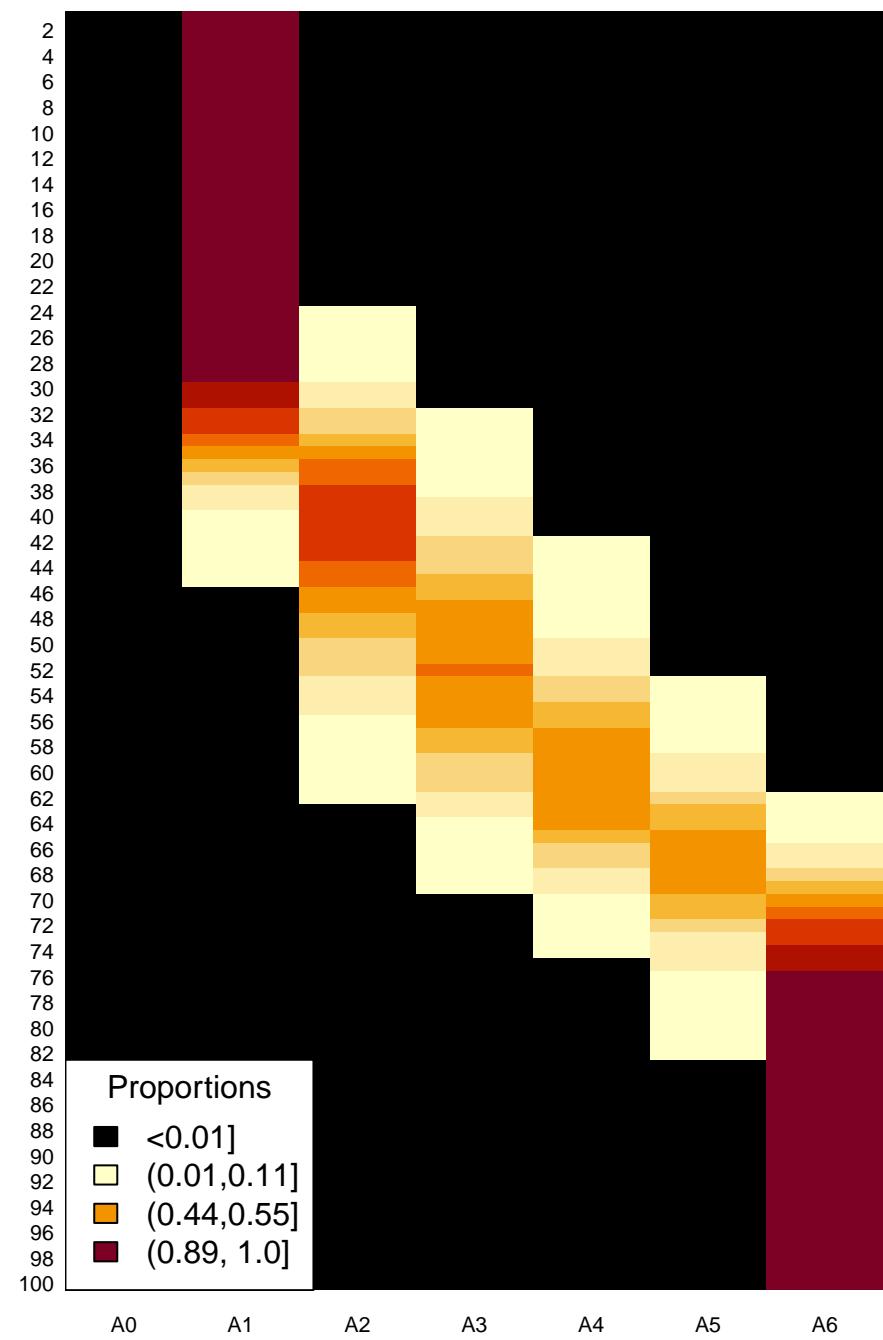
Multinomial ALK, spring 1986



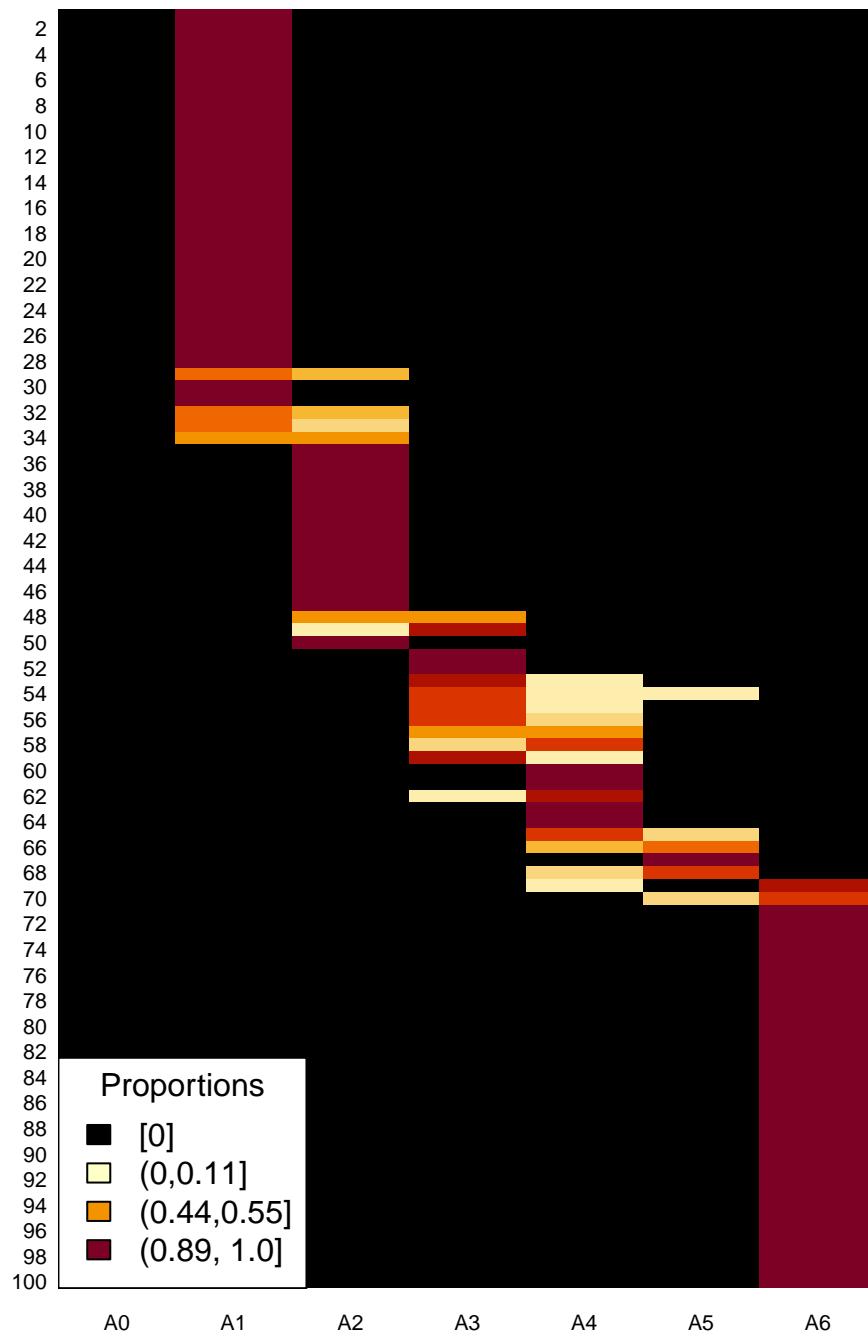
Traditional ALK, spring 1987



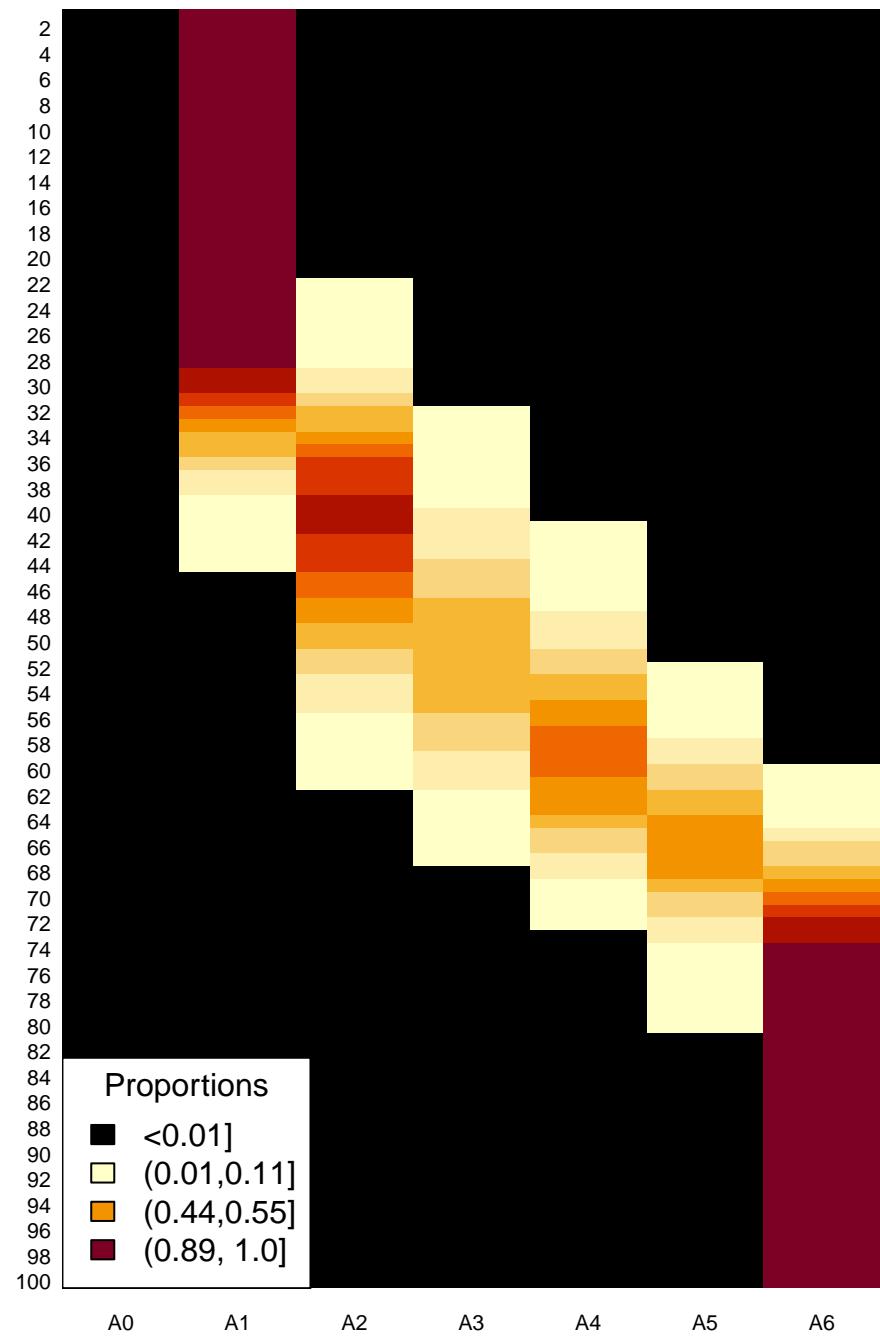
Multinomial ALK, spring 1987



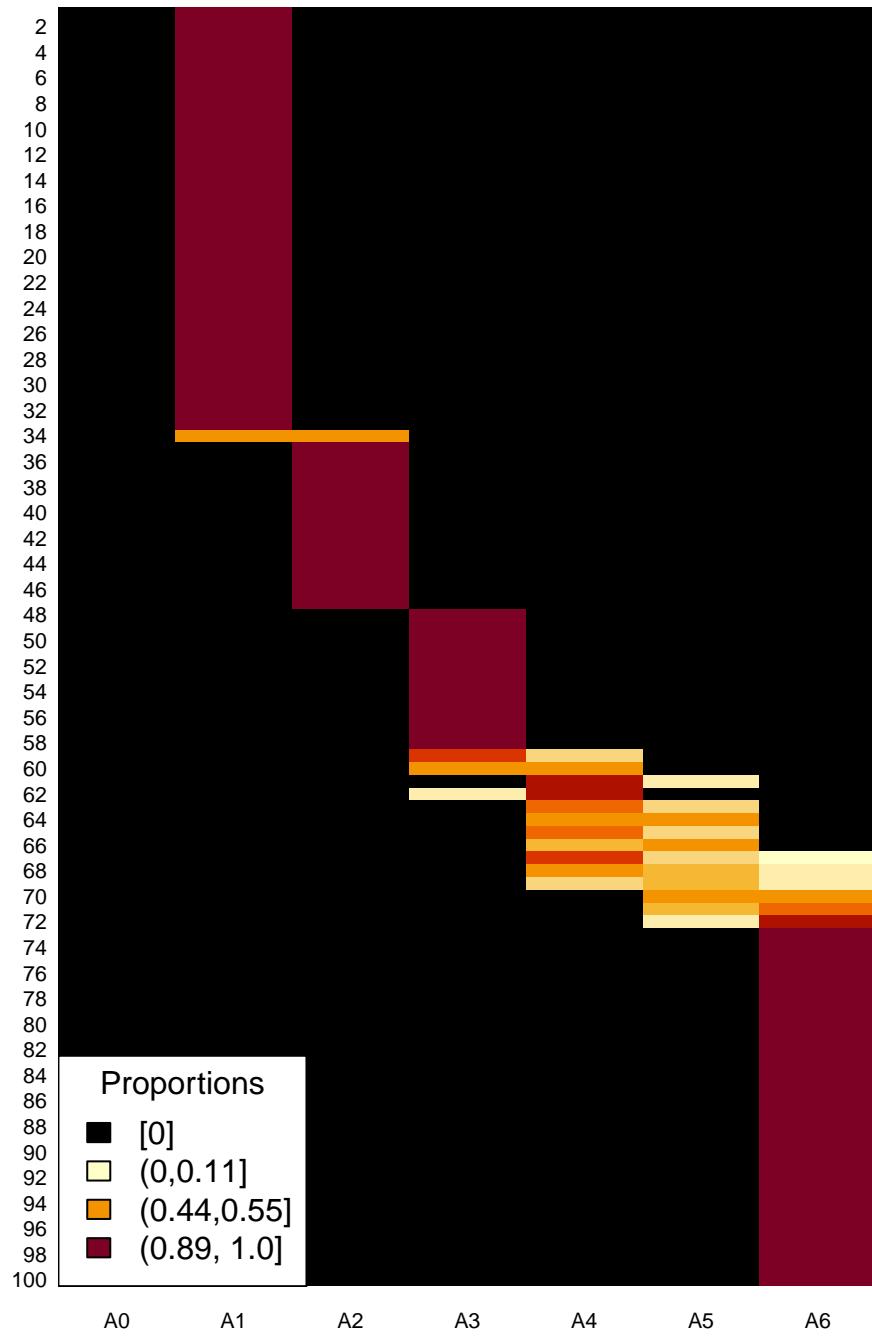
Traditional ALK, spring 1988



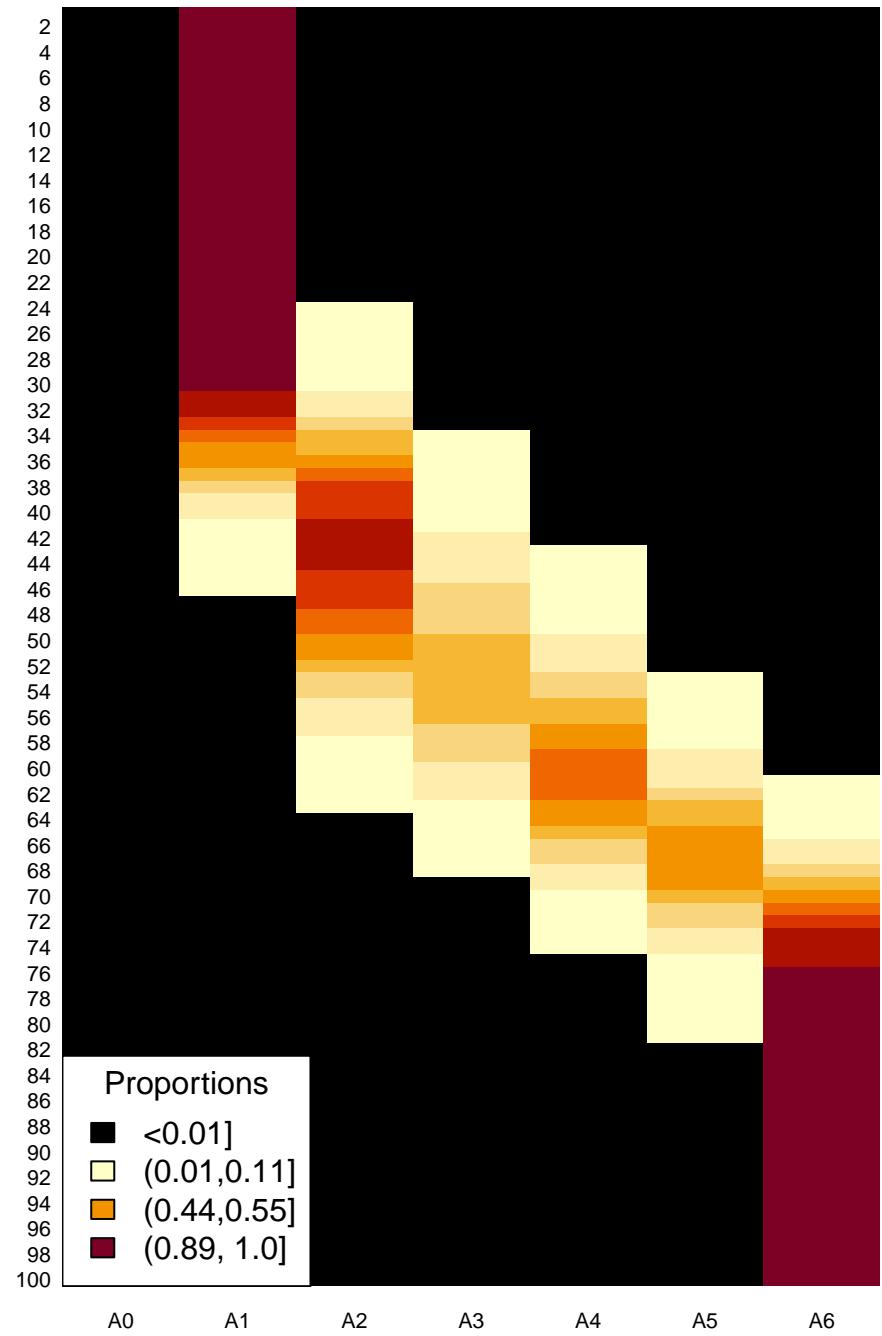
Multinomial ALK, spring 1988



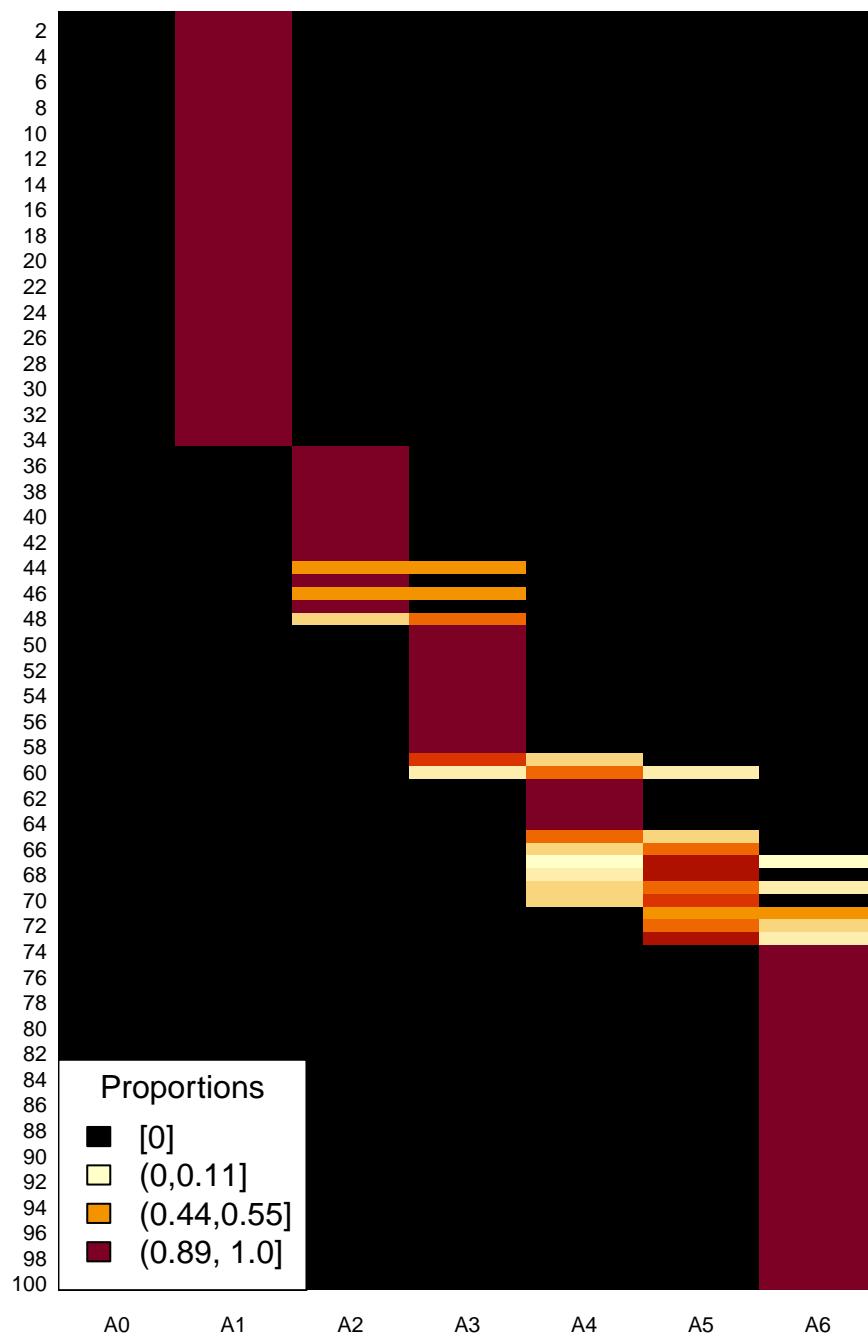
Traditional ALK, spring 1989



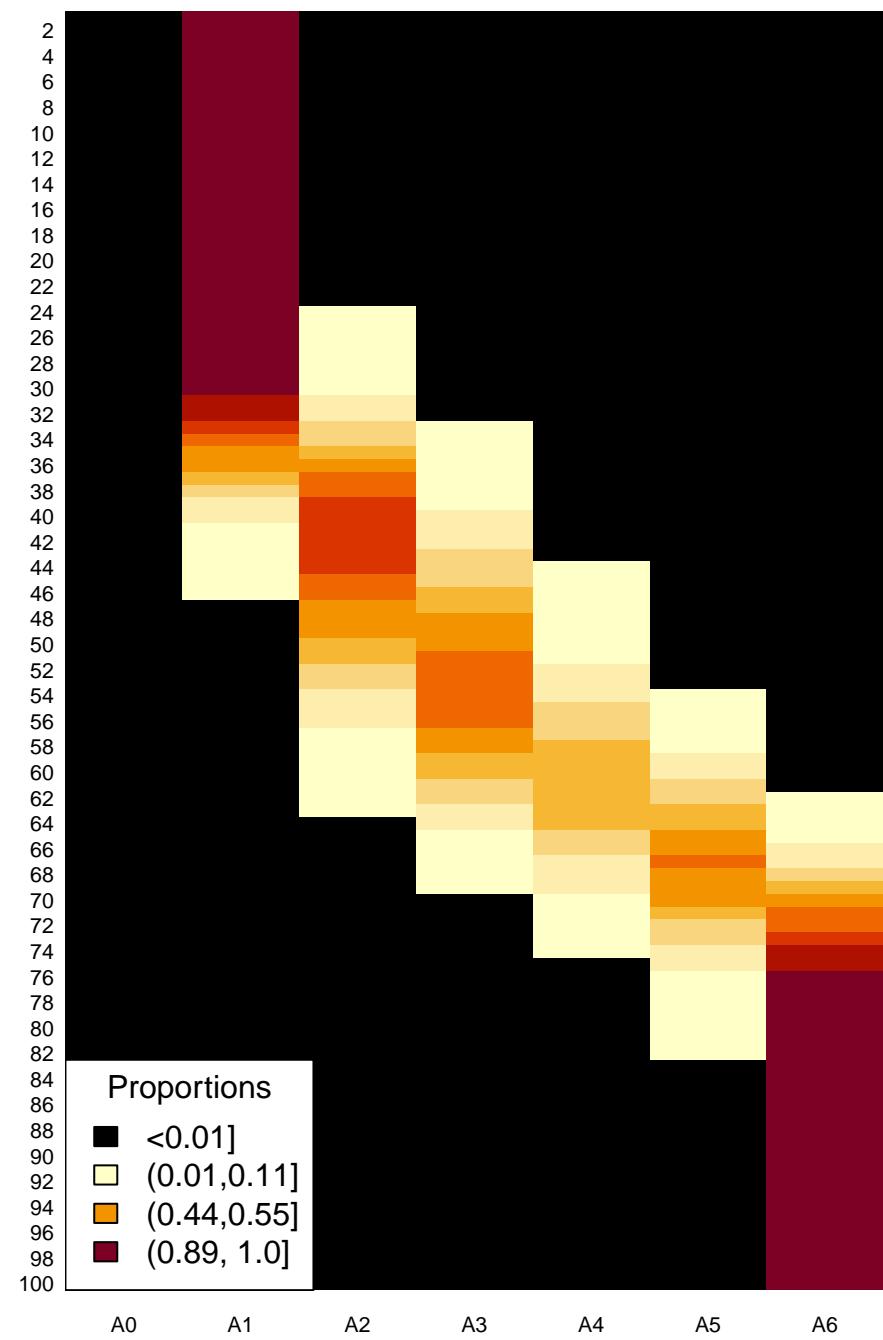
Multinomial ALK, spring 1989



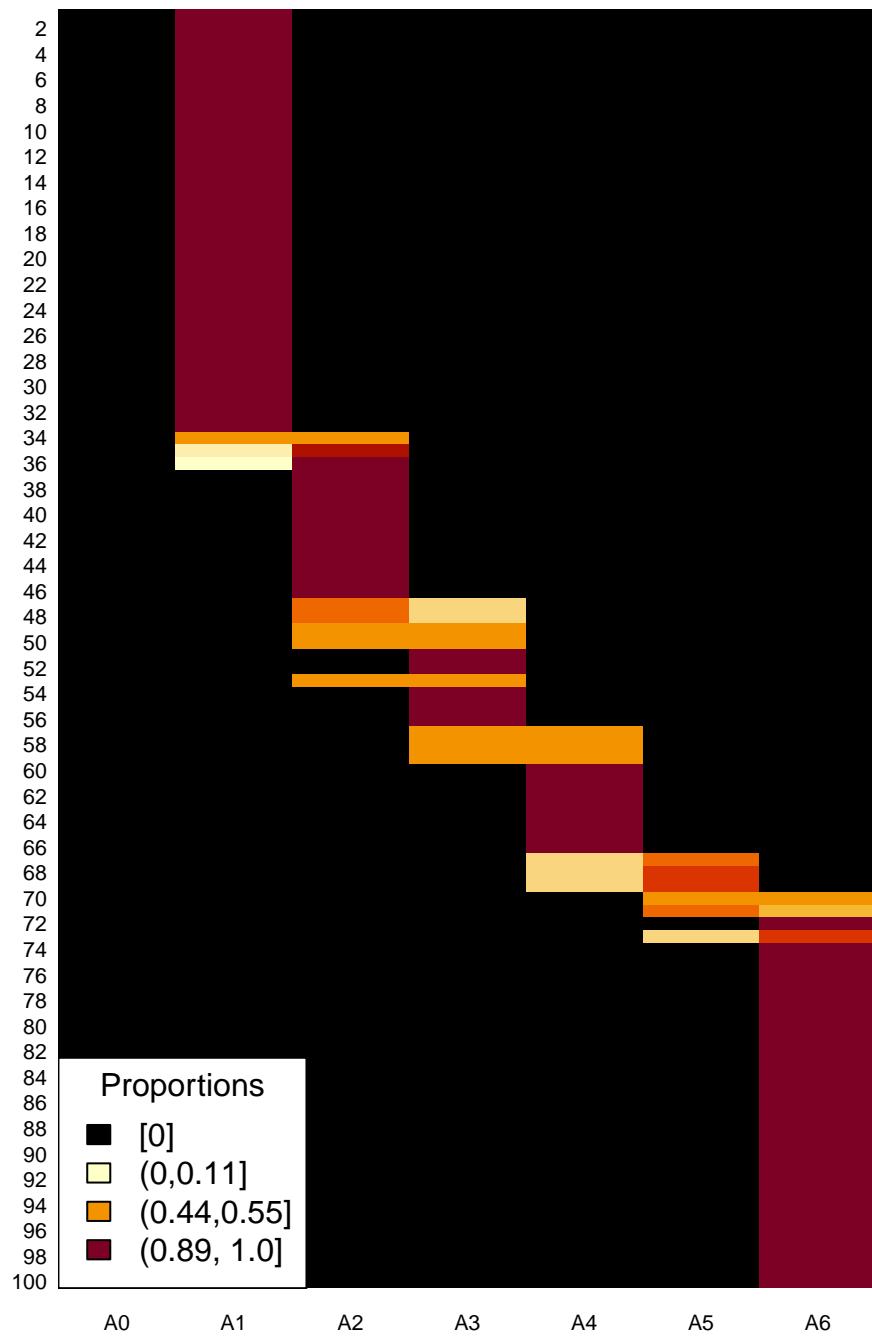
Traditional ALK, spring 1990



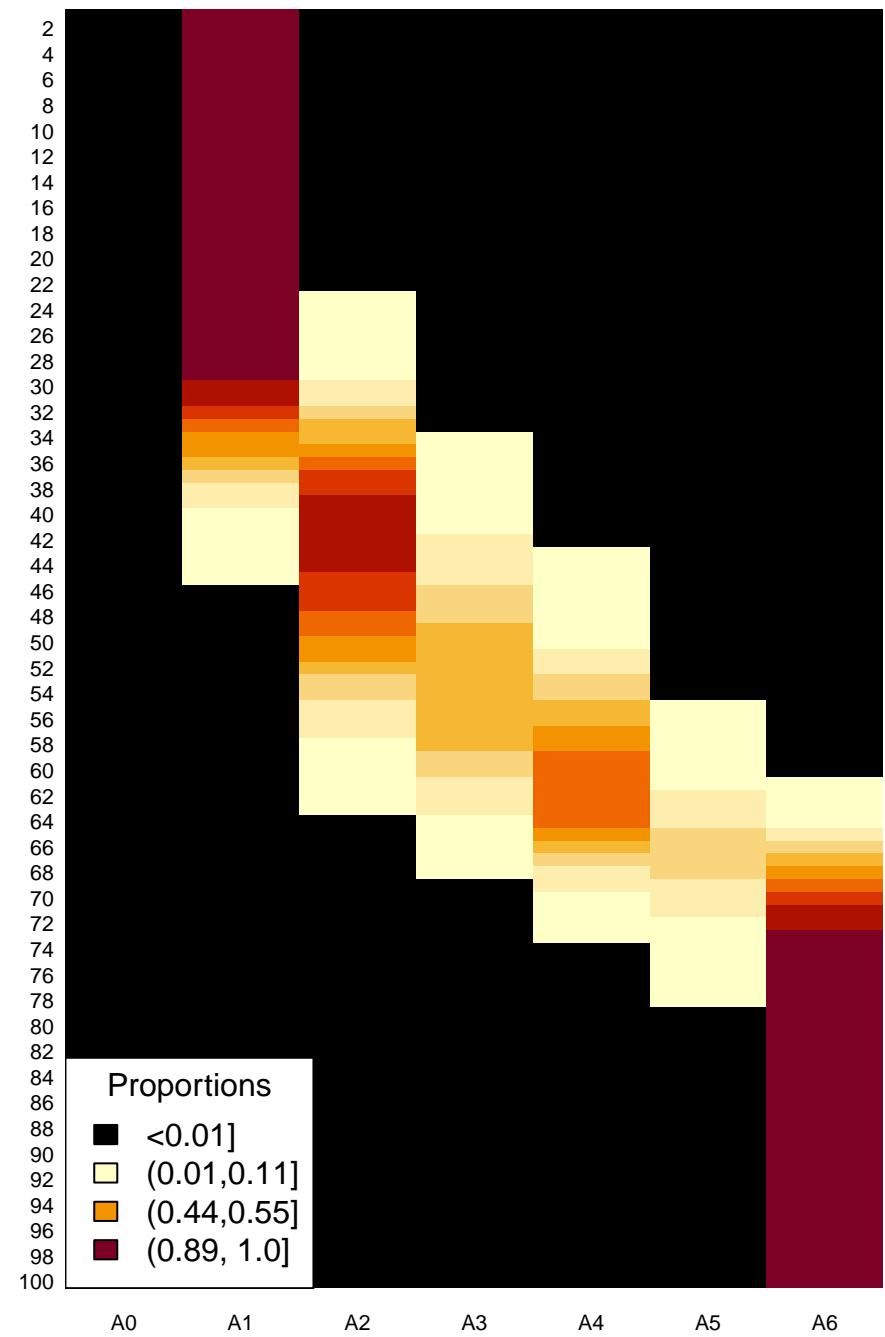
Multinomial ALK, spring 1990



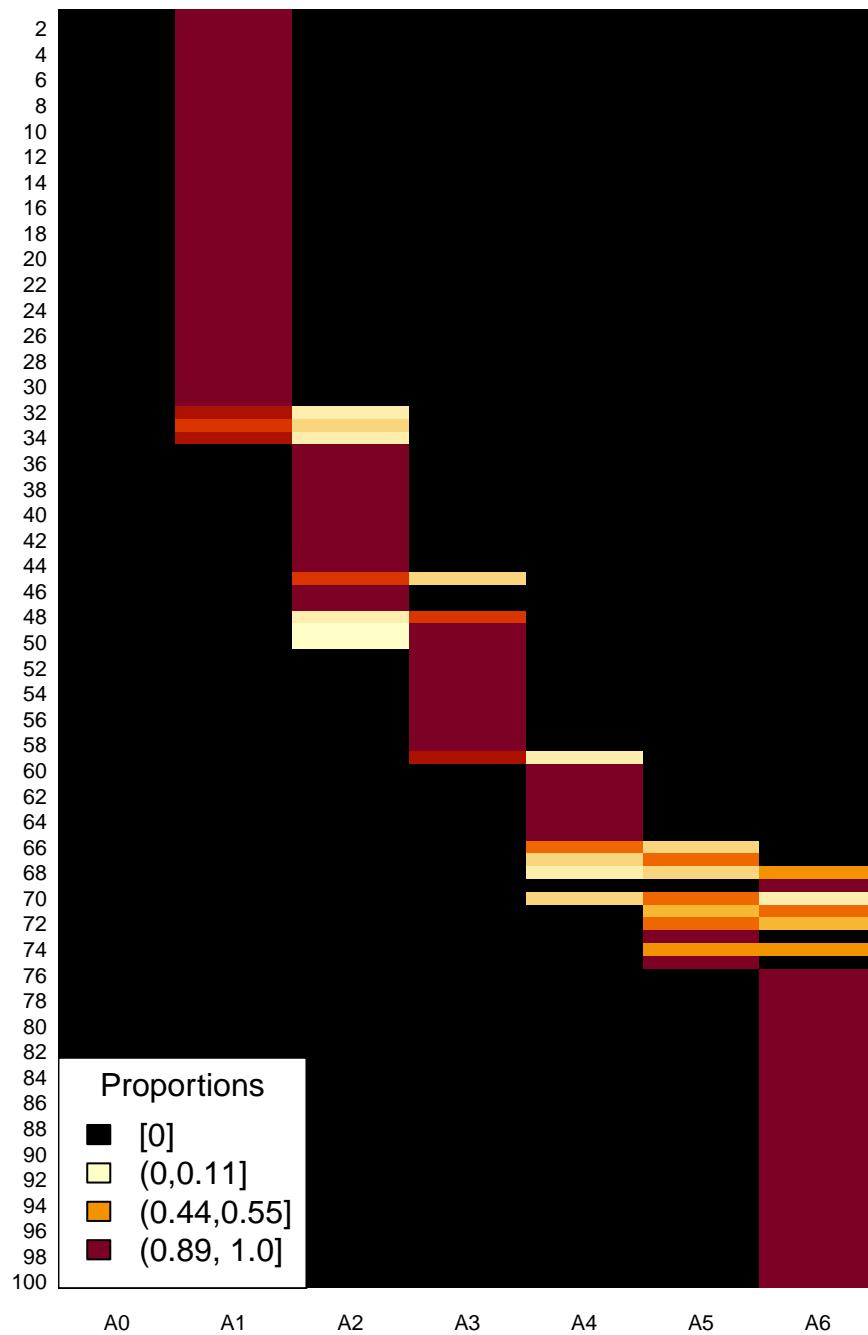
Traditional ALK, spring 1991



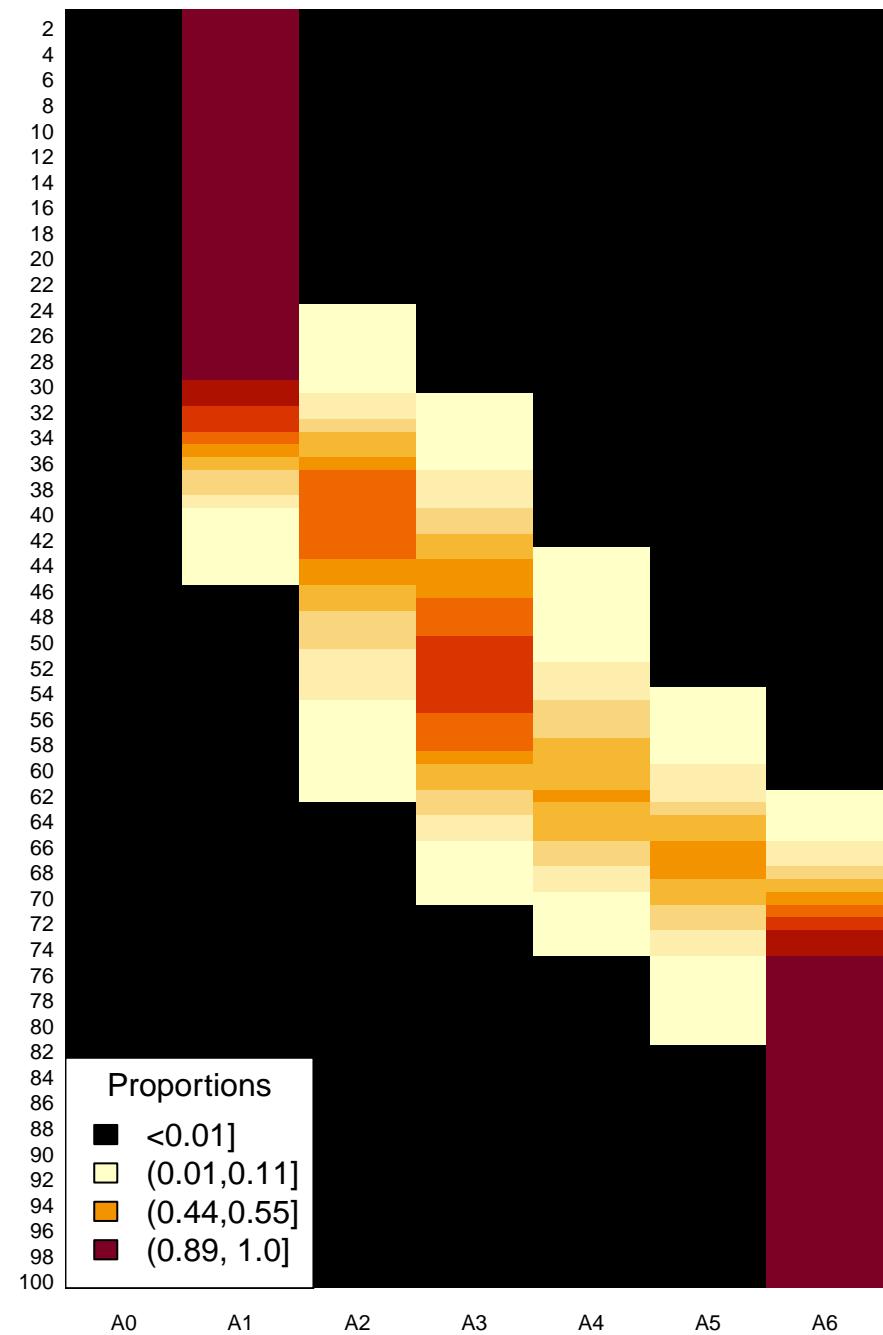
Multinomial ALK, spring 1991



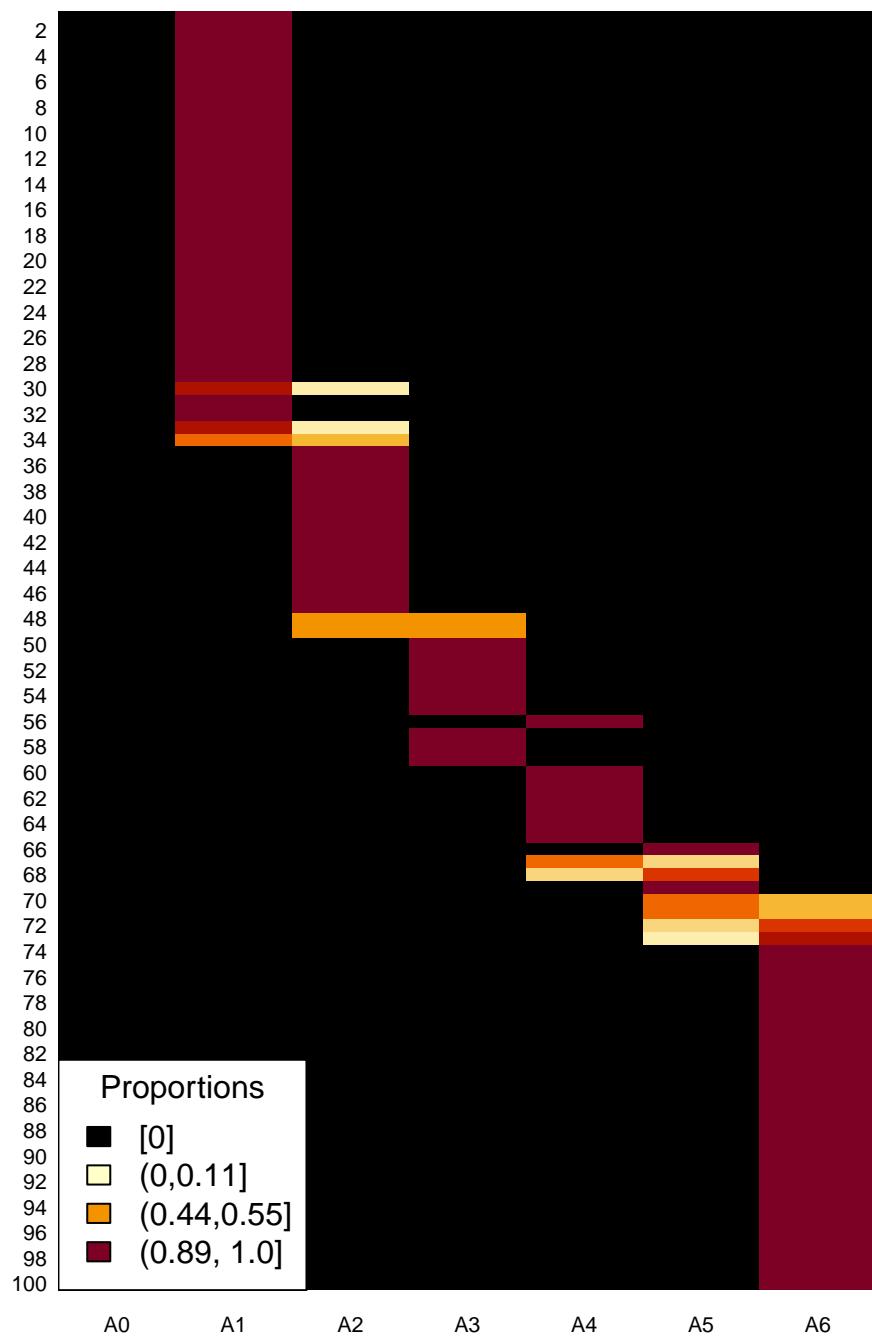
Traditional ALK, spring 1992



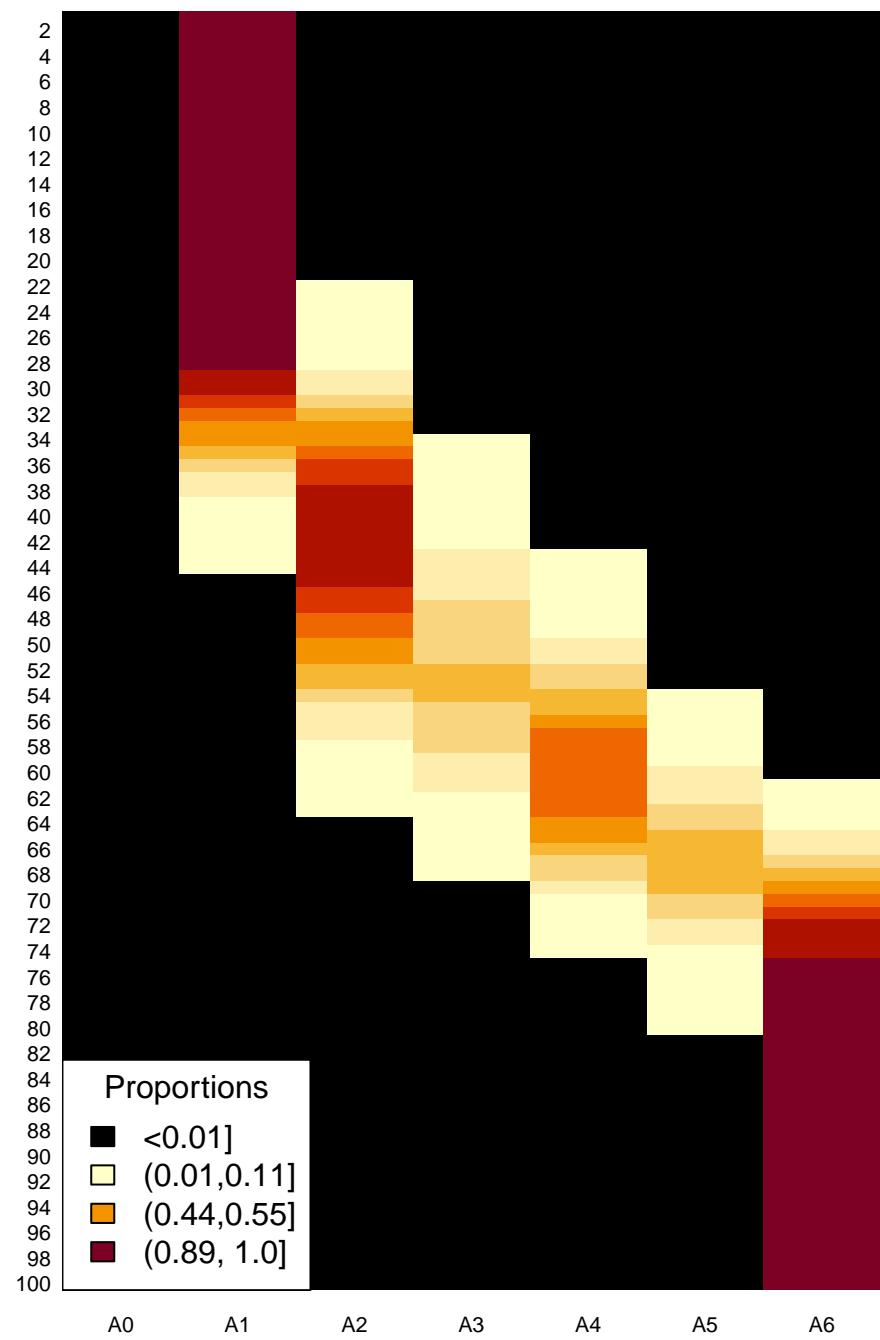
Multinomial ALK, spring 1992



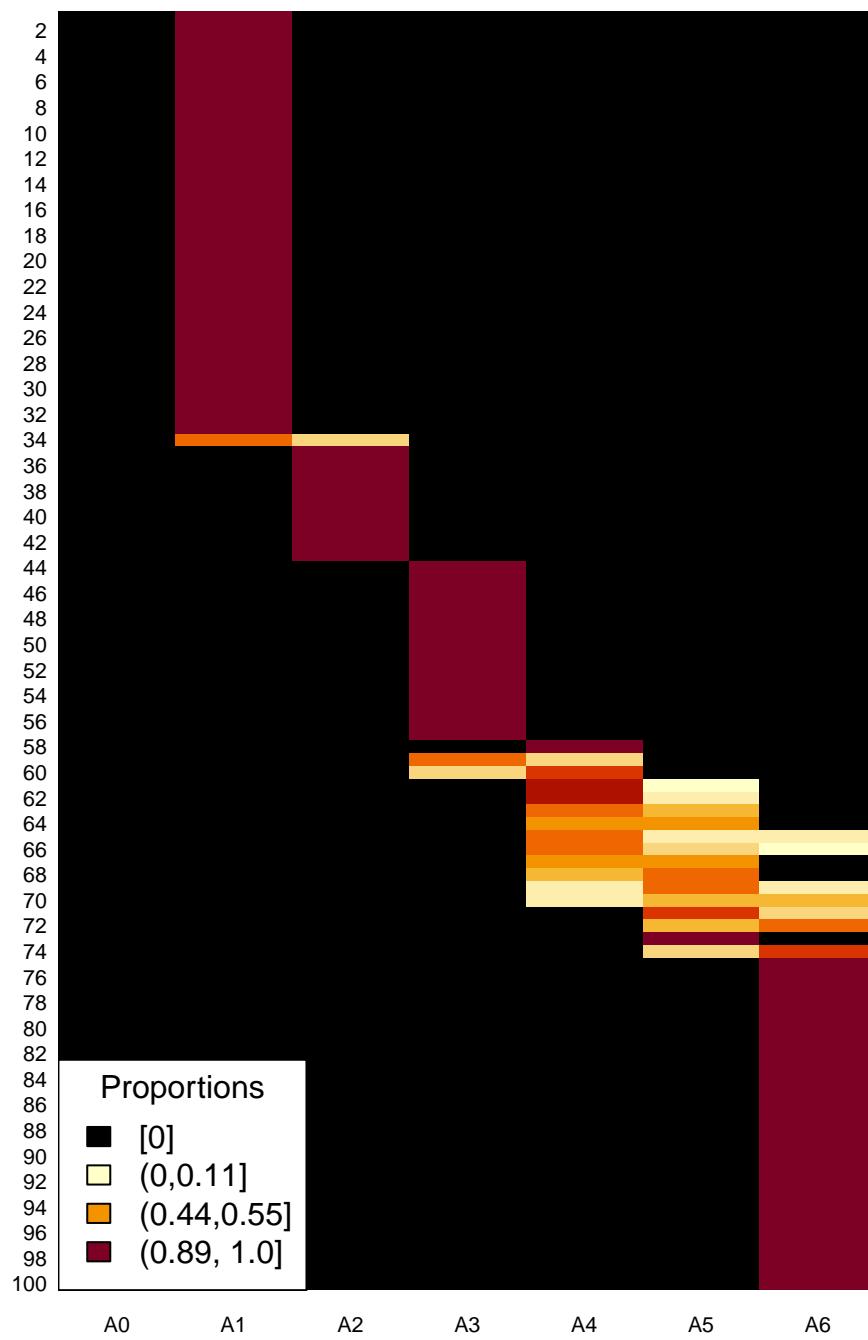
Traditional ALK, spring 1993



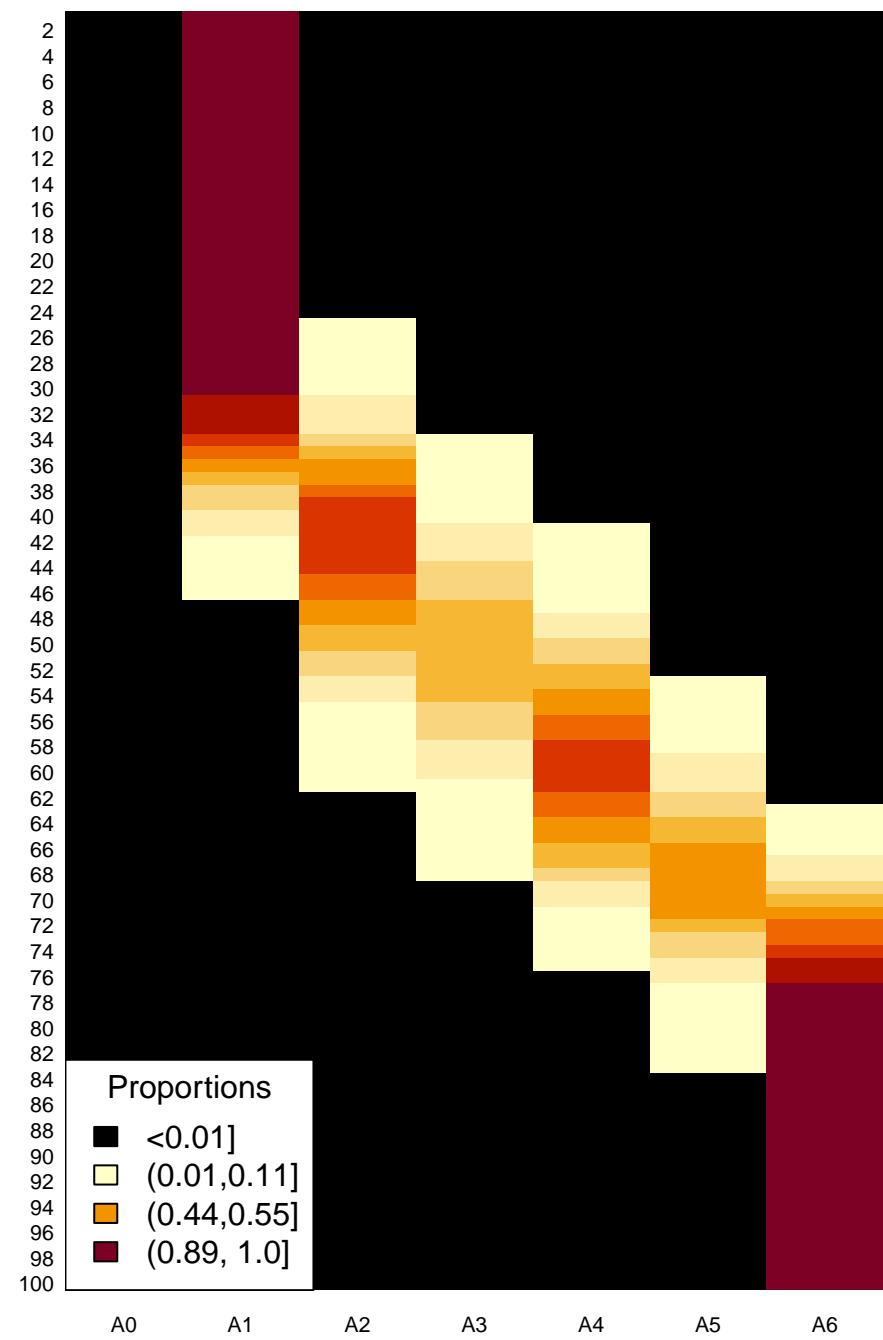
Multinomial ALK, spring 1993



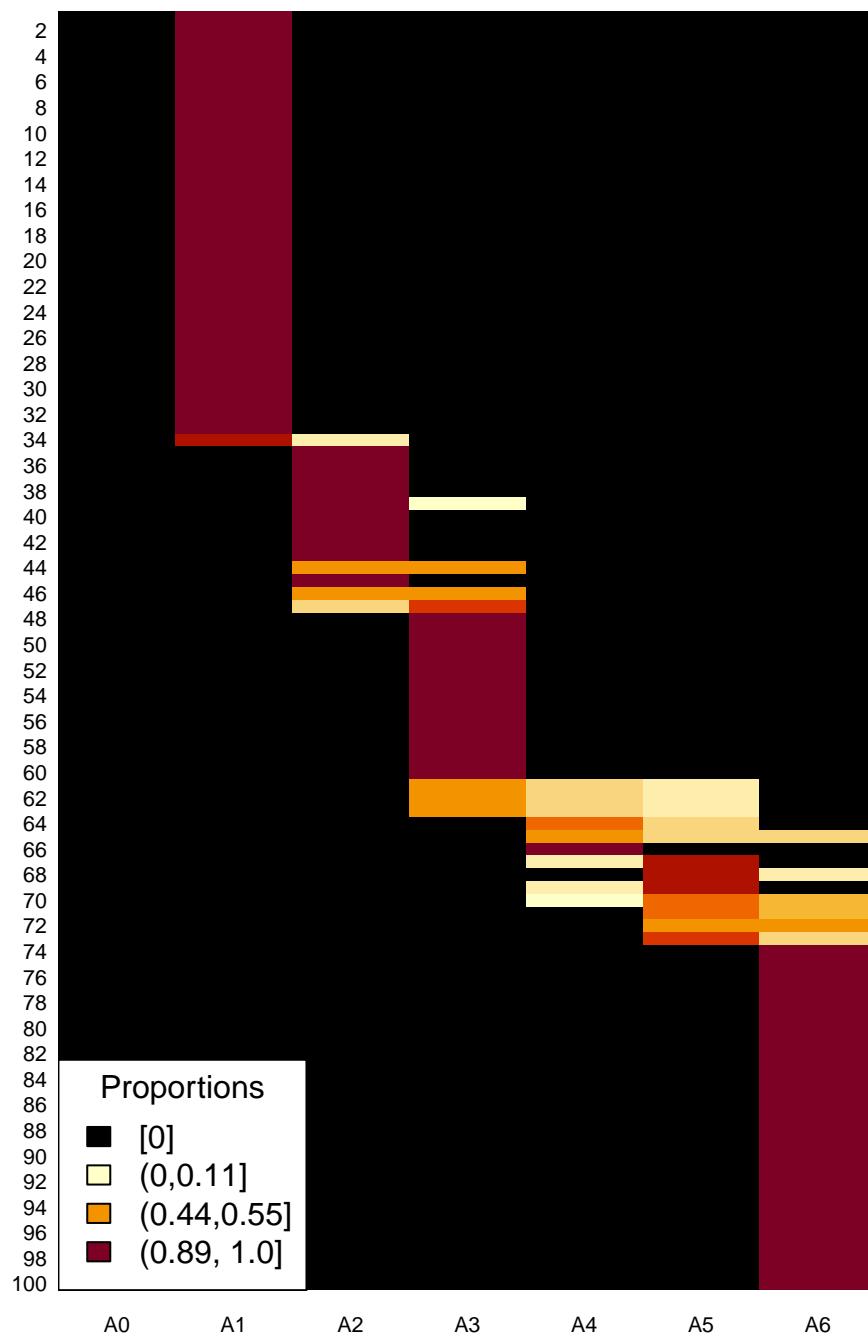
Traditional ALK, spring 1994



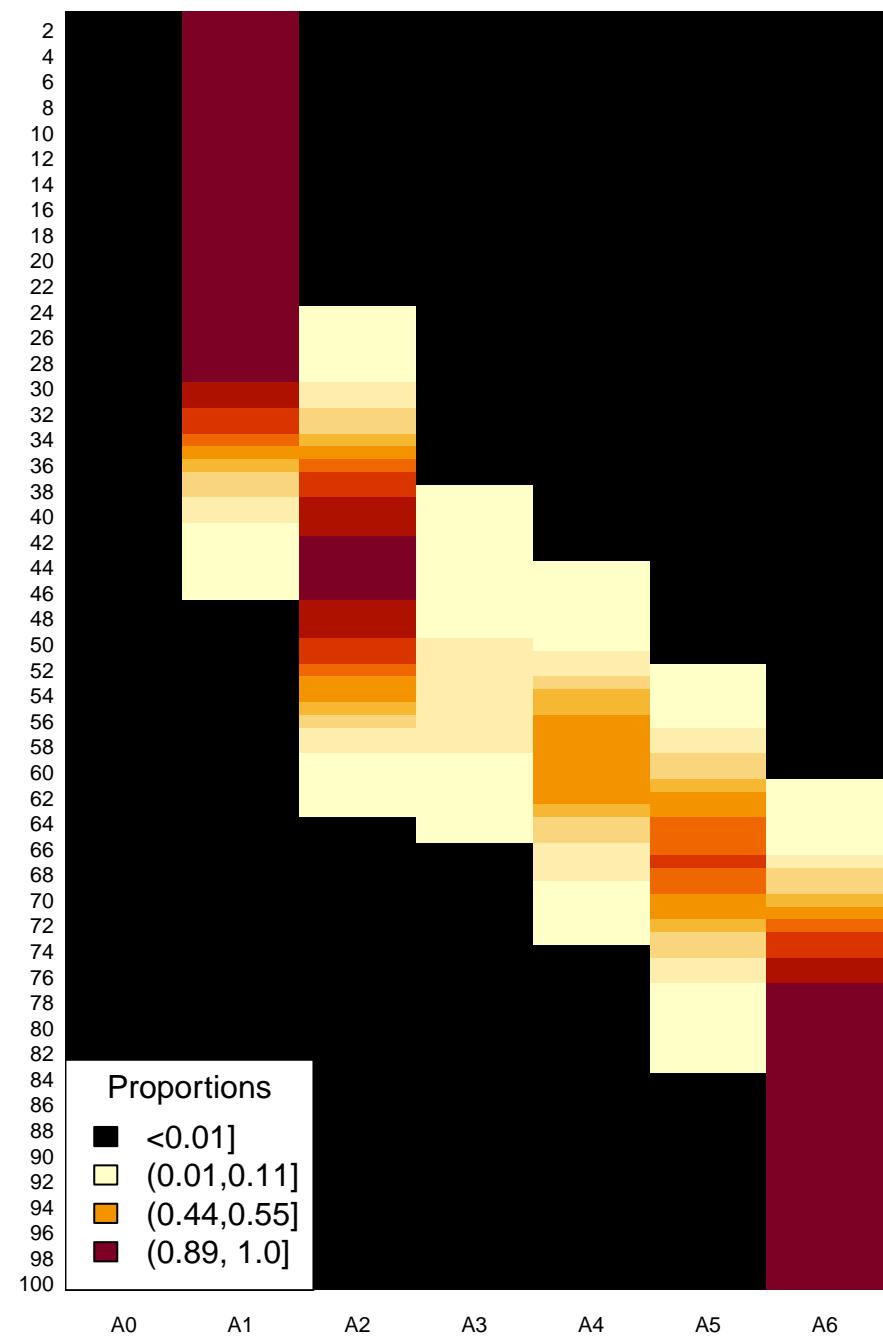
Multinomial ALK, spring 1994



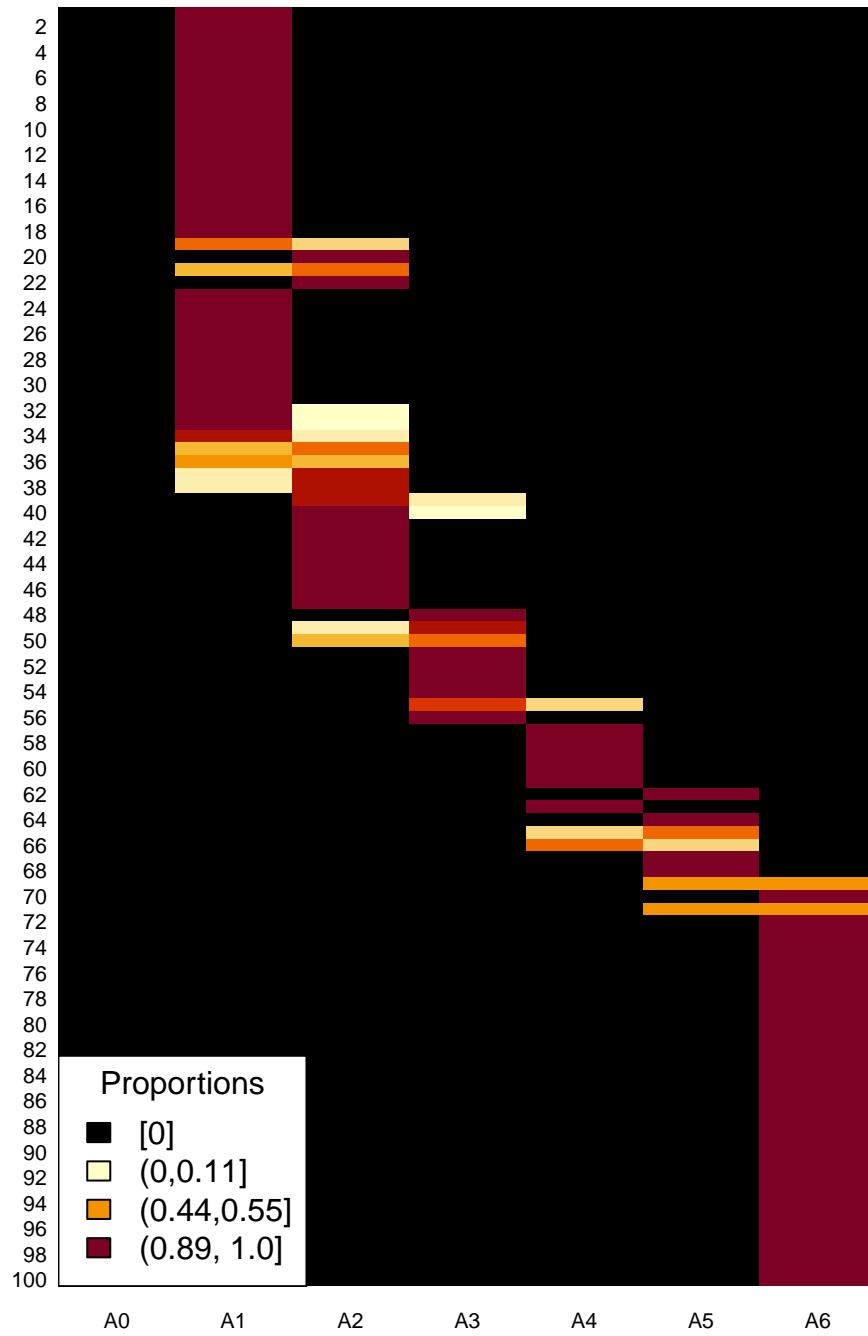
Traditional ALK, spring 1995



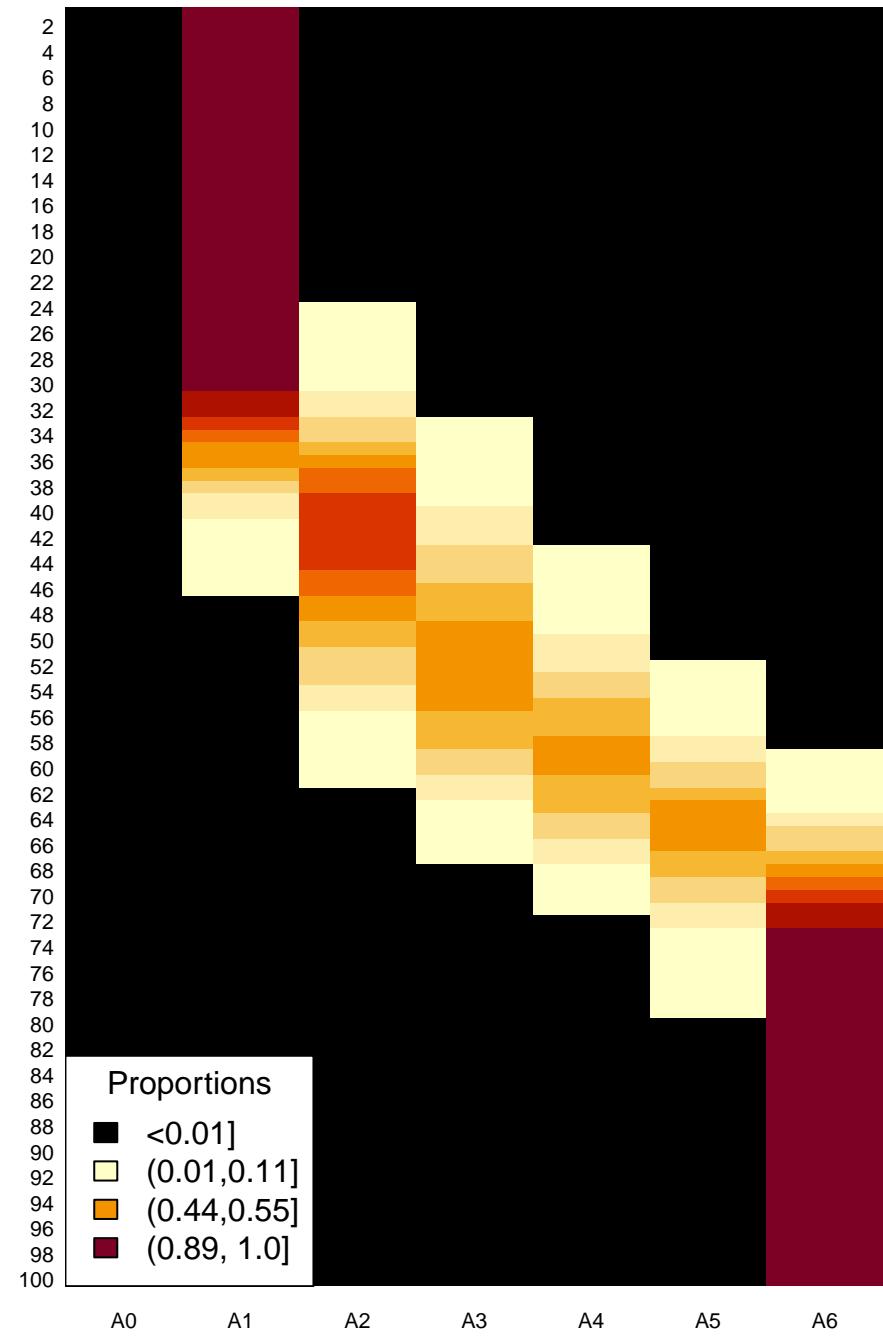
Multinomial ALK, spring 1995



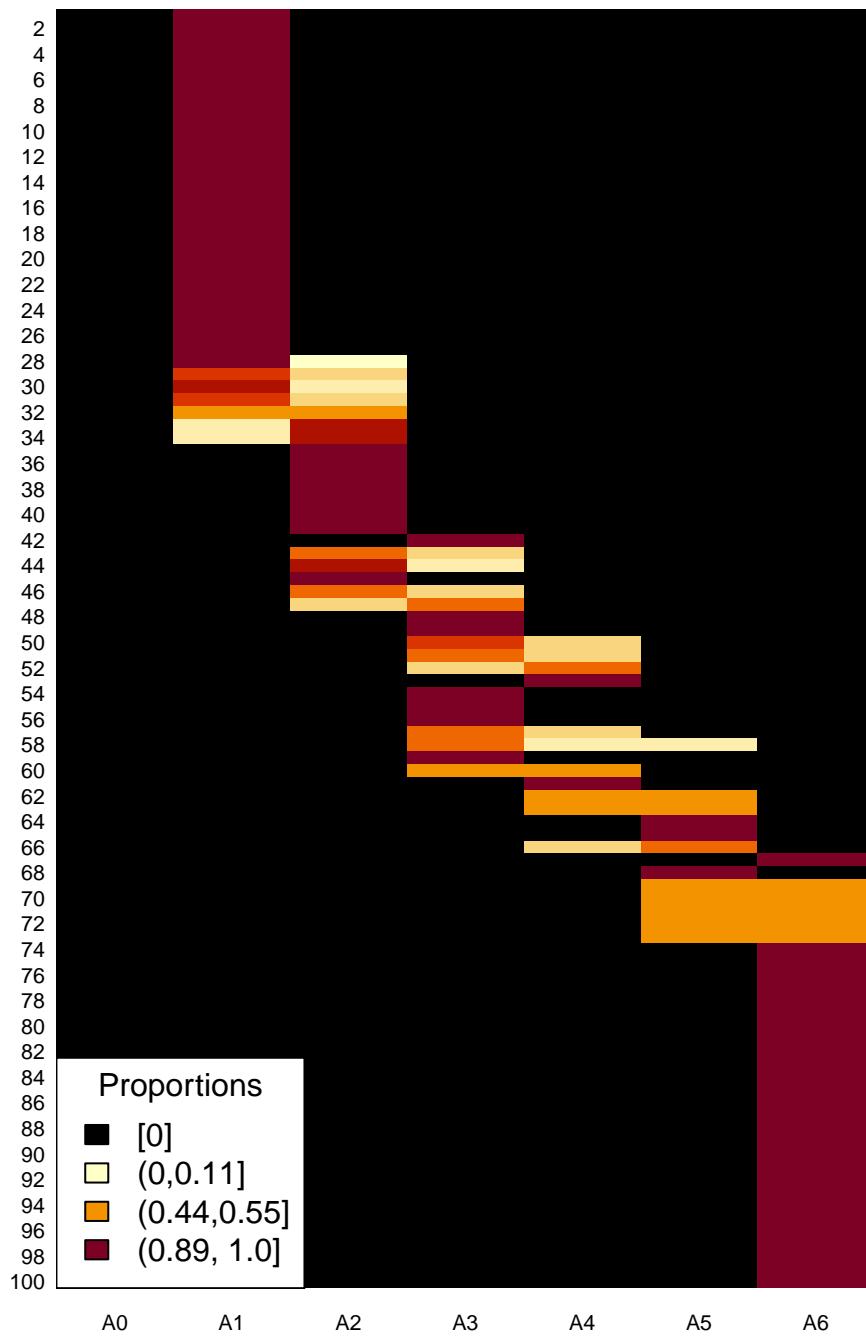
Traditional ALK, spring 1996



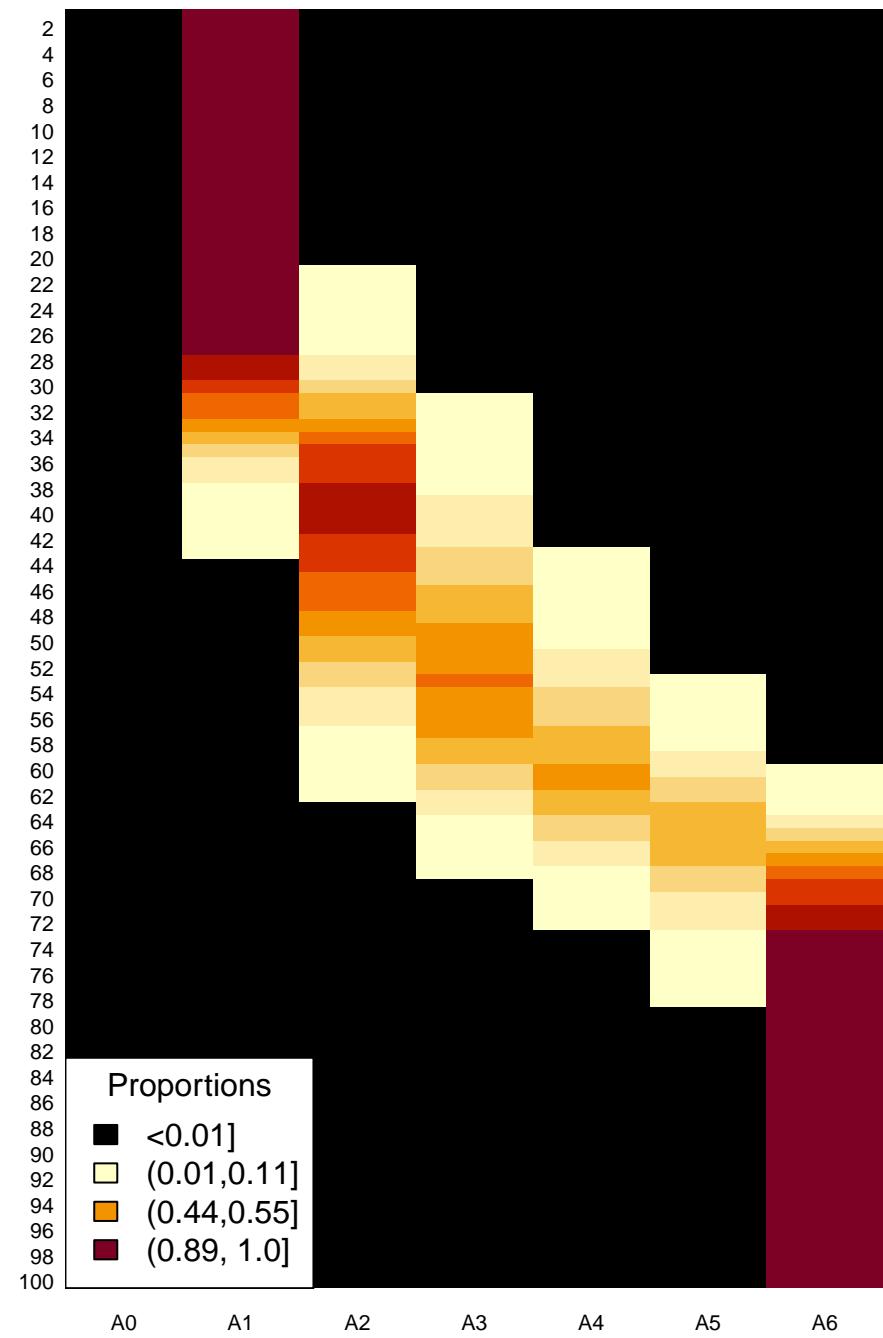
Multinomial ALK, spring 1996



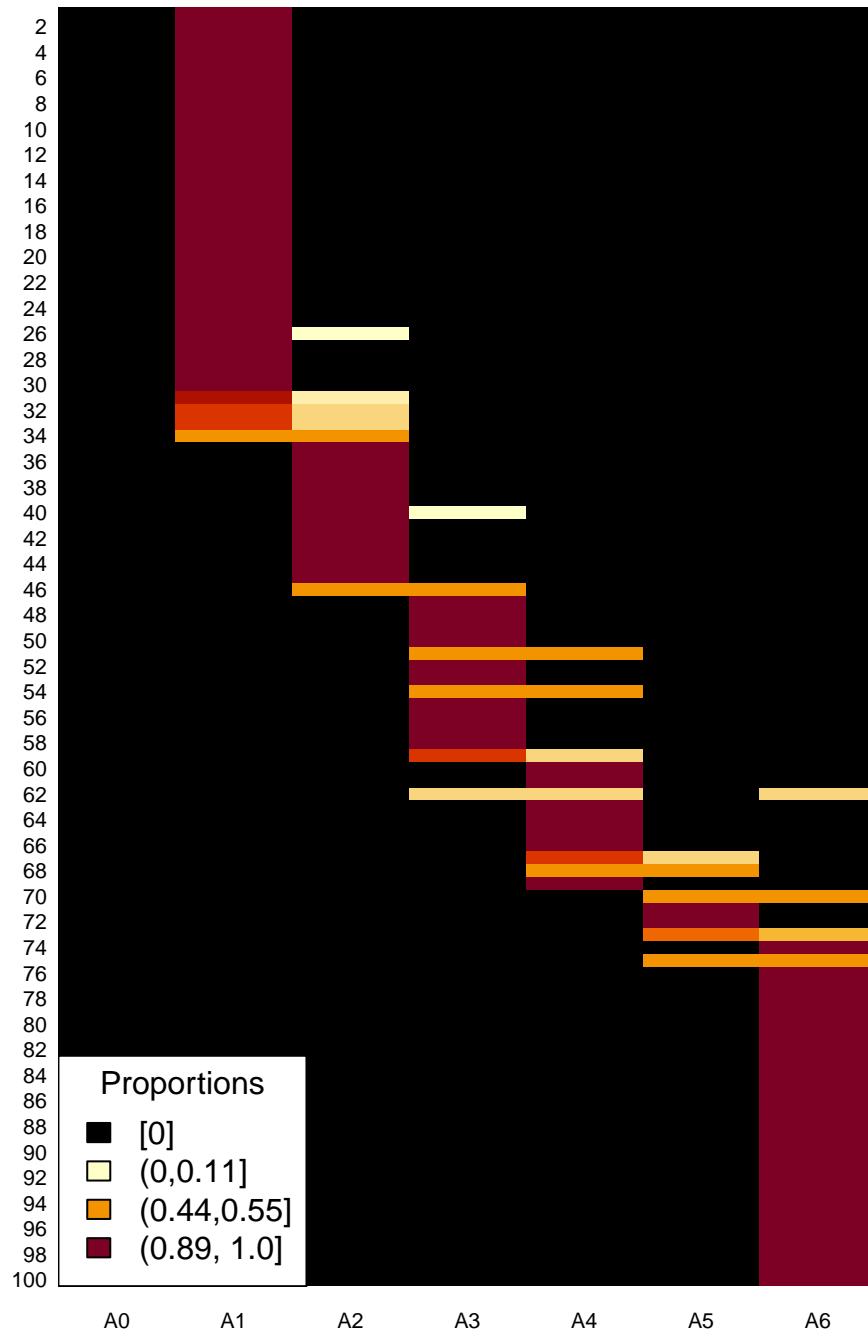
Traditional ALK, spring 1997



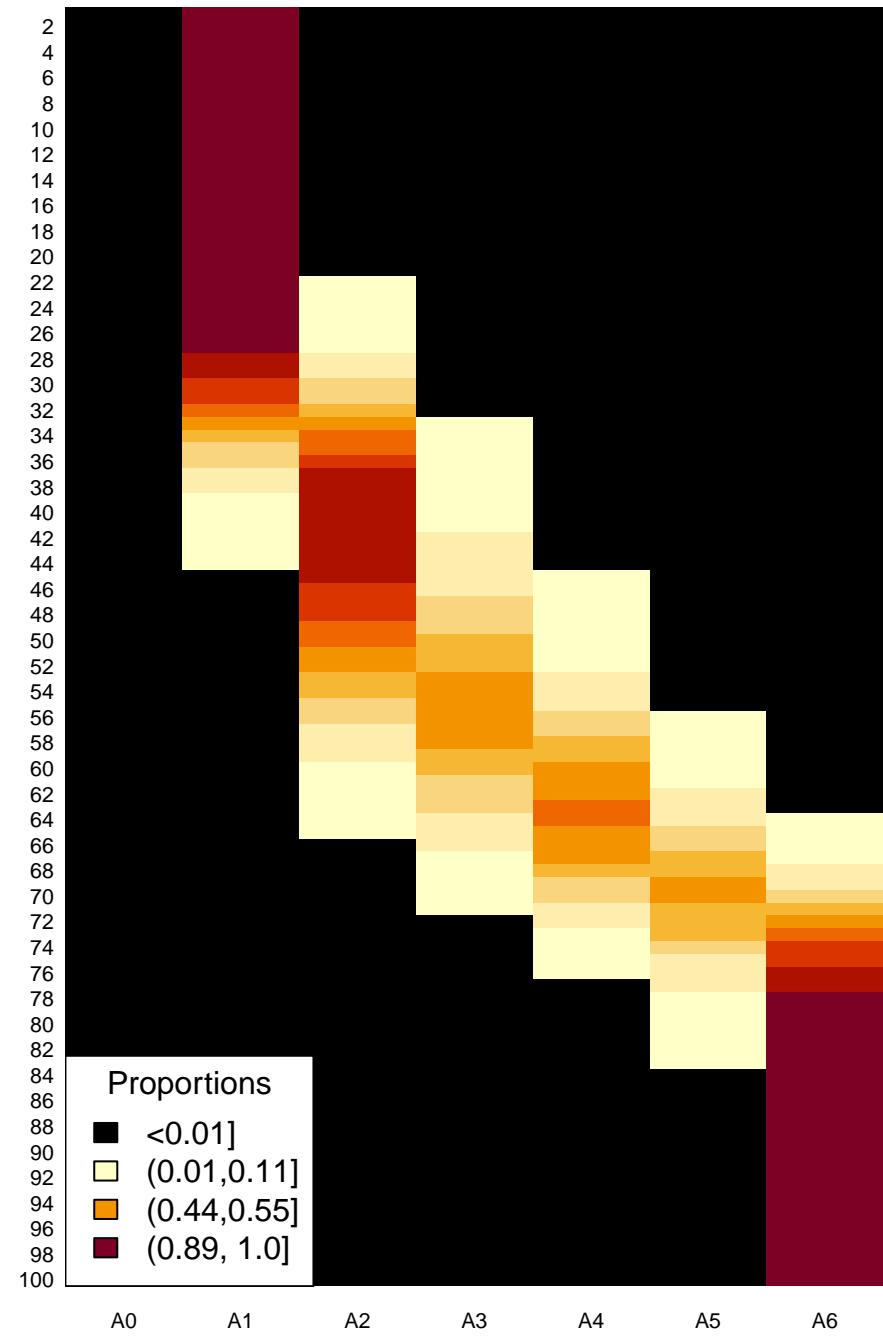
Multinomial ALK, spring 1997



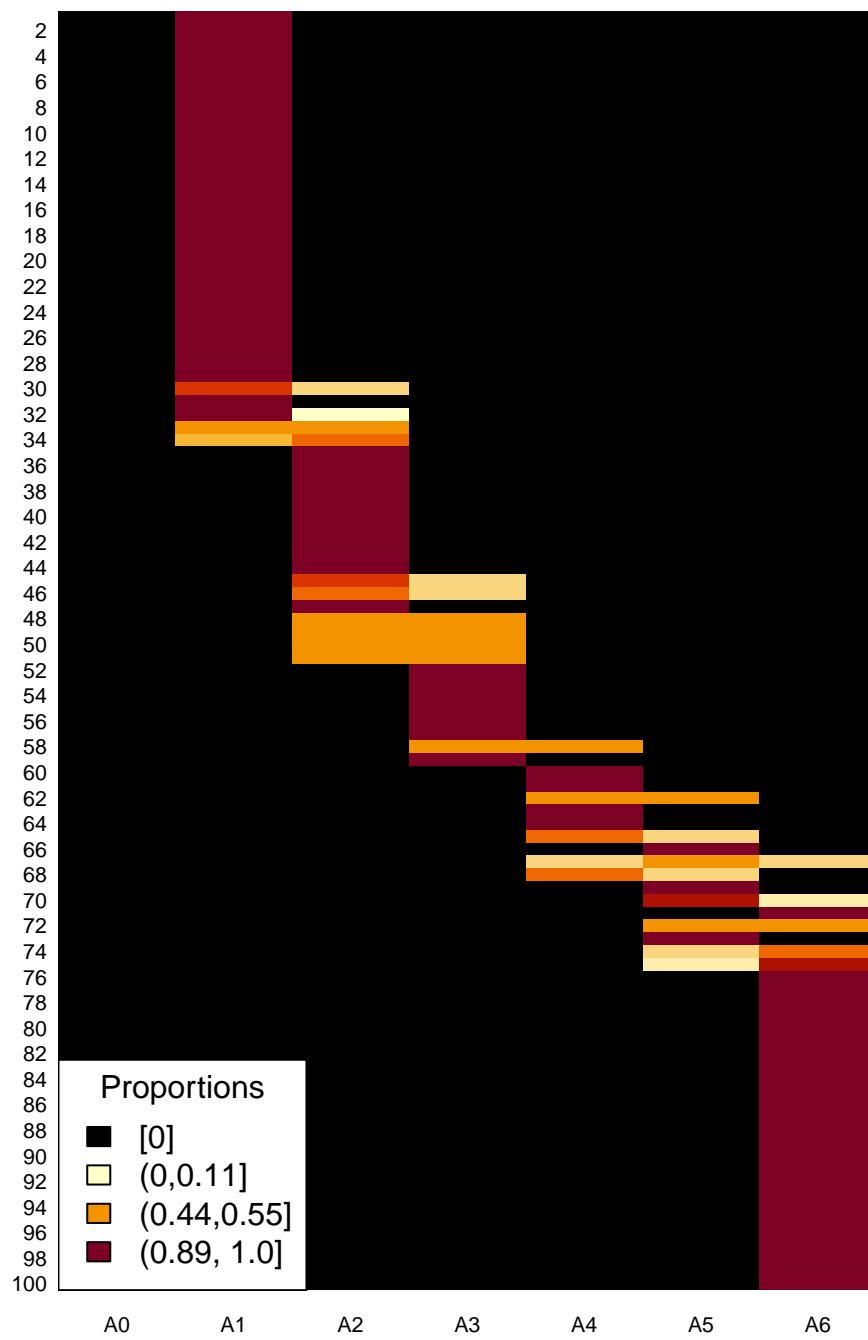
Traditional ALK, spring 1998



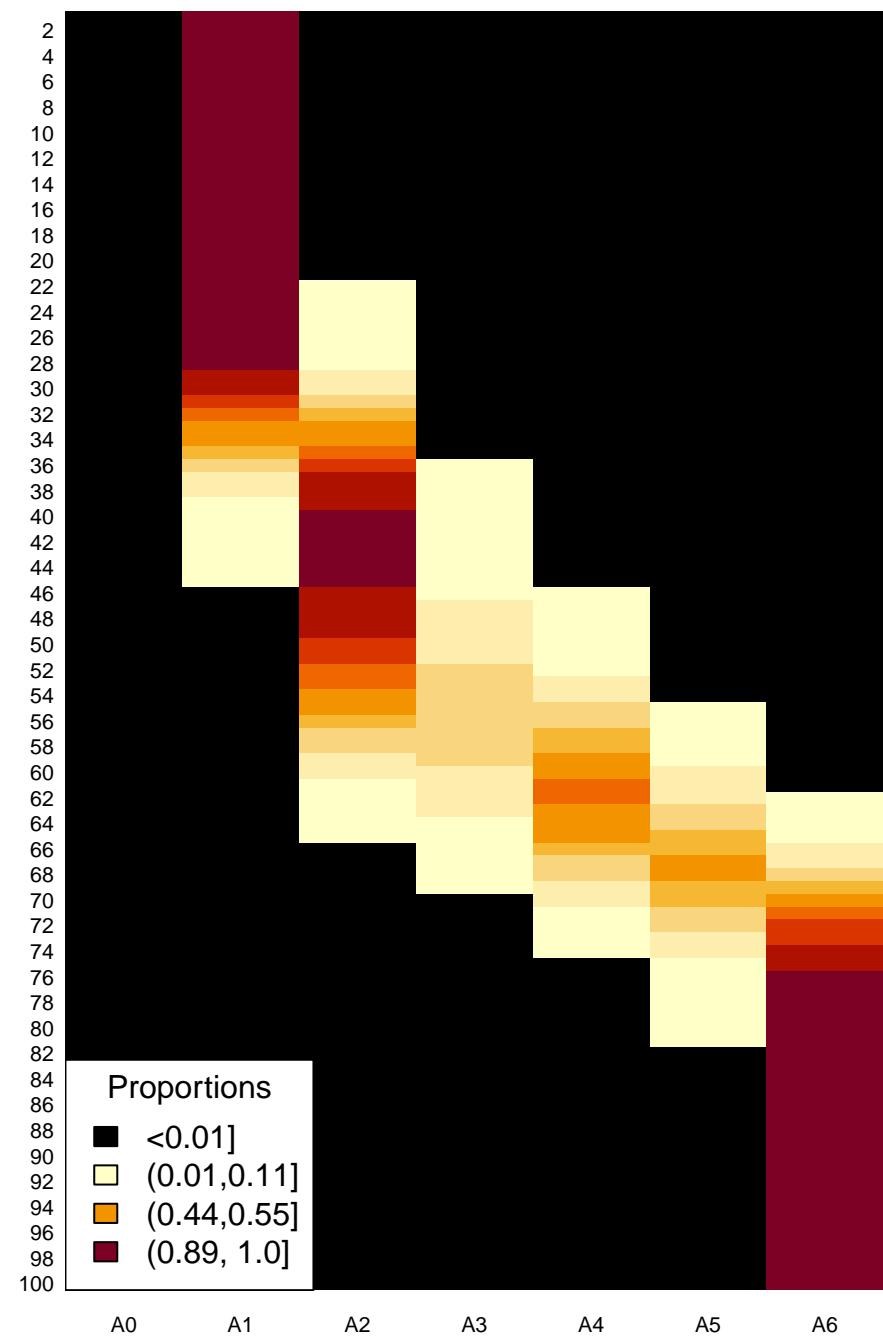
Multinomial ALK, spring 1998



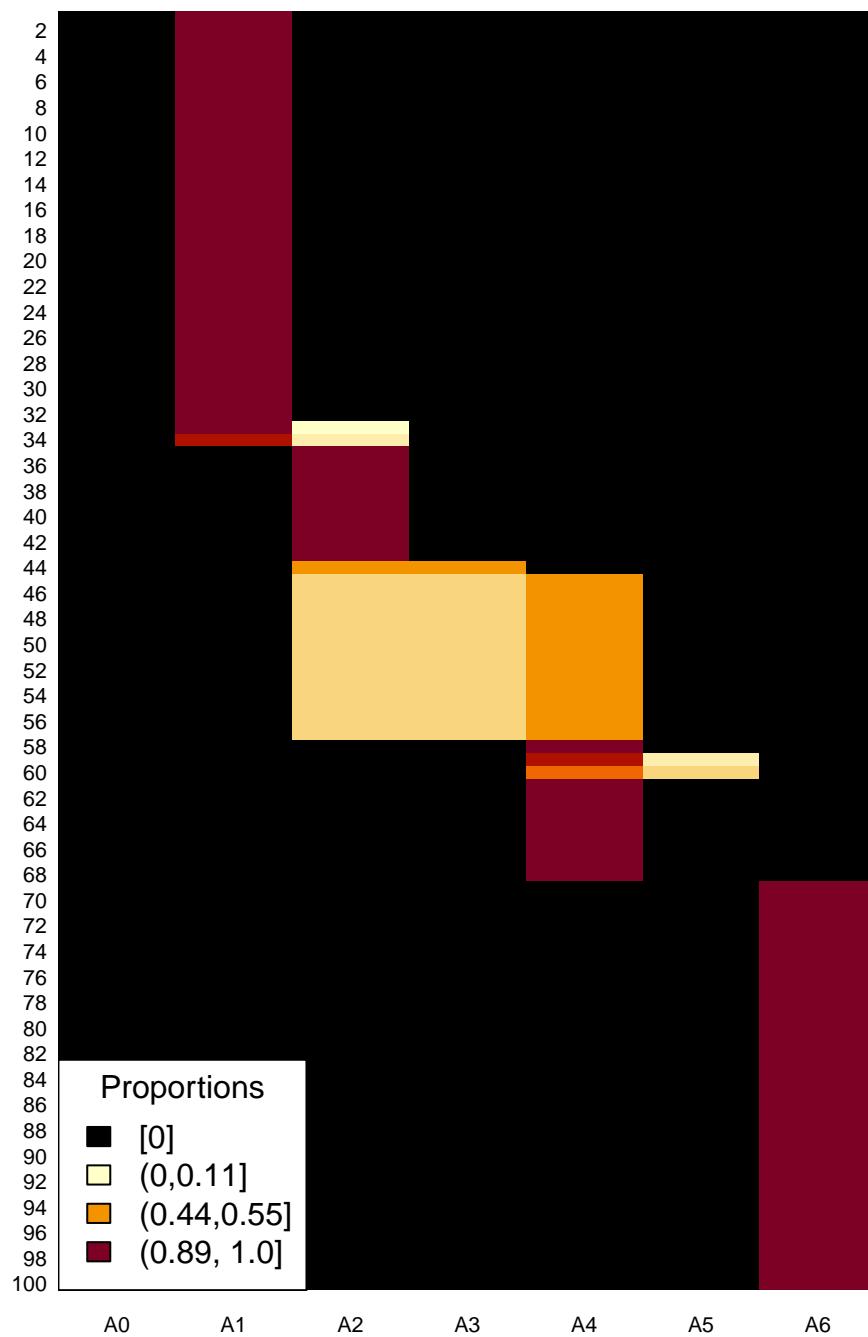
Traditional ALK, spring 1999



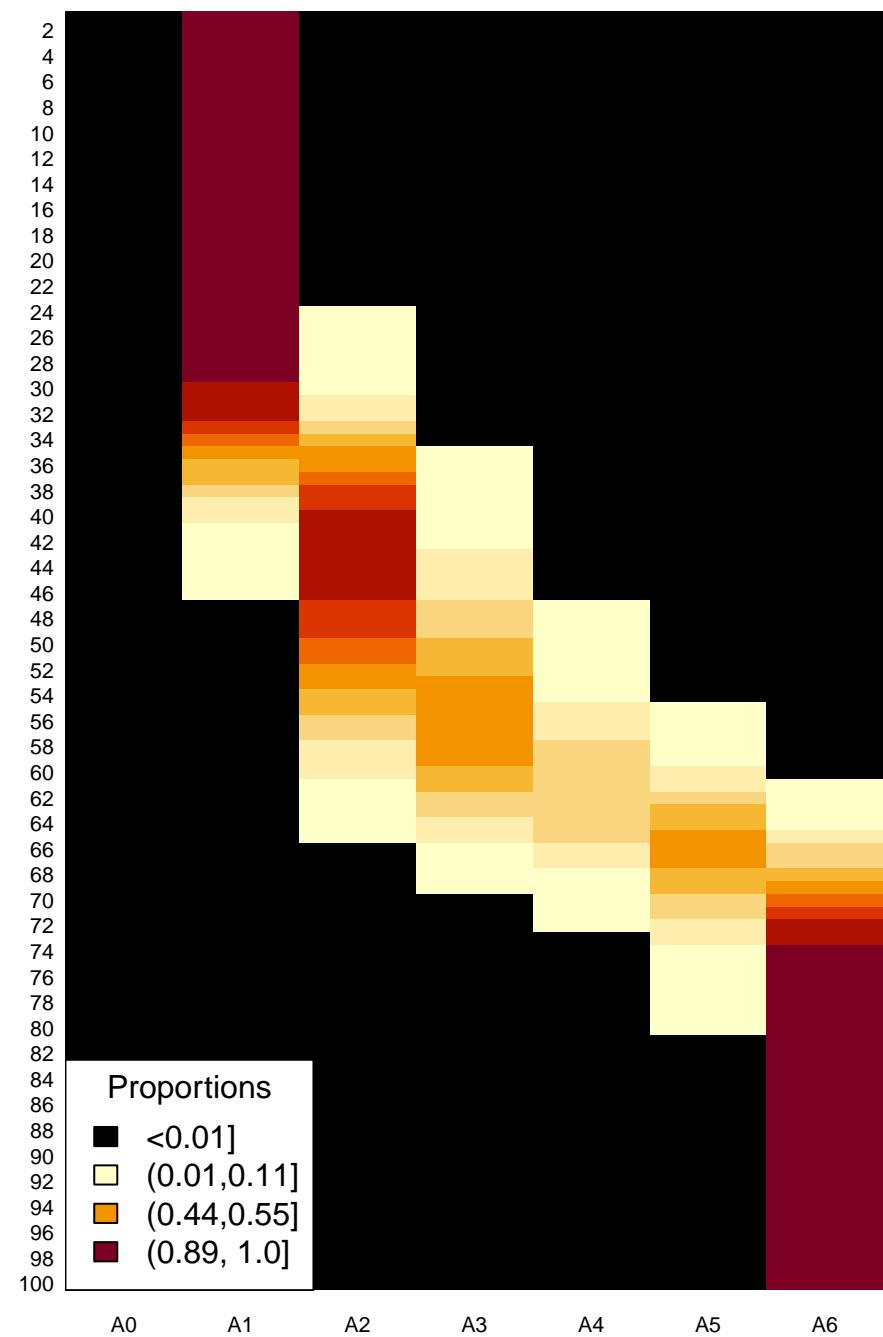
Multinomial ALK, spring 1999



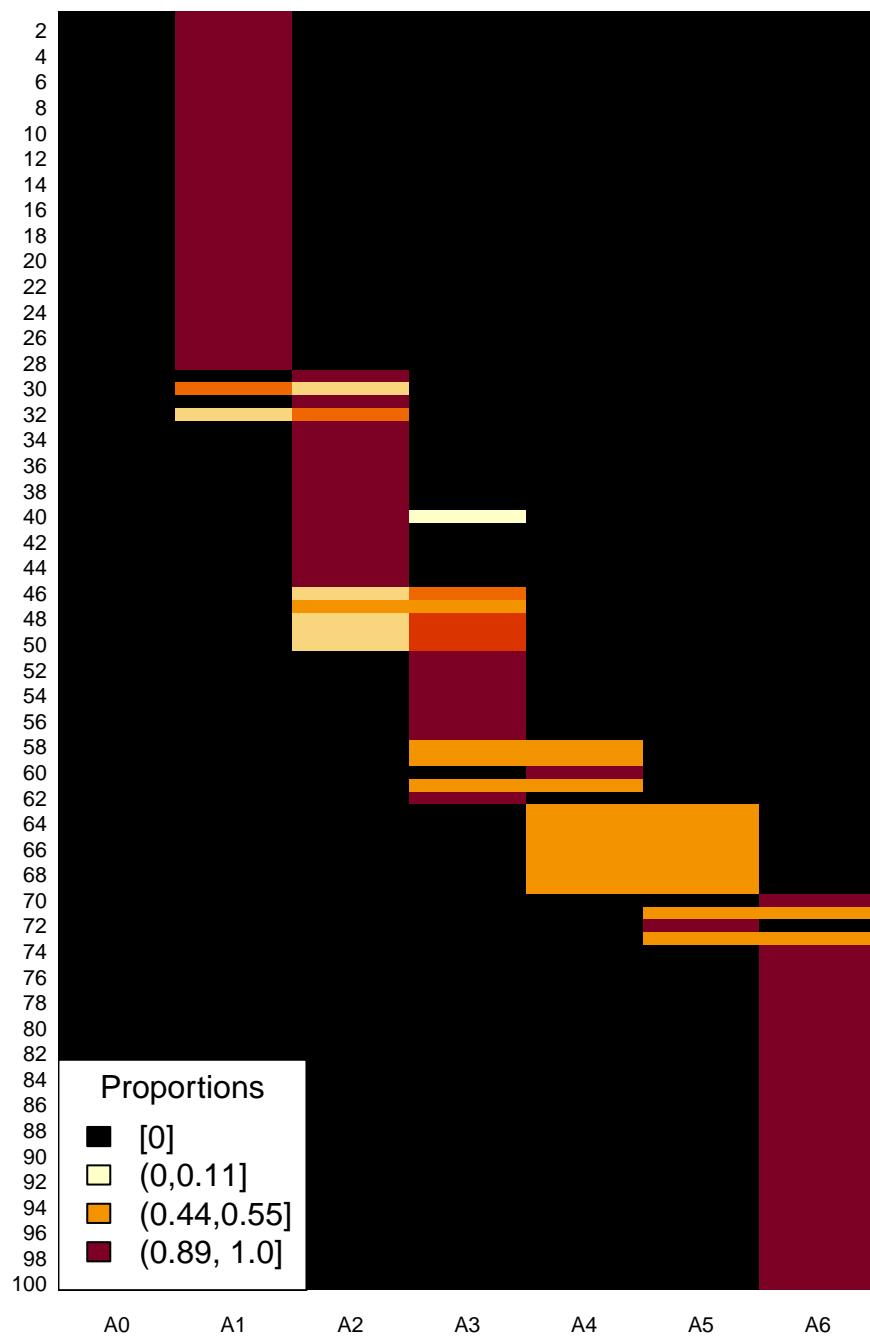
Traditional ALK, spring 2000



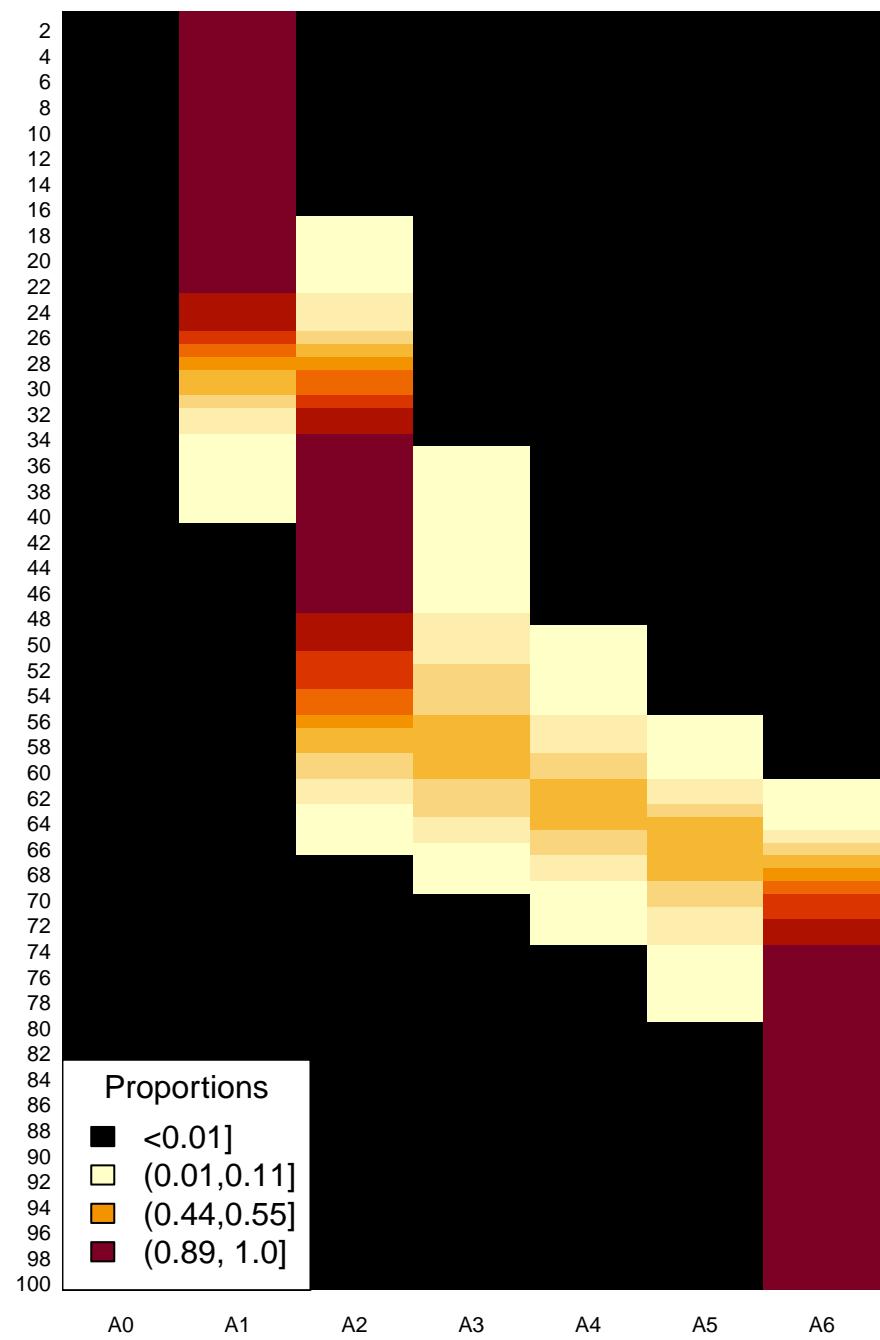
Multinomial ALK, spring 2000



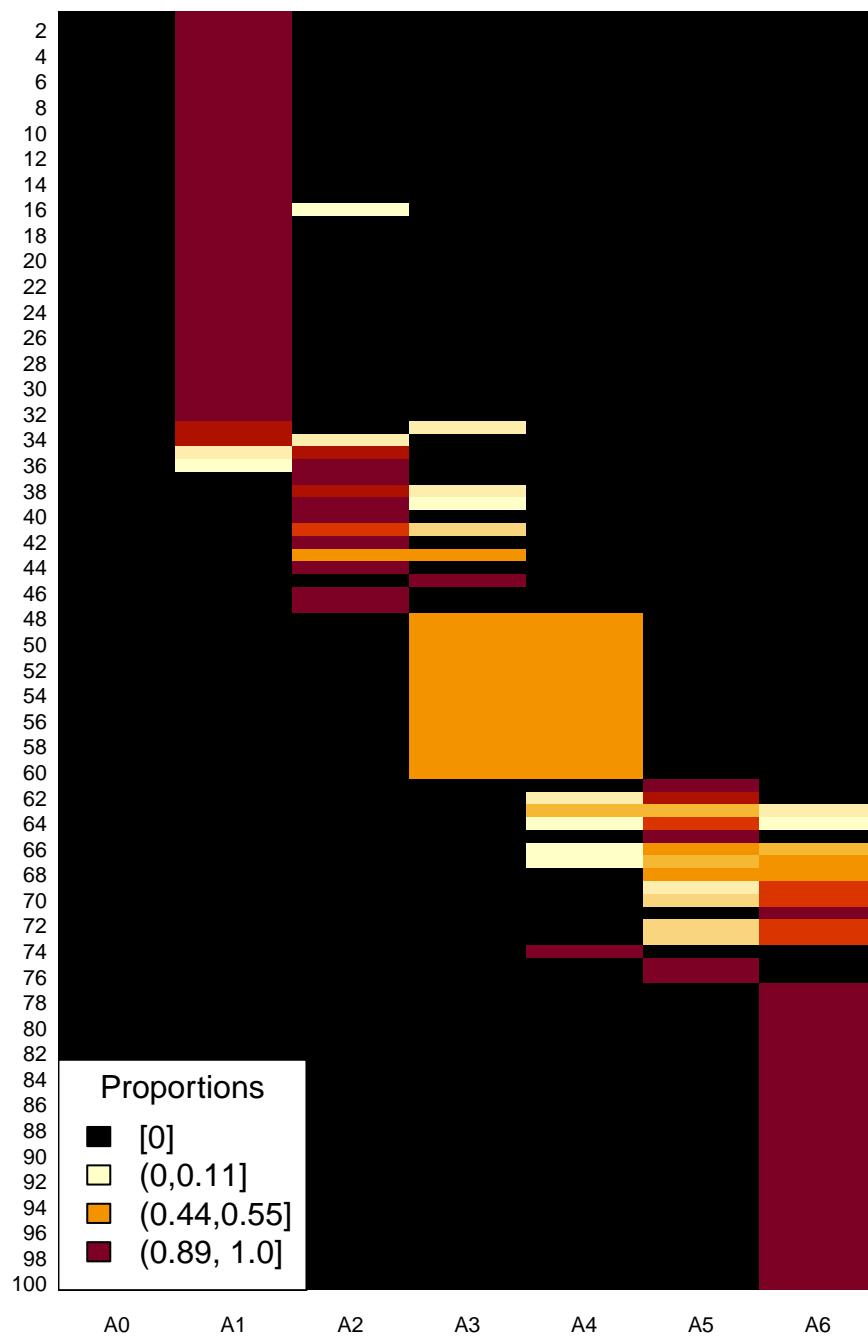
Traditional ALK, spring 2001



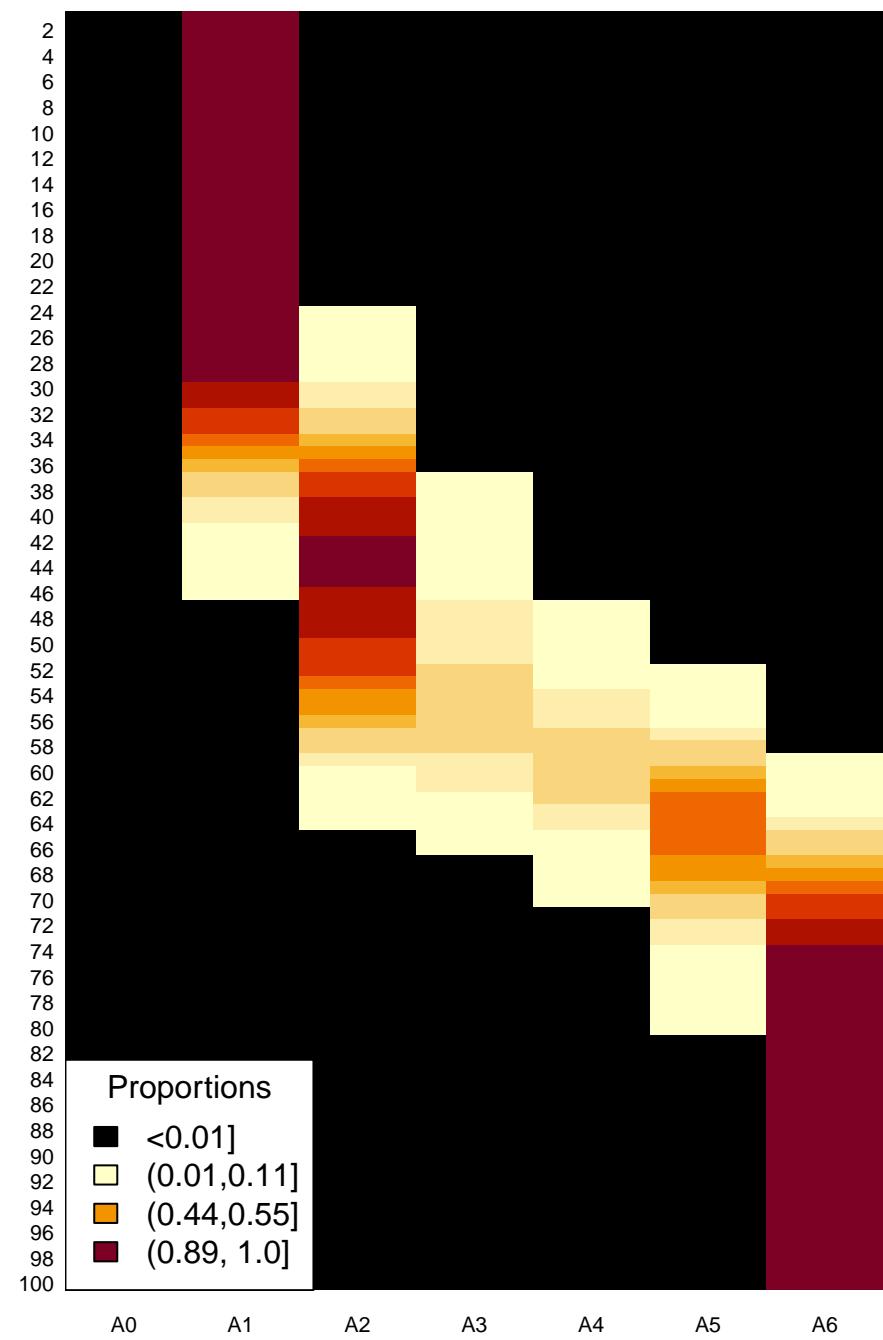
Multinomial ALK, spring 2001



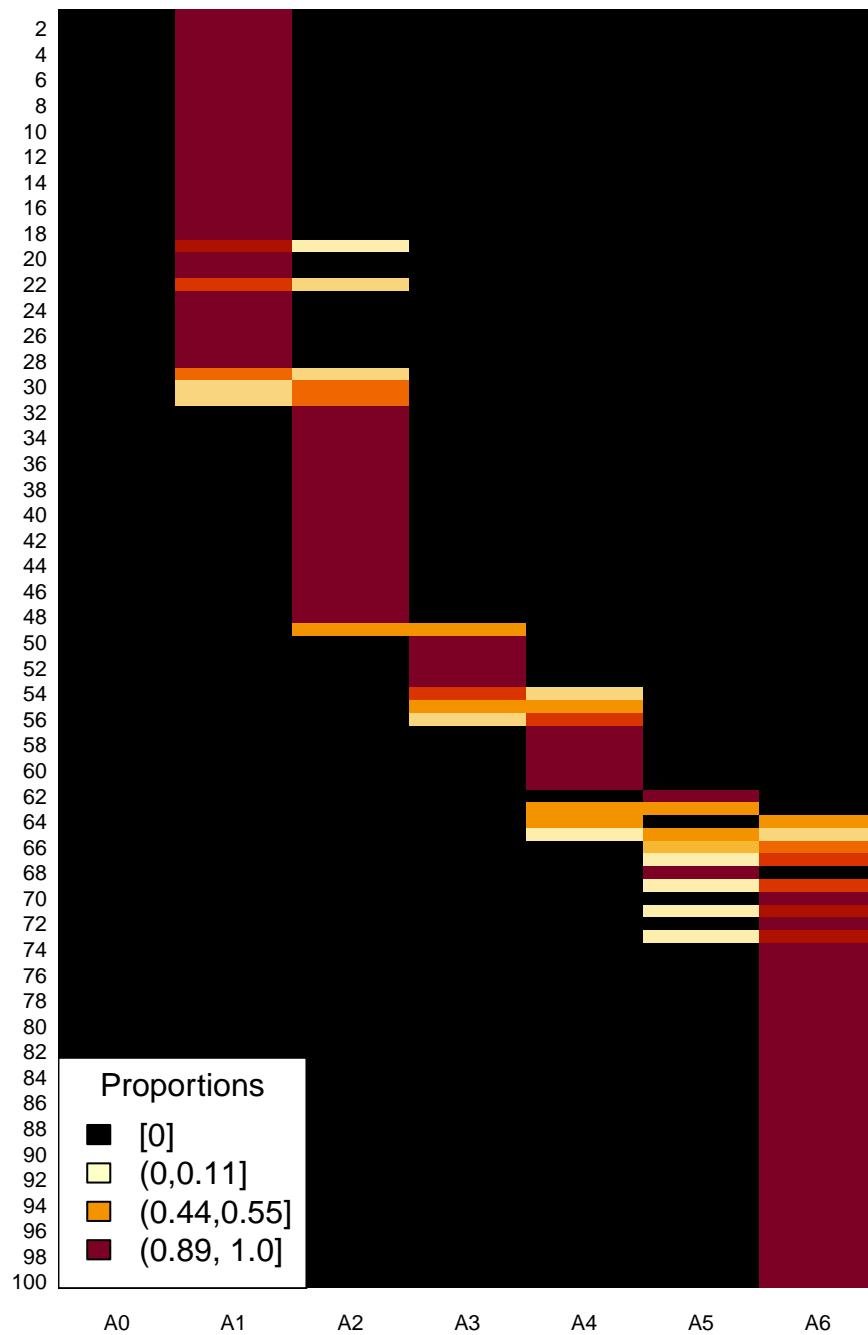
Traditional ALK, spring 2002



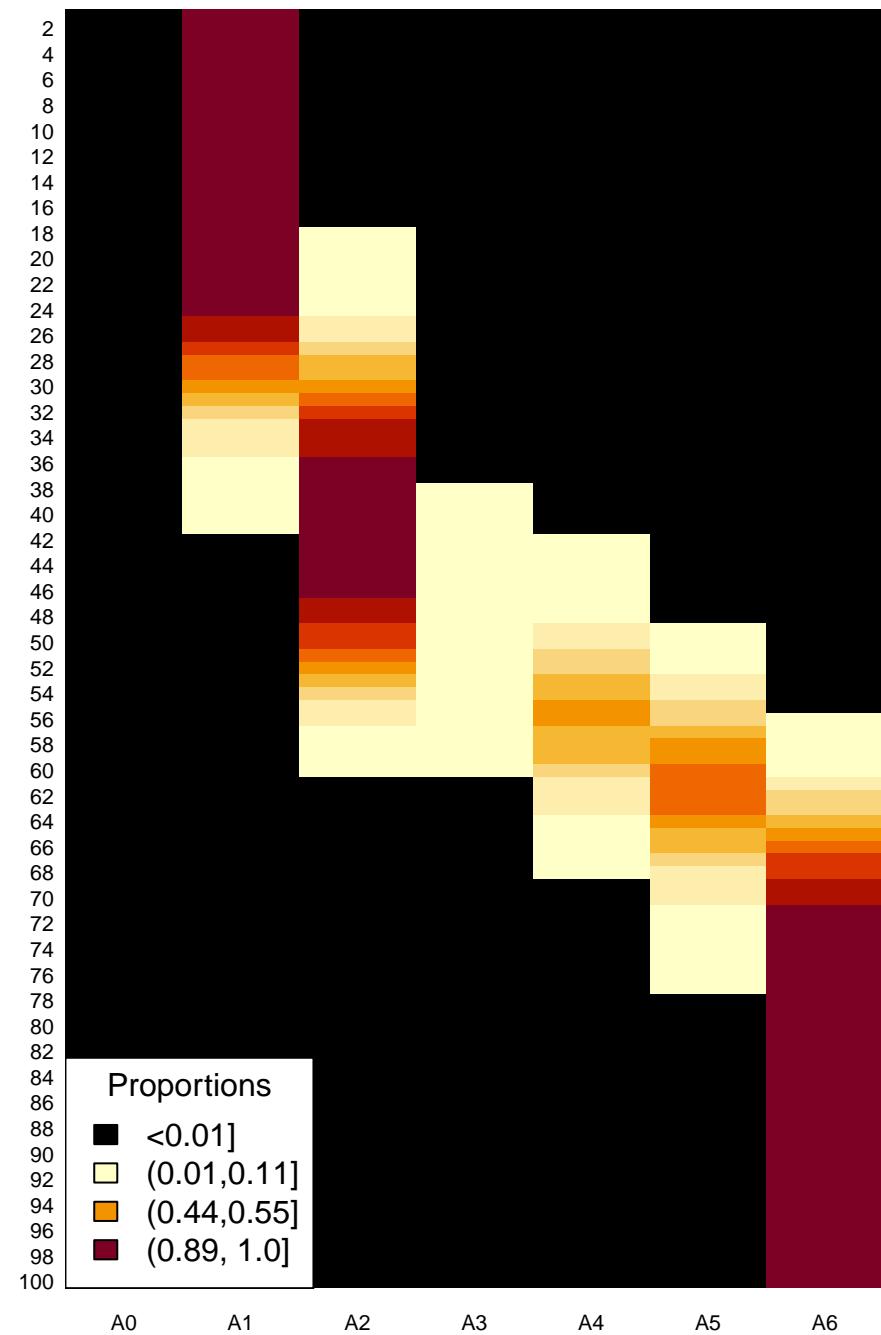
Multinomial ALK, spring 2002



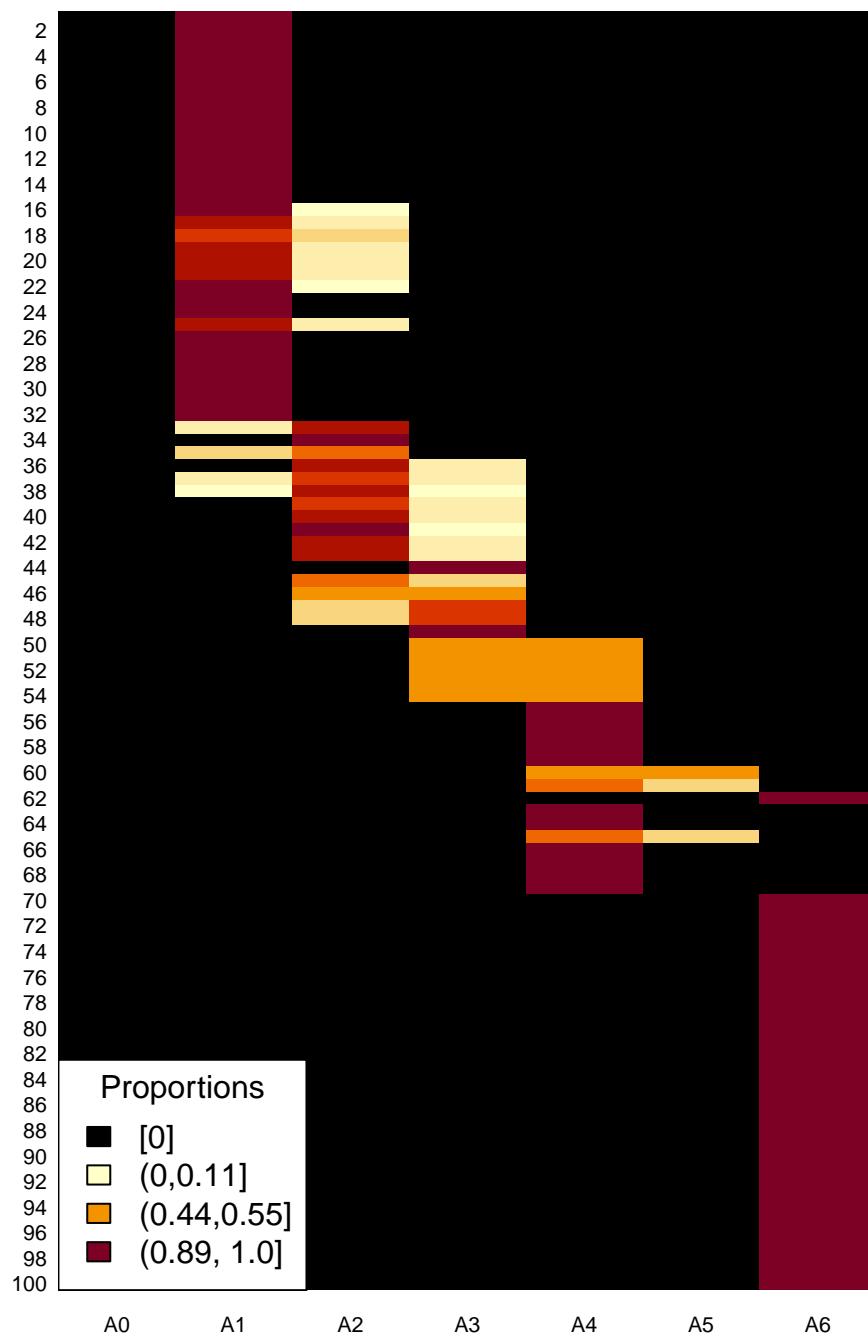
Traditional ALK, spring 2003



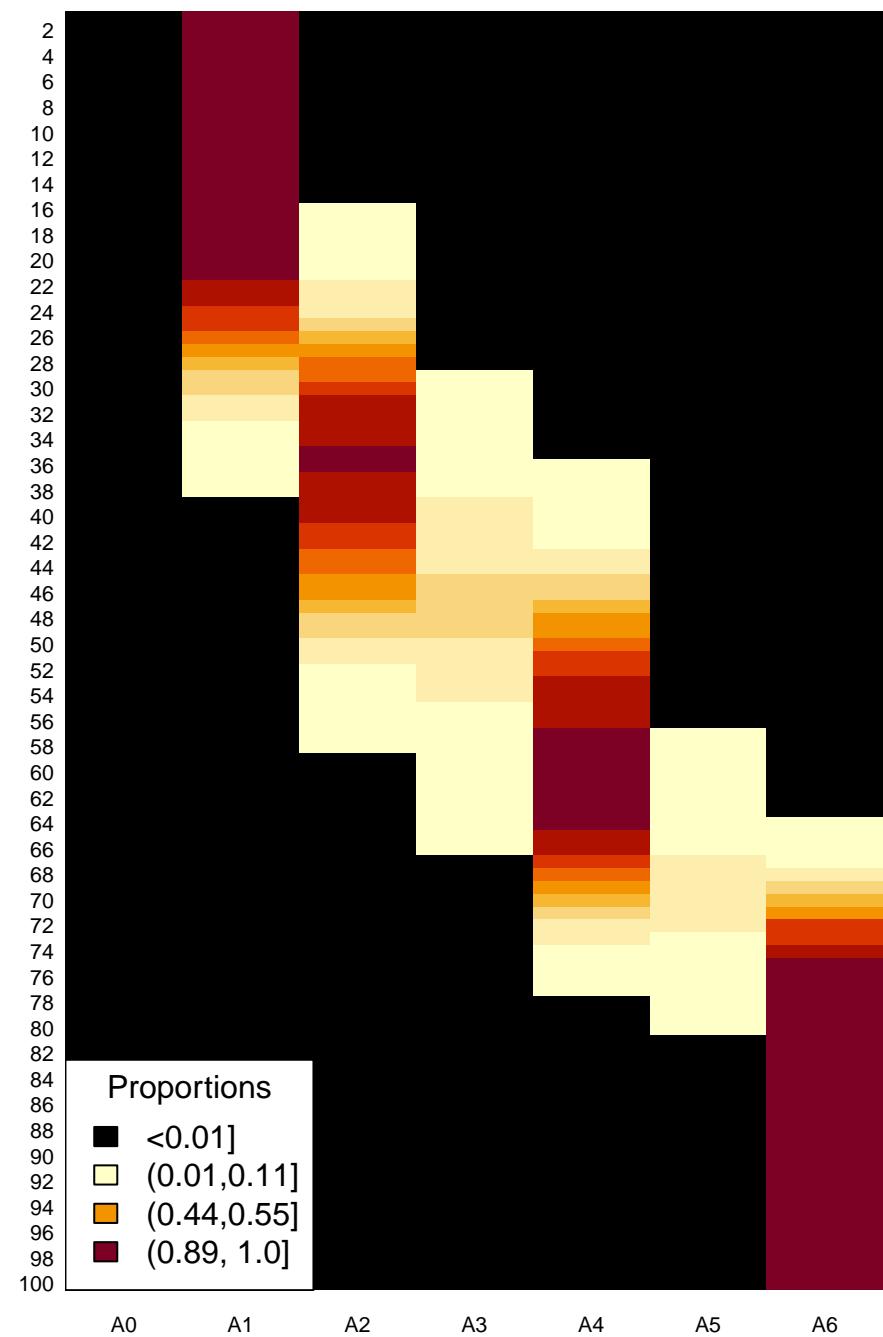
Multinomial ALK, spring 2003



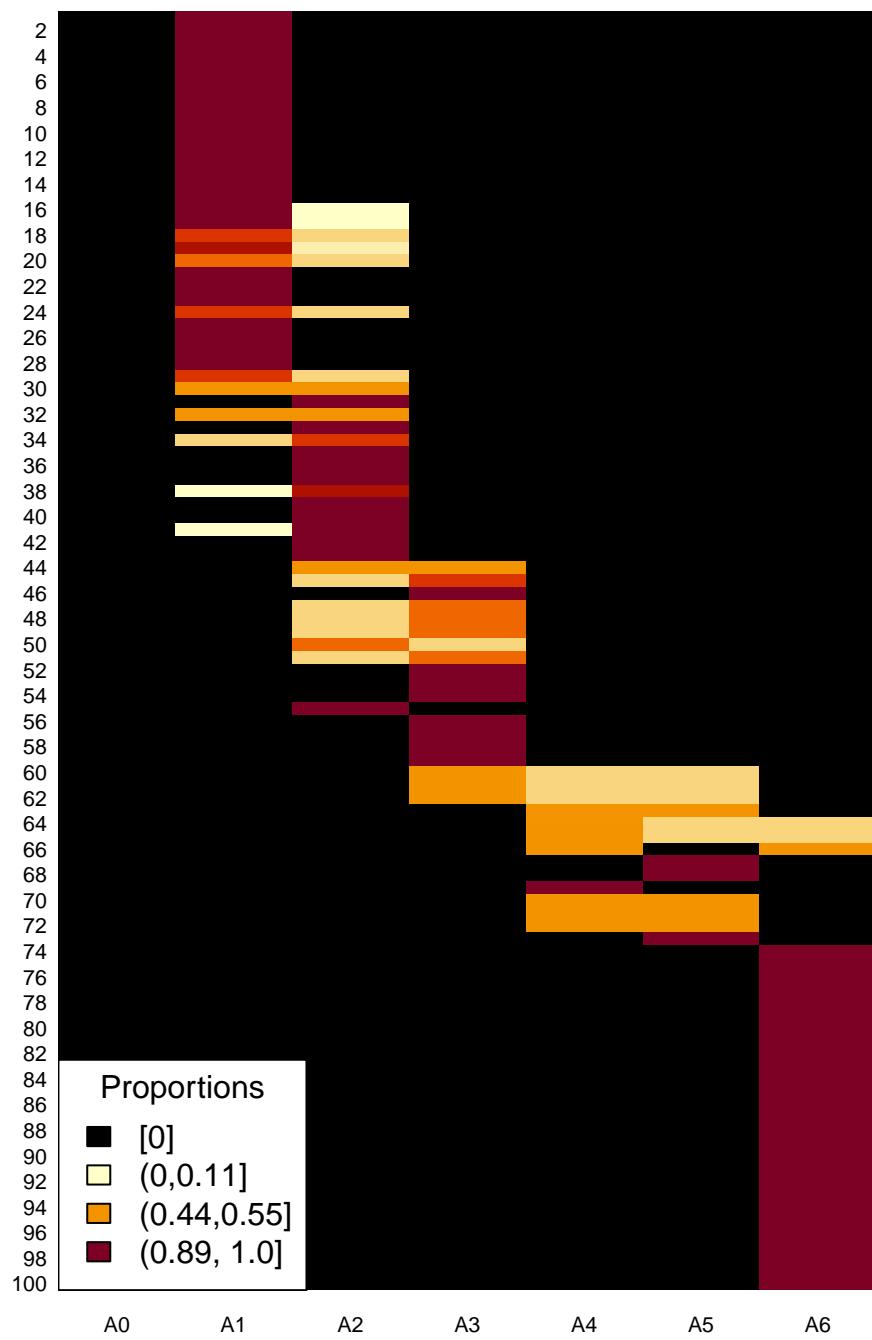
Traditional ALK, spring 2004



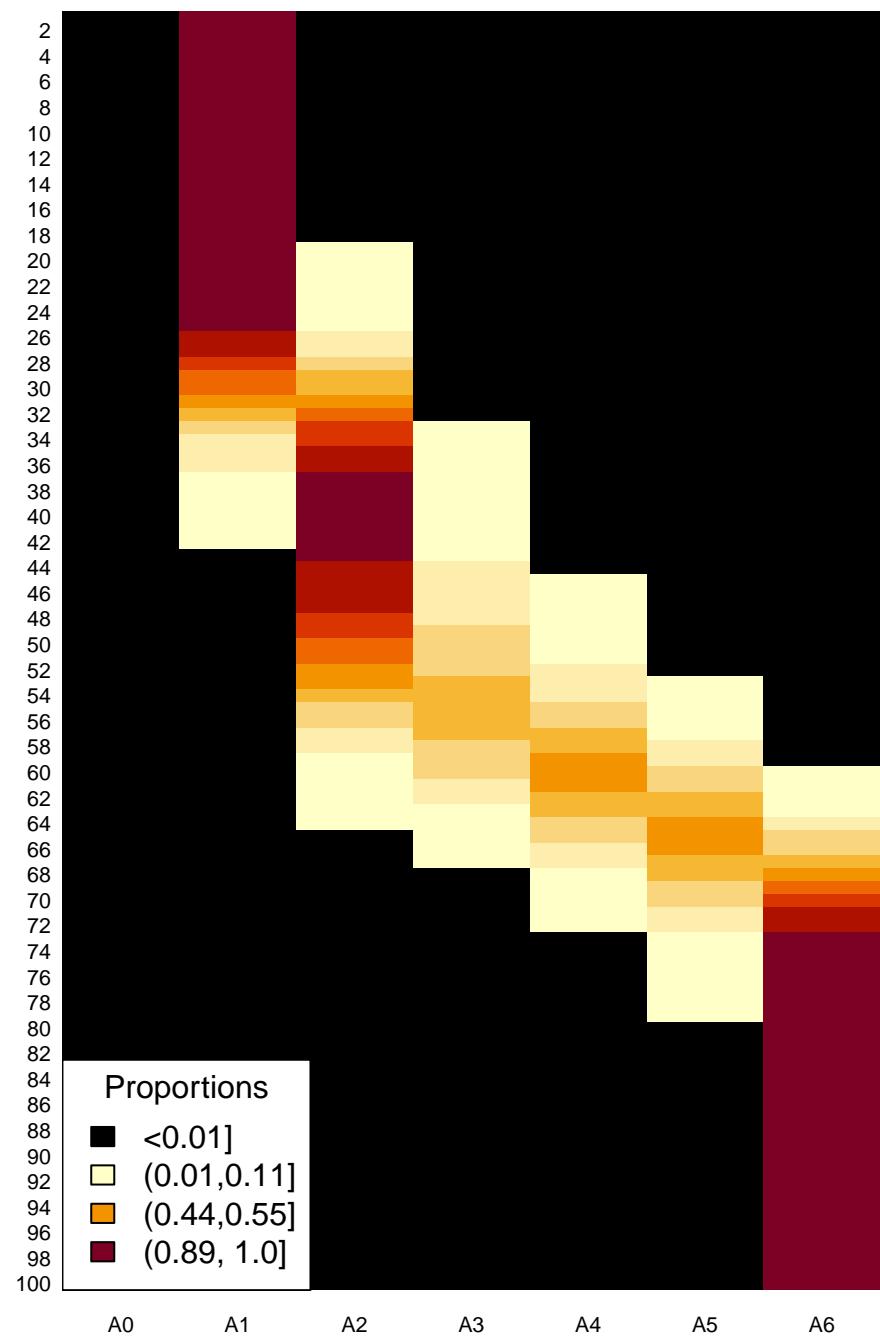
Multinomial ALK, spring 2004



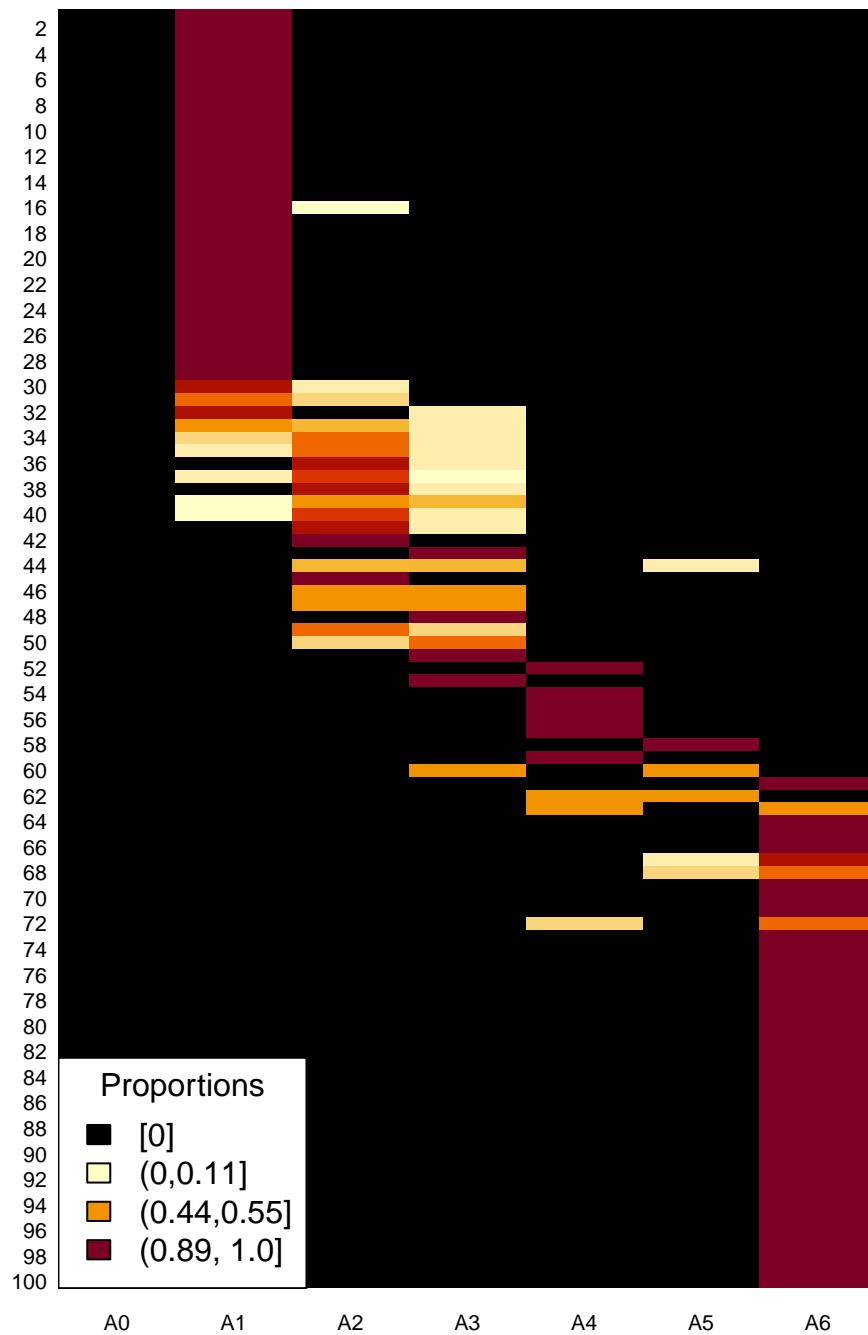
Traditional ALK, spring 2005



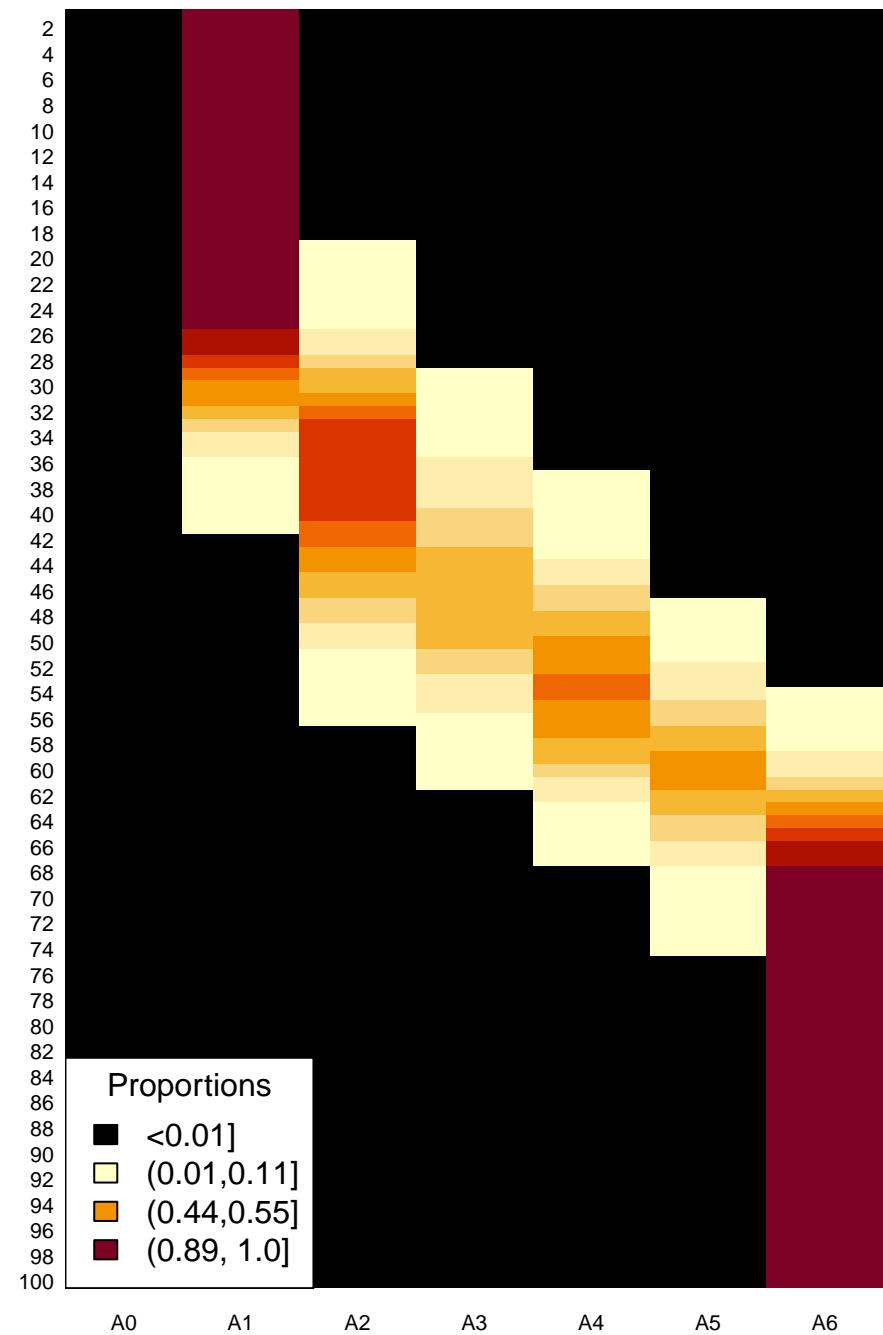
Multinomial ALK, spring 2005



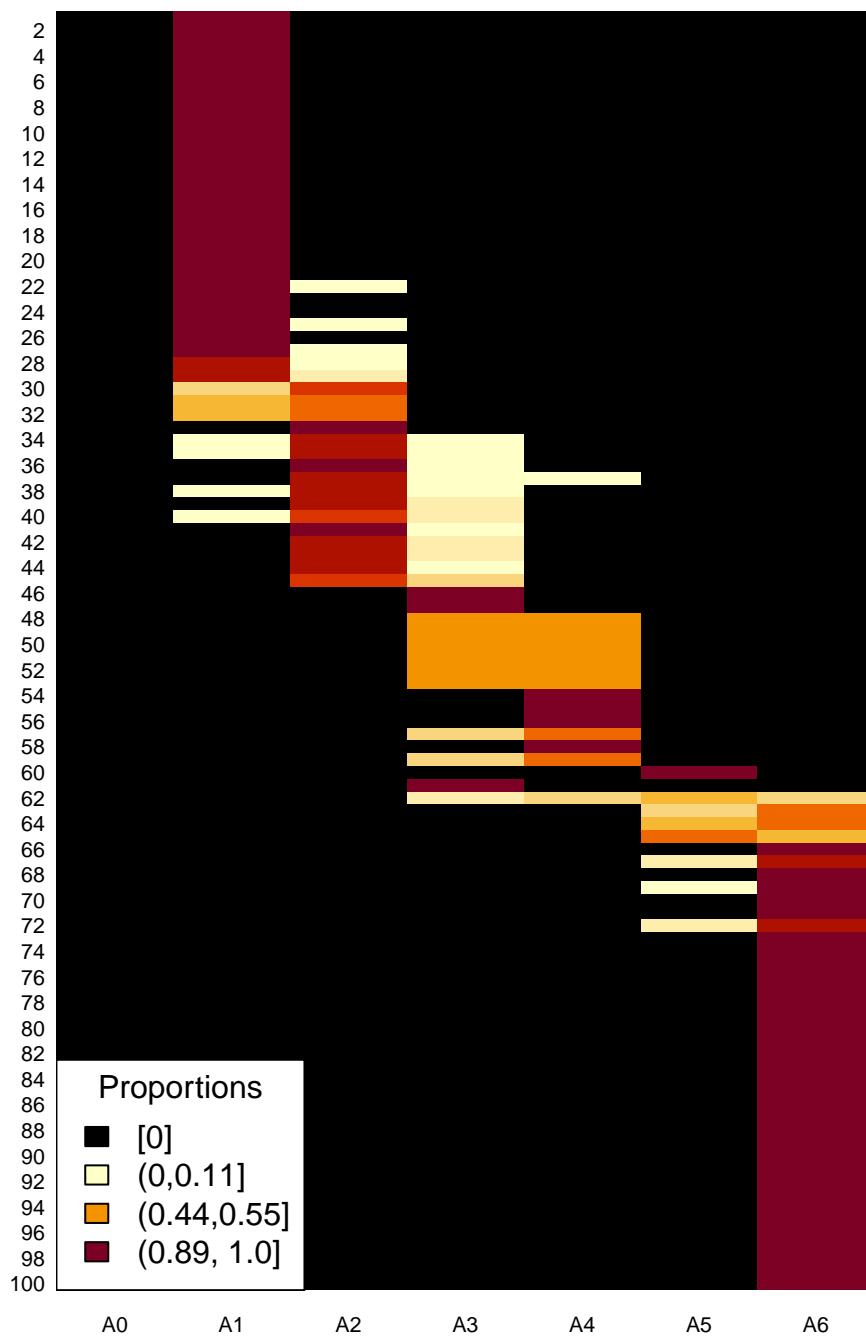
Traditional ALK, spring 2006



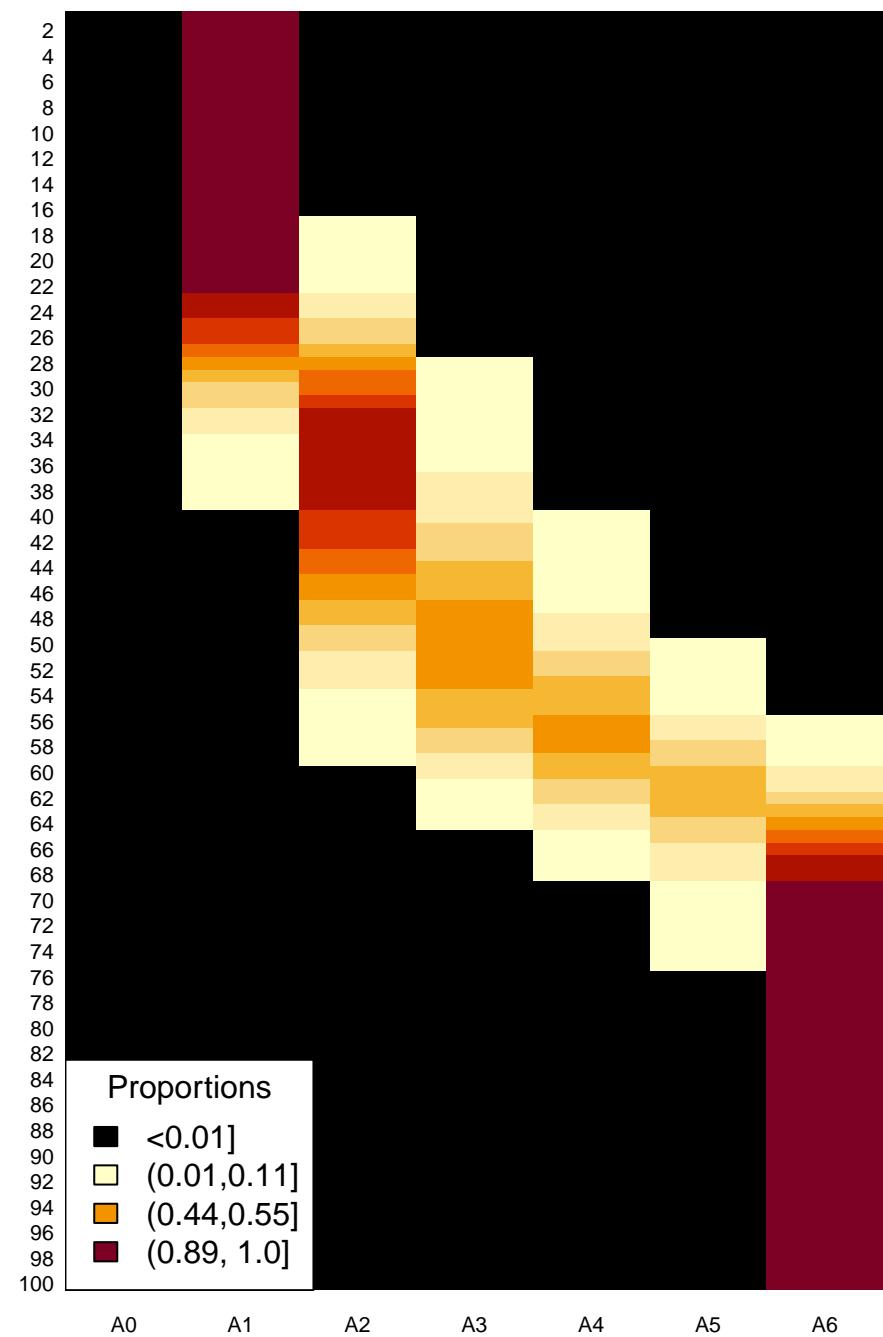
Multinomial ALK, spring 2006



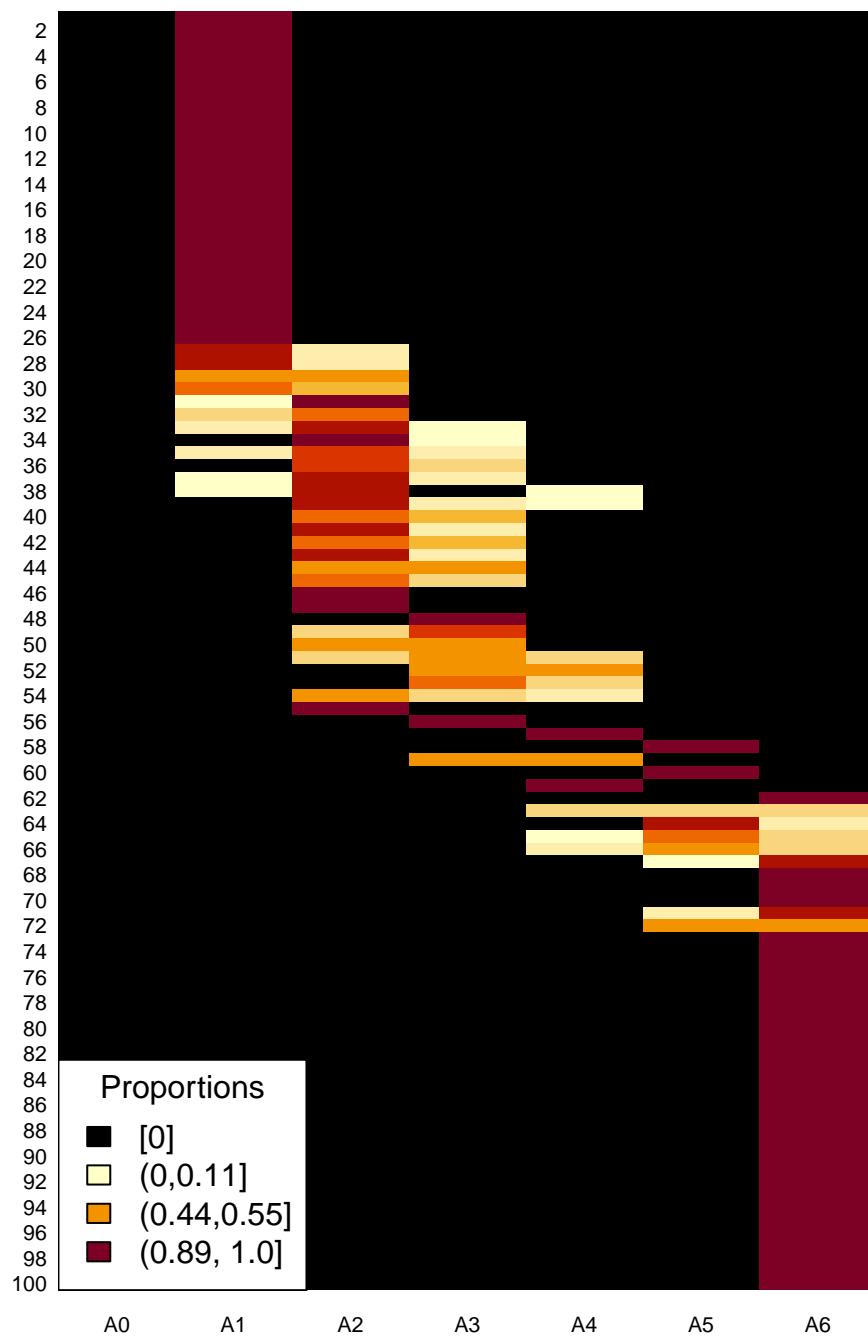
Traditional ALK, spring 2007



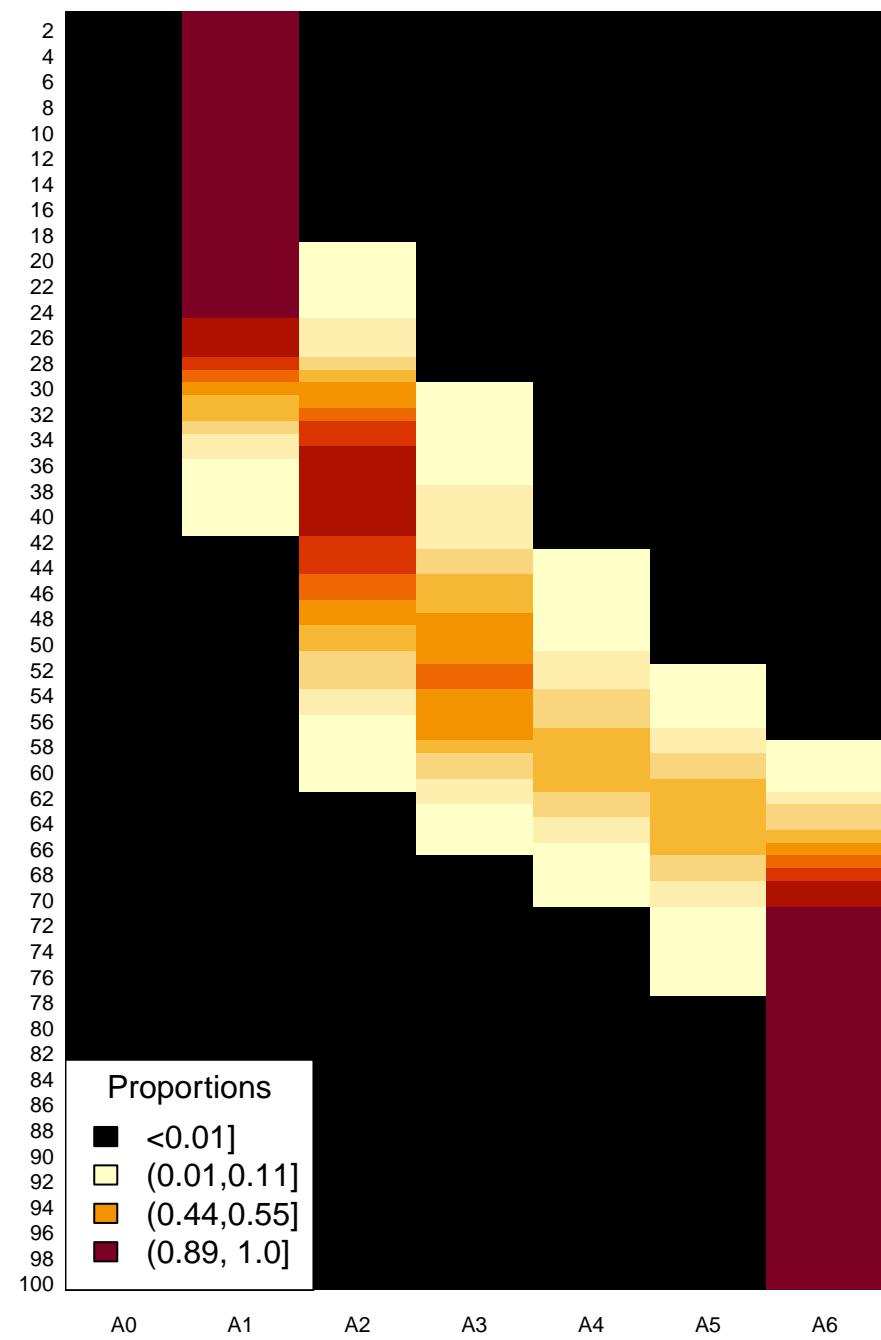
Multinomial ALK, spring 2007



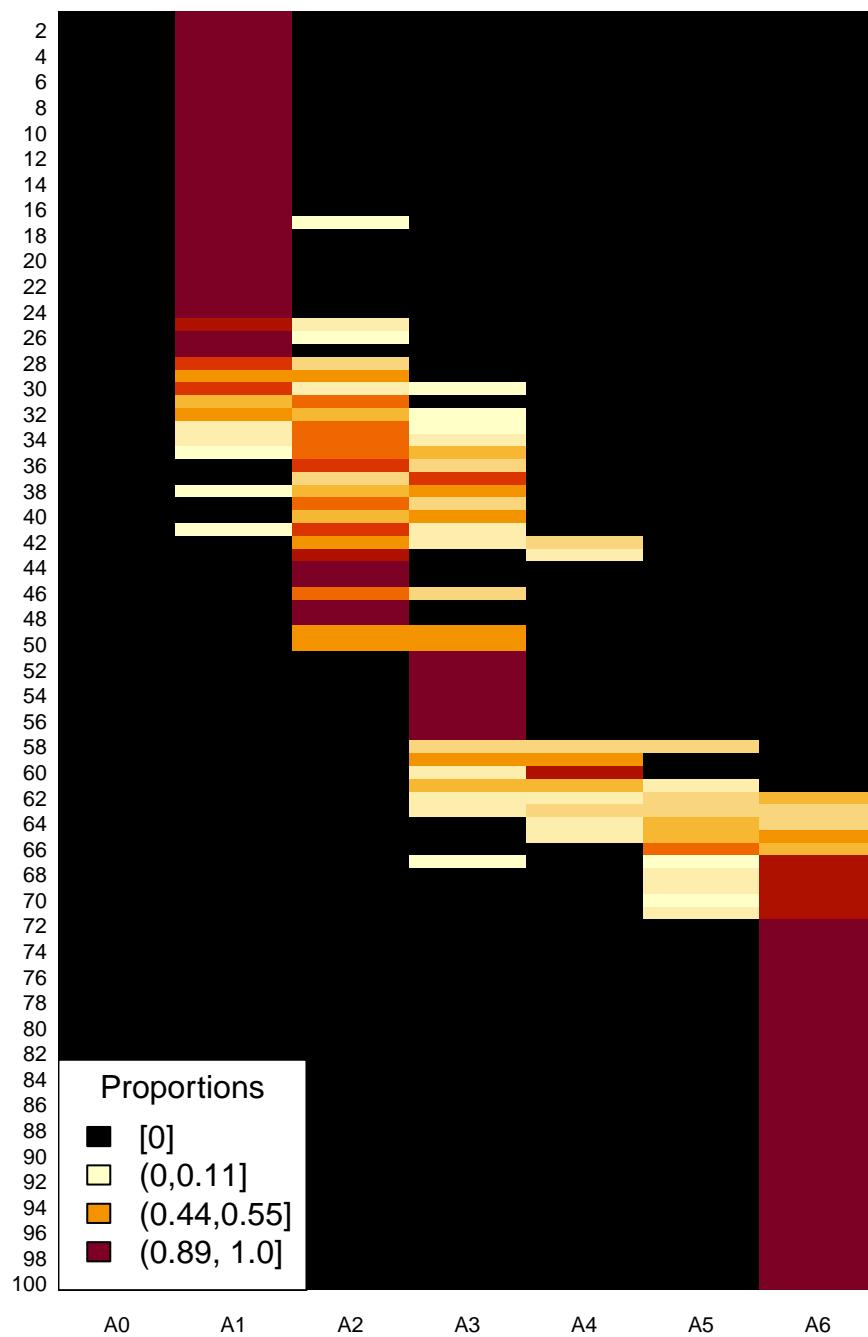
Traditional ALK, spring 2008



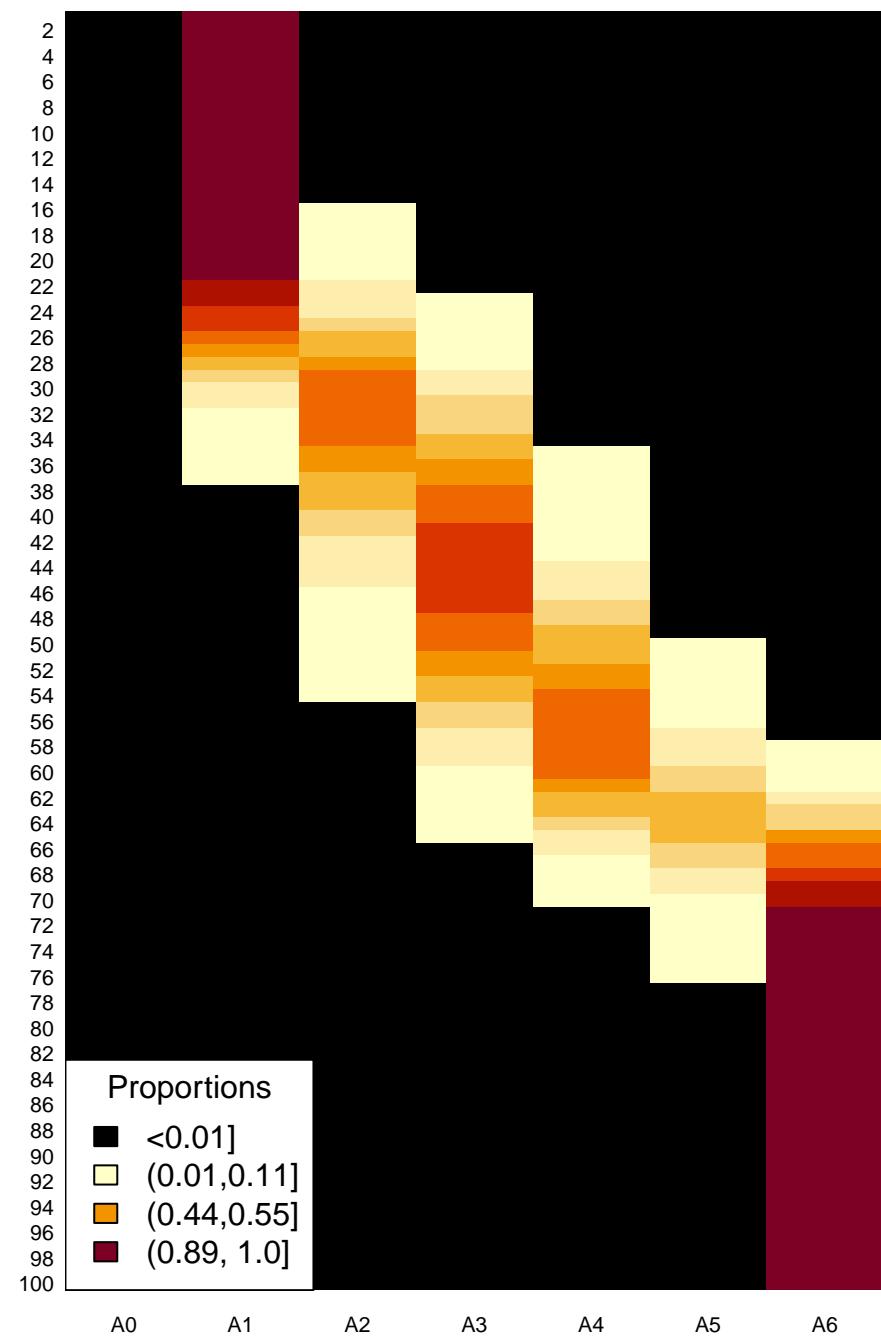
Multinomial ALK, spring 2008



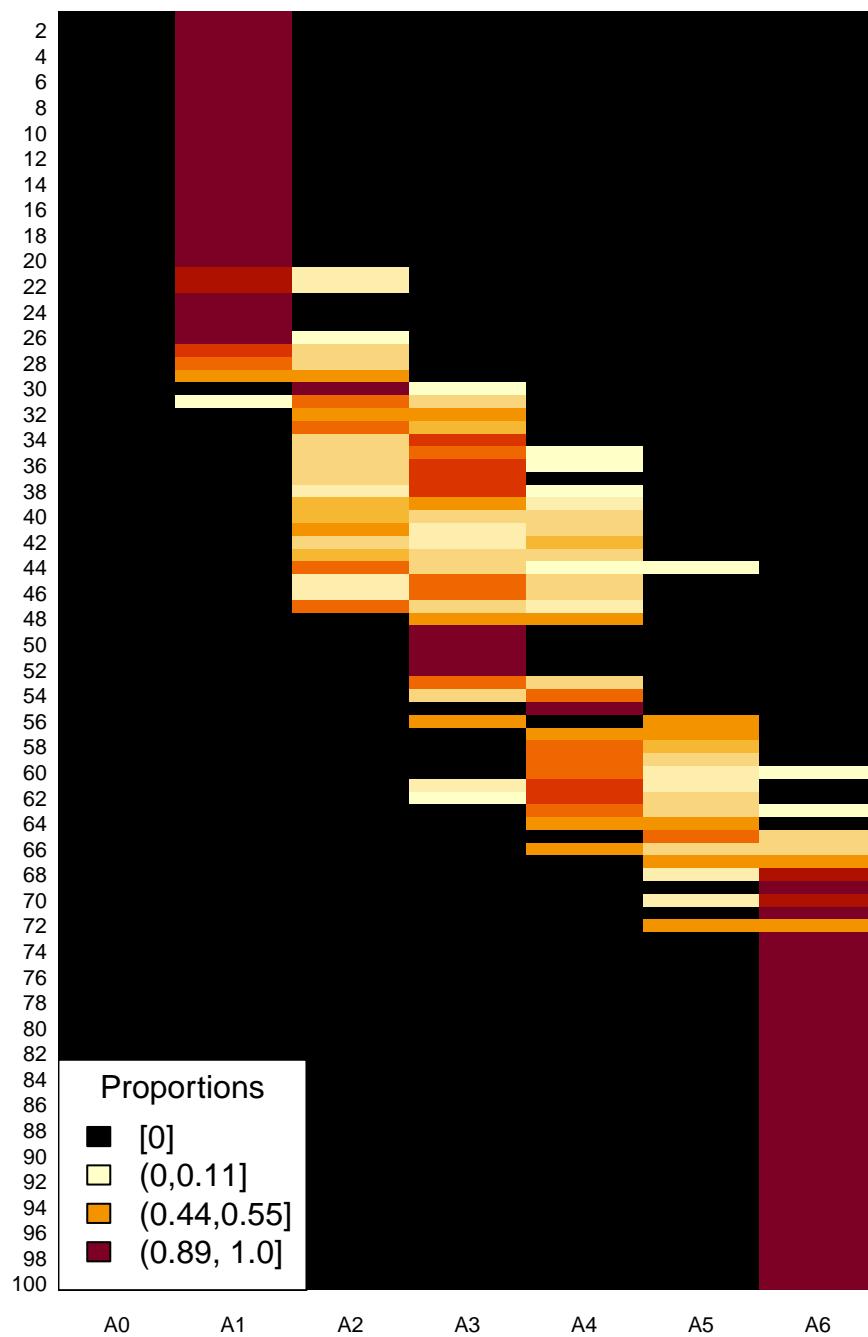
Traditional ALK, spring 2009



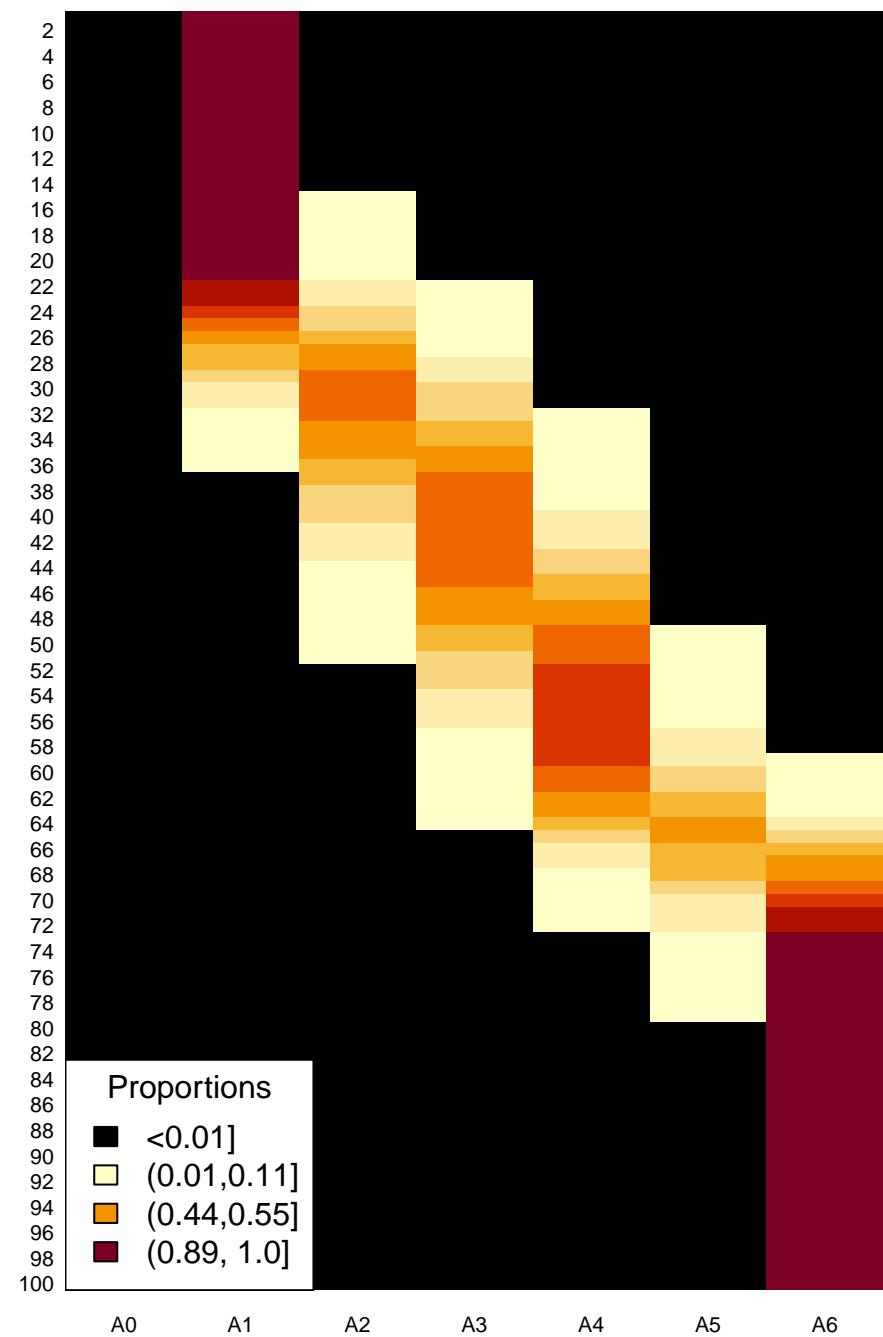
Multinomial ALK, spring 2009



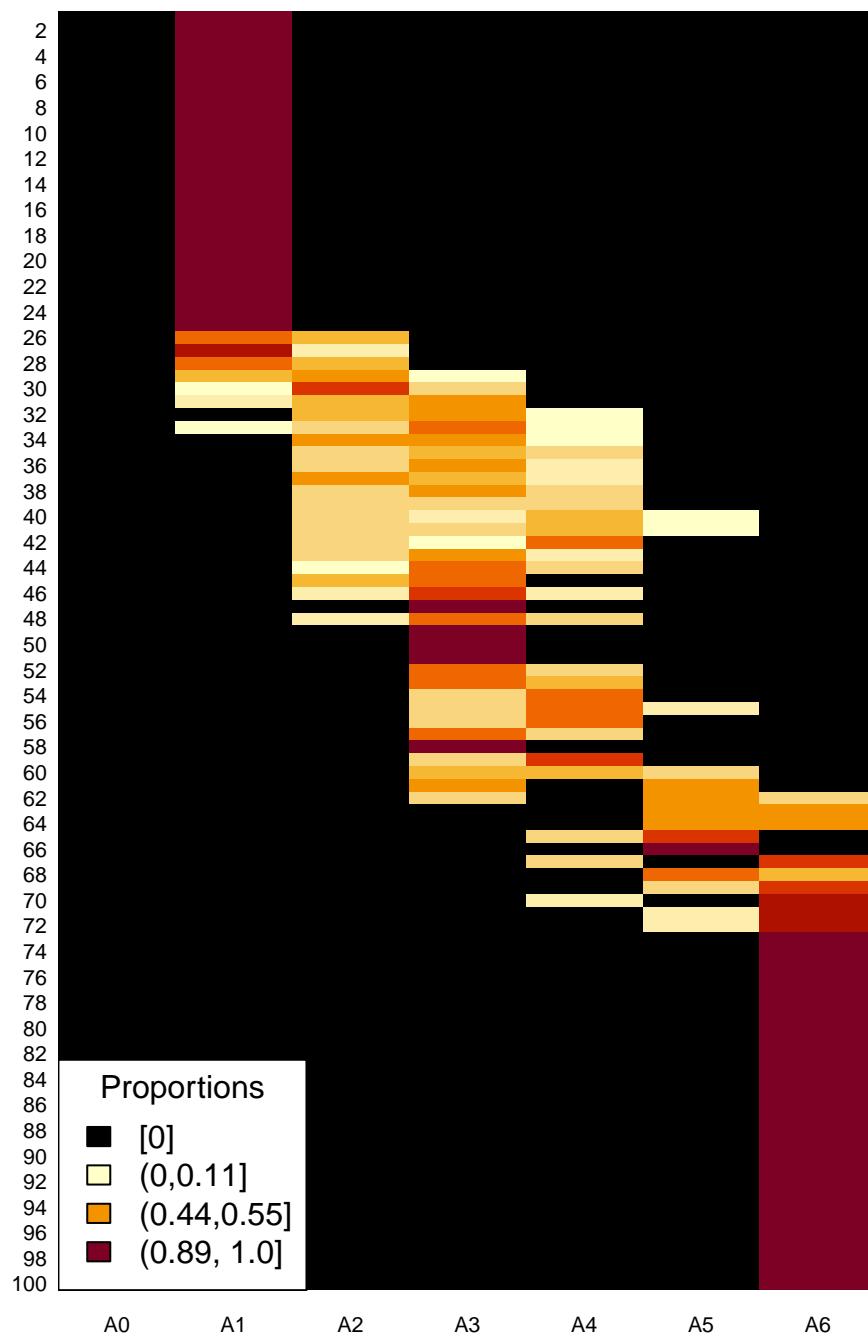
Traditional ALK, spring 2010



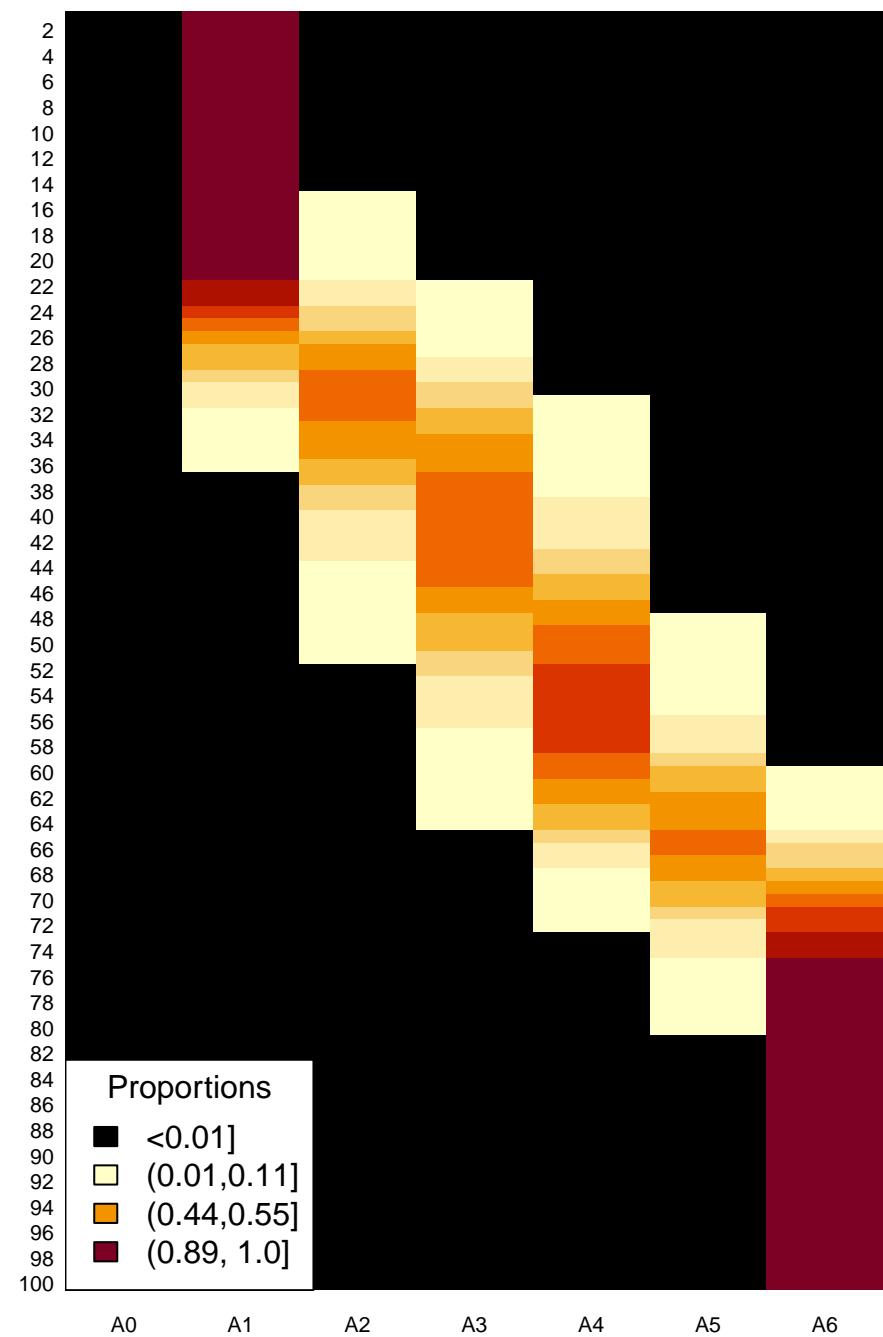
Multinomial ALK, spring 2010



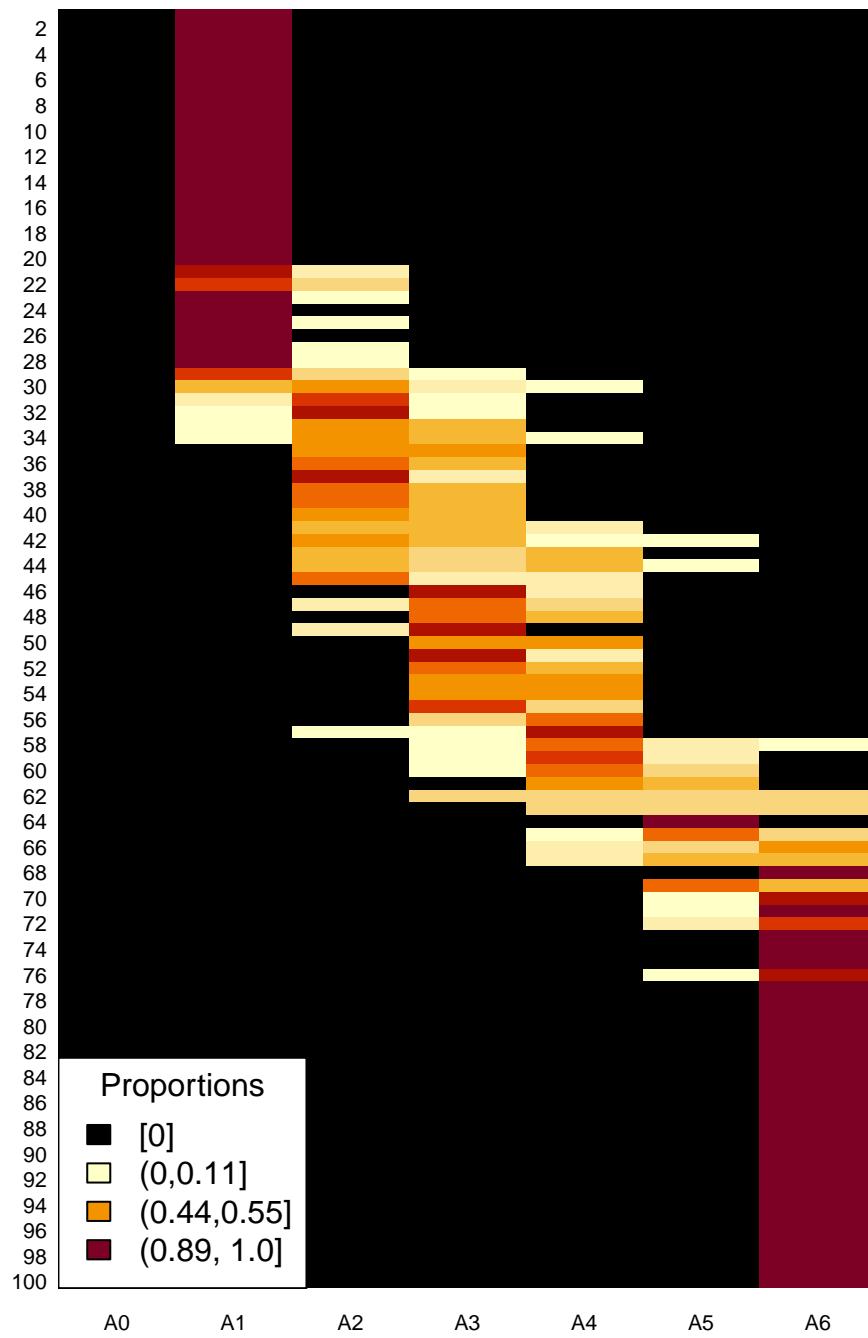
Traditional ALK, spring 2011



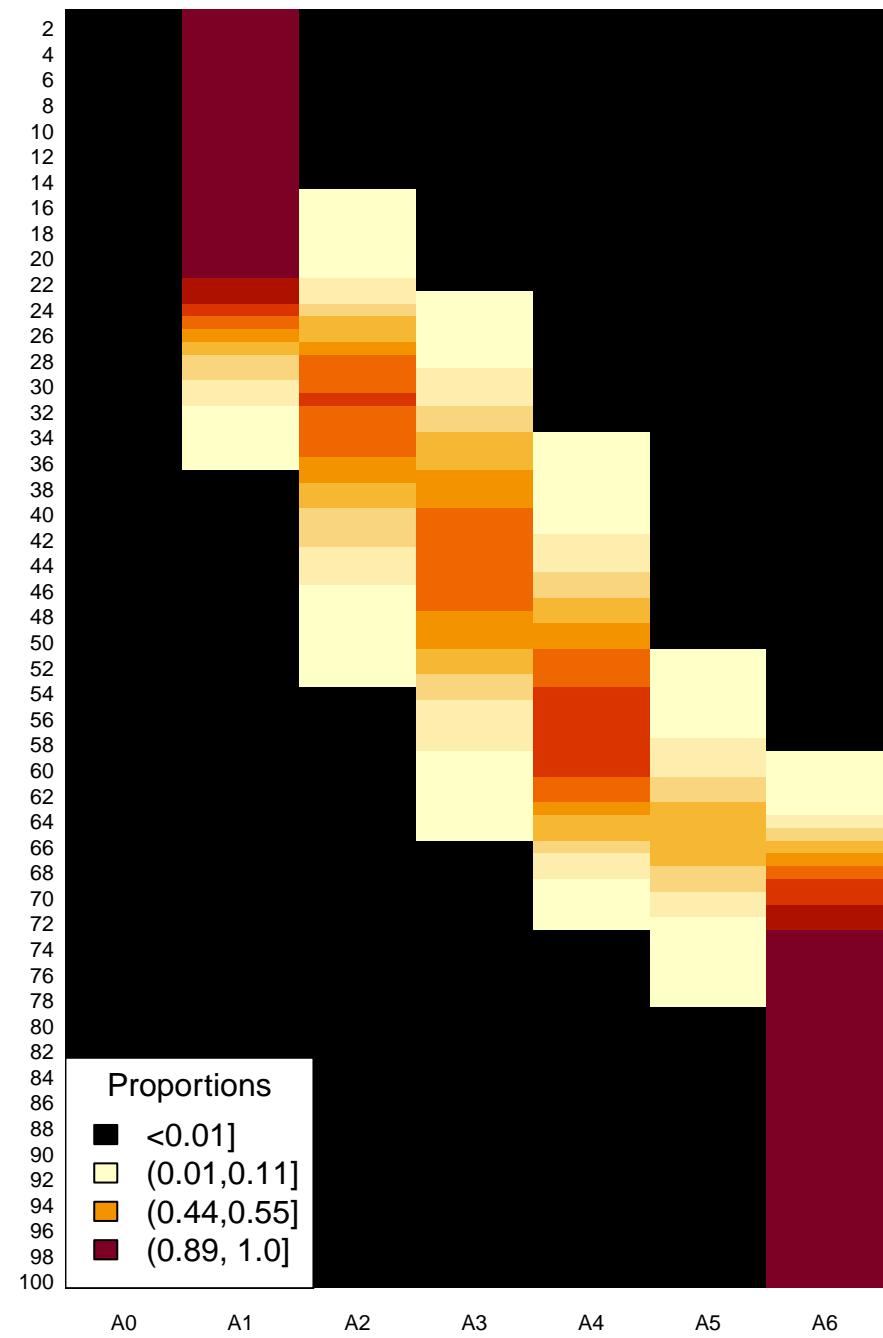
Multinomial ALK, spring 2011



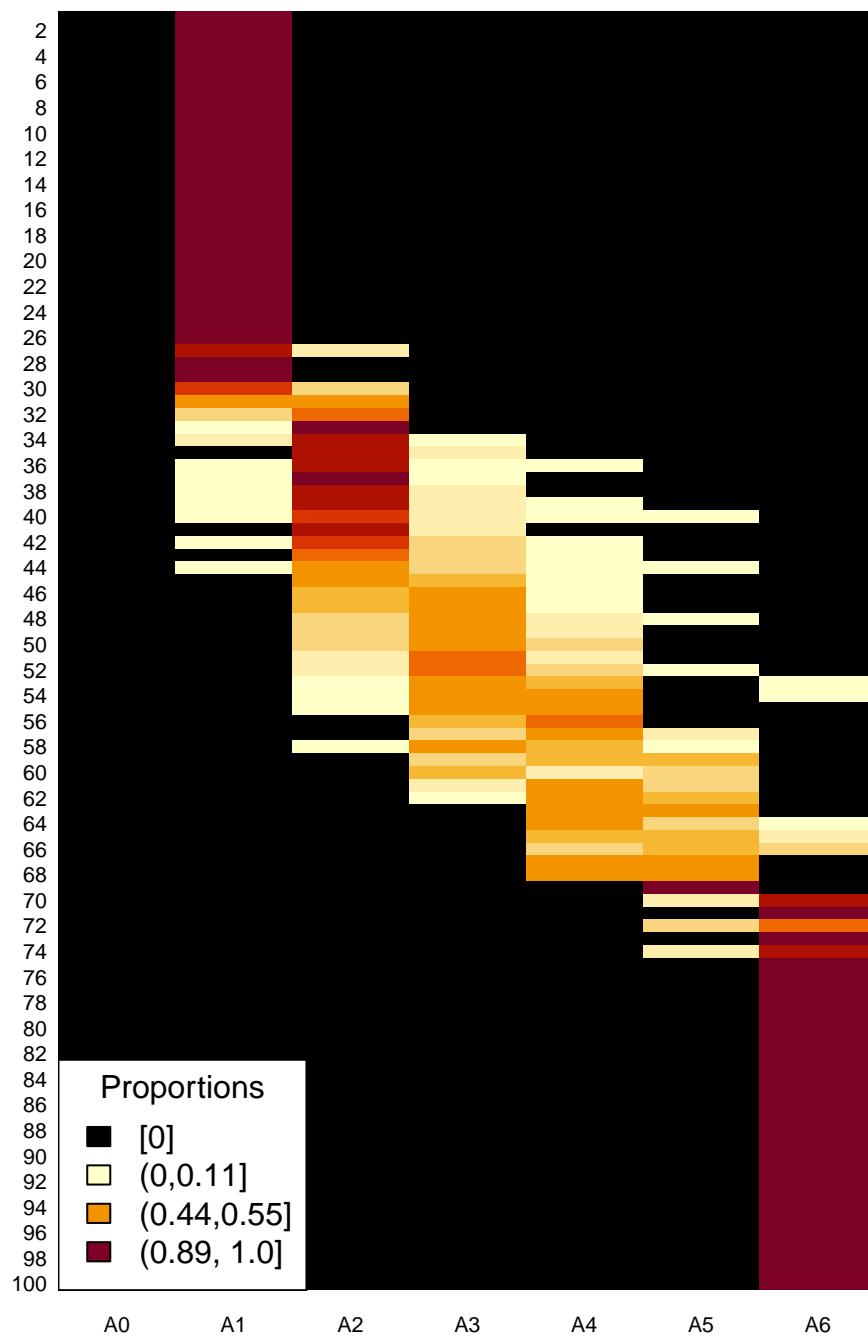
Traditional ALK, spring 2012



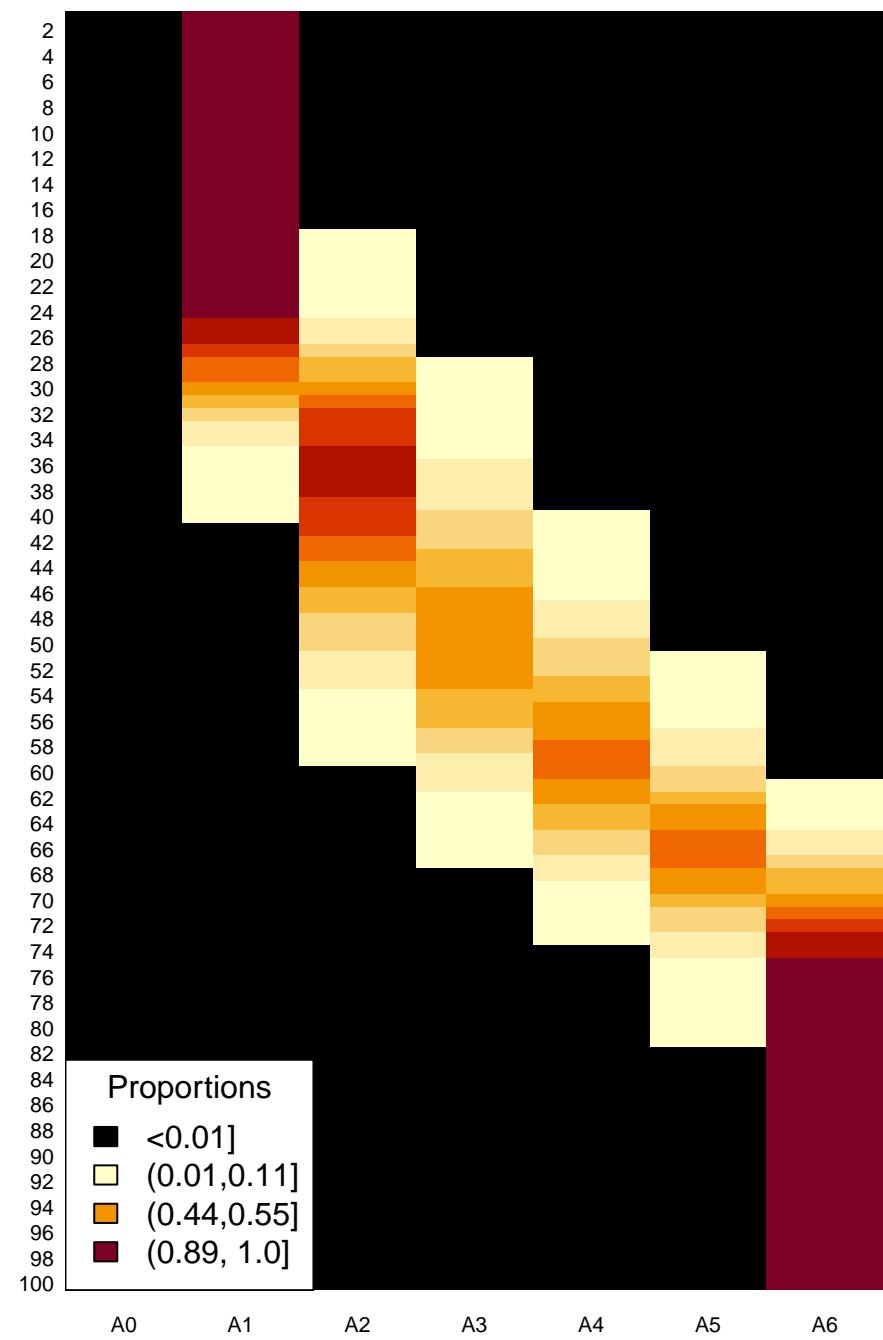
Multinomial ALK, spring 2012



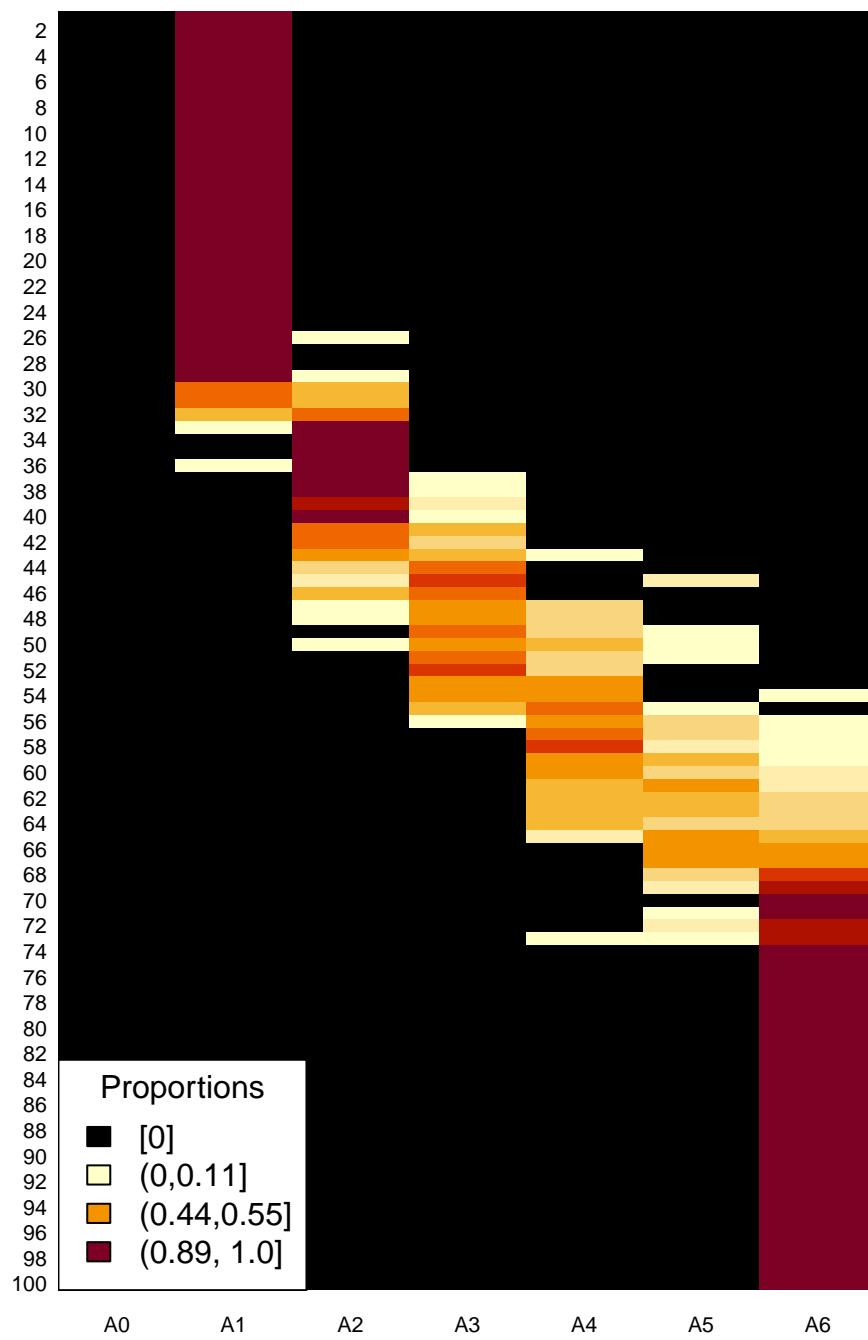
Traditional ALK, spring 2013



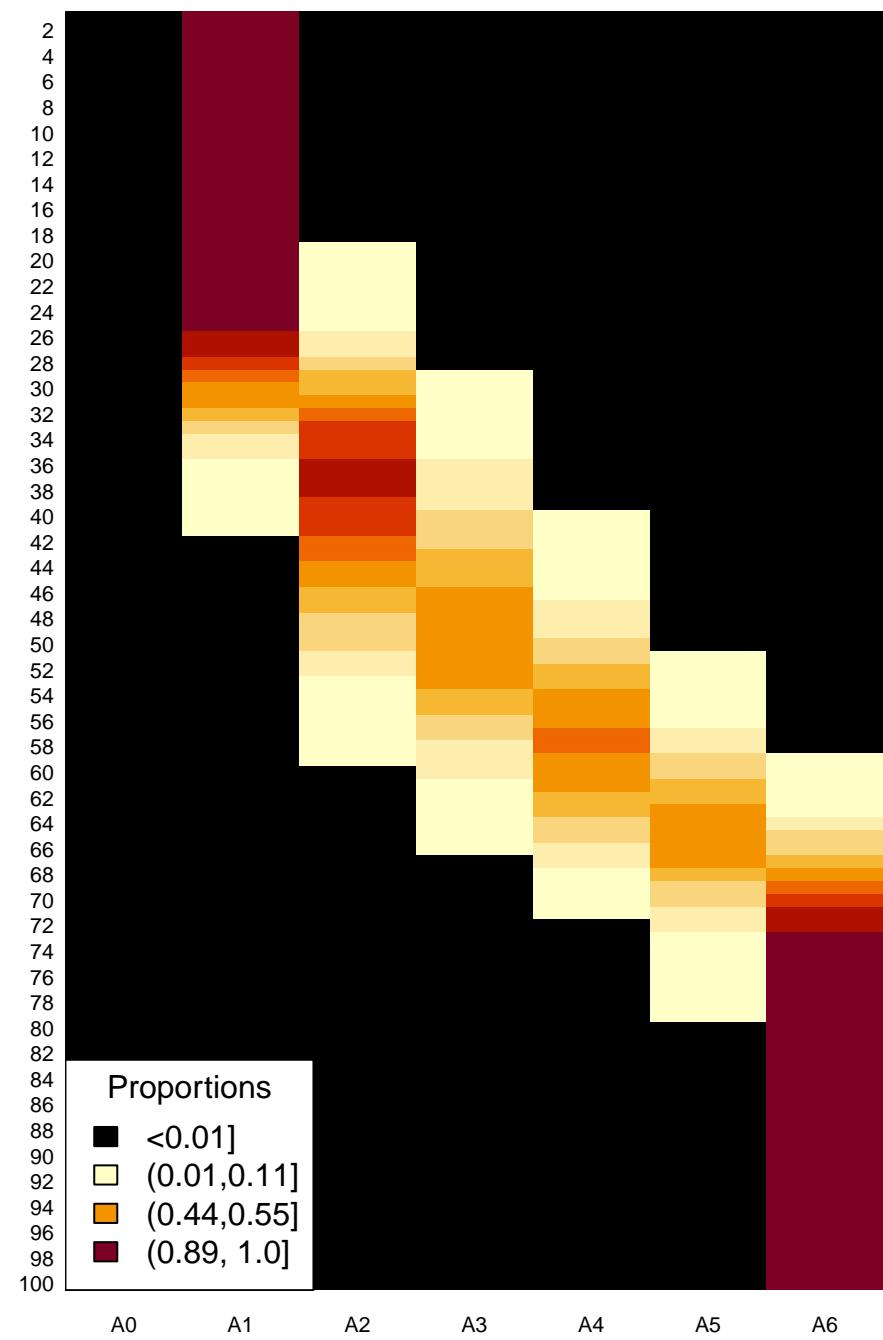
Multinomial ALK, spring 2013



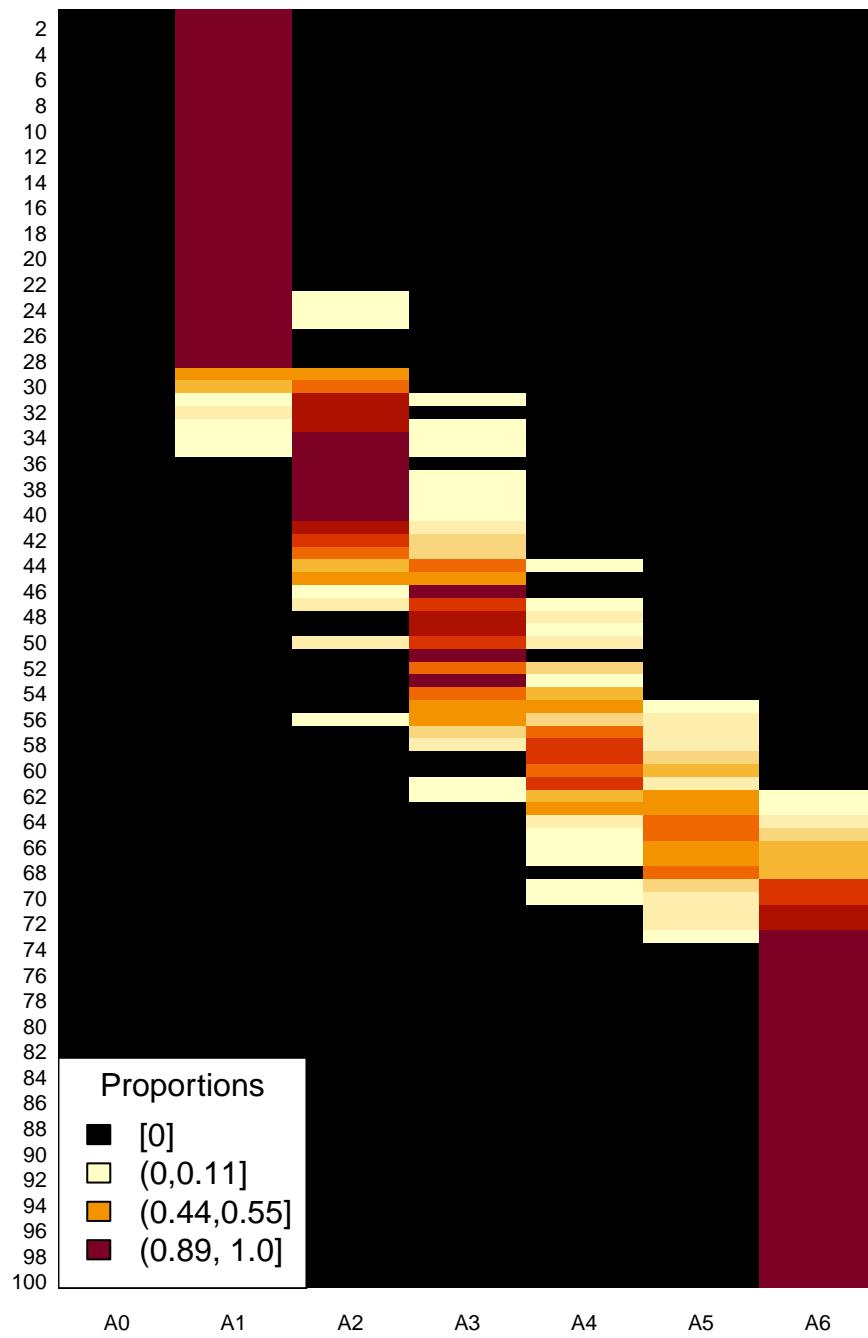
Traditional ALK, spring 2014



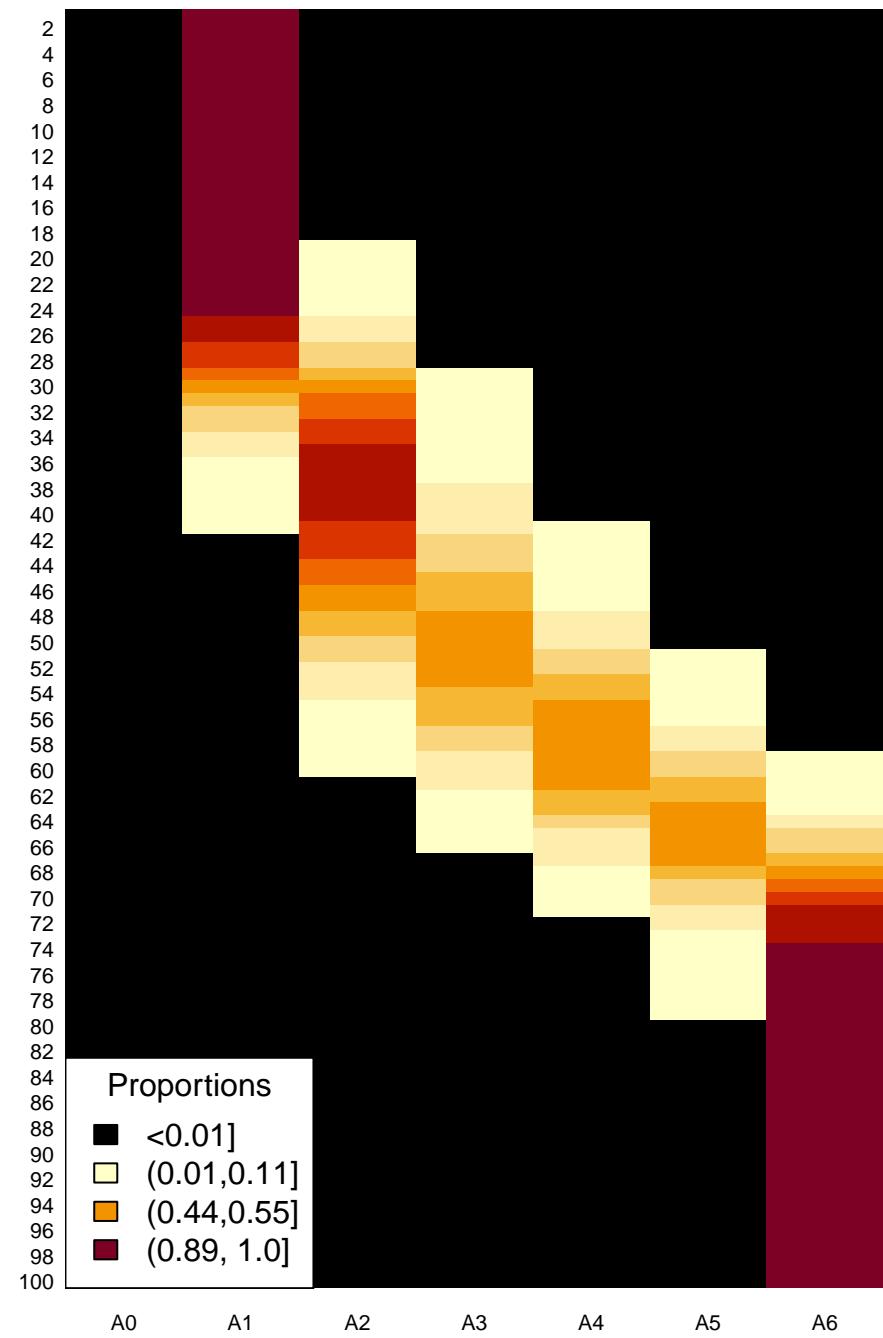
Multinomial ALK, spring 2014



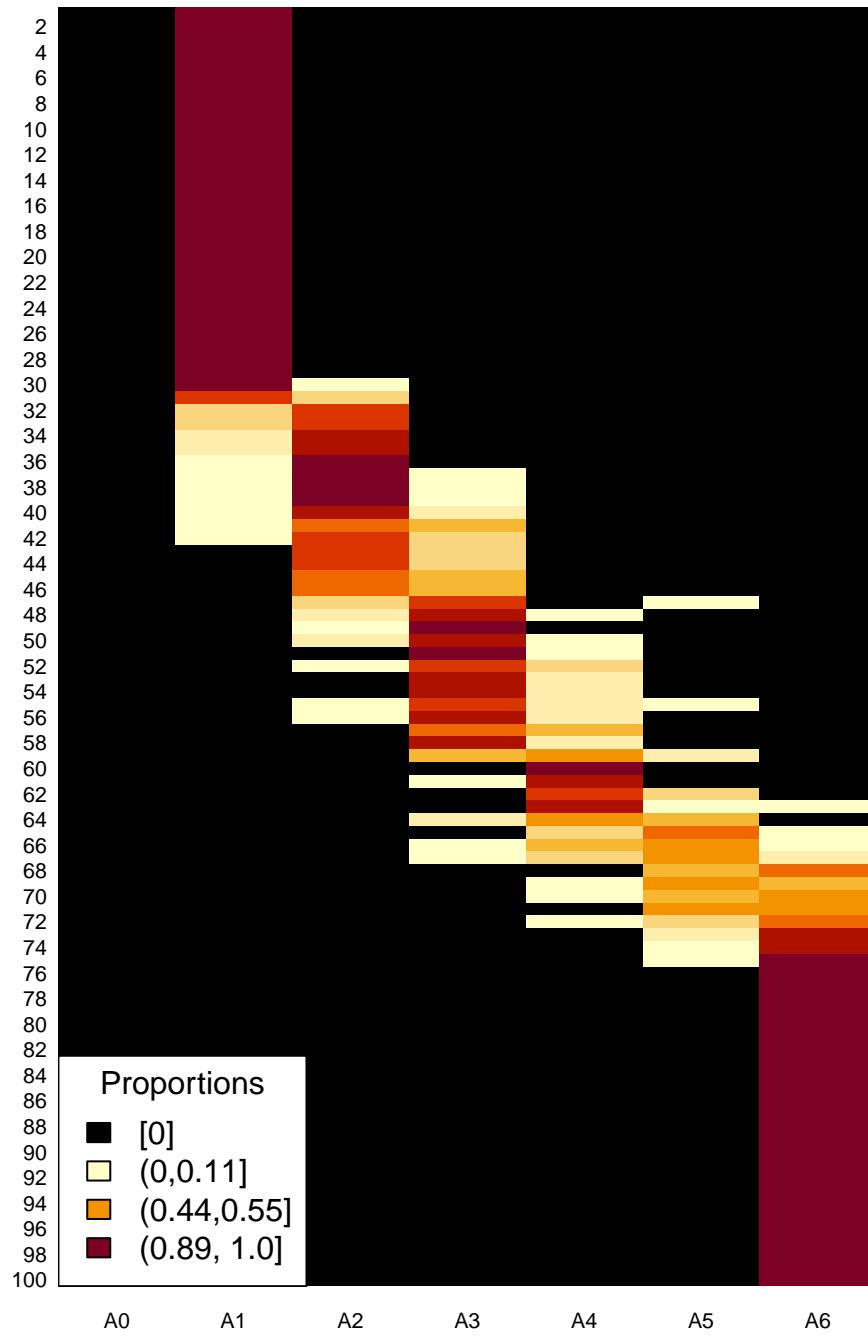
Traditional ALK, spring 2015



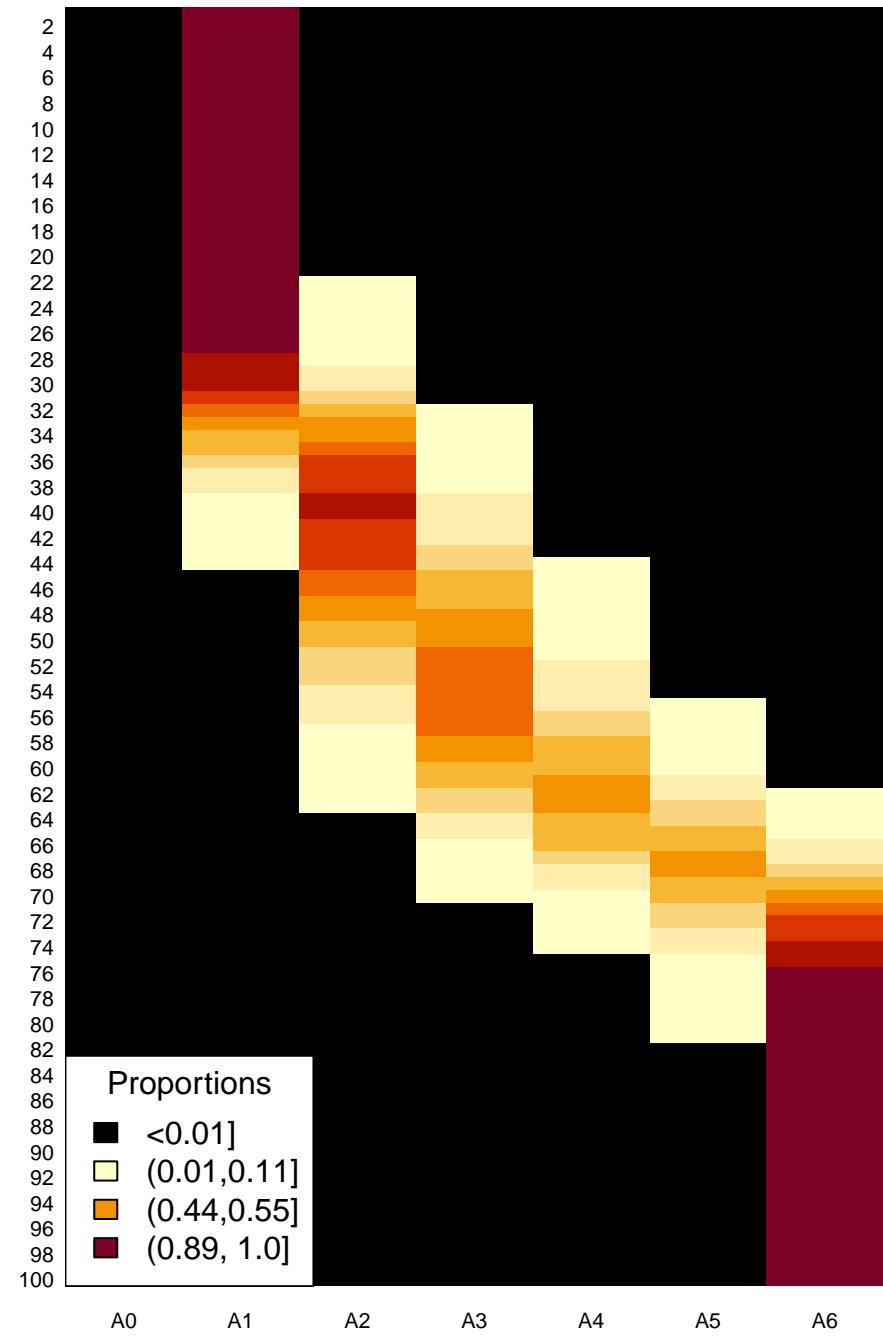
Multinomial ALK, spring 2015



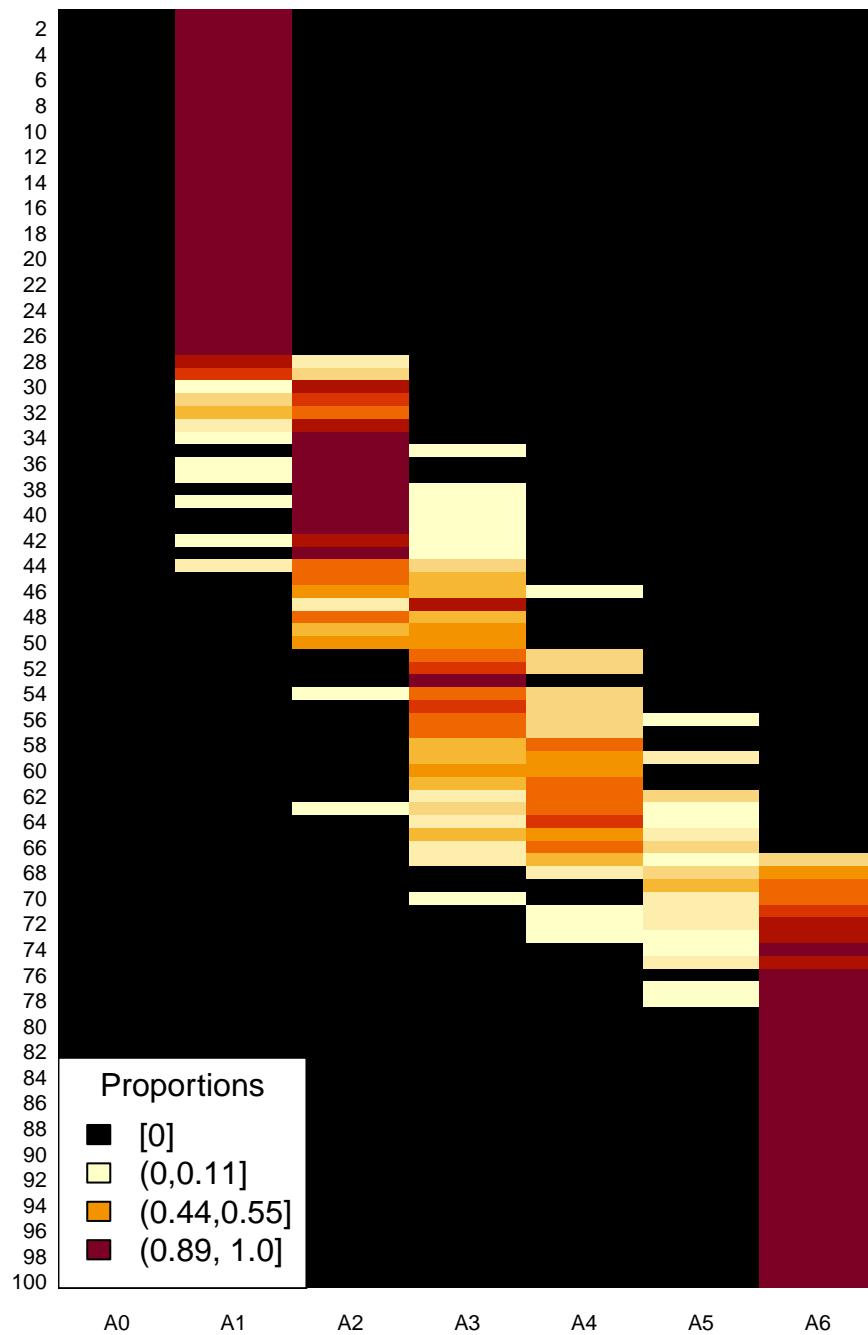
Traditional ALK, spring 2016



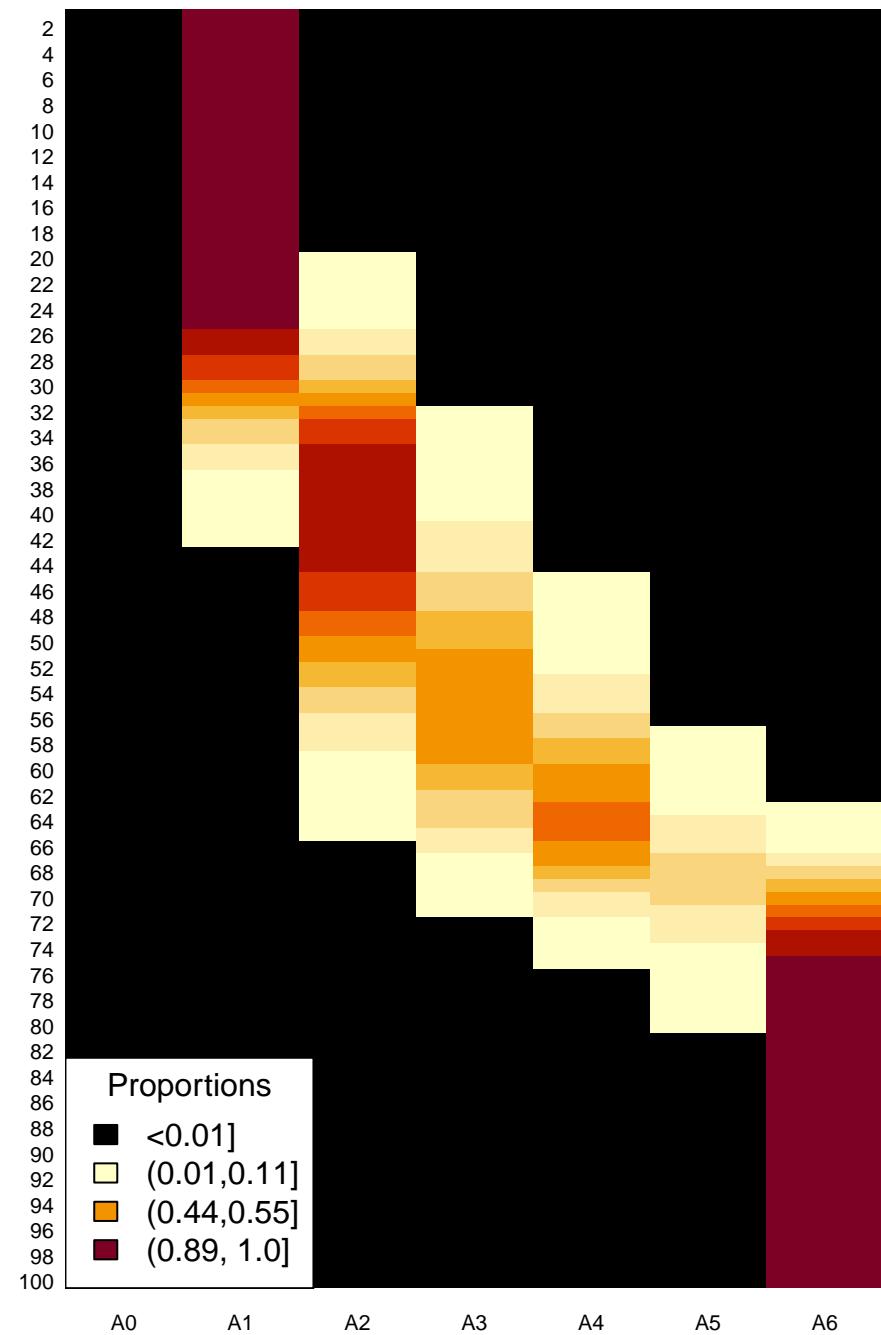
Multinomial ALK, spring 2016



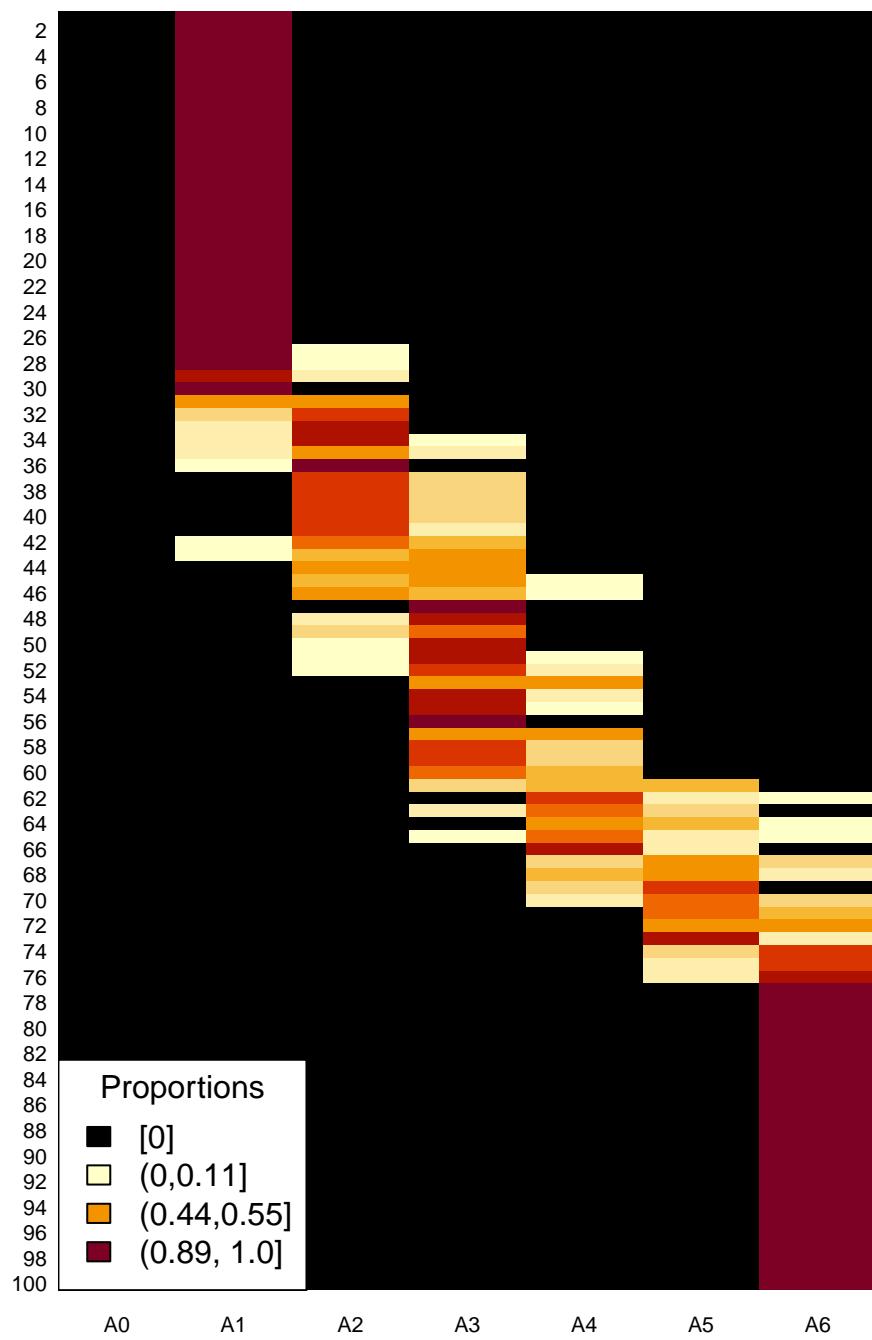
Traditional ALK, spring 2017



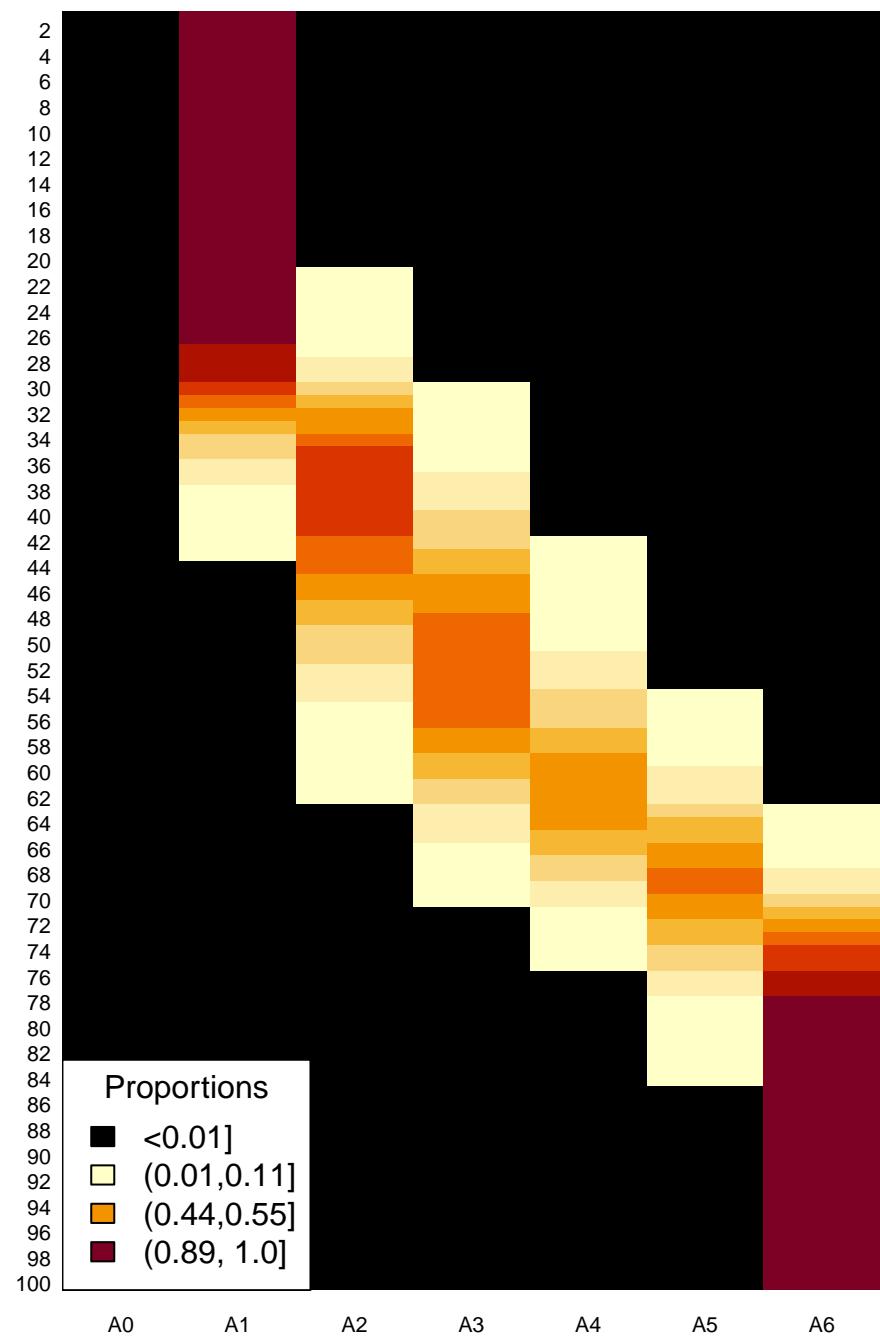
Multinomial ALK, spring 2017



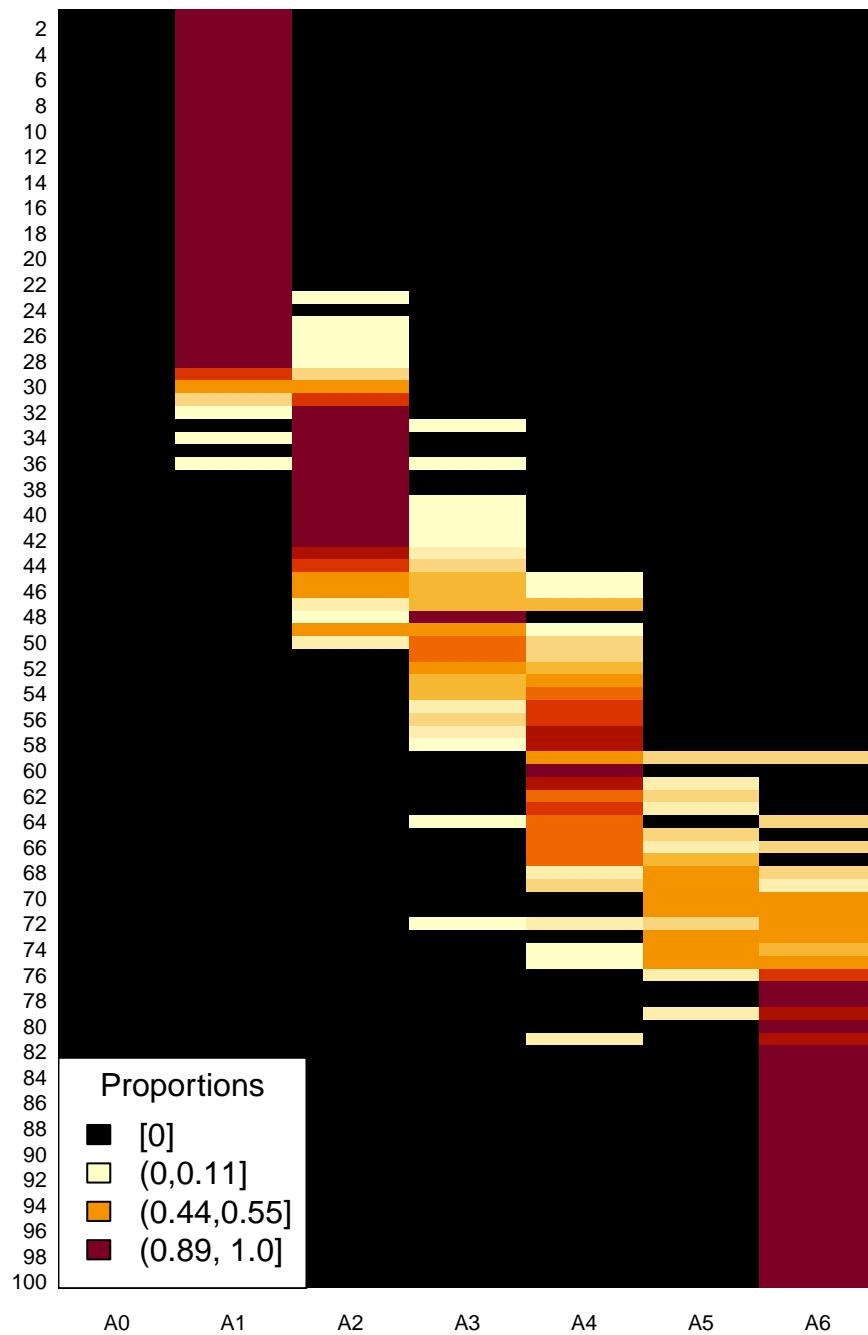
Traditional ALK, spring 2018



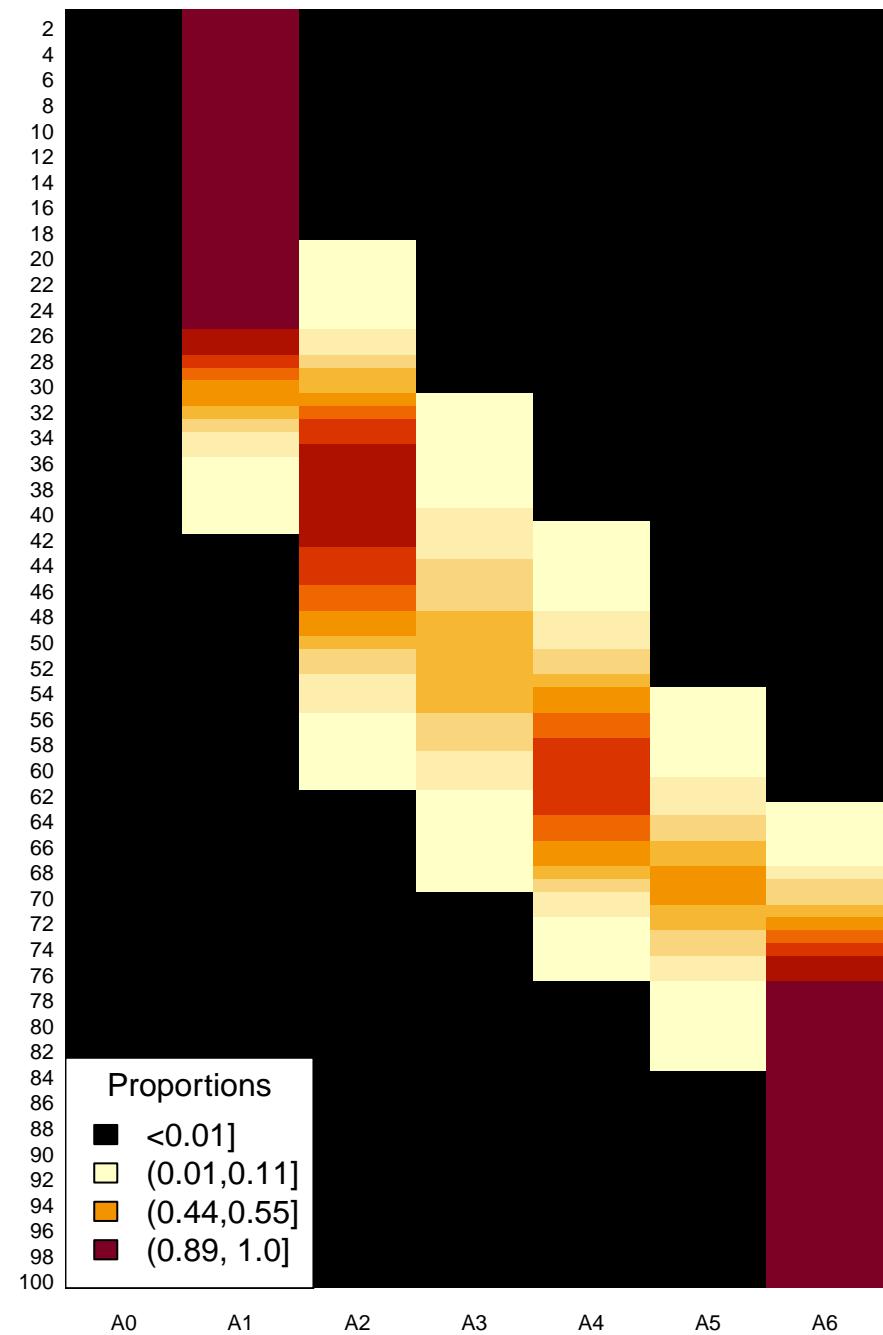
Multinomial ALK, spring 2018



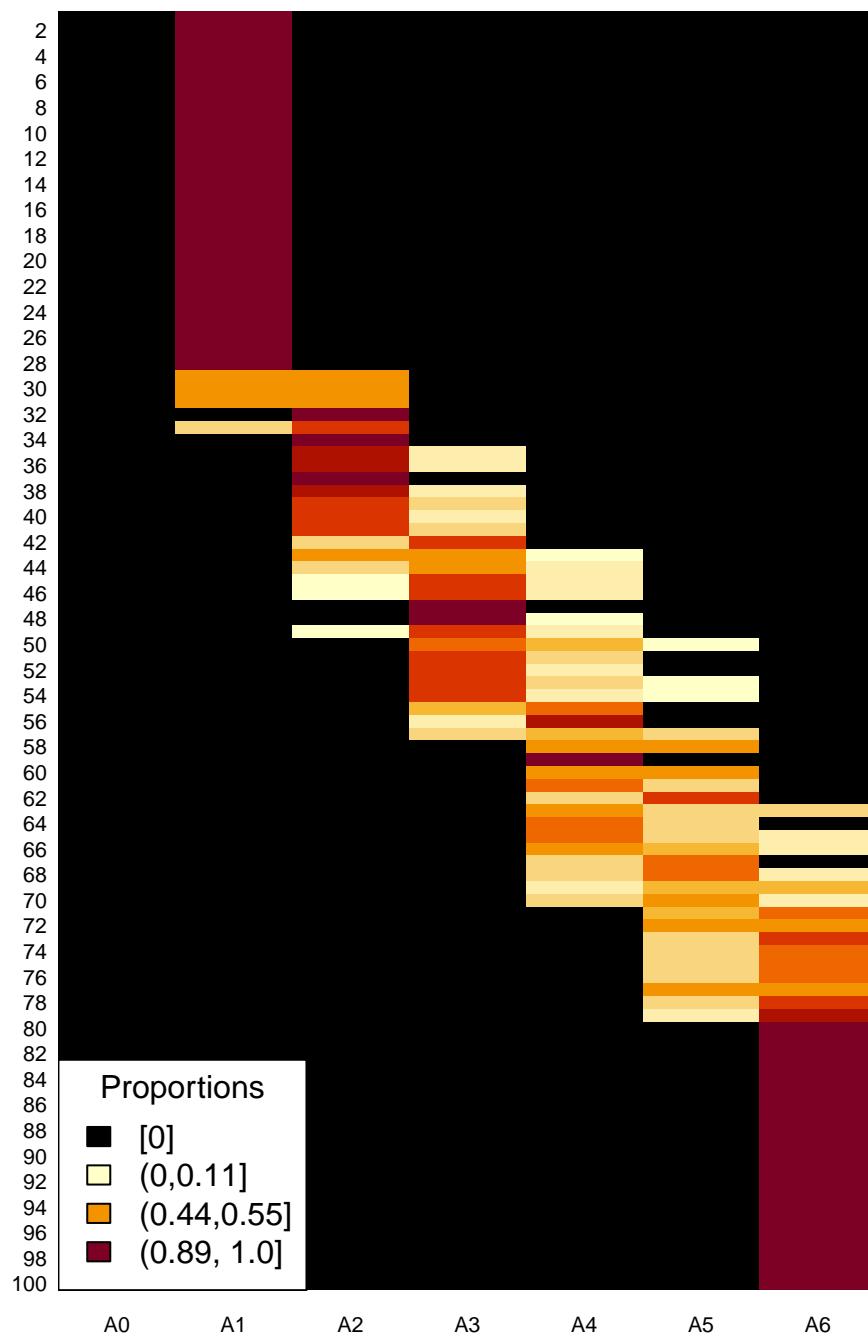
Traditional ALK, spring 2019



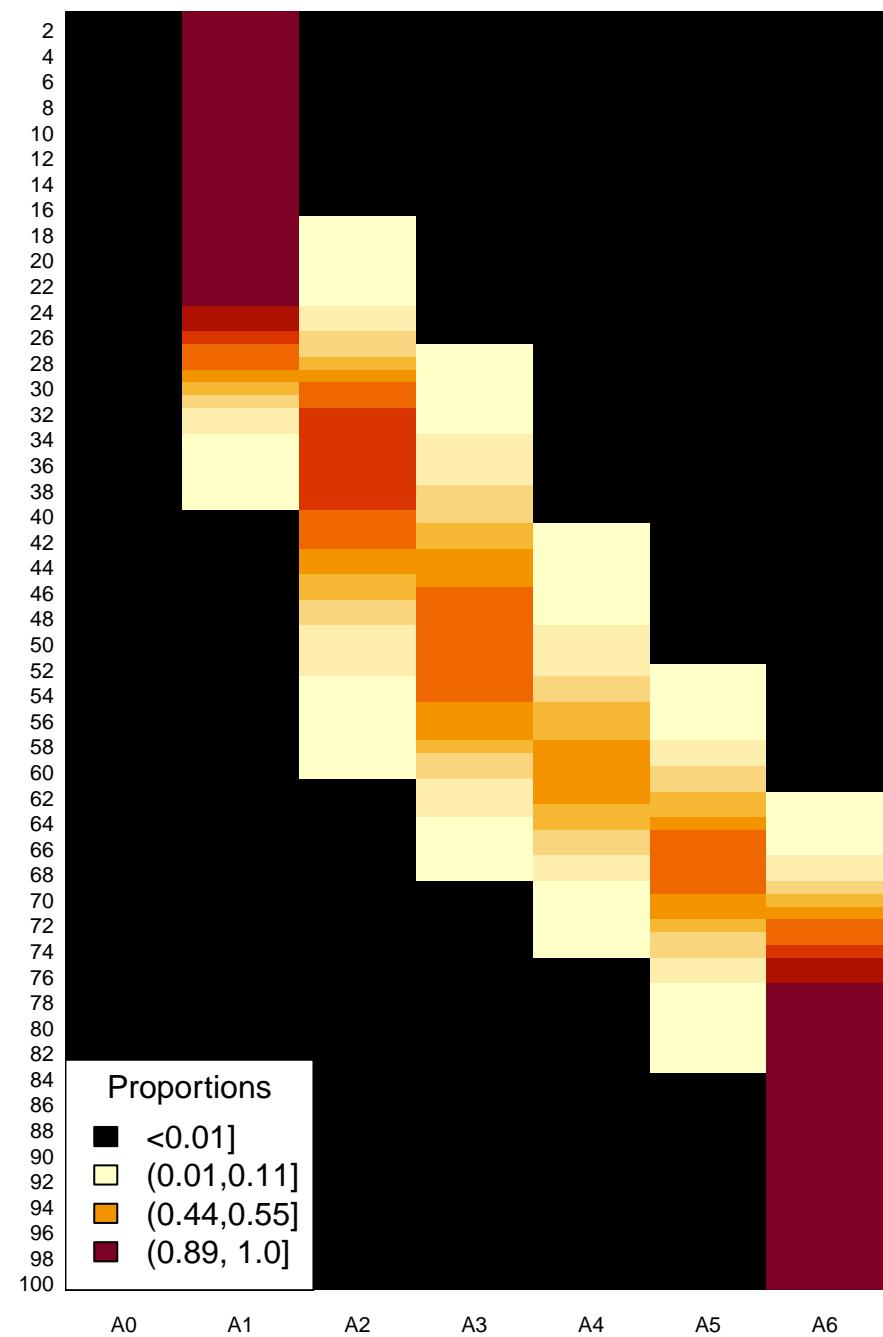
Multinomial ALK, spring 2019



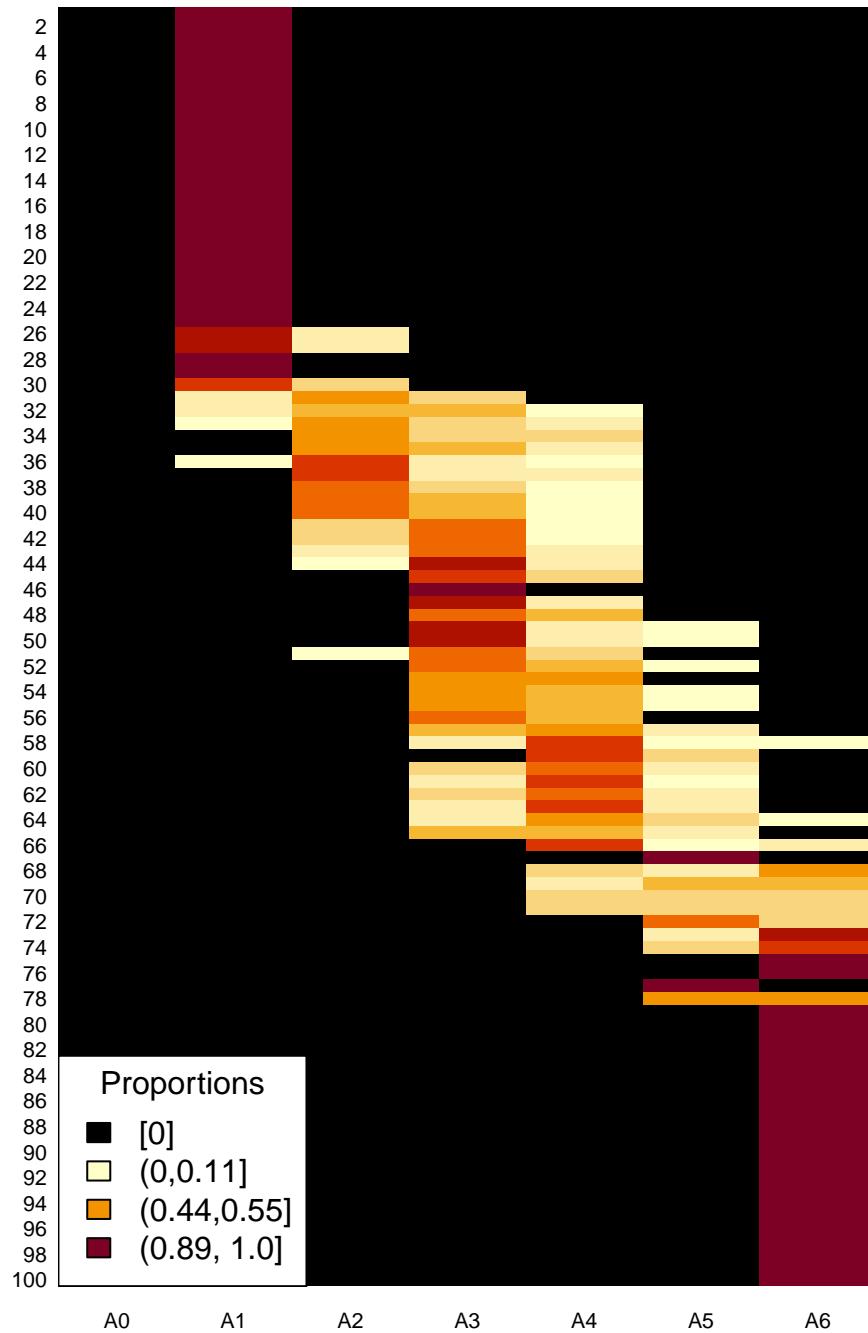
Traditional ALK, spring 2020



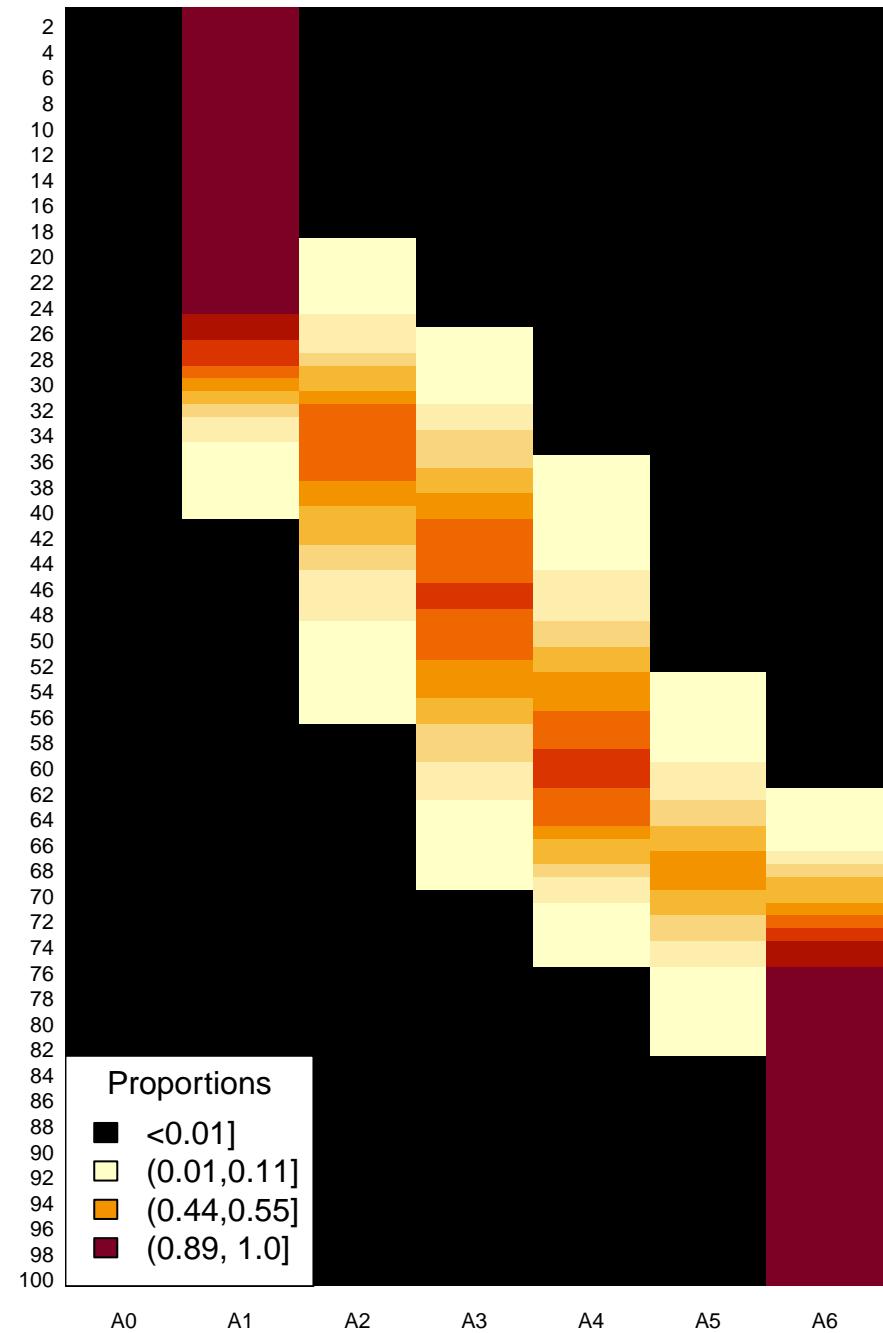
Multinomial ALK, spring 2020



Traditional ALK, spring 2021

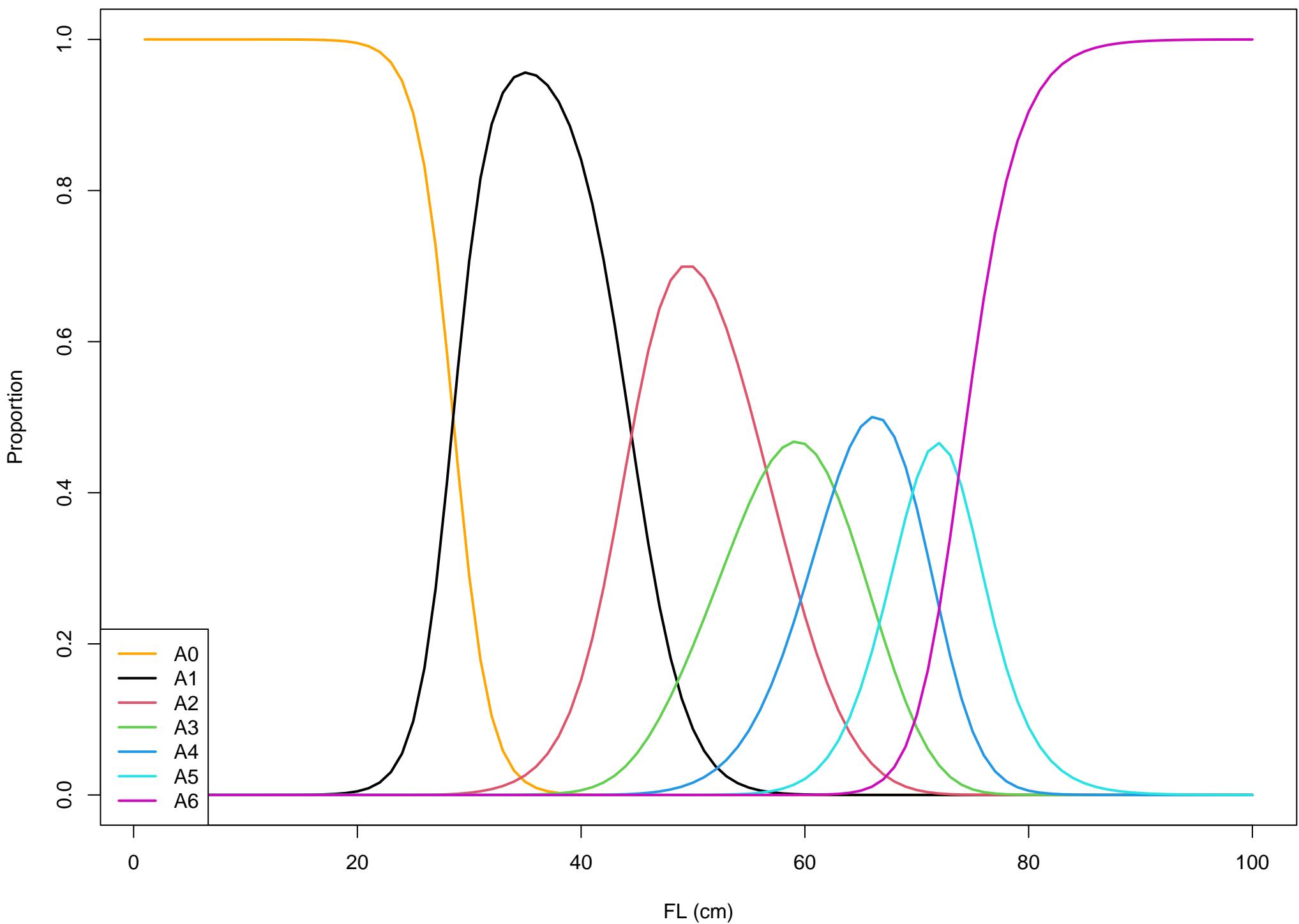


Multinomial ALK, spring 2021

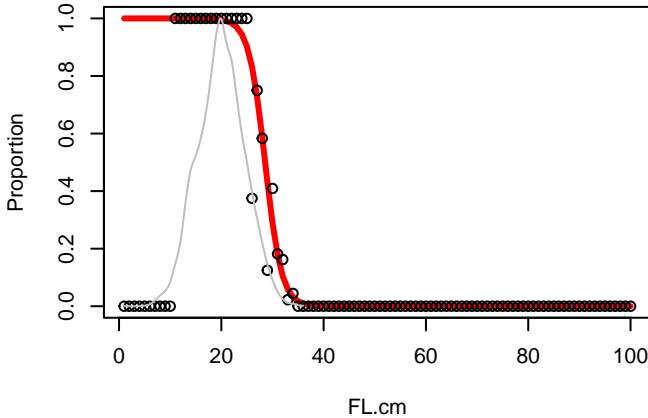


Appendix II

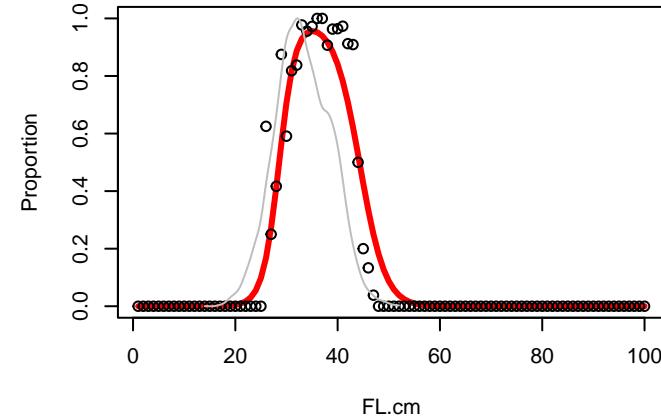
1985
fall



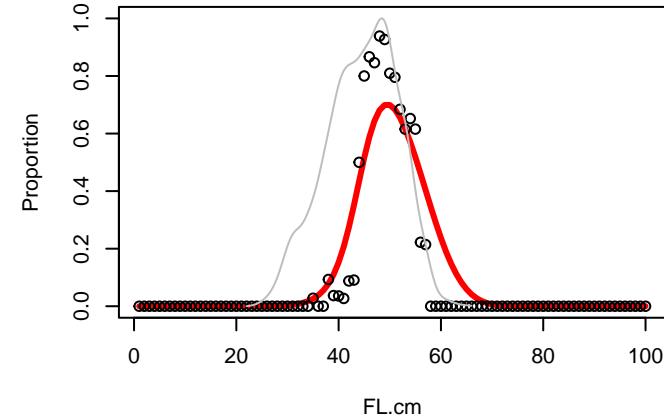
A0, 1985, fall



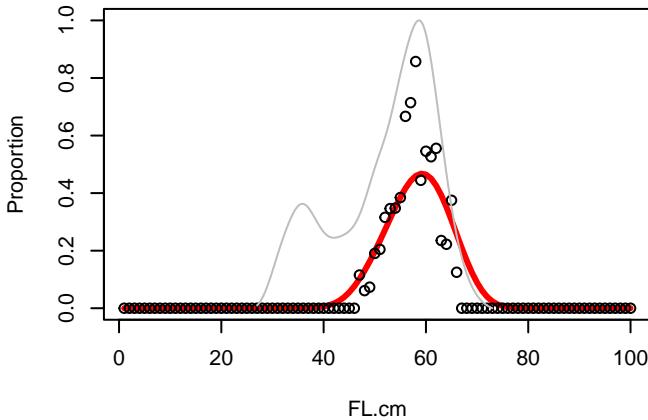
A1



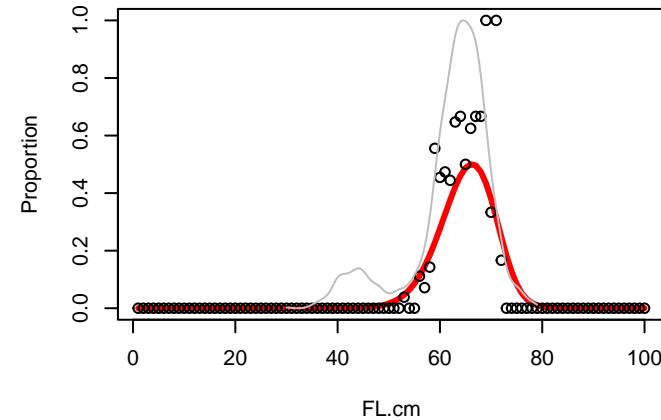
A2



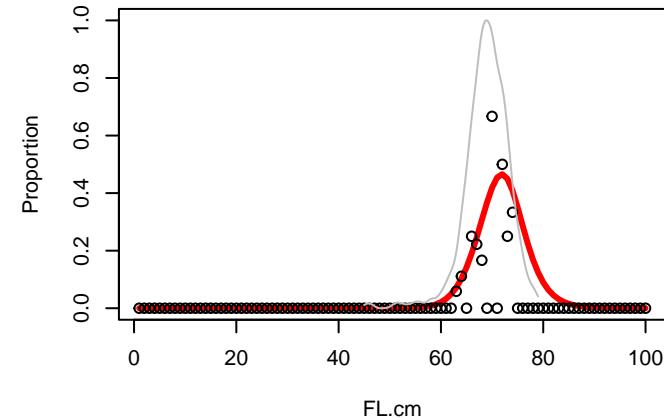
A3



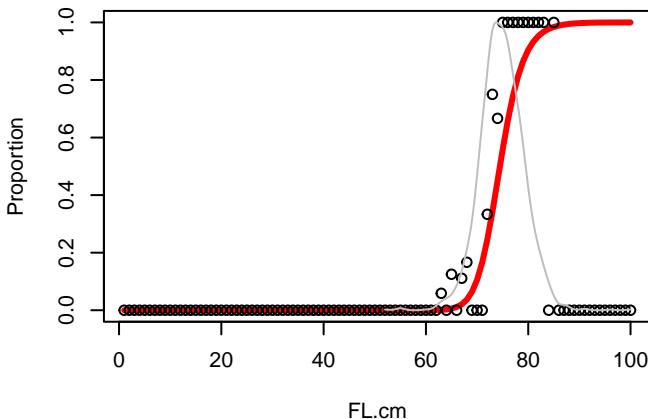
A4



A5

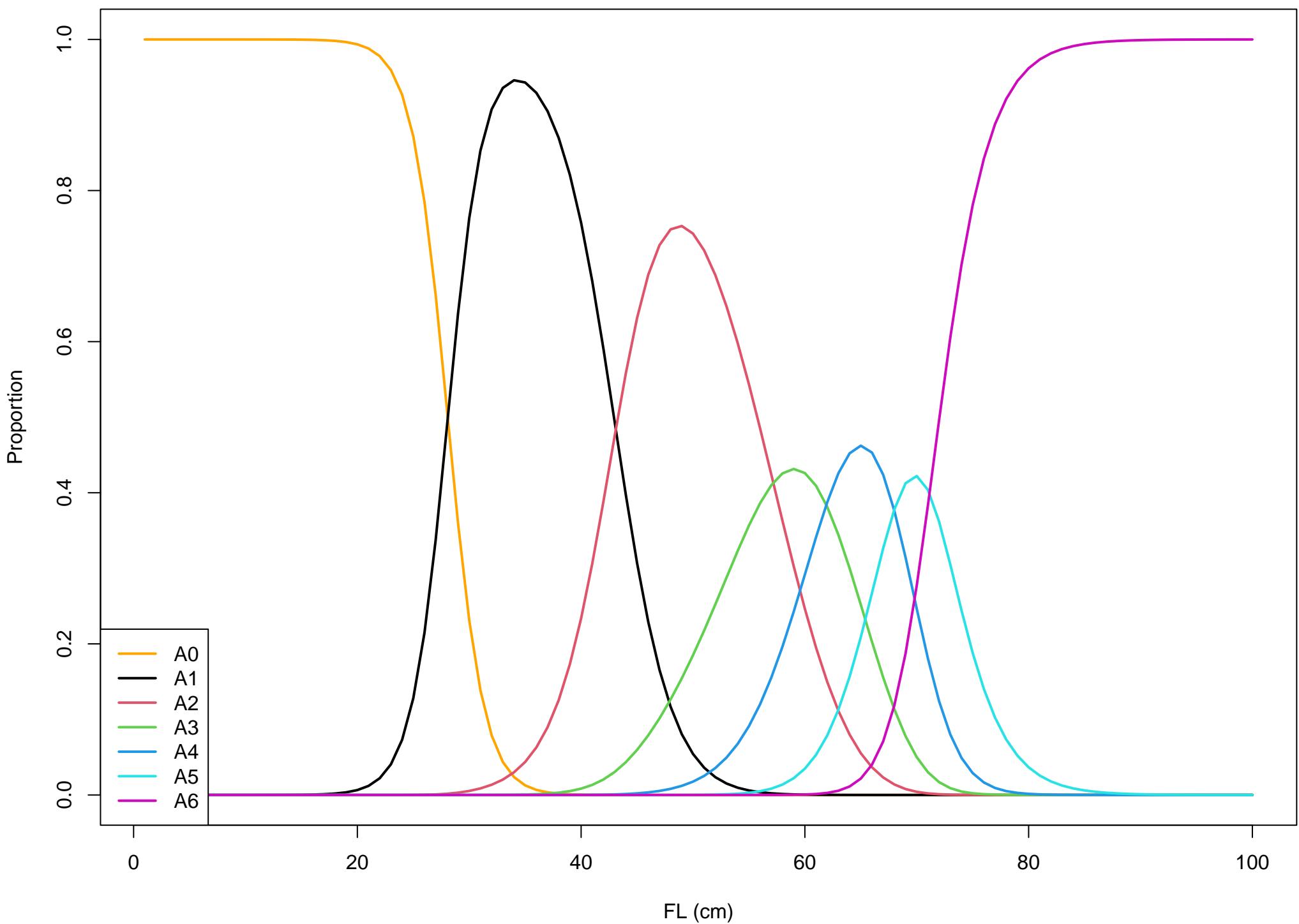


A6

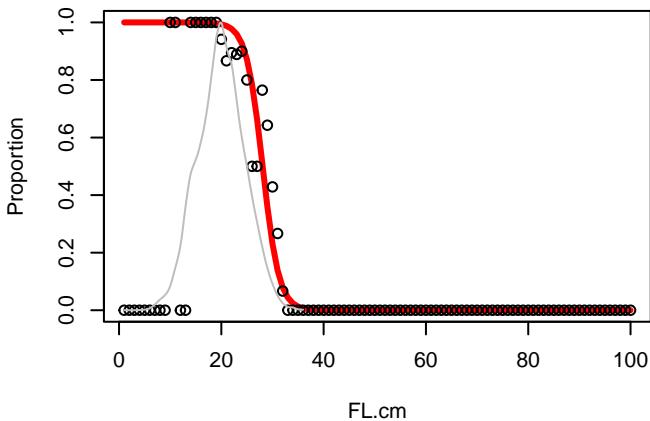


All fall
1985 fall pred
○ 1985 fall obs

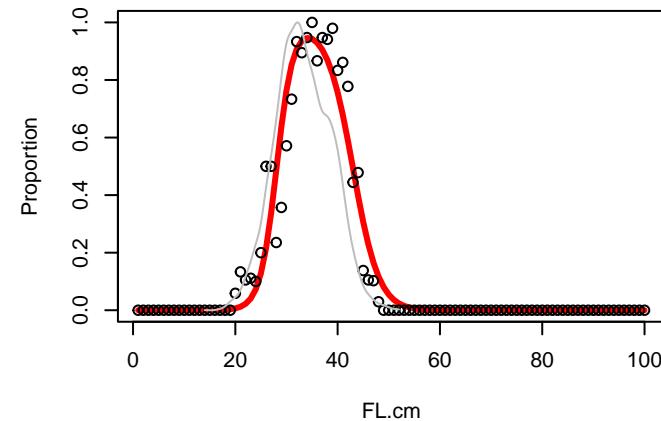
1986
fall



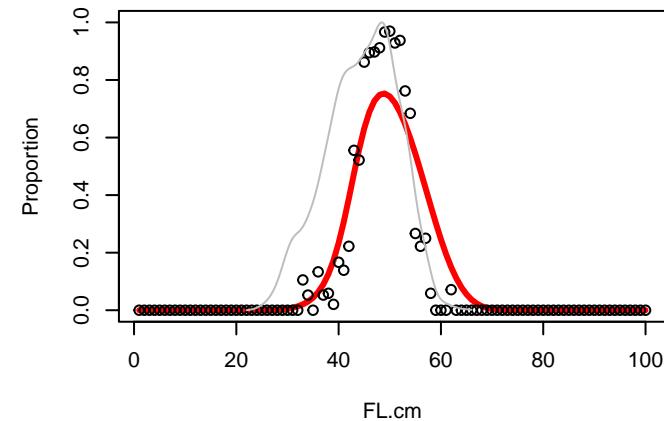
A0, 1986, fall



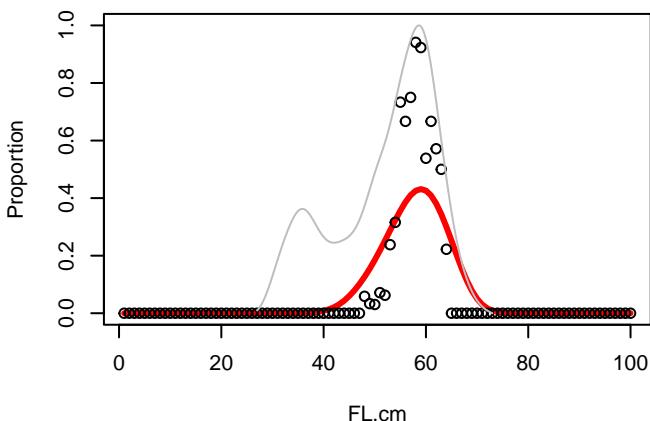
A1



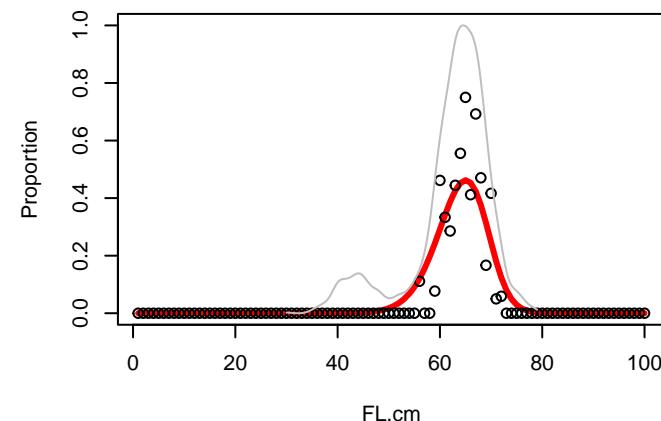
A2



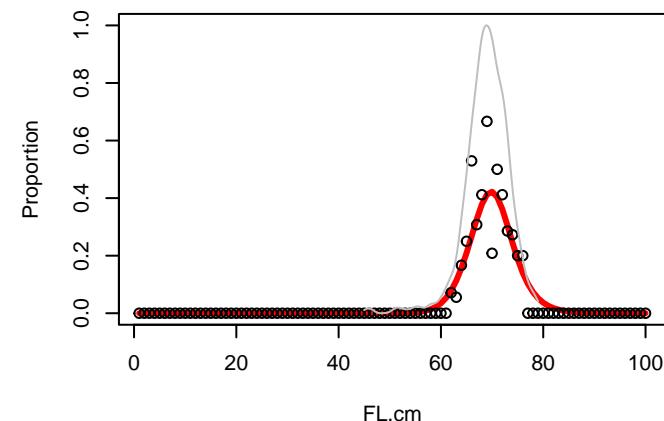
A3



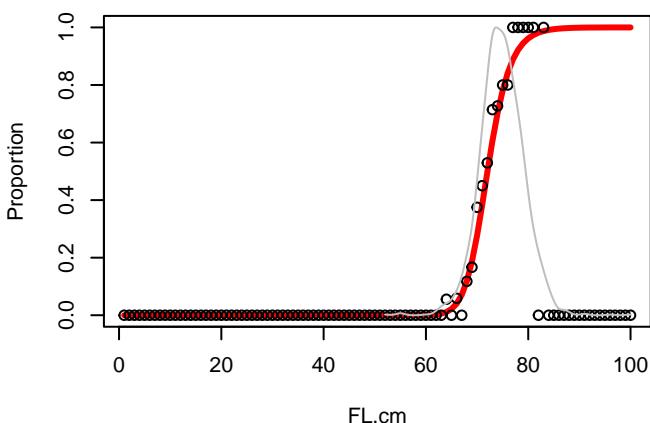
A4



A5

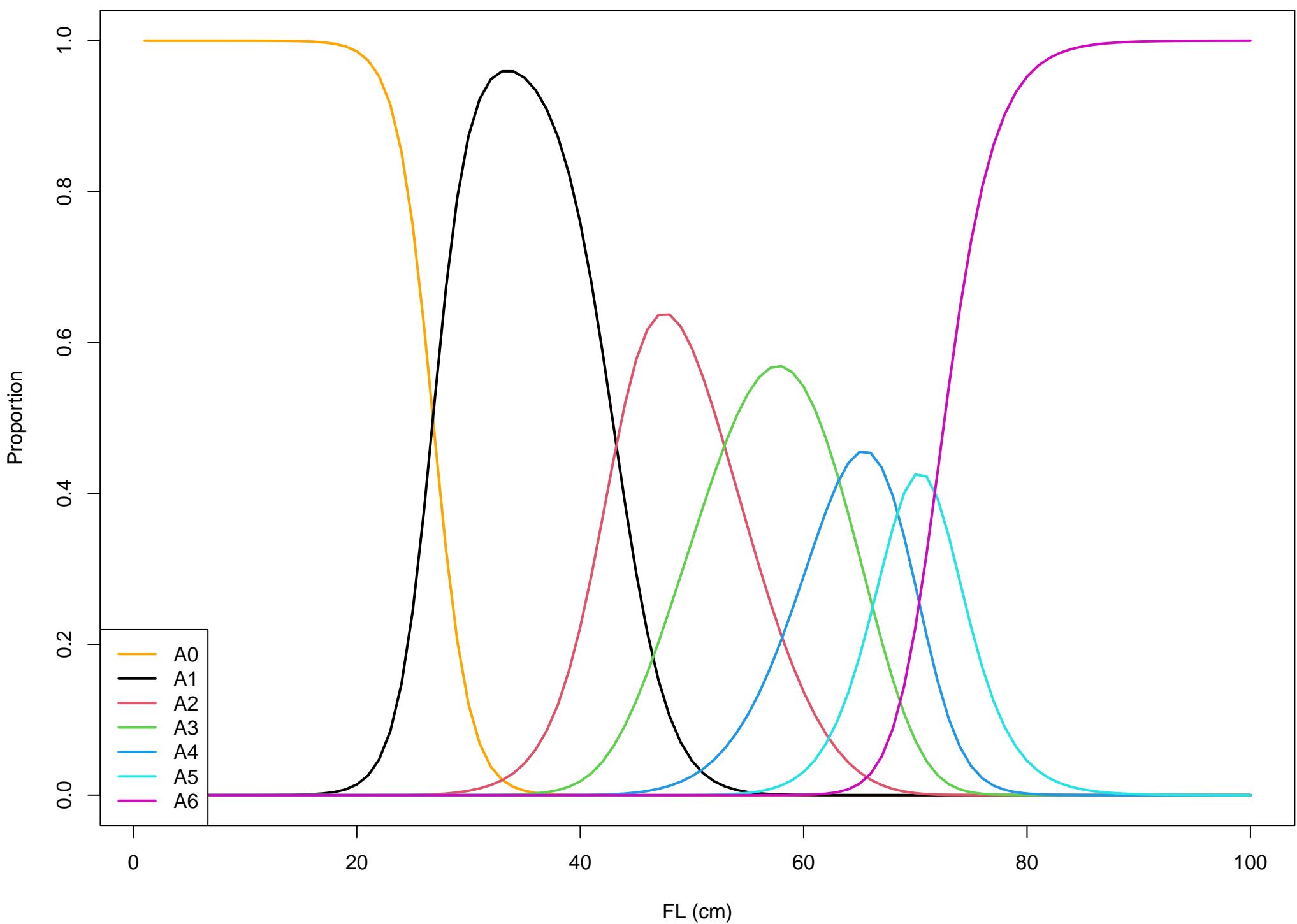


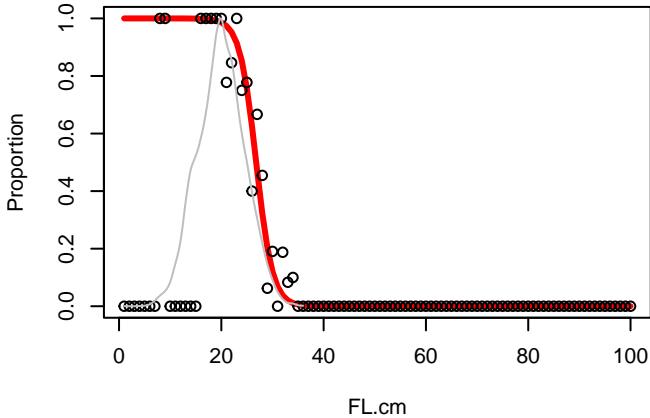
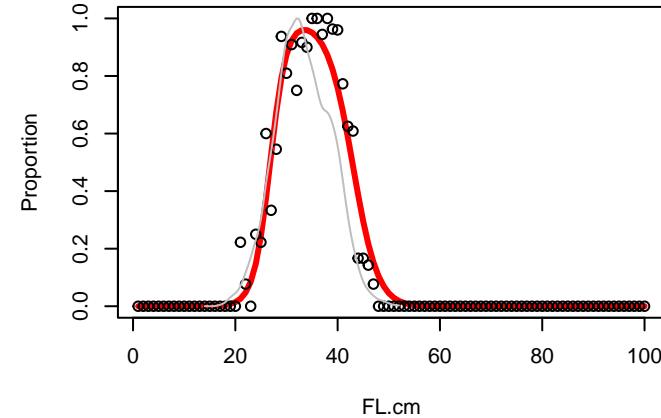
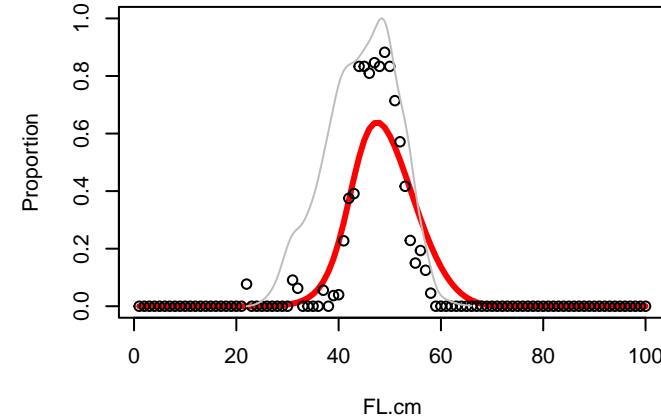
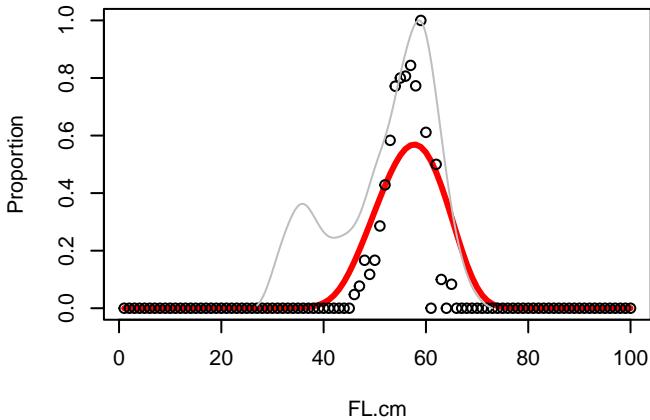
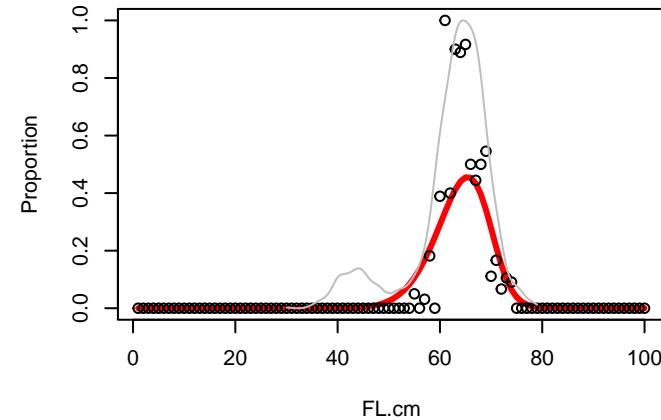
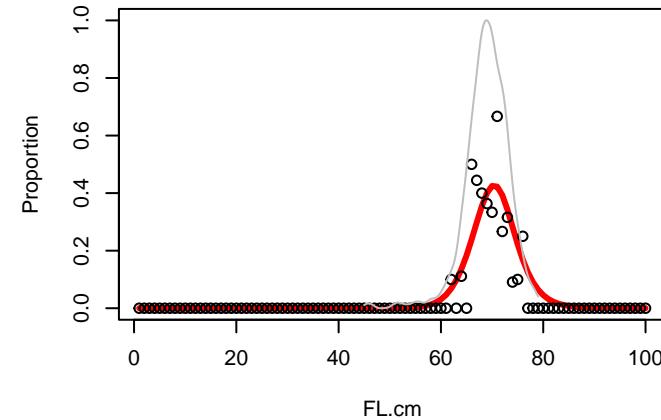
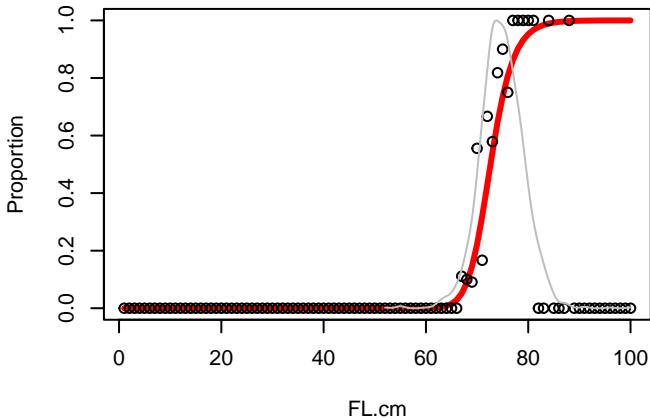
A6



All fall
1986 fall pred
1986 fall obs

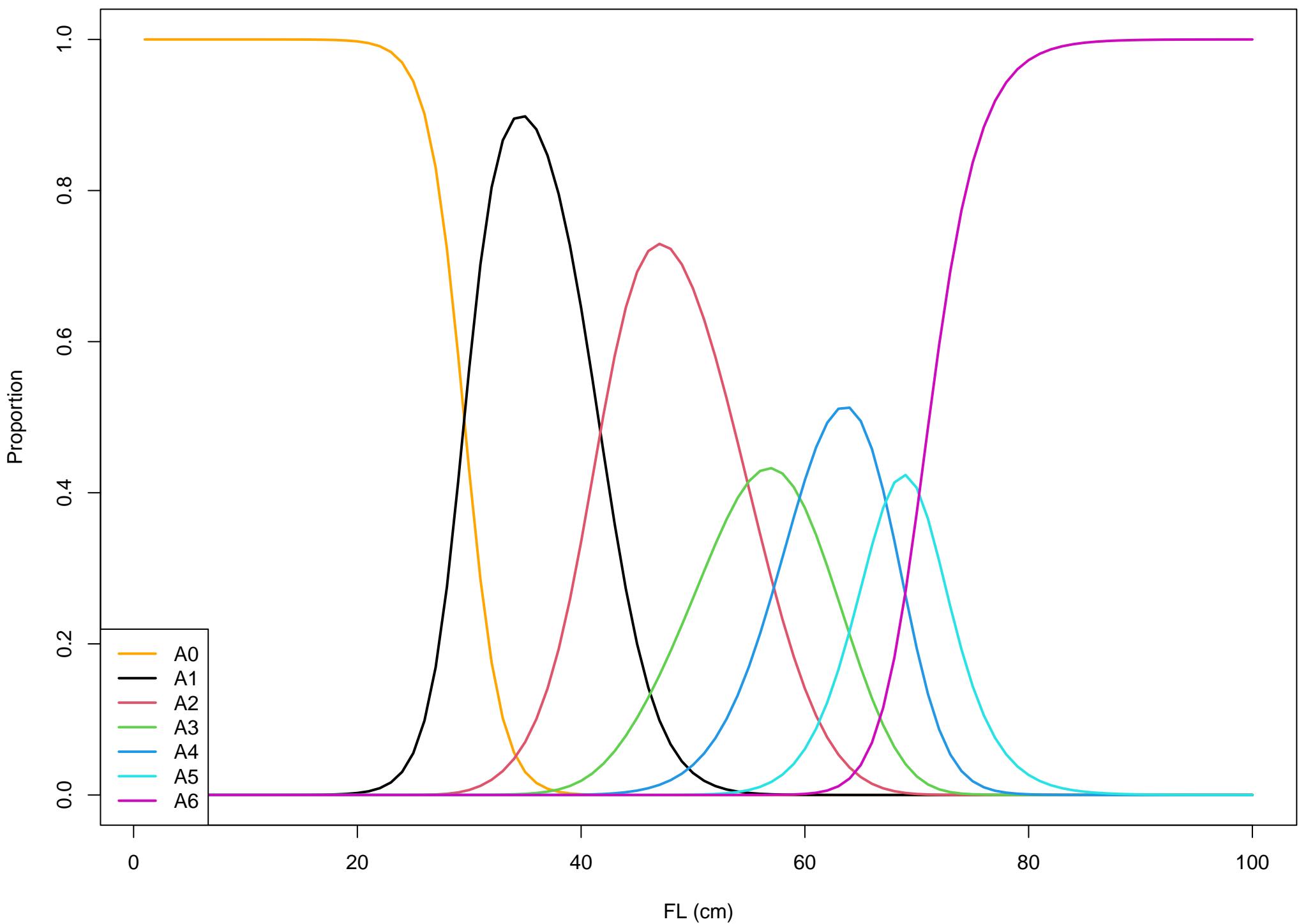
1987
fall

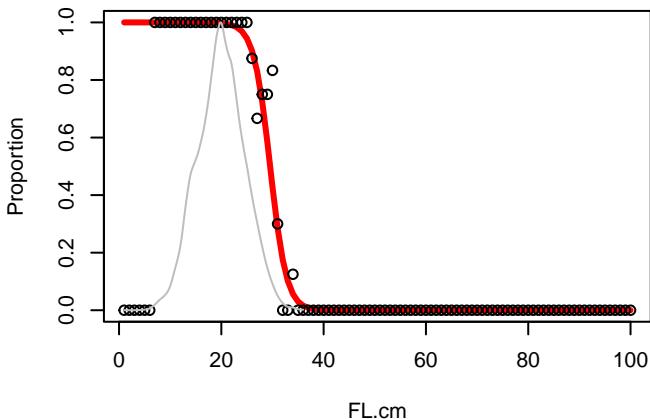
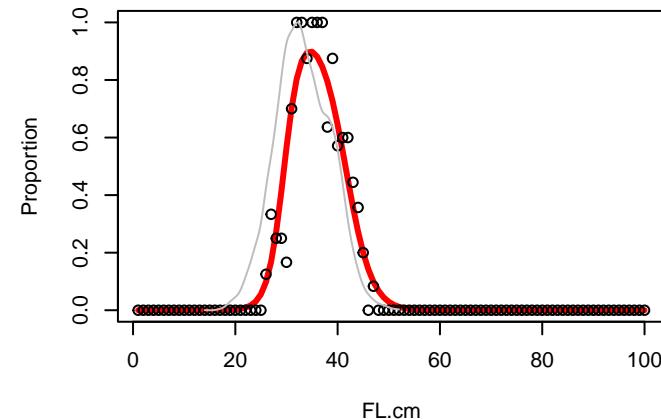
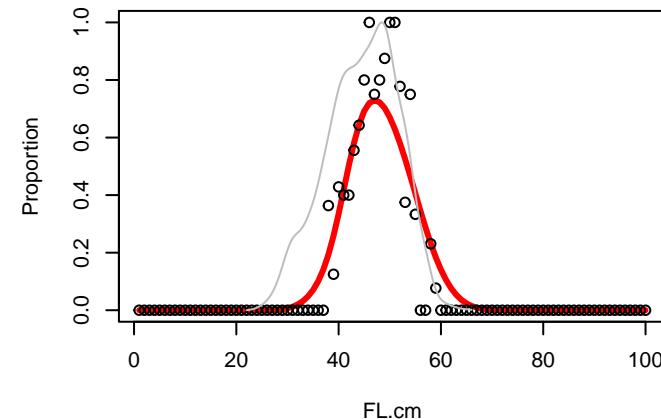
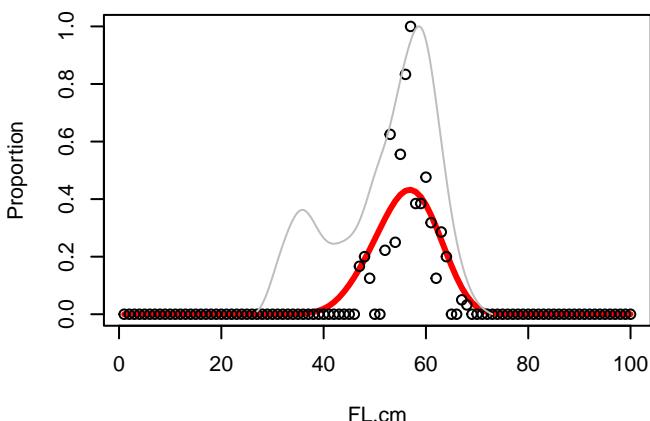
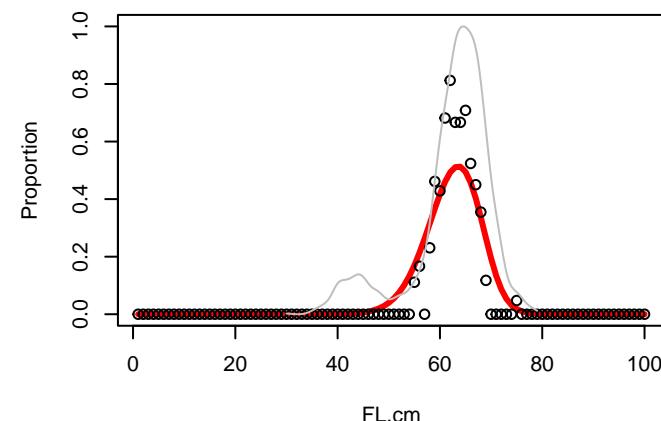
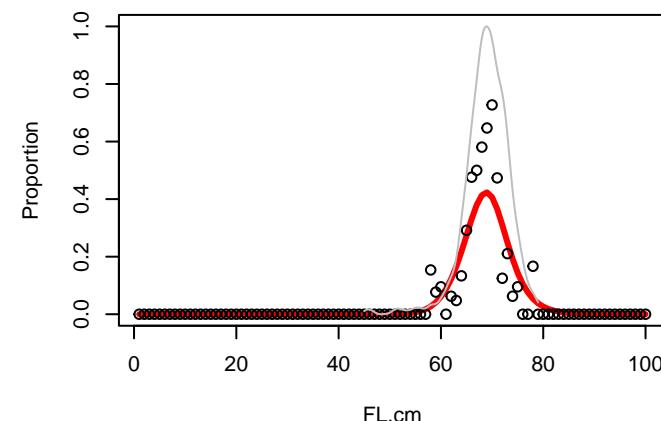
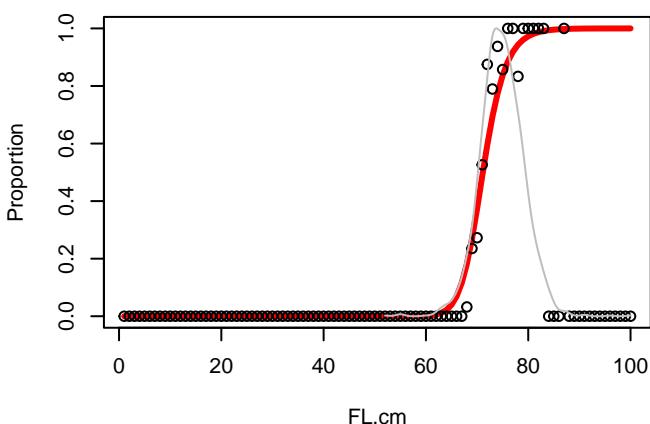


A0, 1987, fall**A1****A2****A3****A4****A5****A6**

All fall
1987 fall pred
1987 fall obs

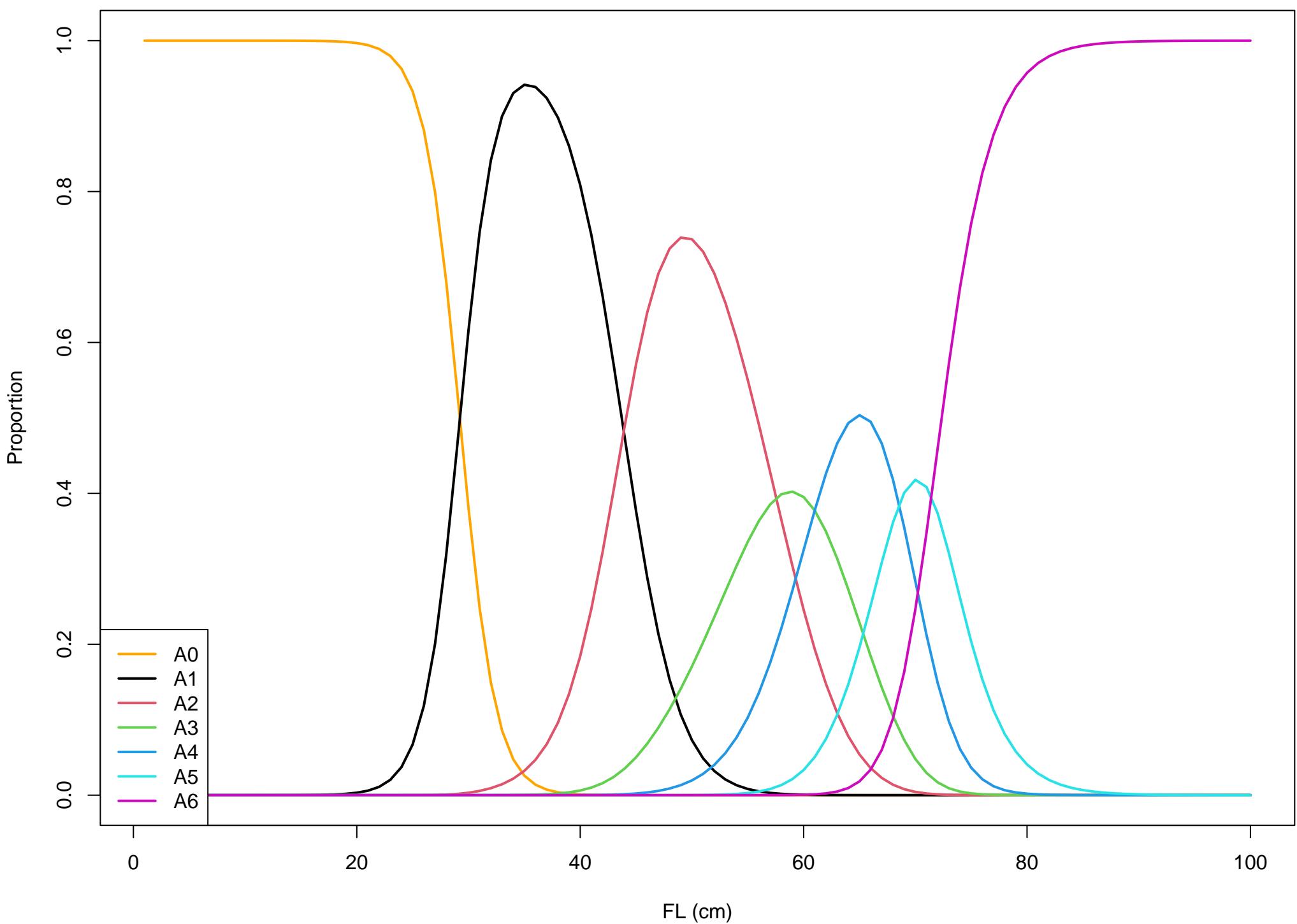
1988
fall

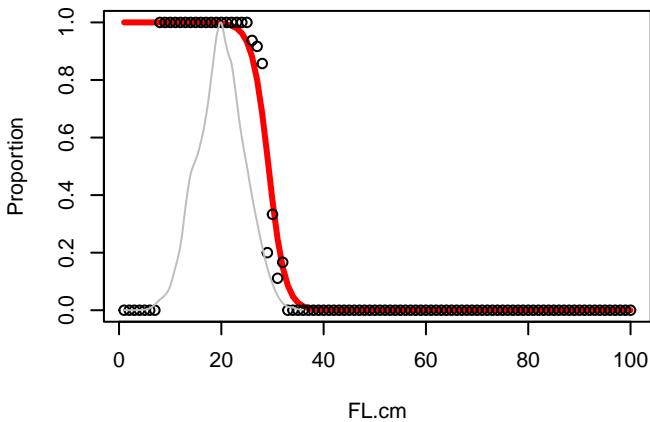
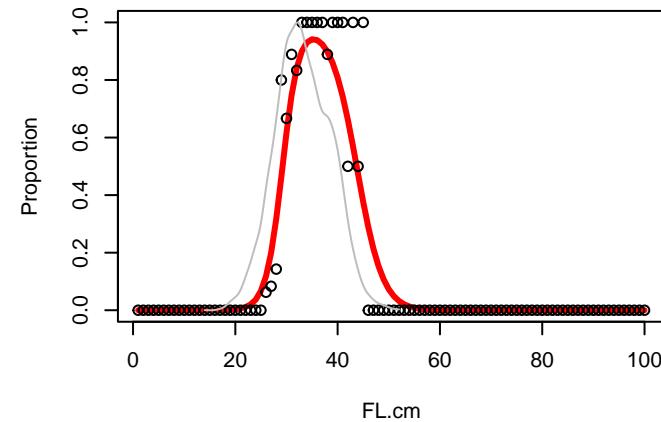
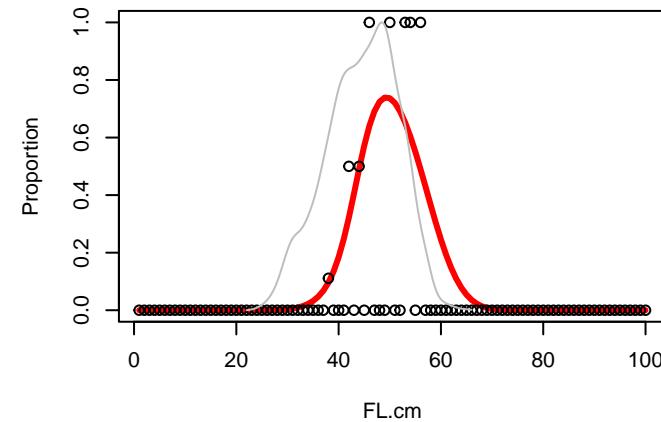
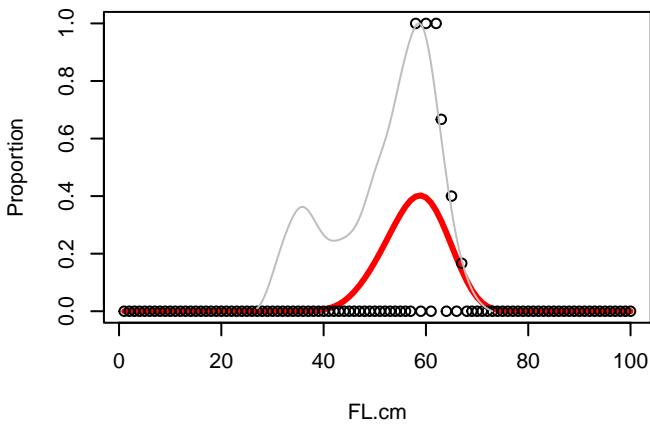
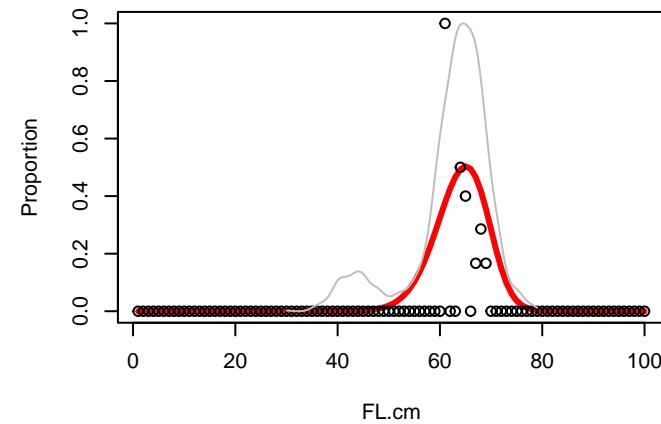
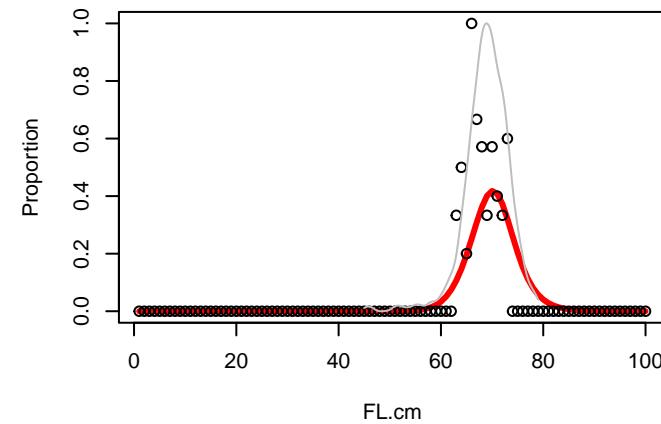
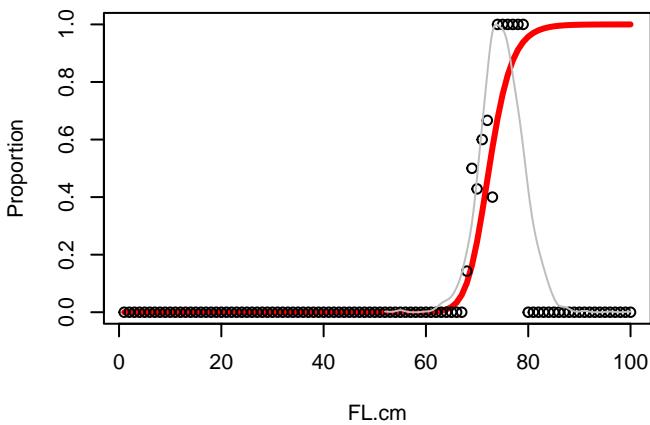


A0, 1988, fall**A1****A2****A3****A4****A5****A6**

— All fall
— 1988 fall pred
○ 1988 fall obs

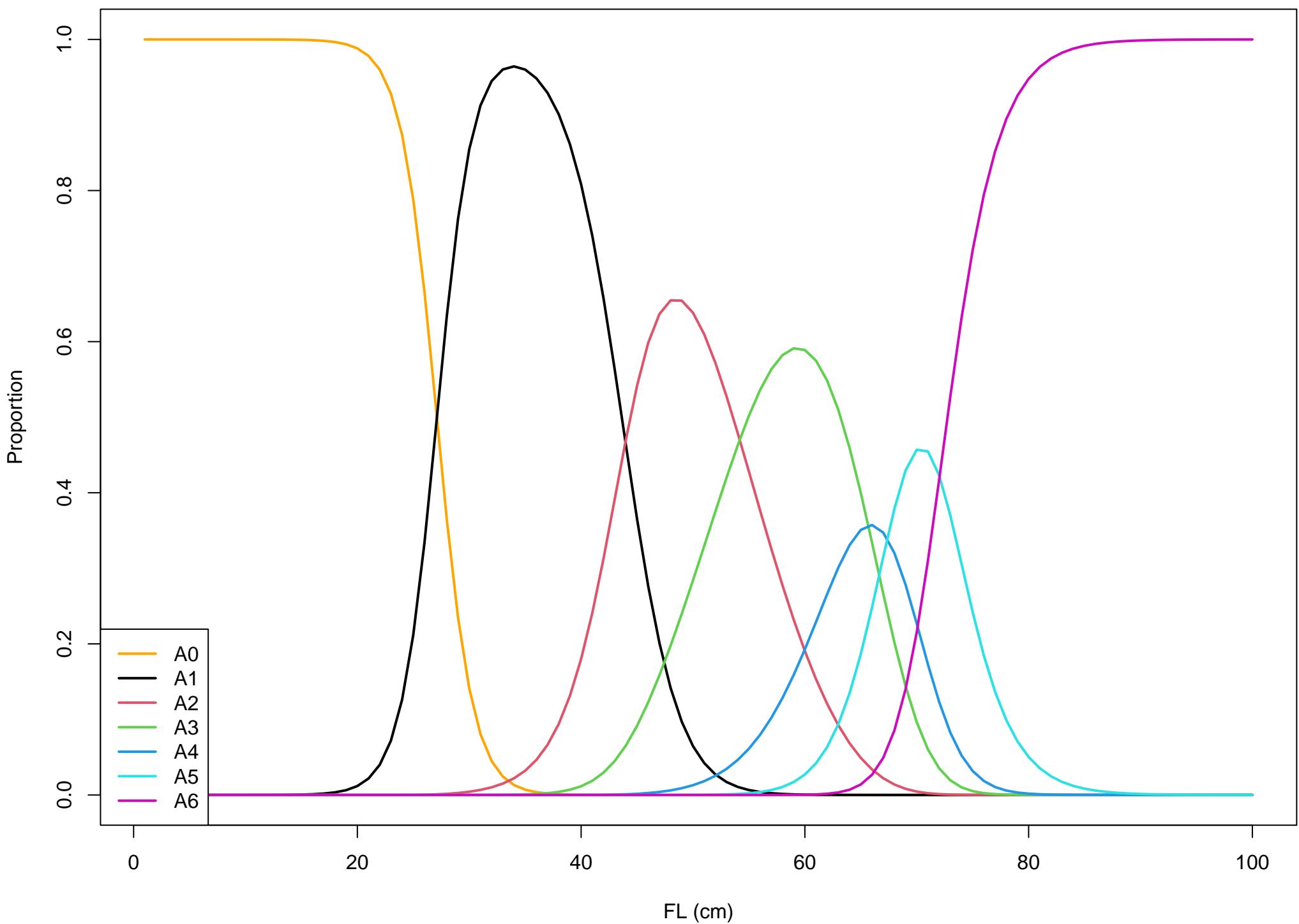
1989
fall

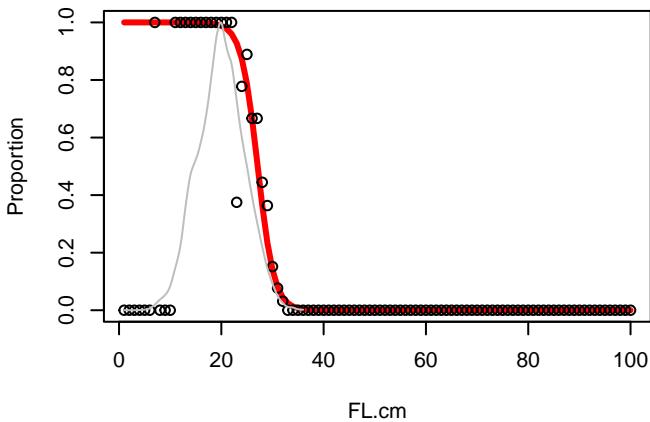
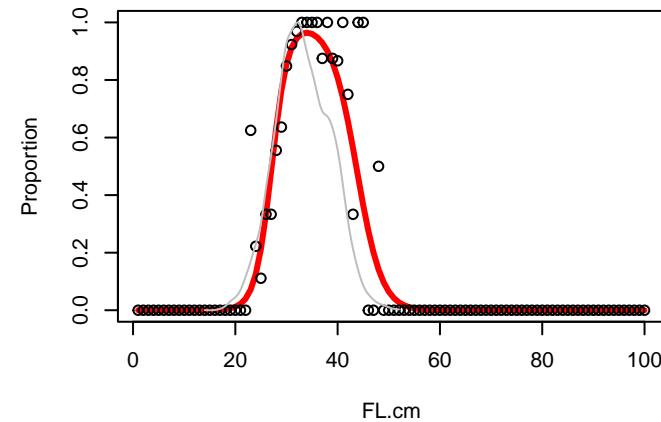
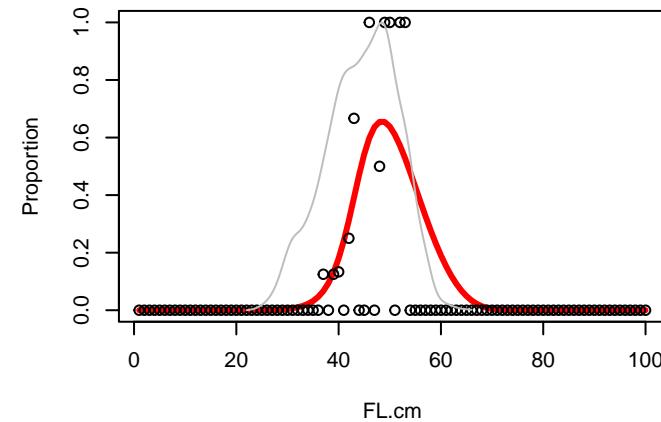
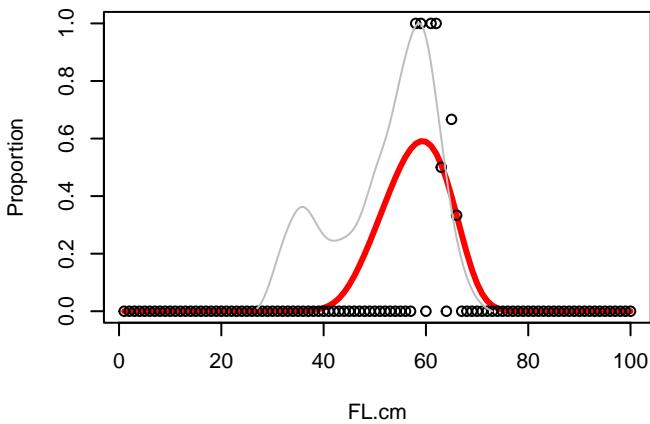
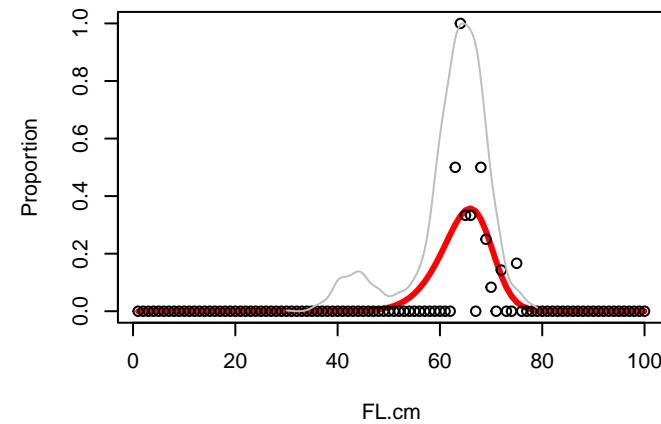
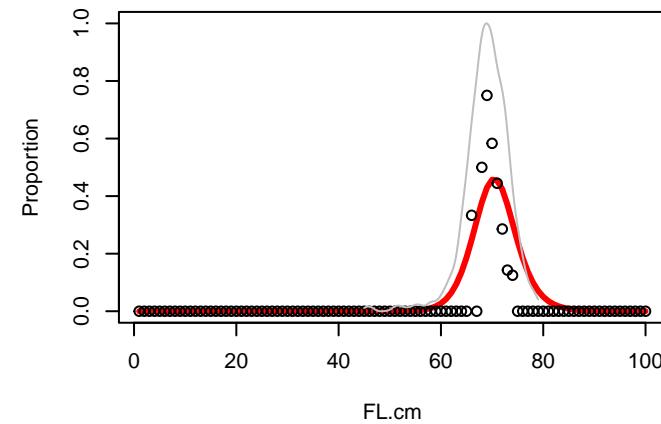
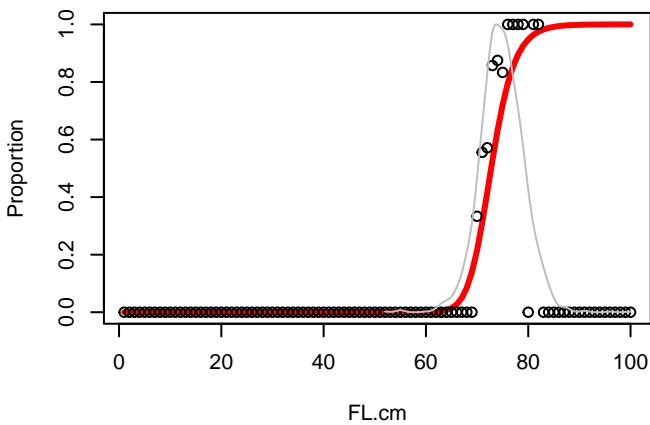


A0, 1989, fall**A1****A2****A3****A4****A5****A6**

All fall
1989 fall pred
1989 fall obs

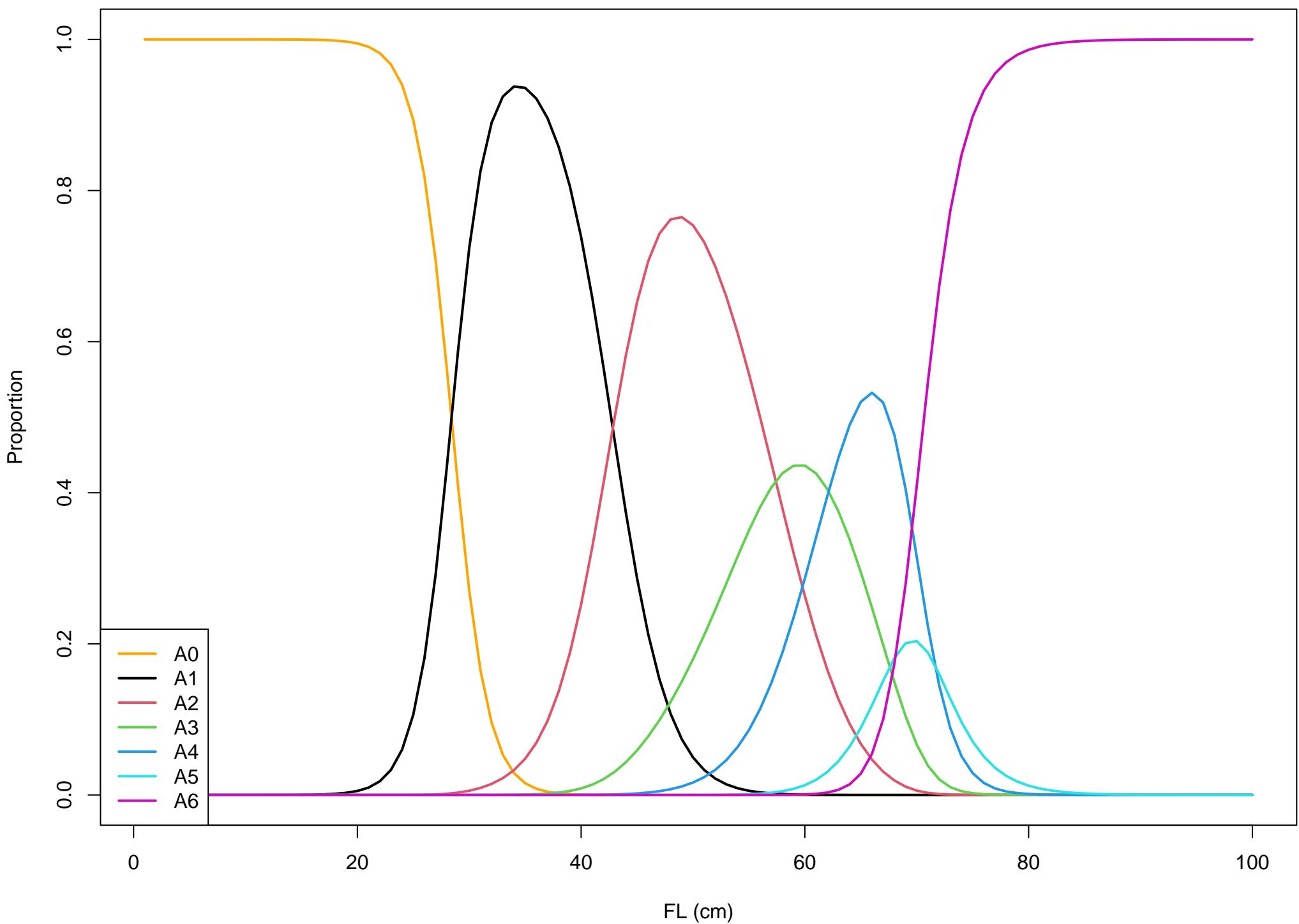
**1990
fall**

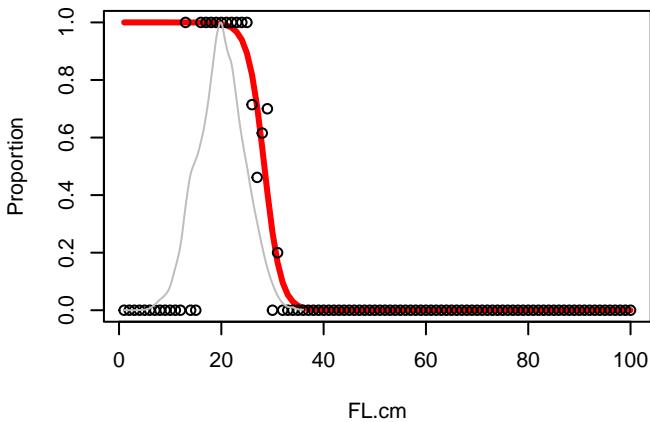
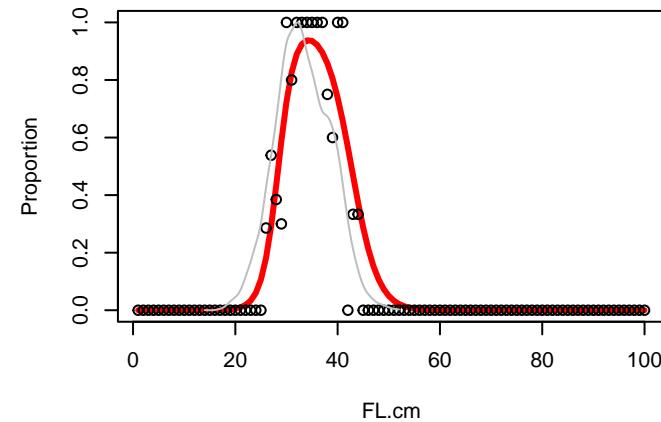
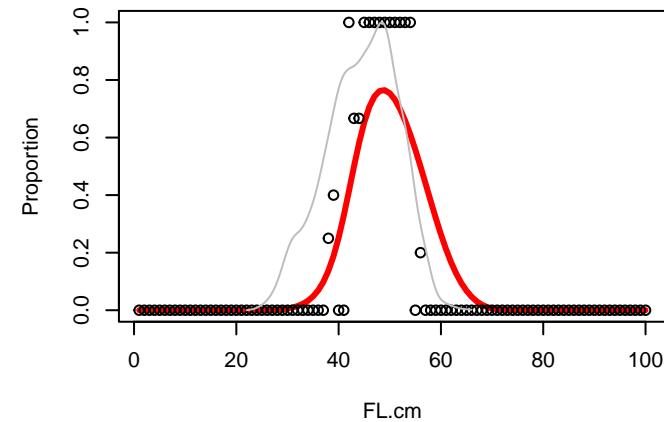
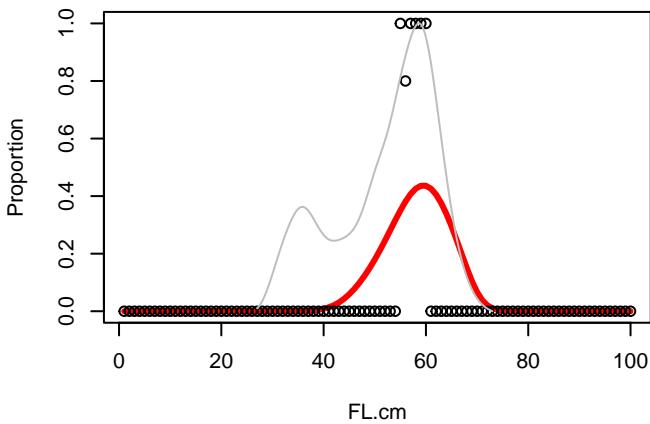
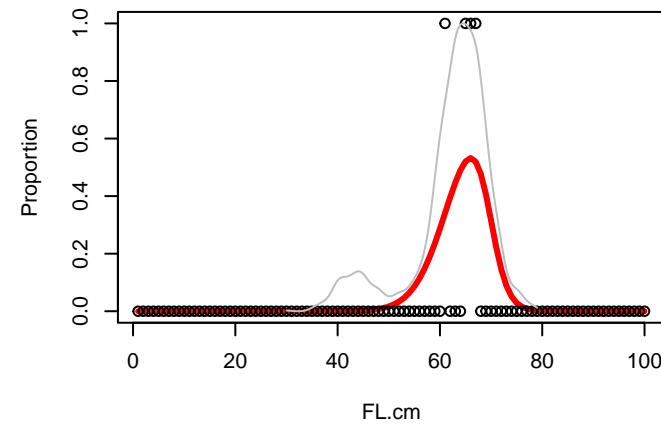
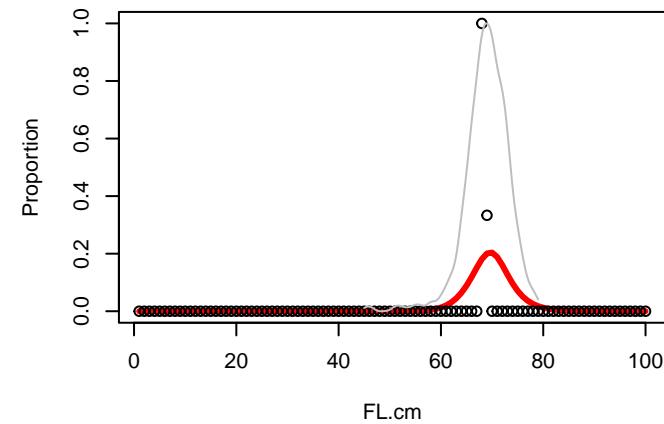
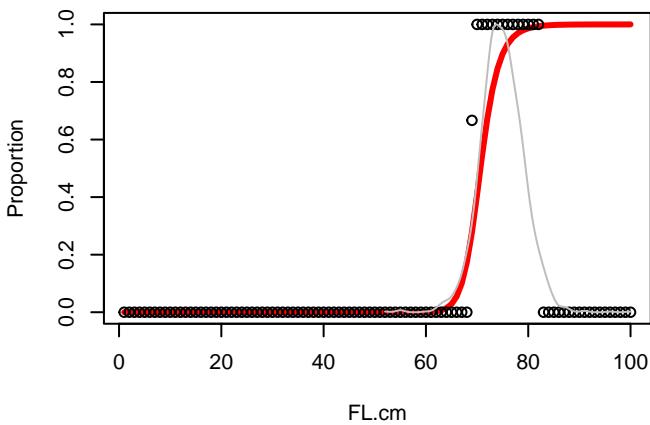


A0, 1990, fall**A1****A2****A3****A4****A5****A6**

All fall
1990 fall pred
○ 1990 fall obs

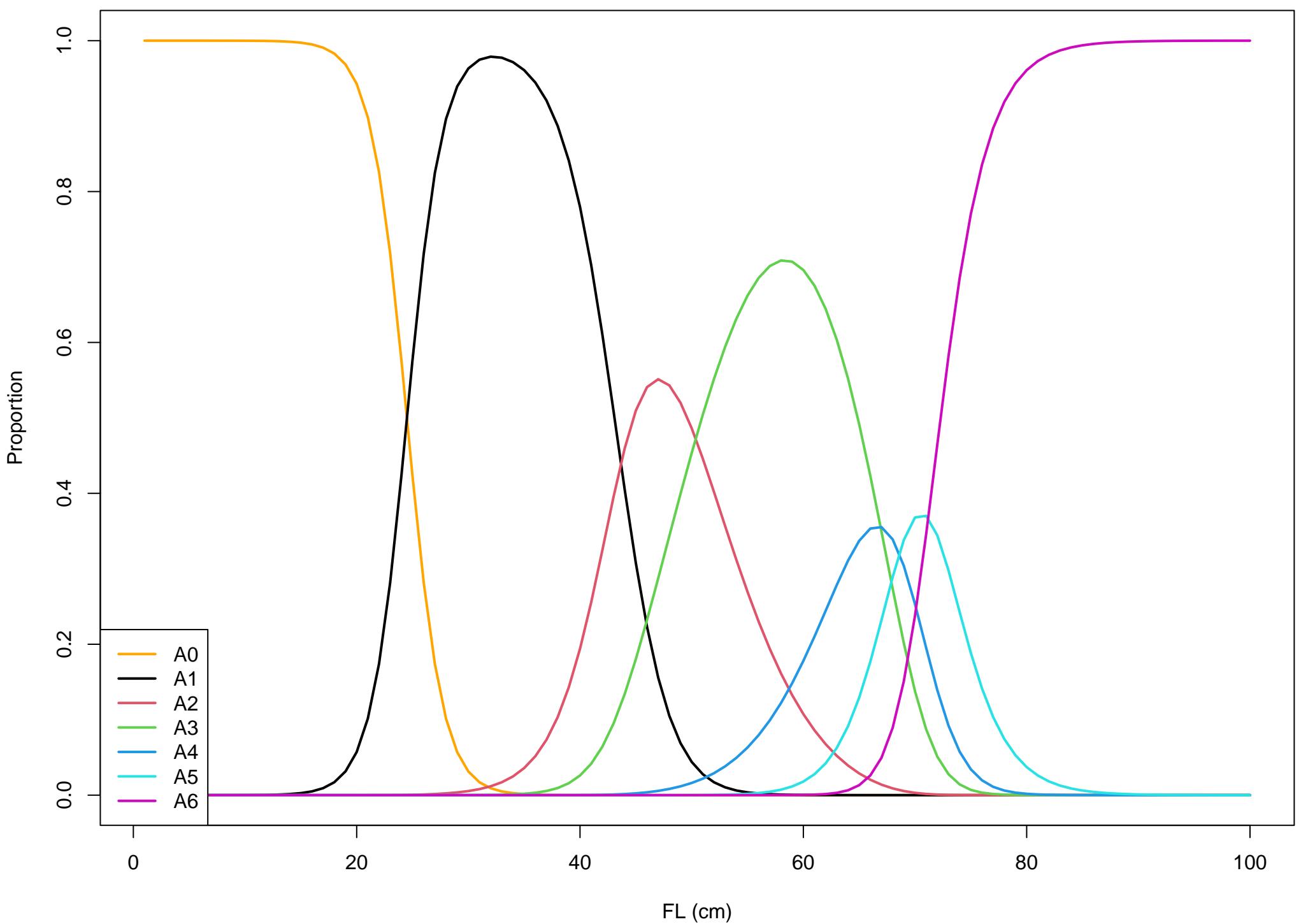
1991
fall

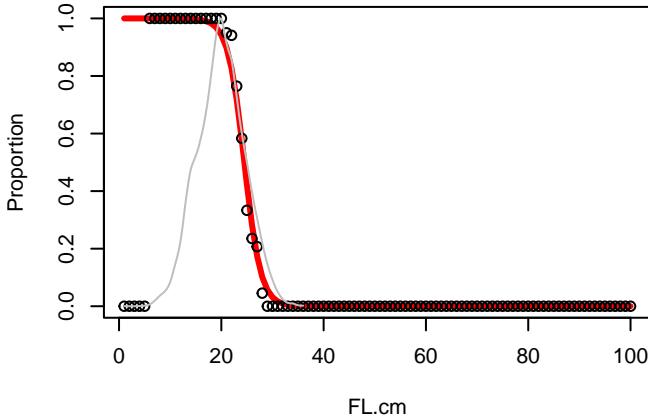
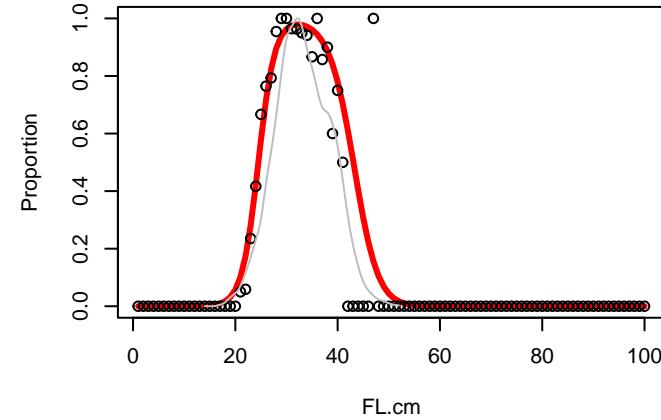
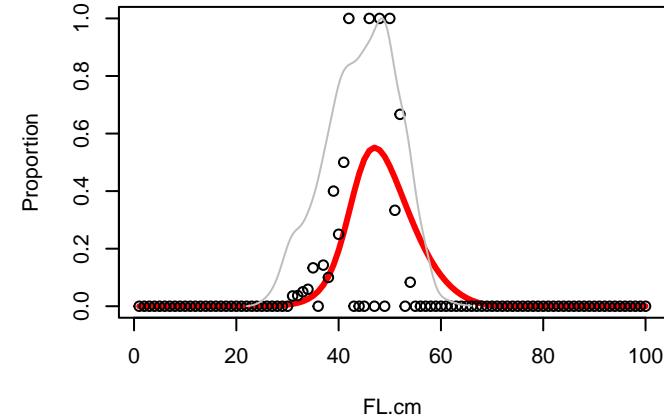
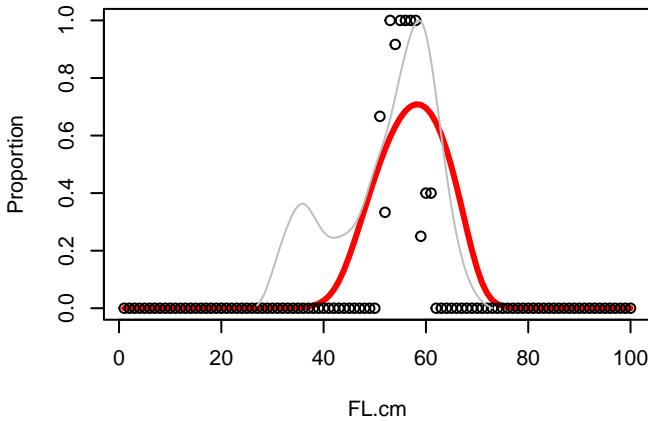
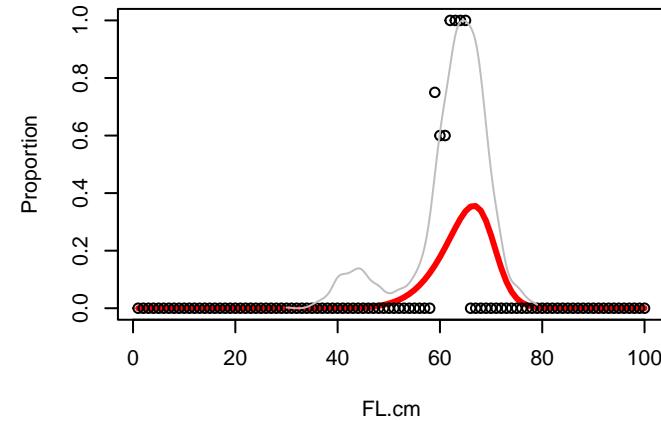
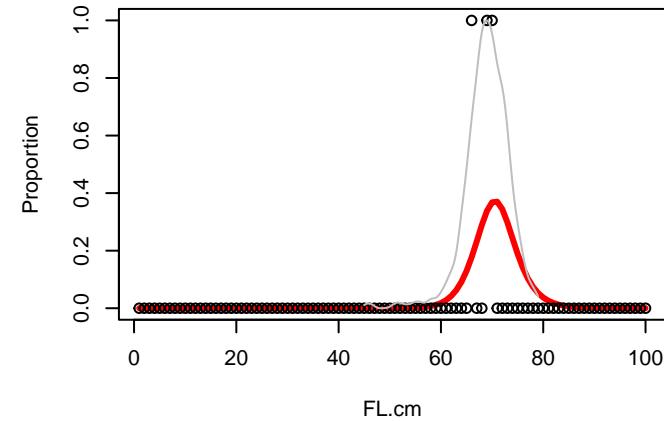
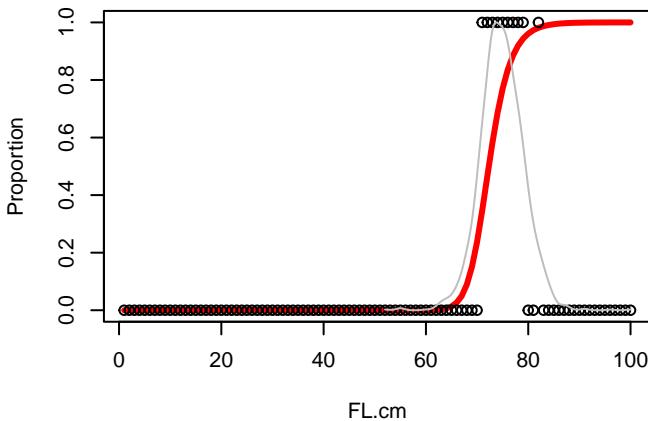


A0, 1991, fall**A1****A2****A3****A4****A5****A6**

All fall
1991 fall pred
1991 fall obs

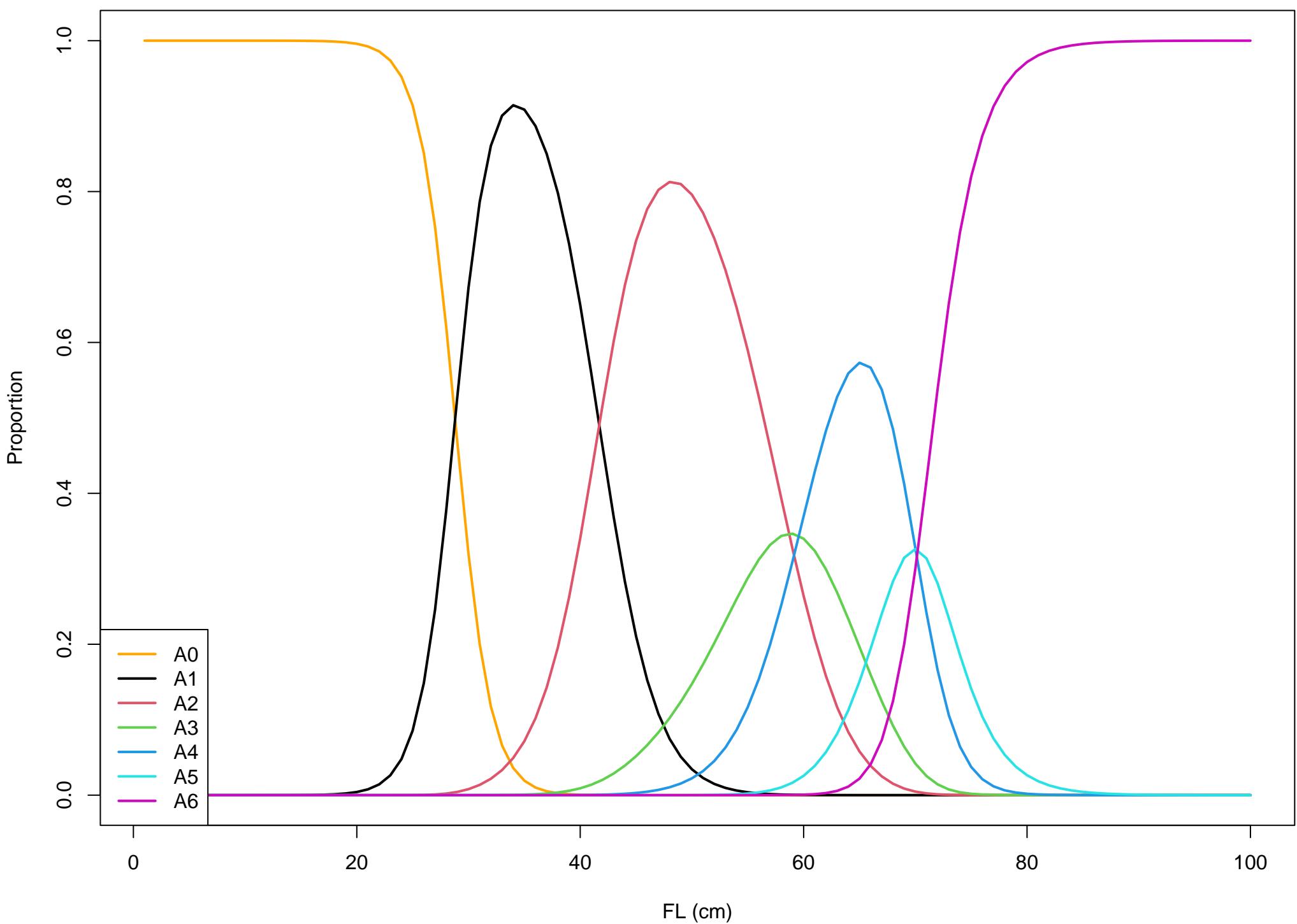
1992
fall



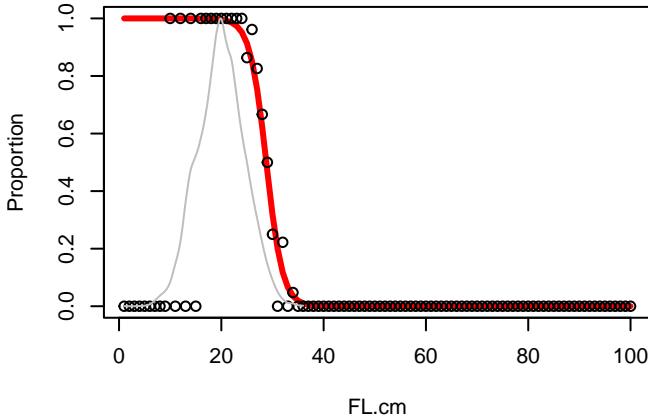
A0, 1992, fall**A1****A2****A3****A4****A5****A6**

All fall
1992 fall pred
○ 1992 fall obs

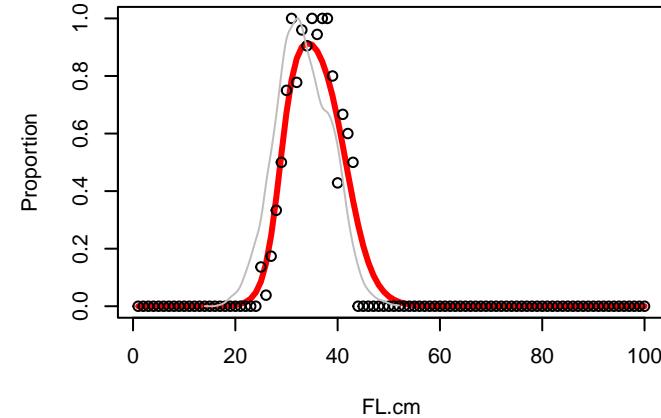
1993
fall



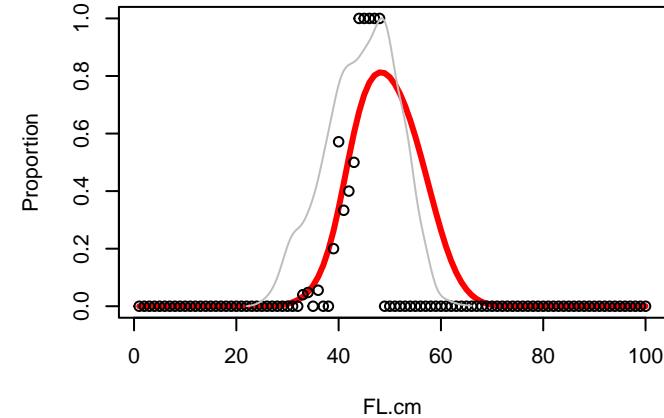
A0, 1993, fall



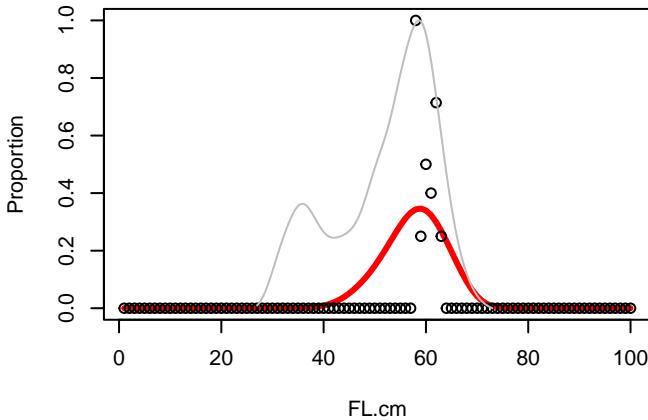
A1



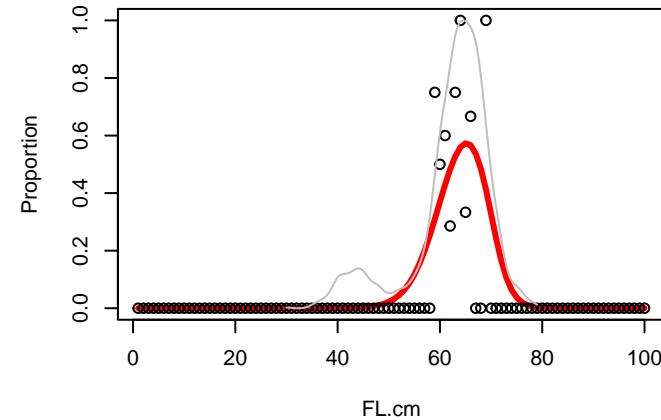
A2



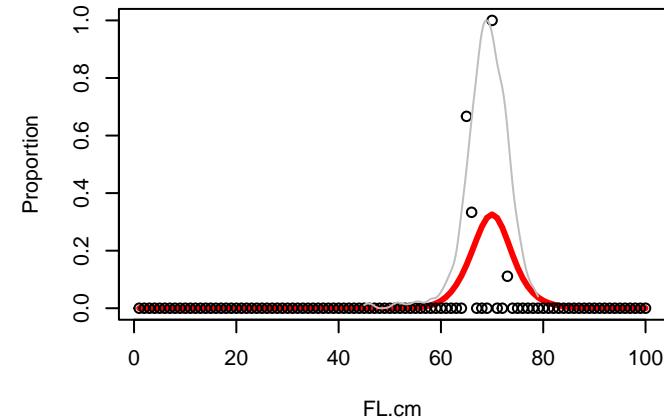
A3



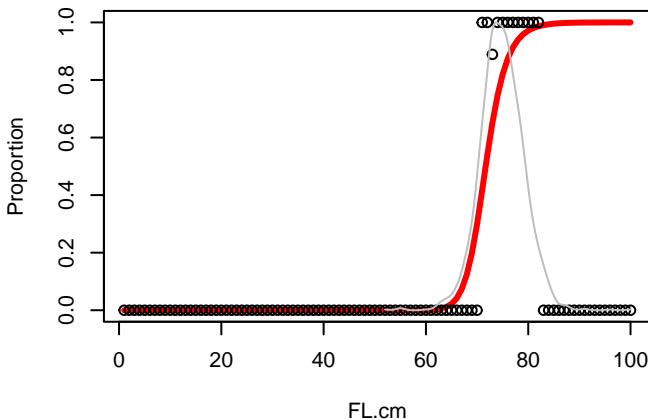
A4



A5

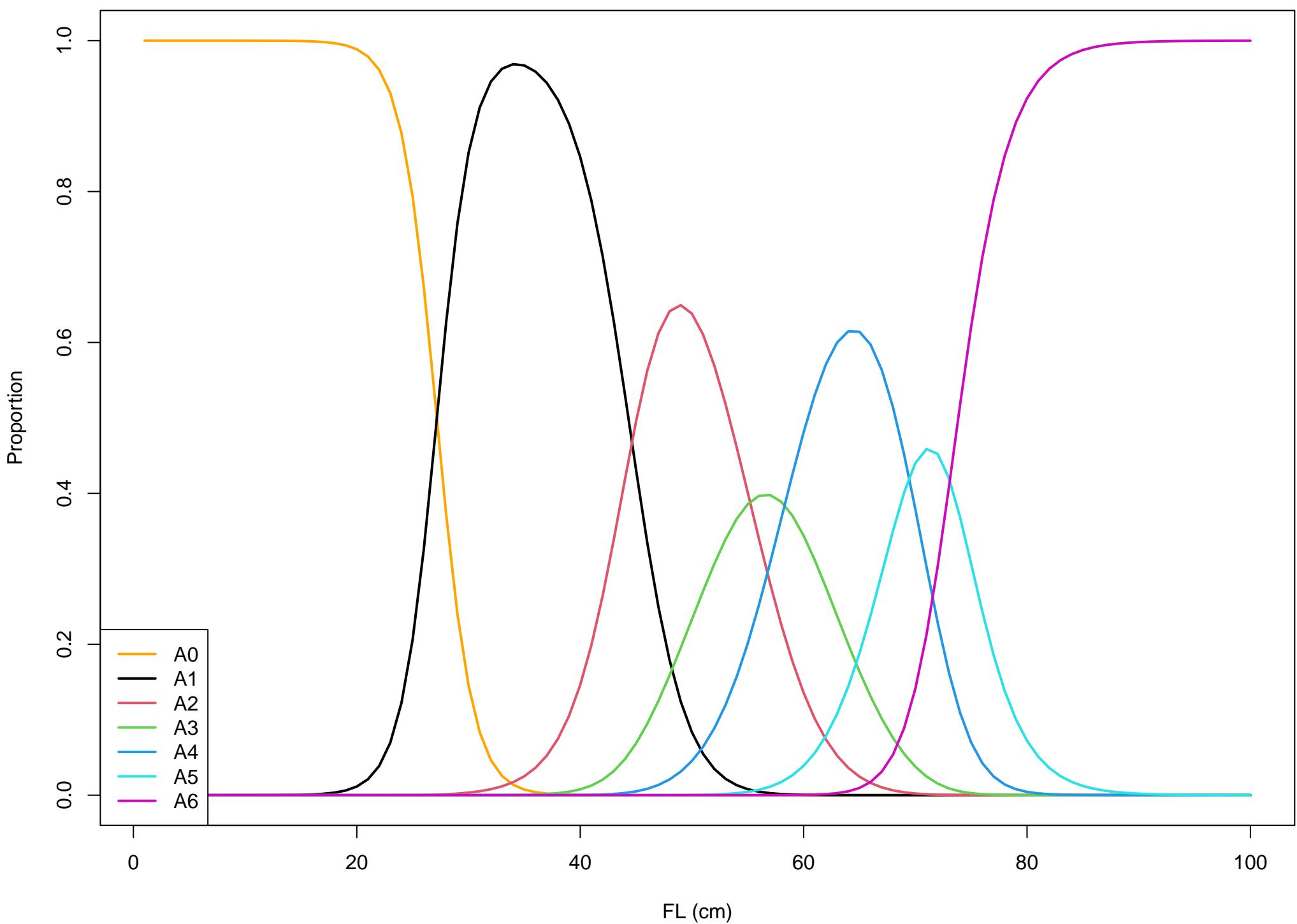


A6

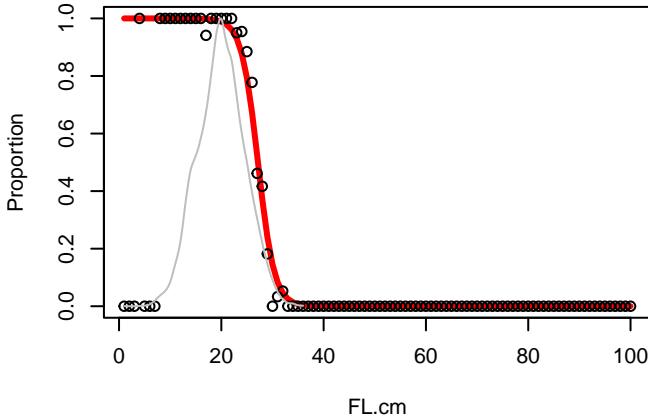


All fall
1993 fall pred
○ 1993 fall obs

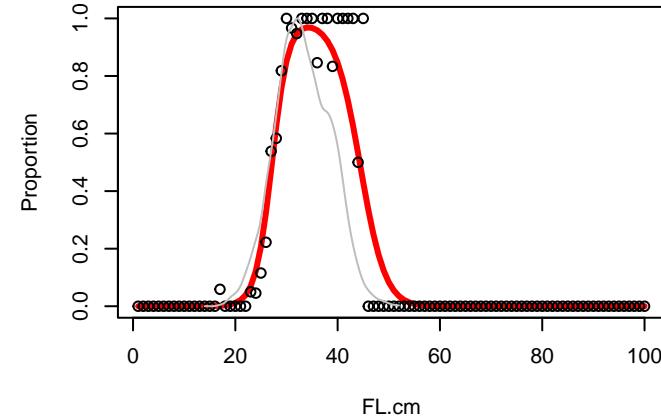
1994
fall



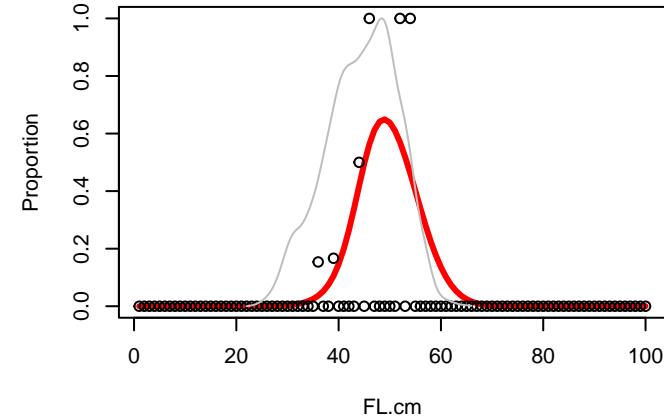
A0, 1994, fall



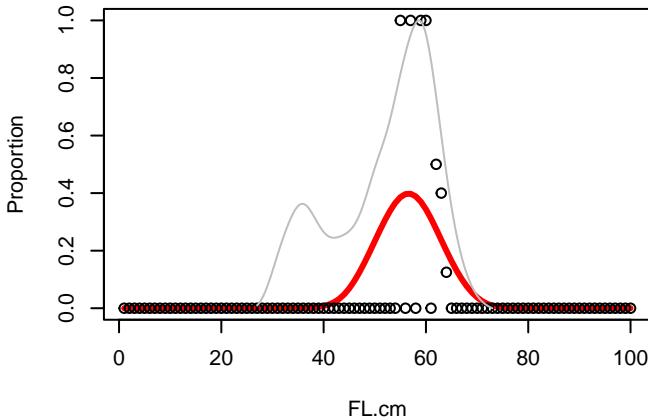
A1



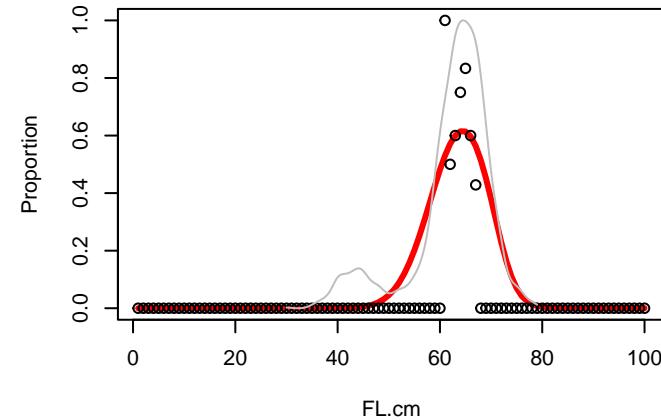
A2



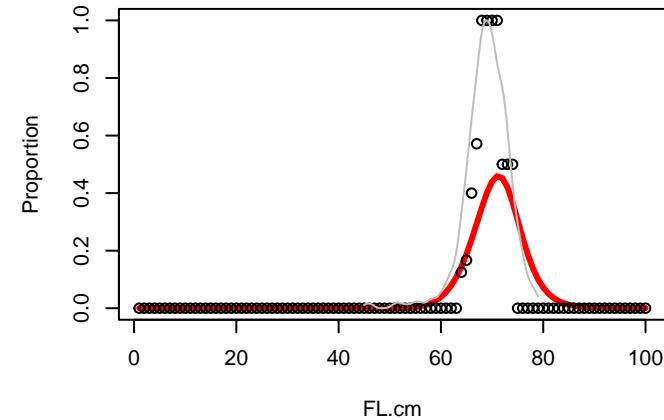
A3



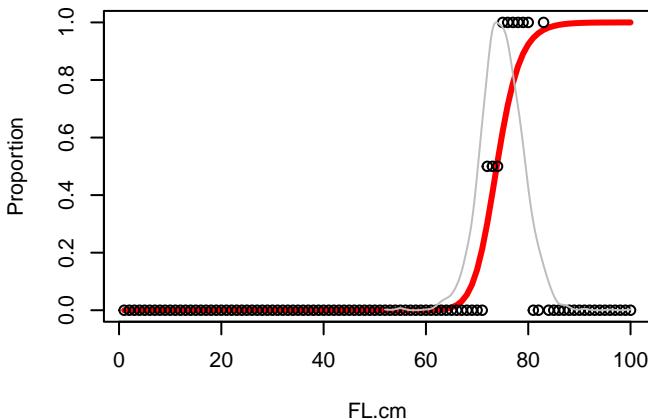
A4



A5

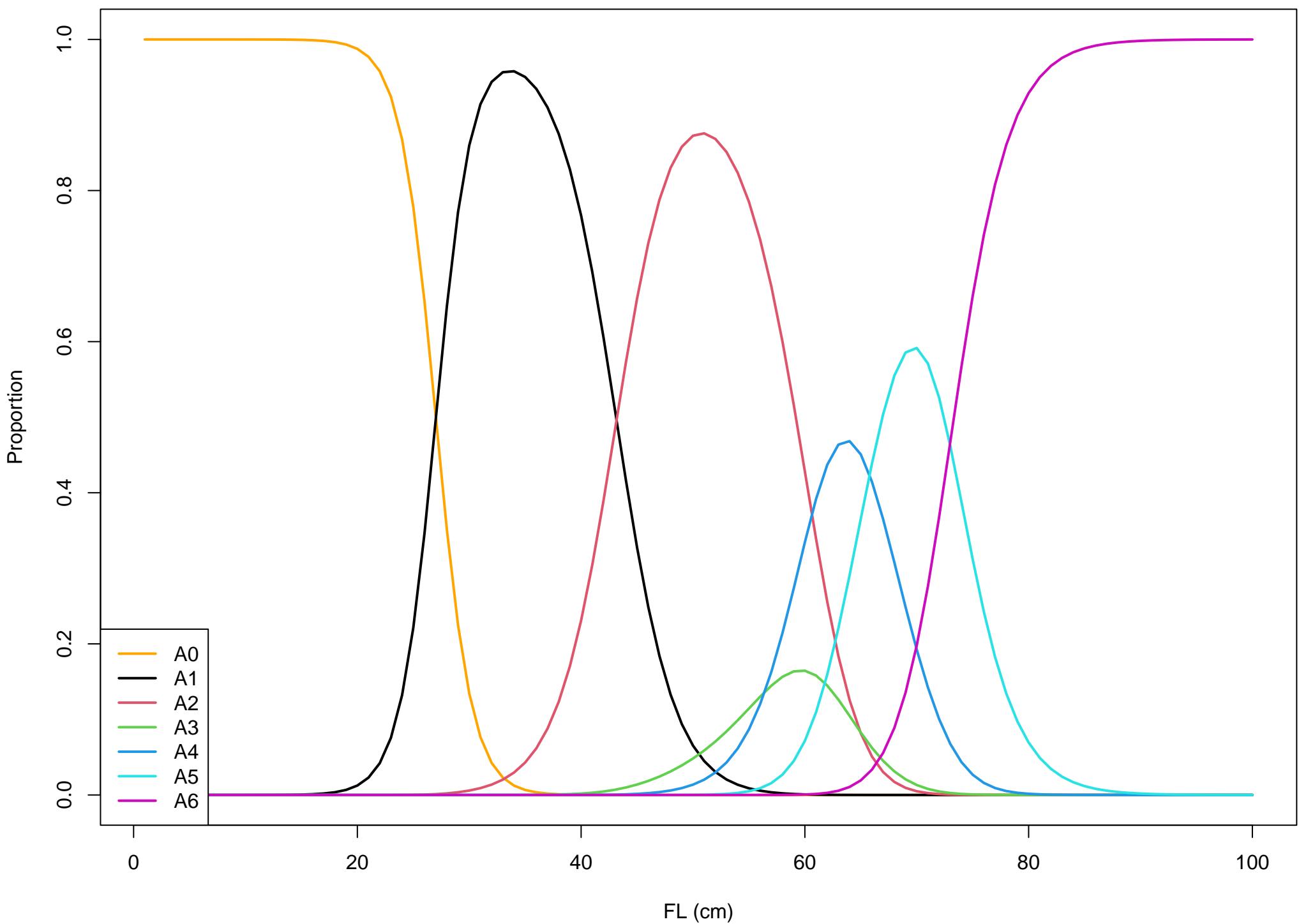


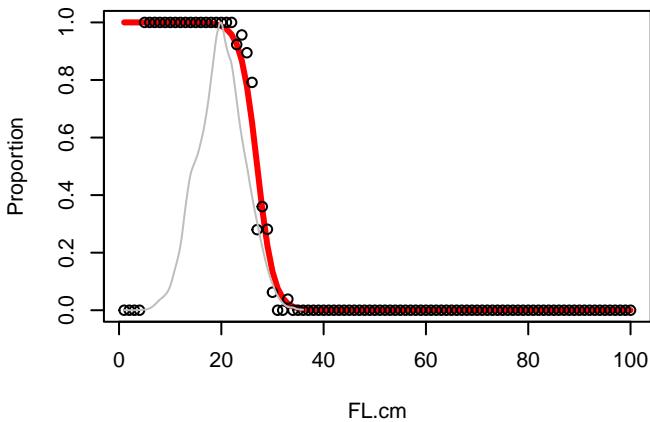
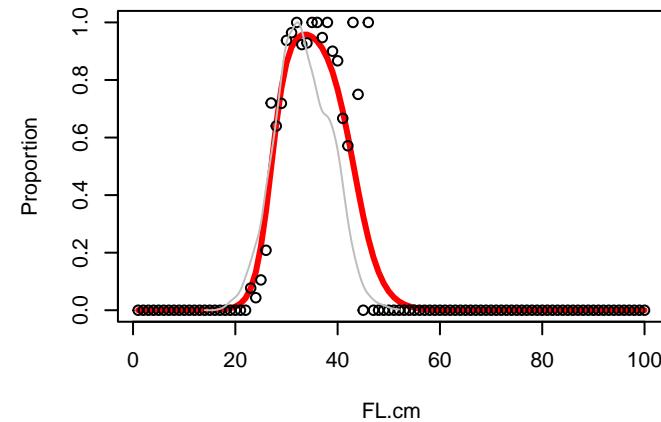
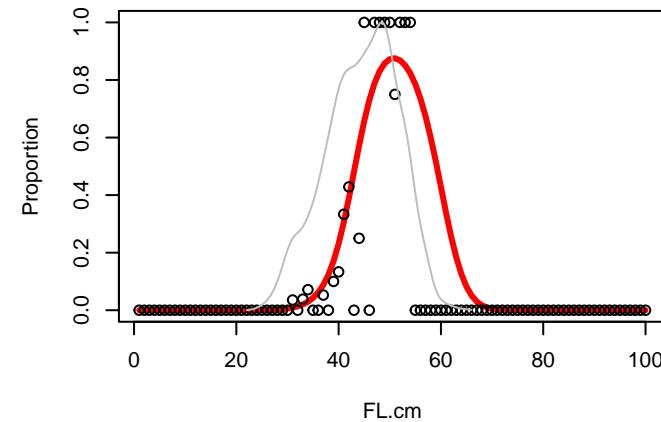
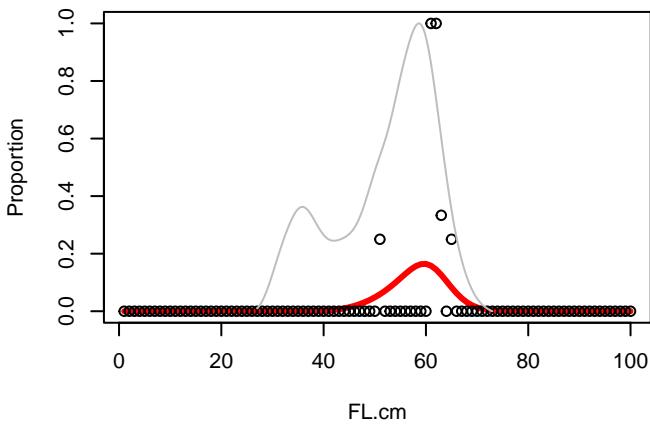
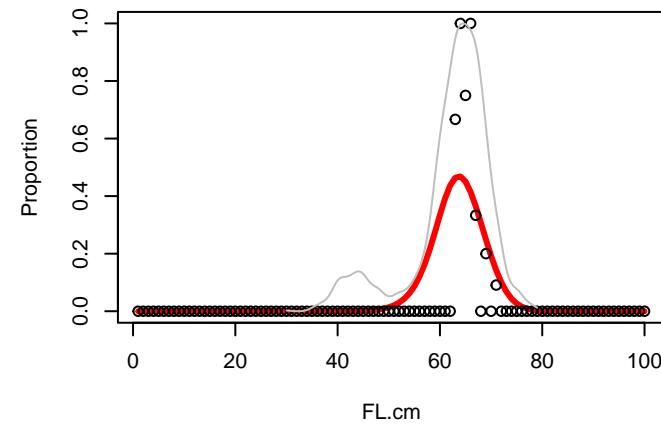
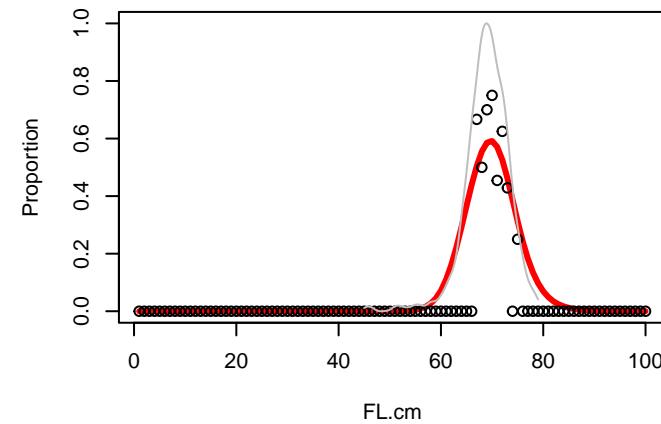
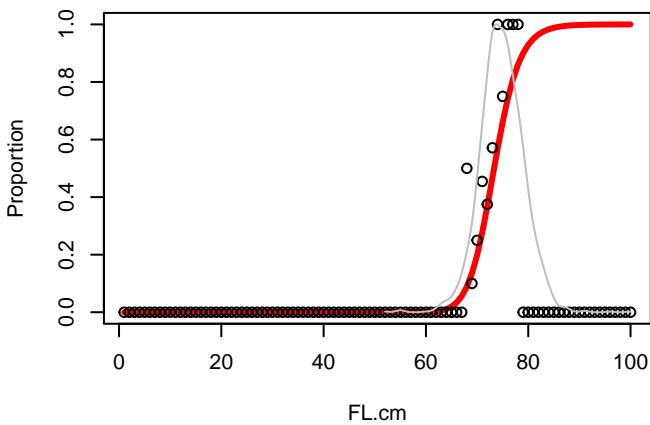
A6



All fall
1994 fall pred
○ 1994 fall obs

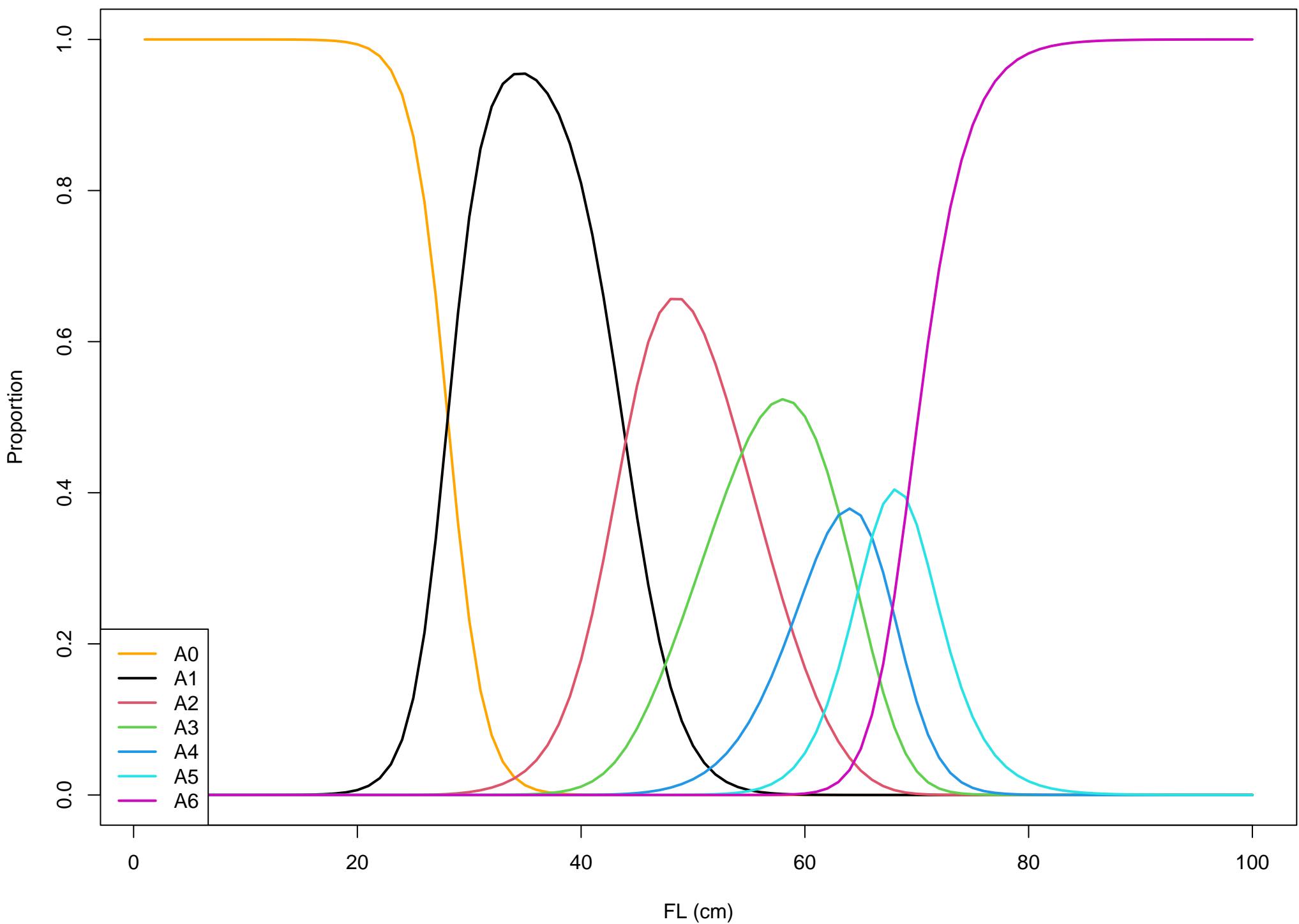
1995
fall



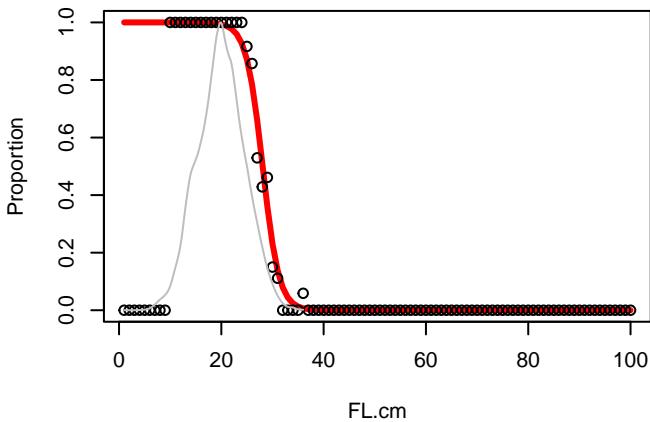
A0, 1995, fall**A1****A2****A3****A4****A5****A6**

All fall
1995 fall pred
1995 fall obs

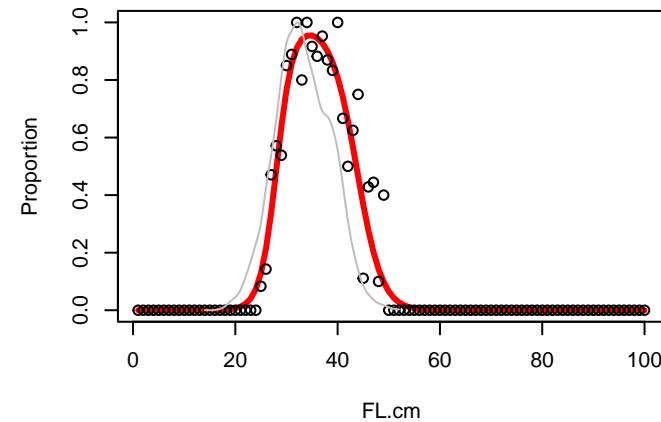
1996
fall



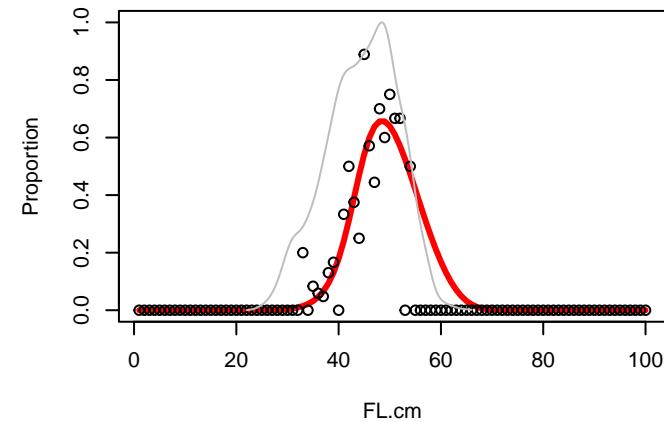
A0, 1996, fall



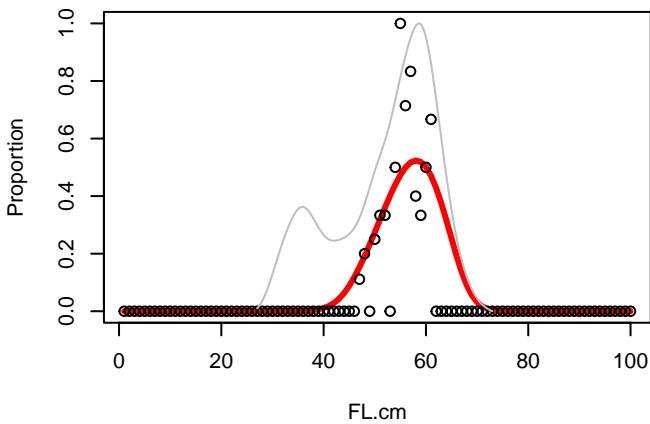
A1



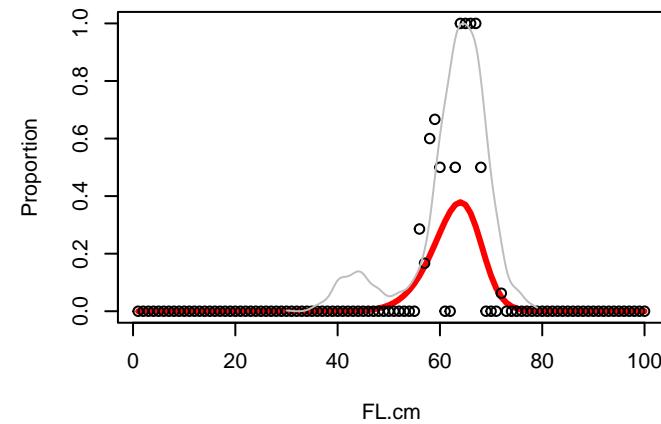
A2



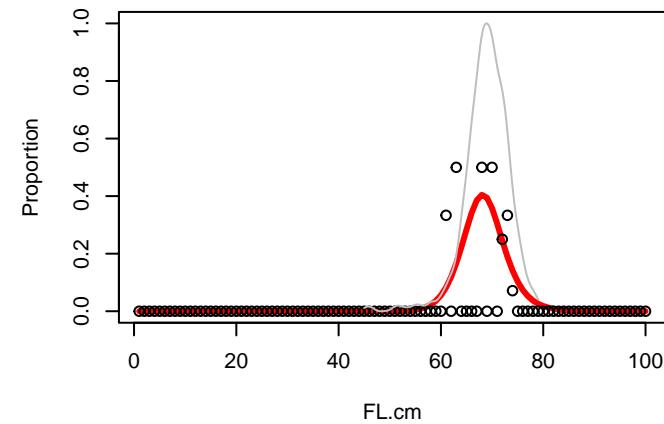
A3



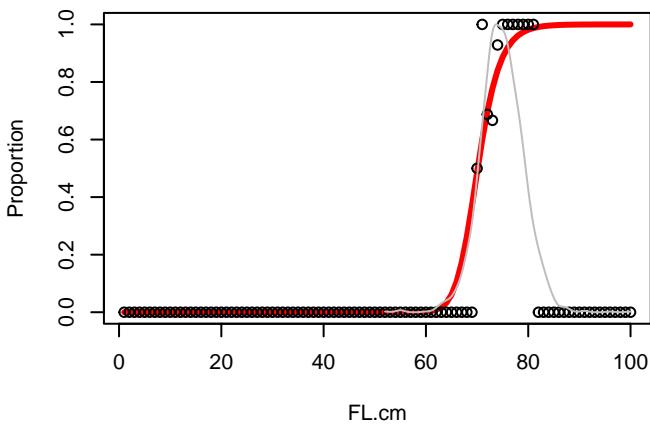
A4



A5

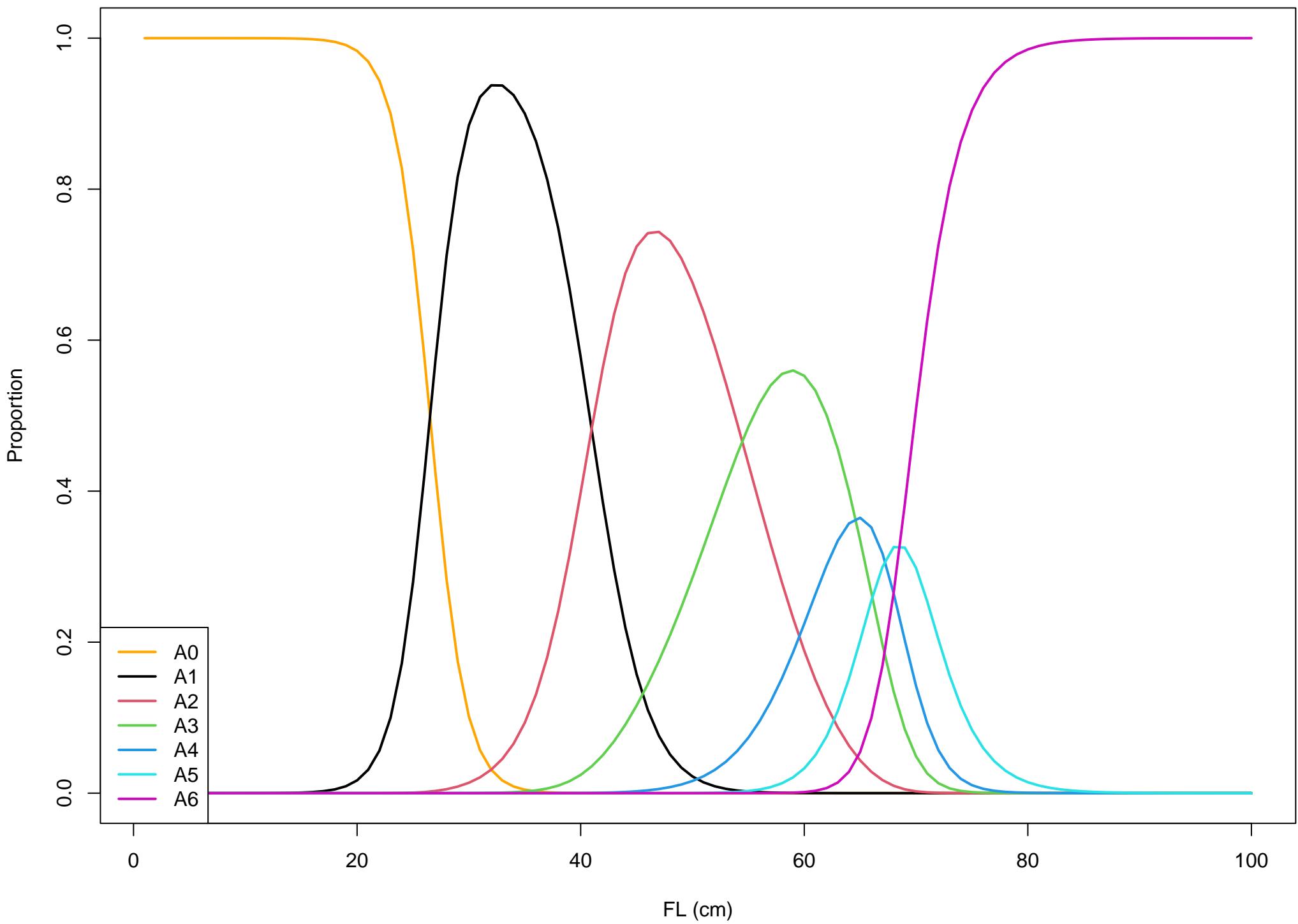


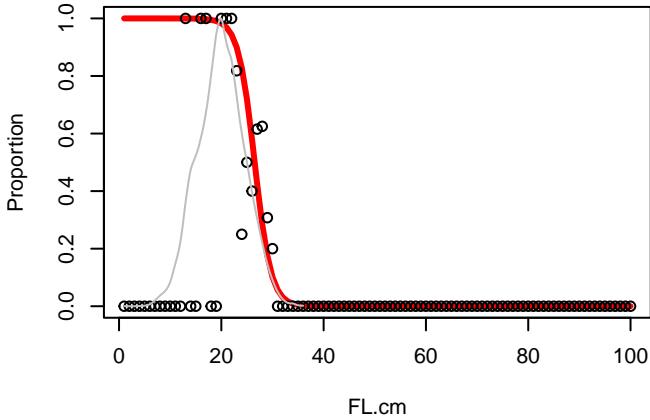
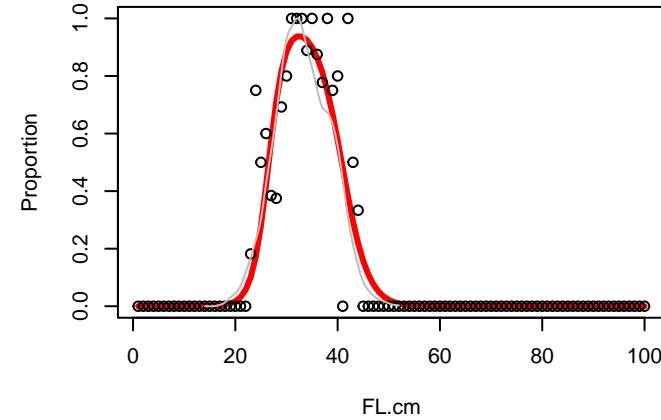
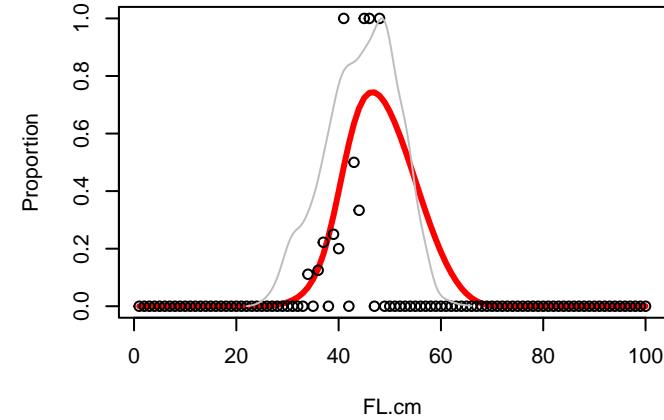
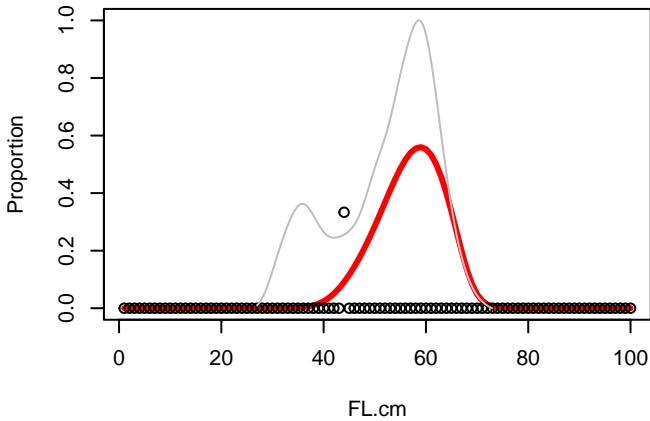
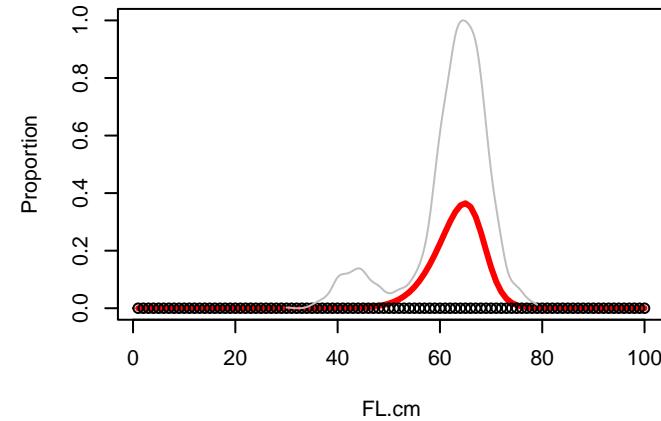
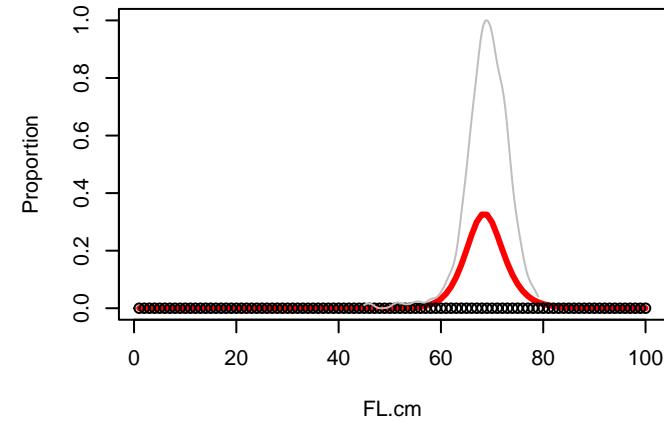
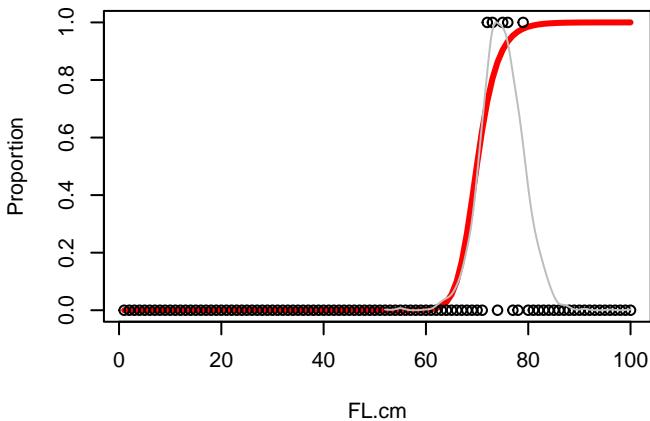
A6



All fall
1996 fall pred
1996 fall obs

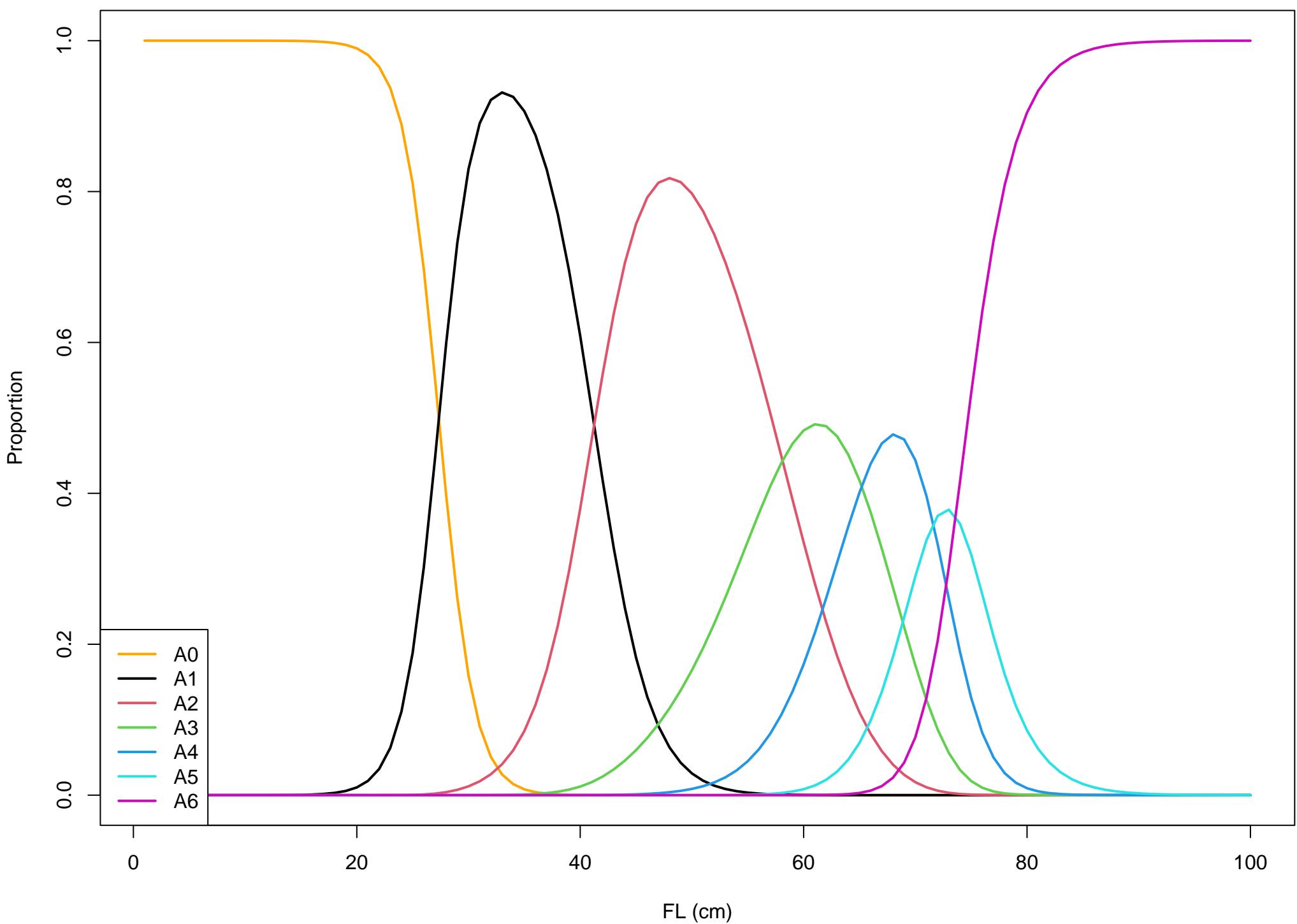
**1997
fall**

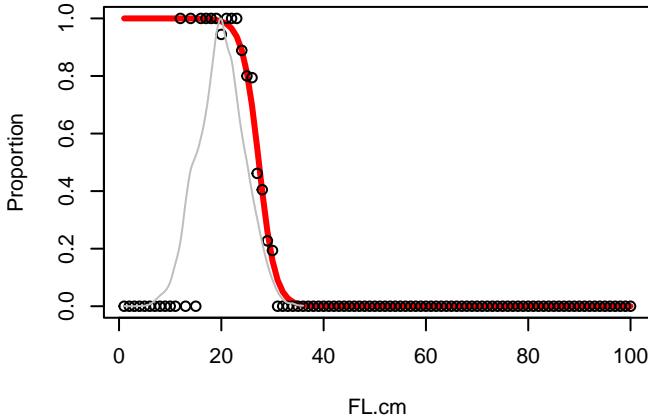
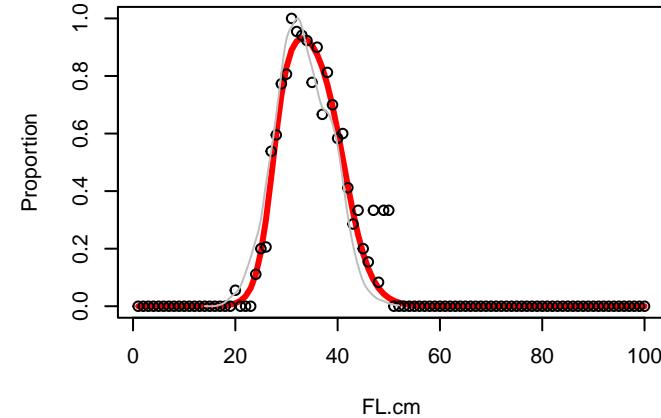
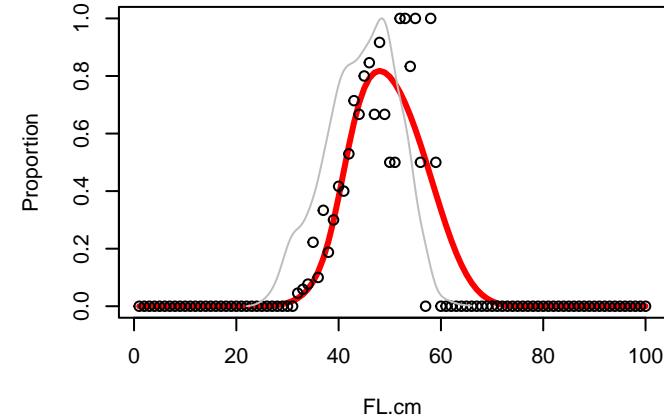
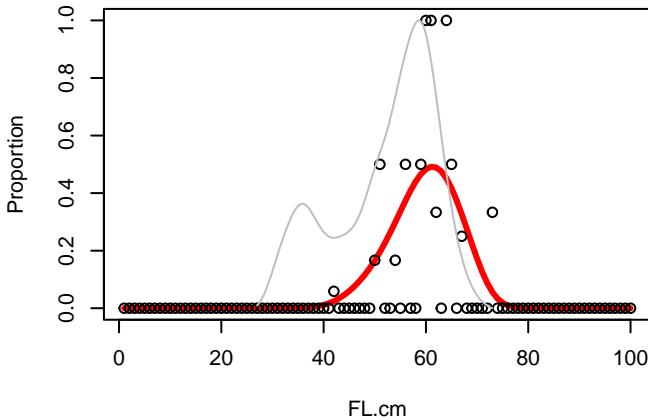
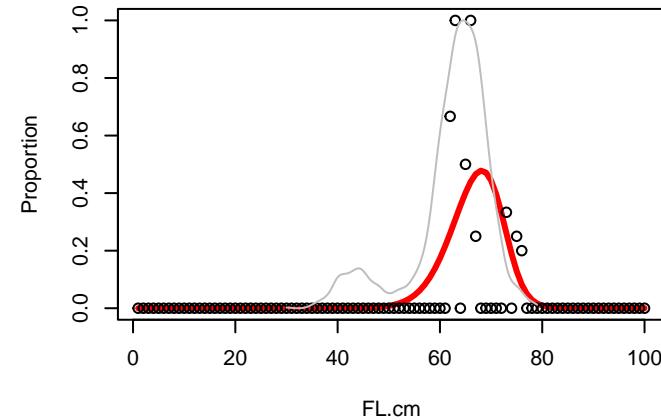
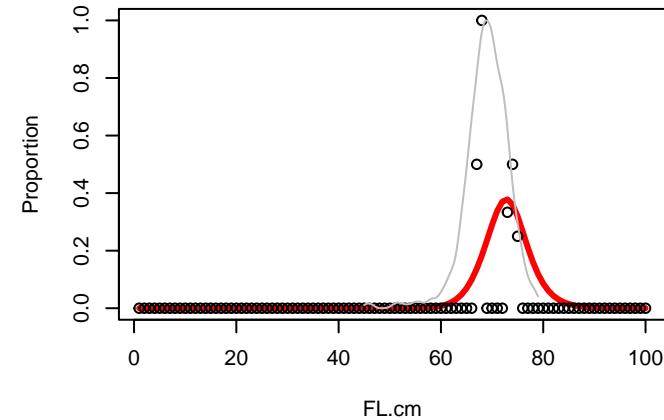
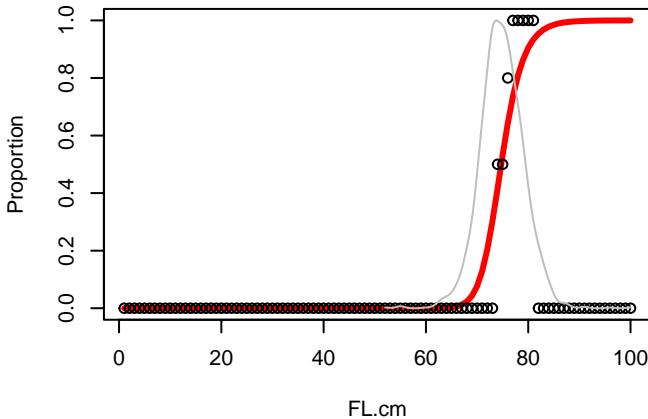


A0, 1997, fall**A1****A2****A3****A4****A5****A6**

All fall
1997 fall pred
○ 1997 fall obs

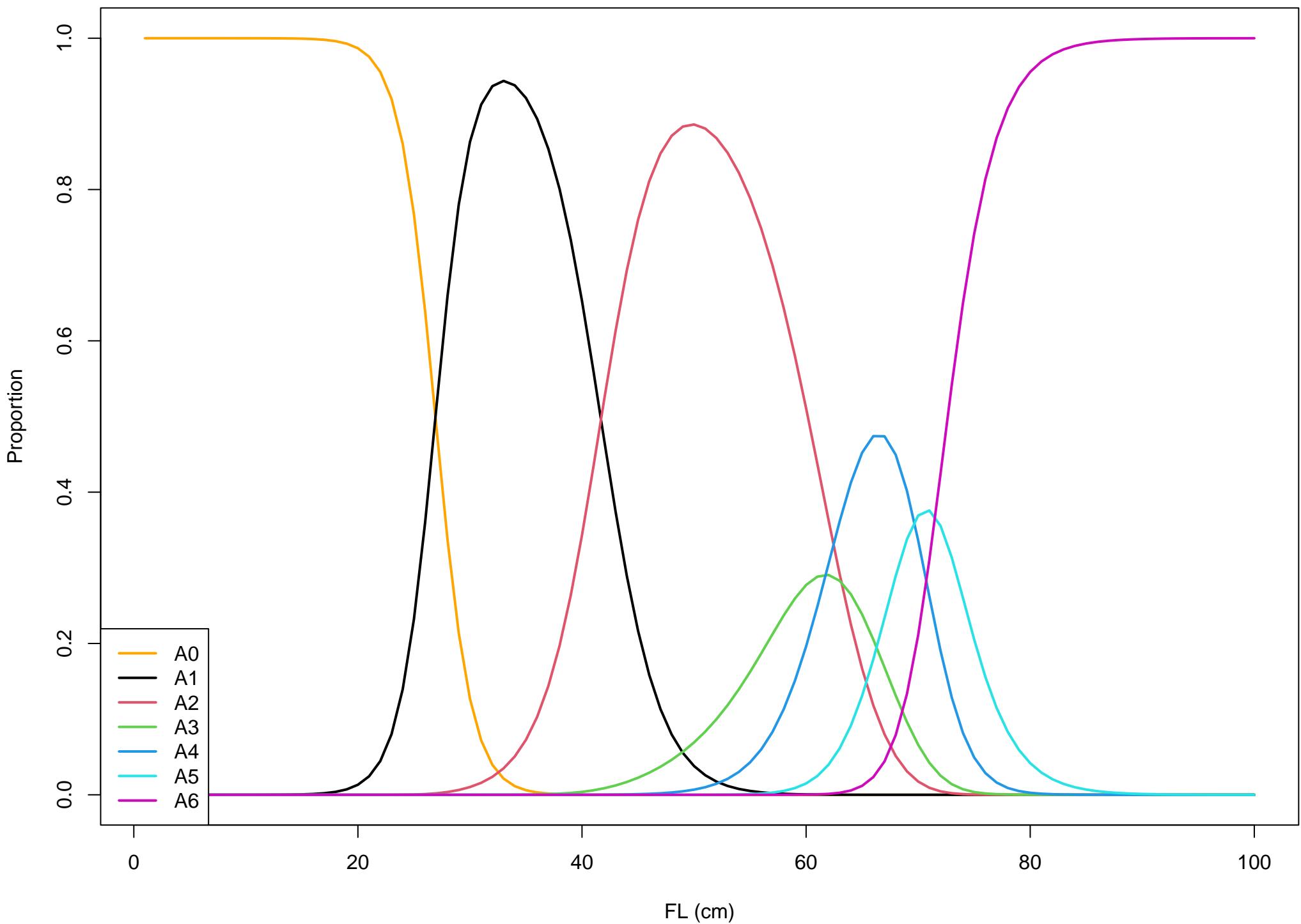
1998
fall

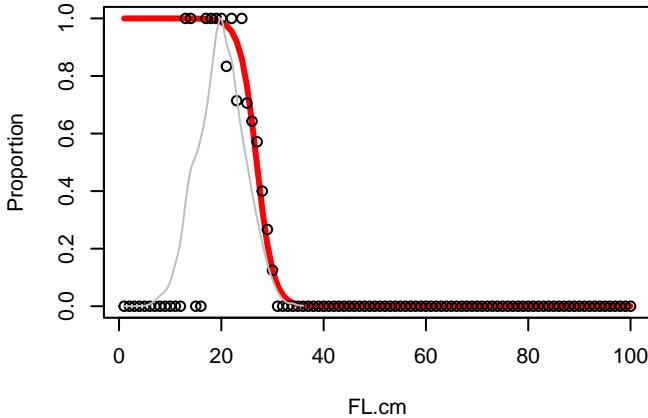
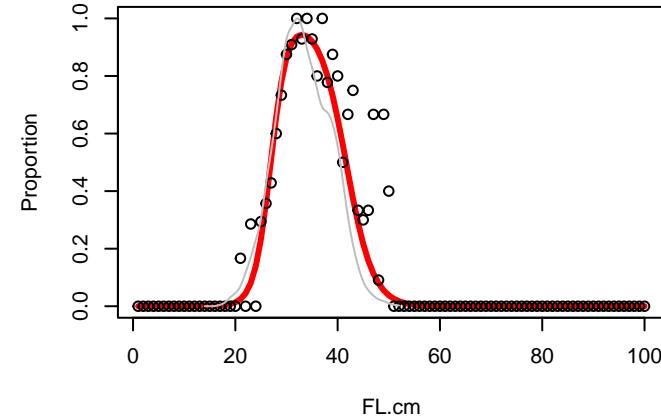
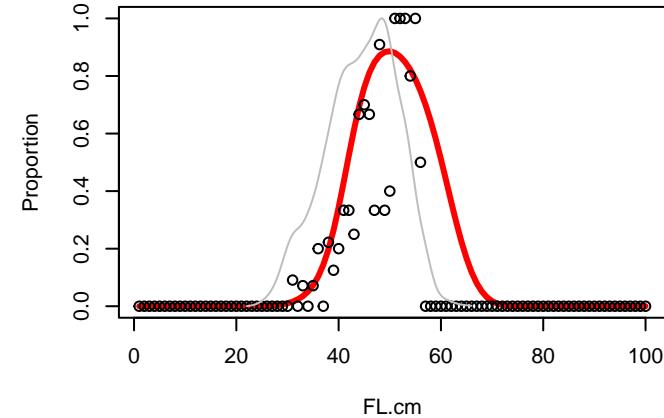
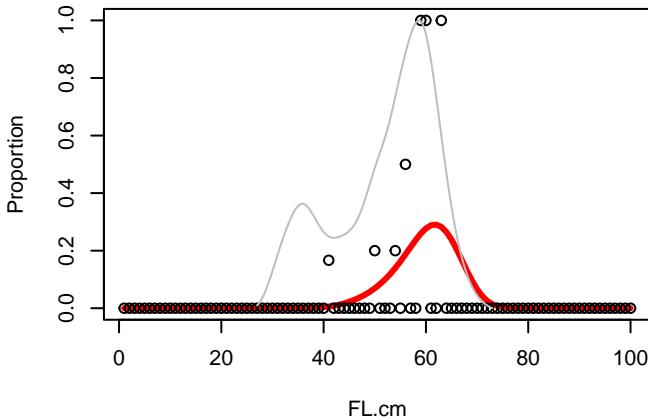
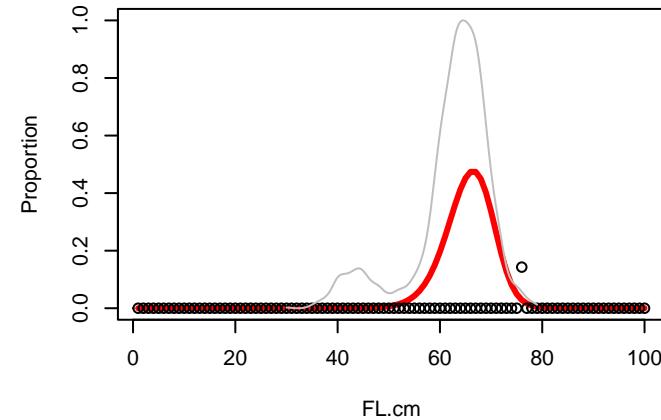
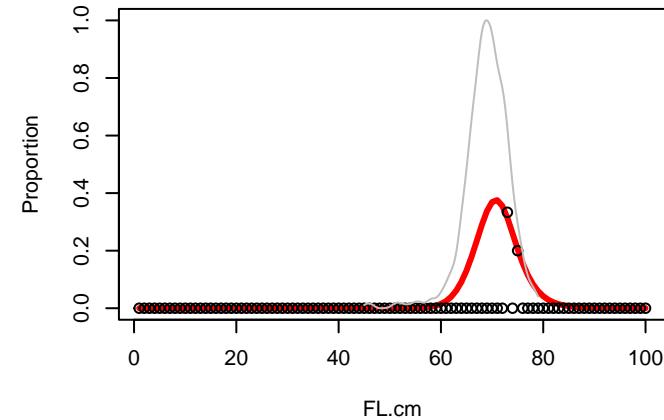
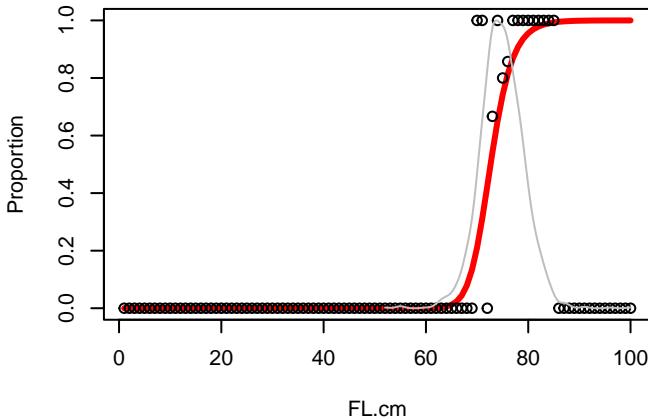


A0, 1998, fall**A1****A2****A3****A4****A5****A6**

All fall
1998 fall pred
1998 fall obs

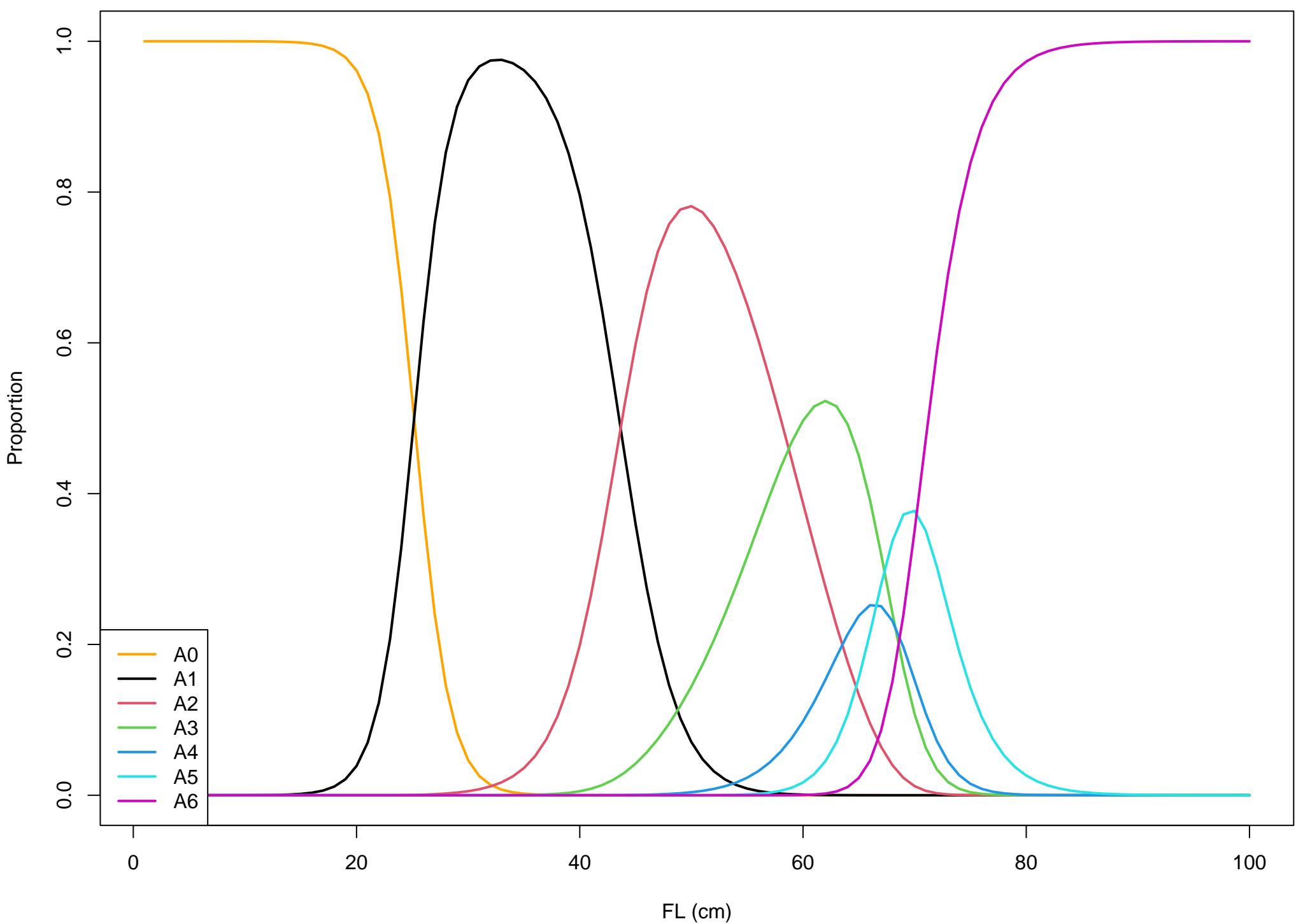
**1999
fall**

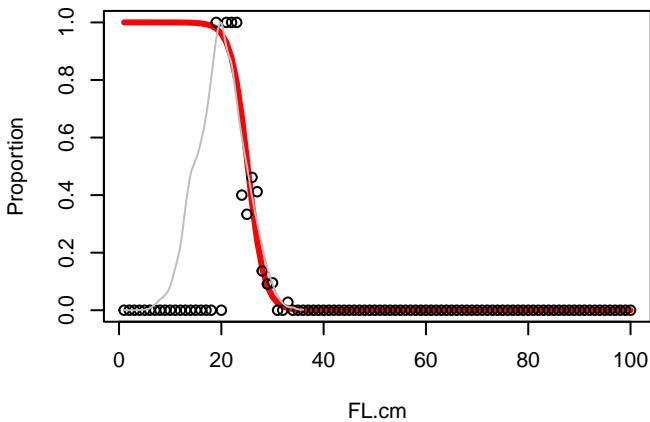
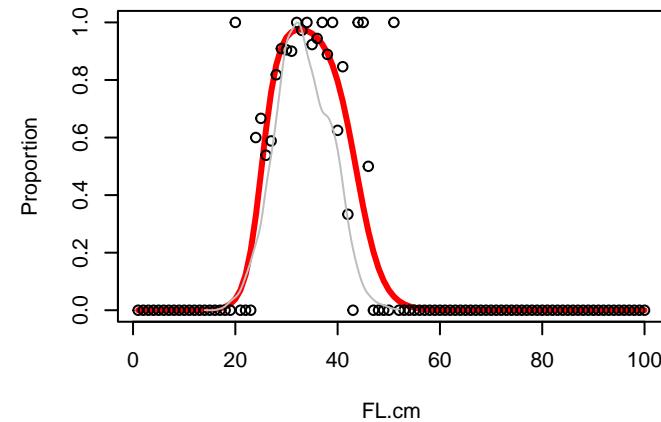
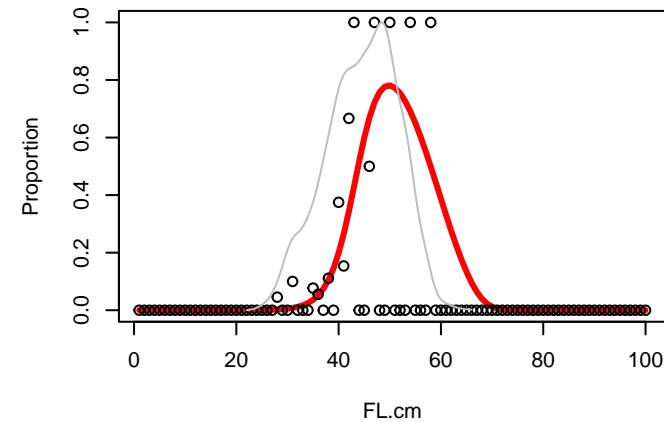
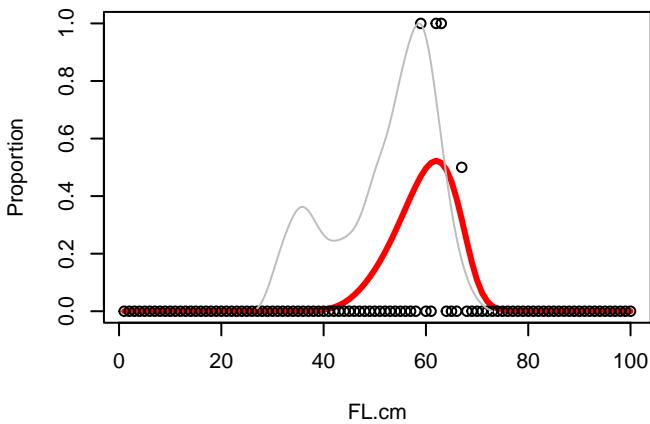
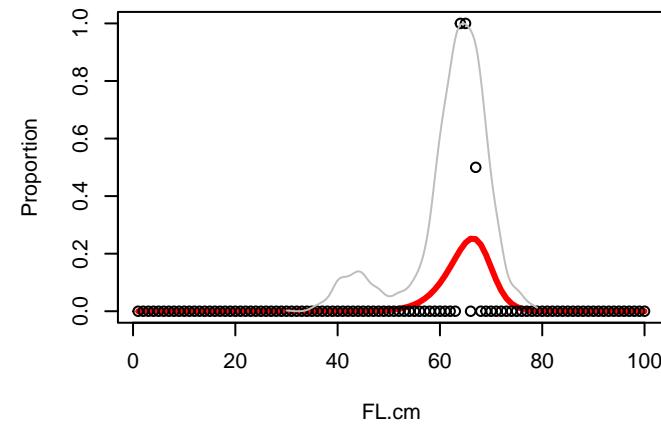
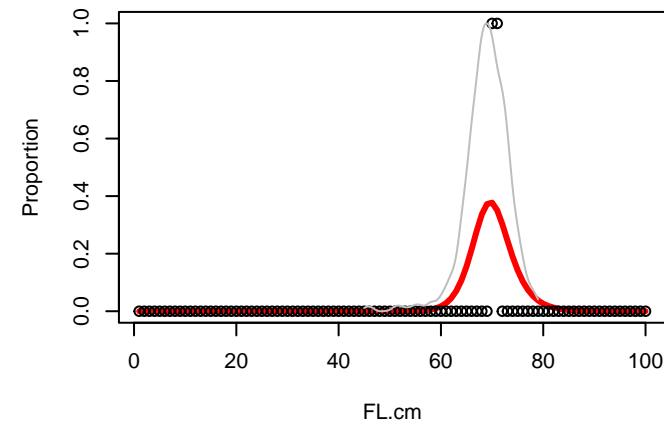
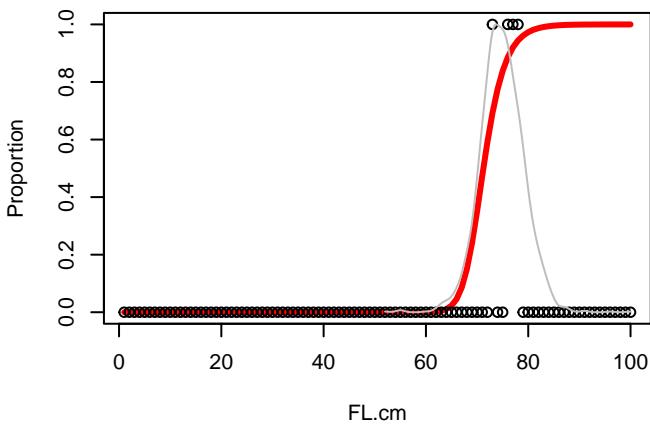


A0, 1999, fall**A1****A2****A3****A4****A5****A6**

All fall
1999 fall pred
○ 1999 fall obs

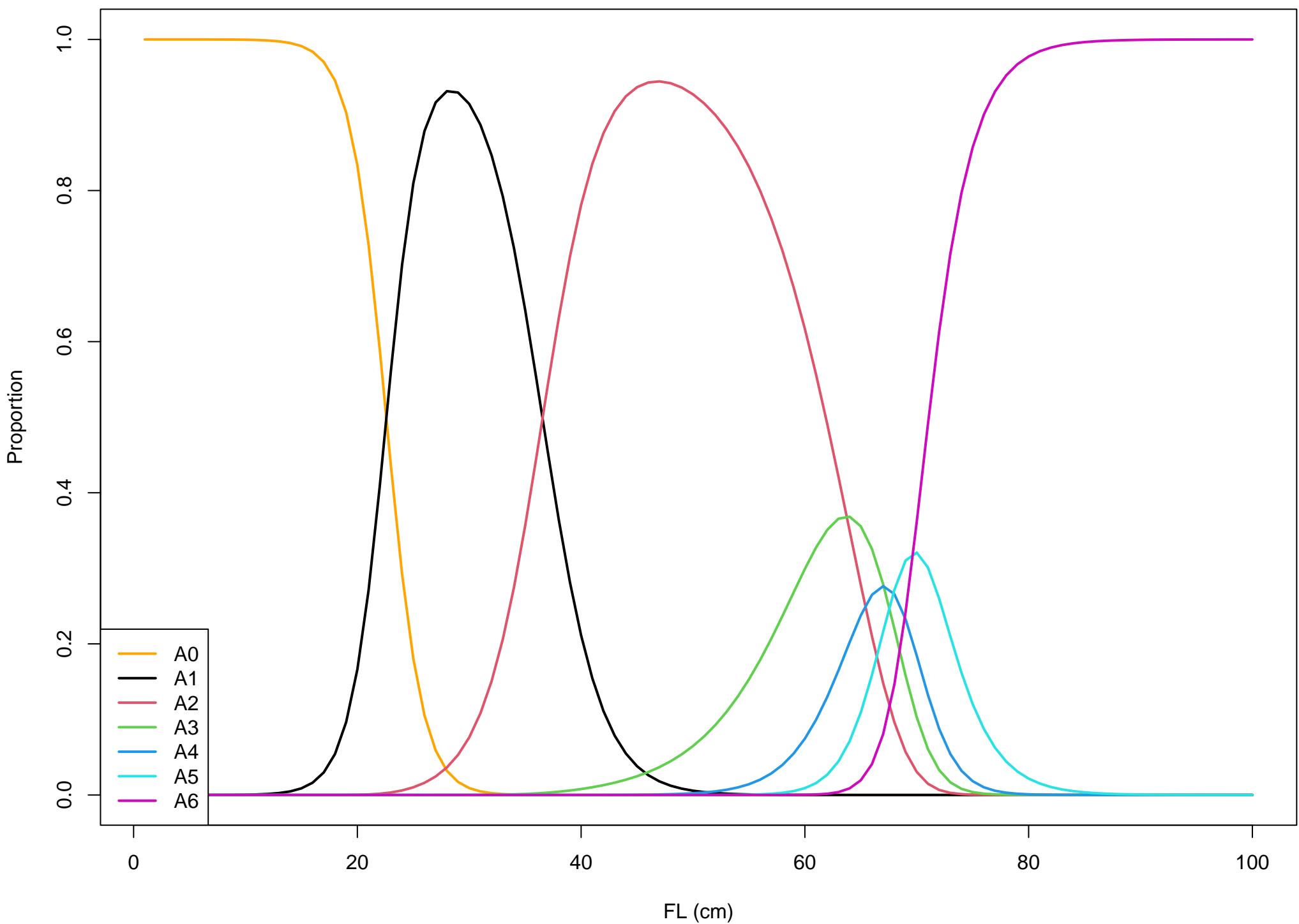
2000
fall

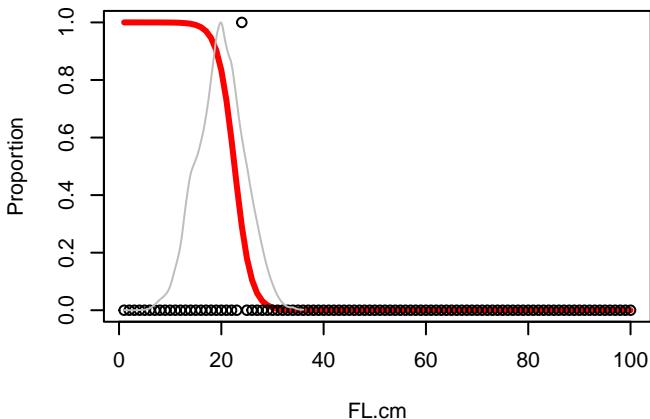
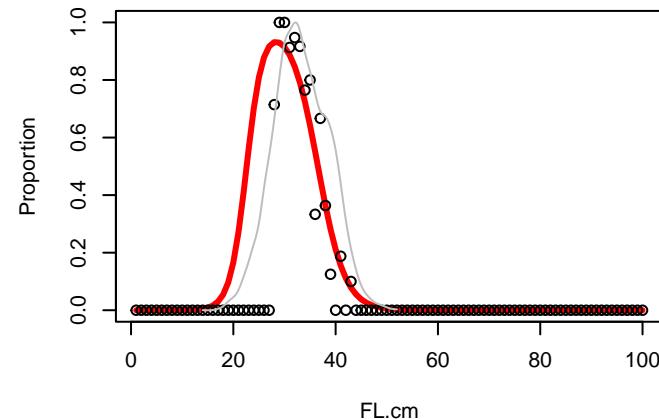
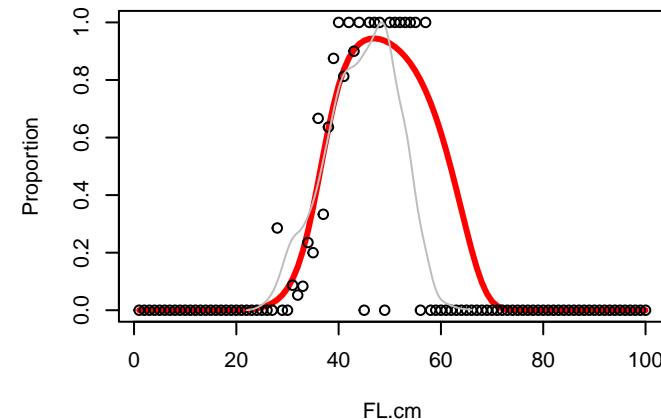
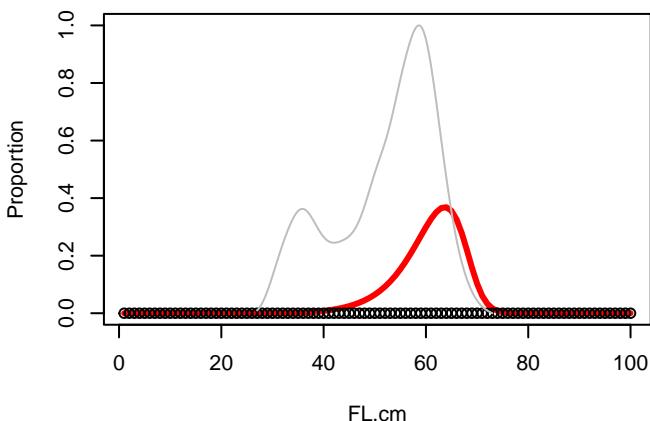
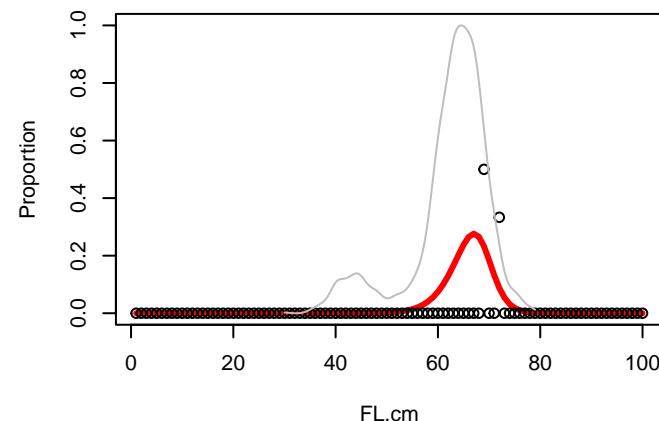
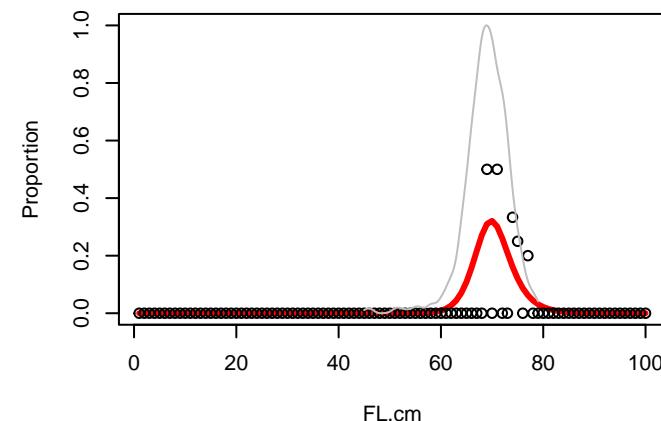
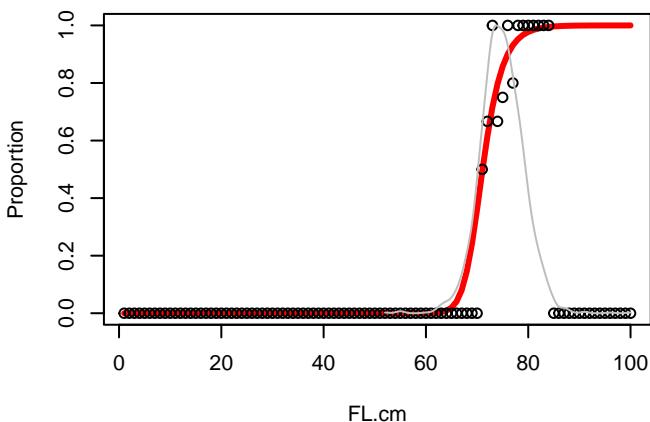


A0, 2000, fall**A1****A2****A3****A4****A5****A6**

All fall
2000 fall pred
○ 2000 fall obs

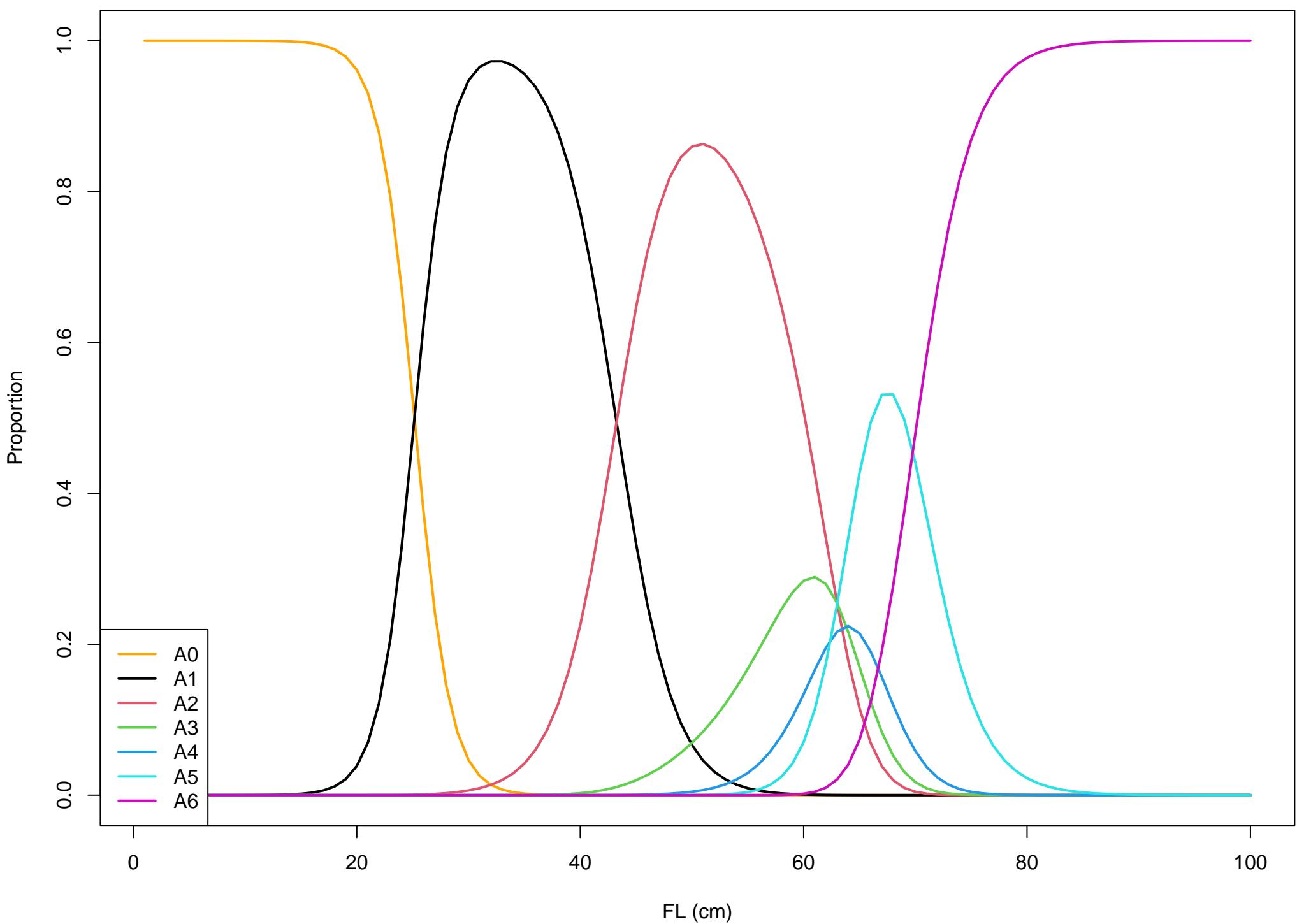
2001
fall

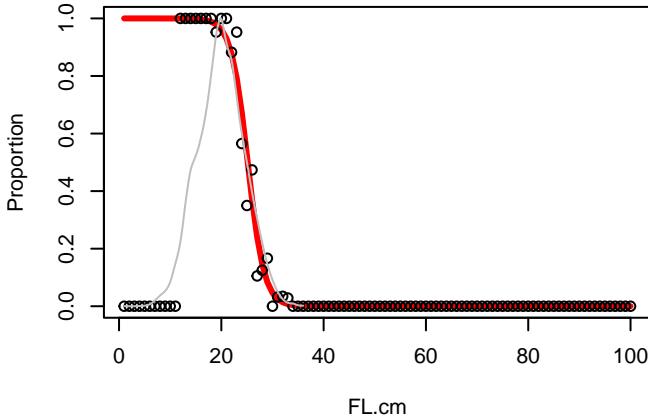
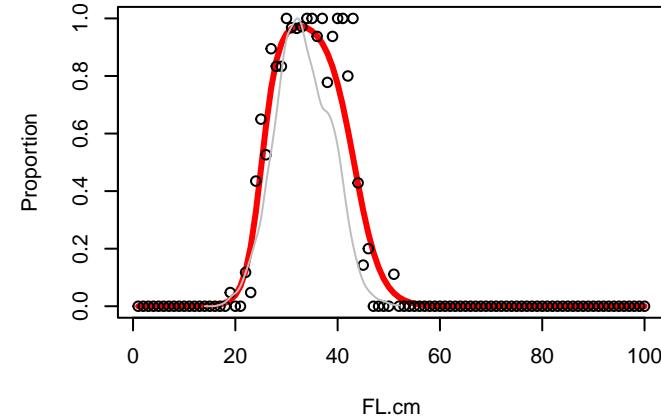
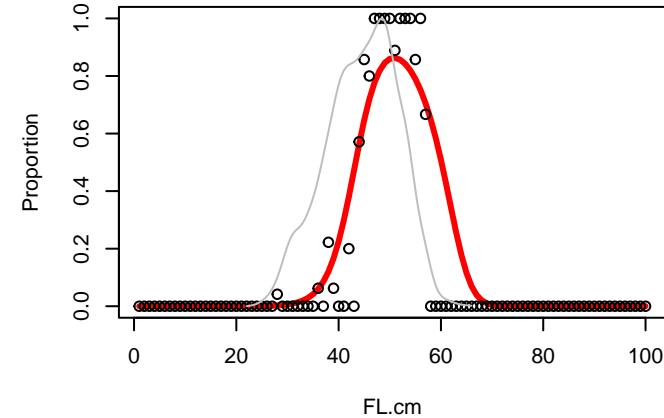
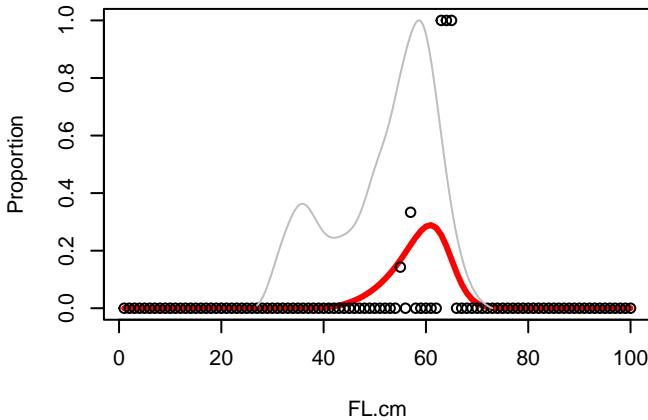
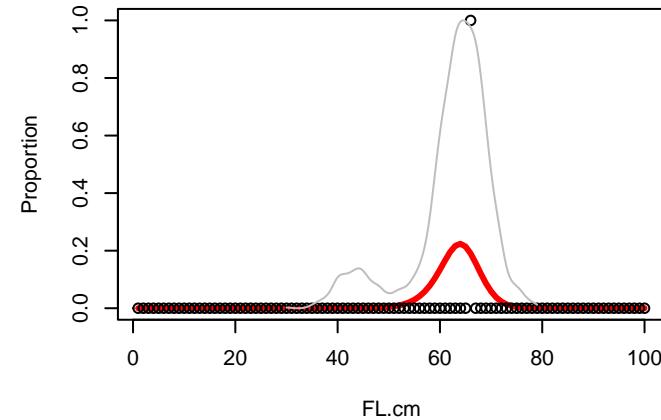
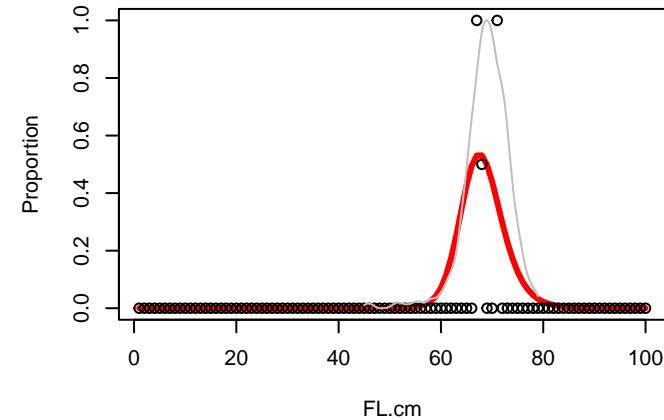
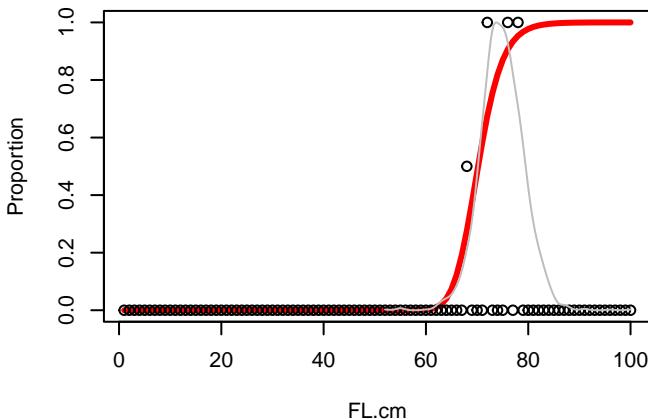


A0, 2001, fall**A1****A2****A3****A4****A5****A6**

All fall
2001 fall pred
2001 fall obs

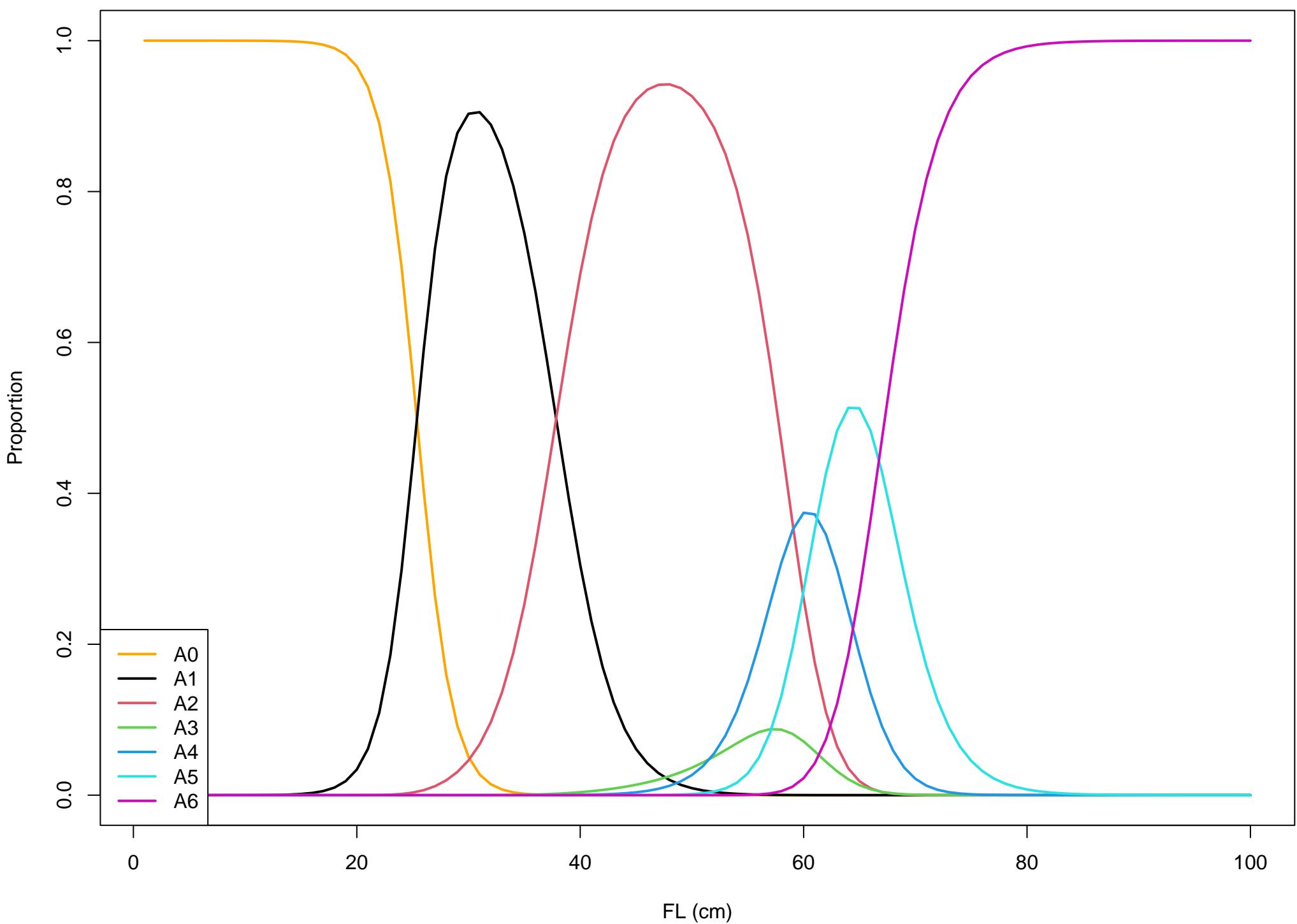
2002
fall

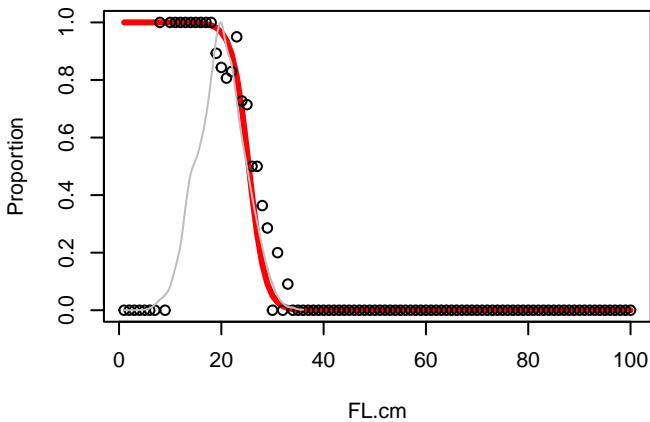
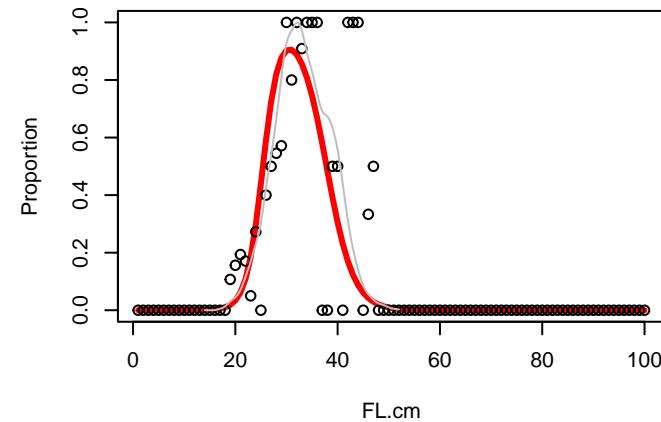
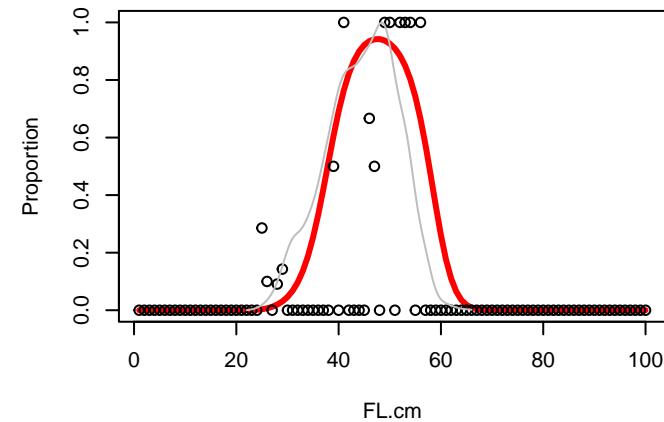
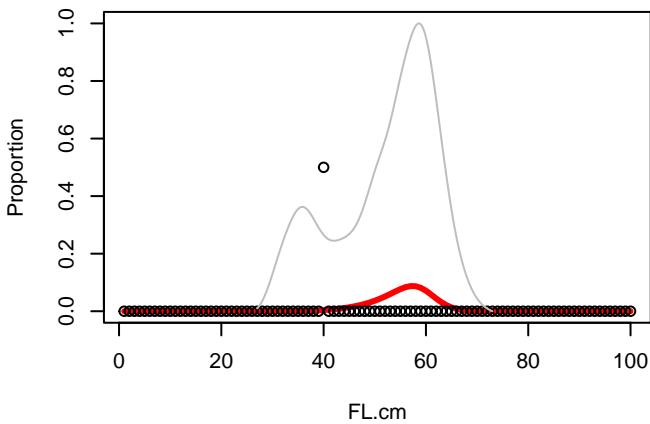
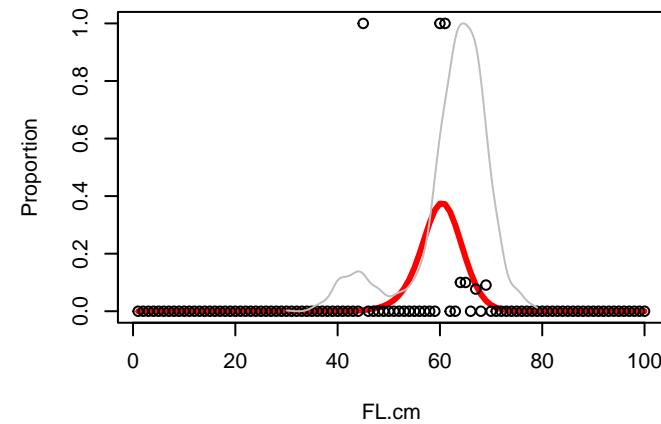
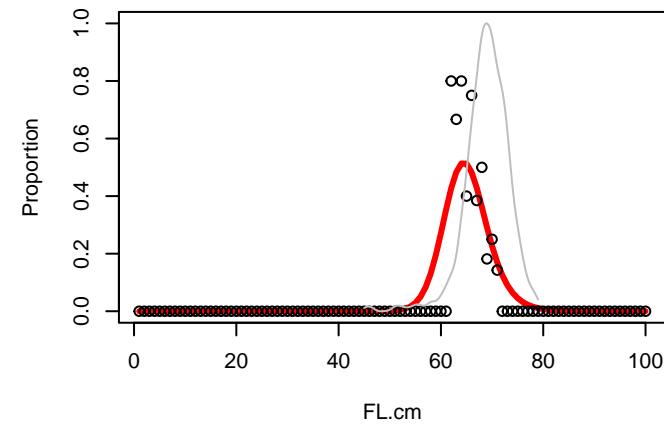
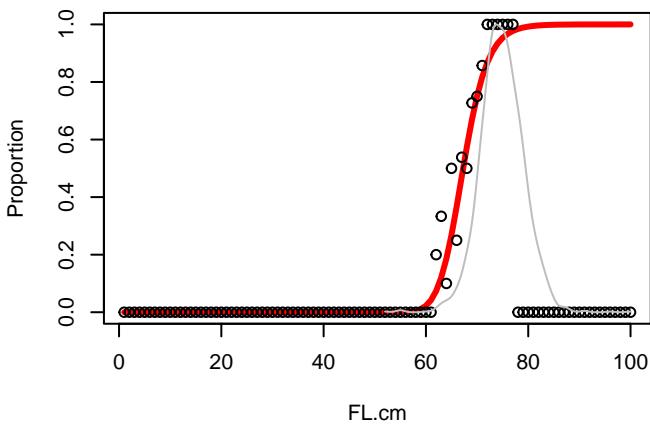


A0, 2002, fall**A1****A2****A3****A4****A5****A6**

All fall
2002 fall pred
2002 fall obs

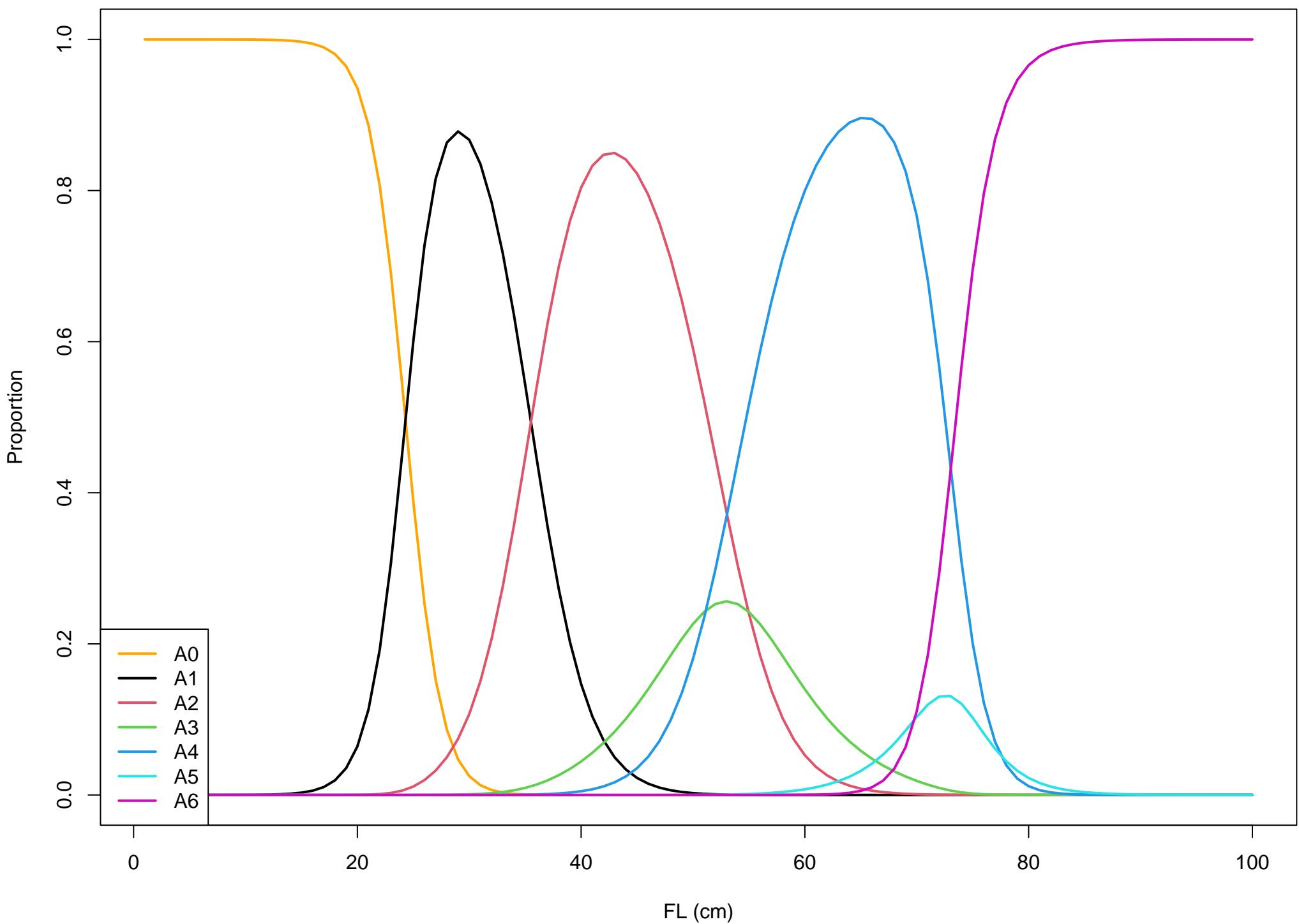
2003
fall

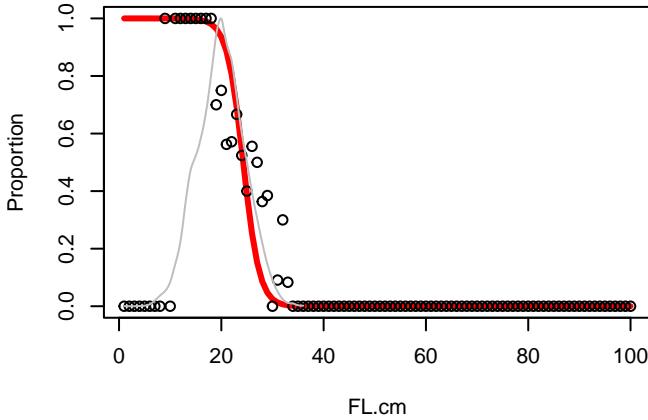
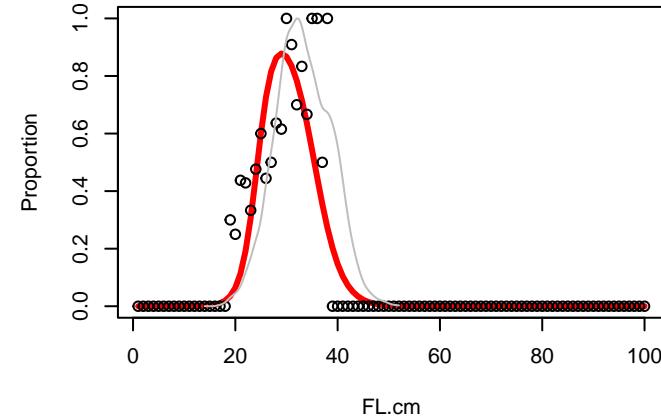
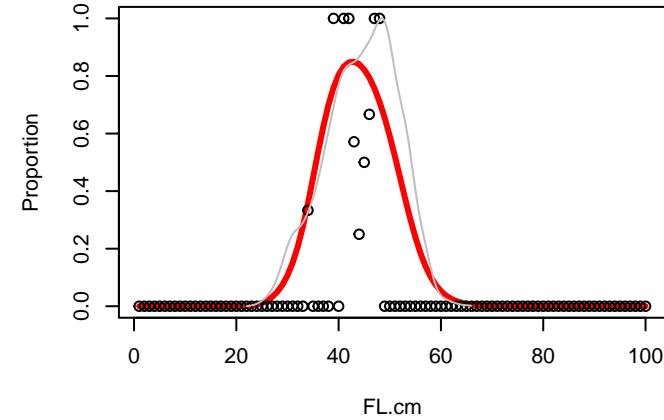
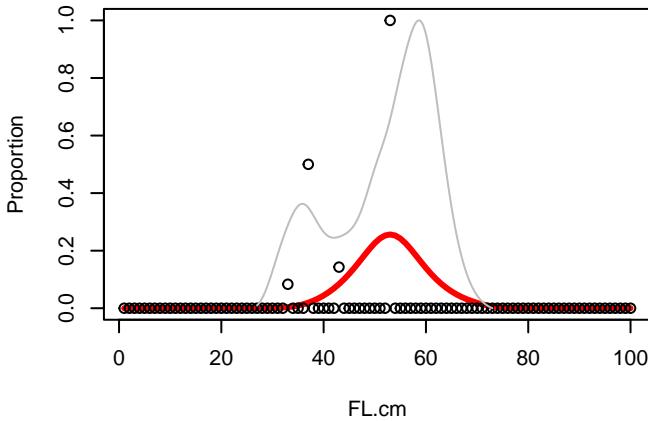
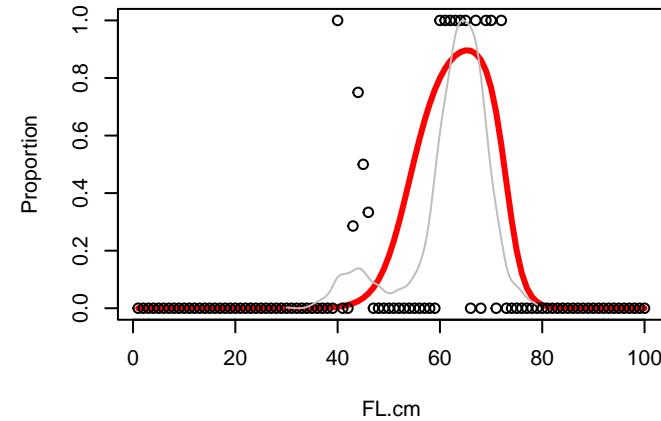
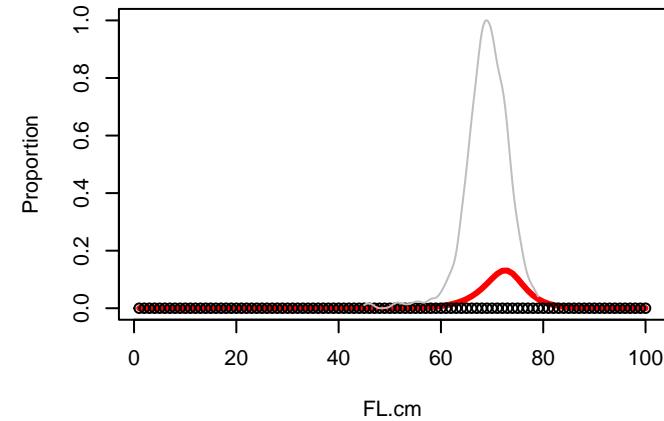
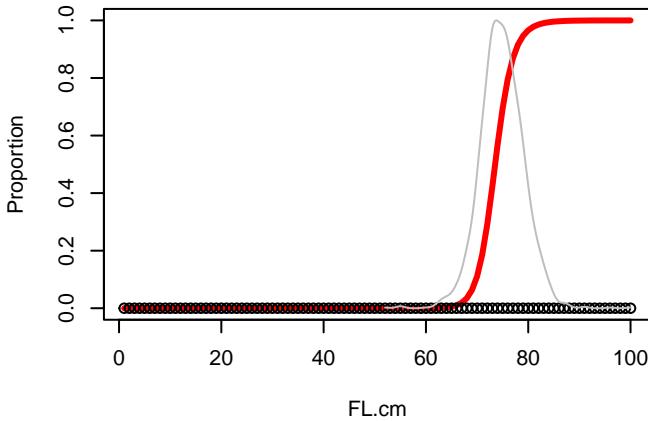


A0, 2003, fall**A1****A2****A3****A4****A5****A6**

— All fall
— 2003 fall pred
○ 2003 fall obs

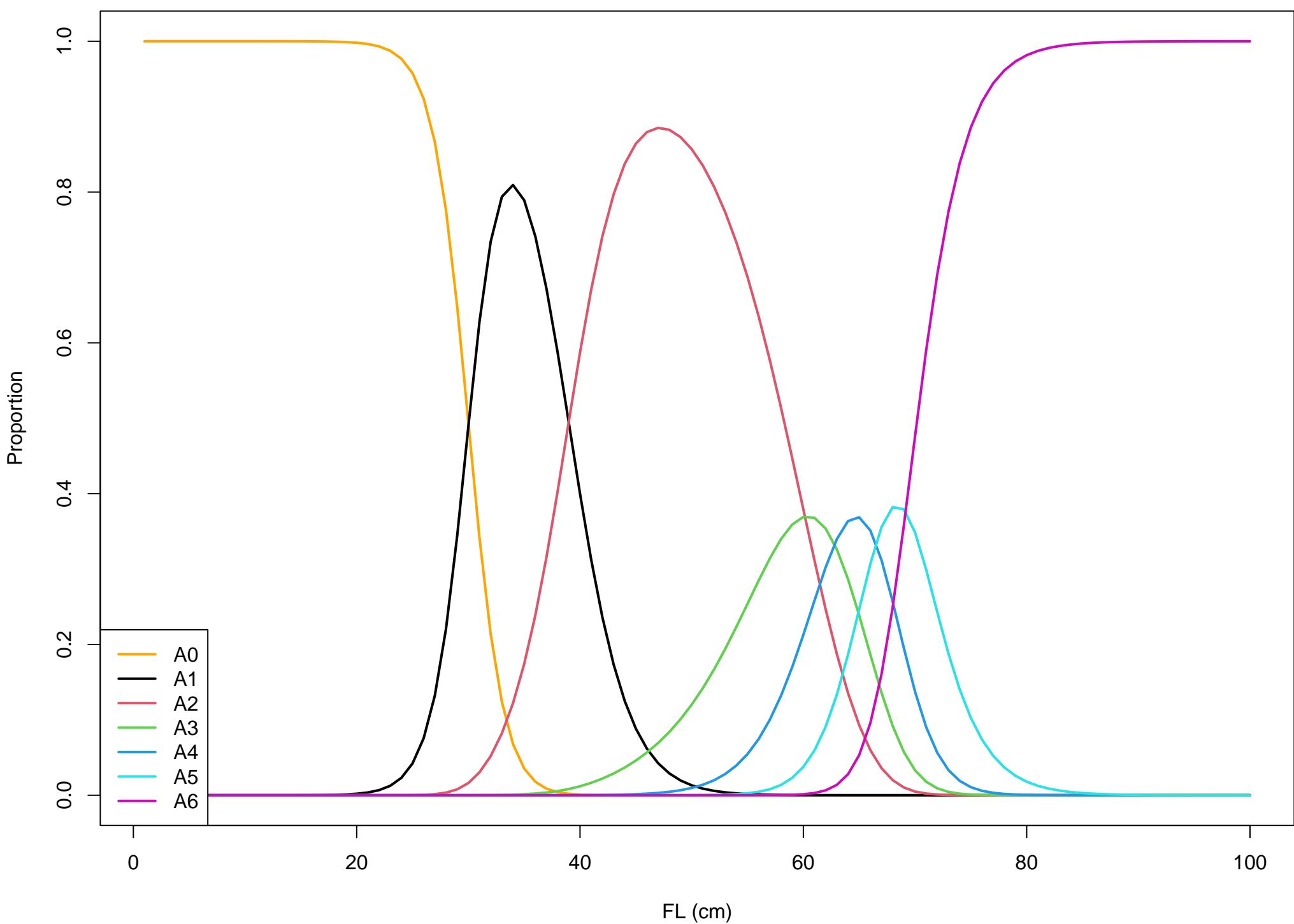
2004
fall



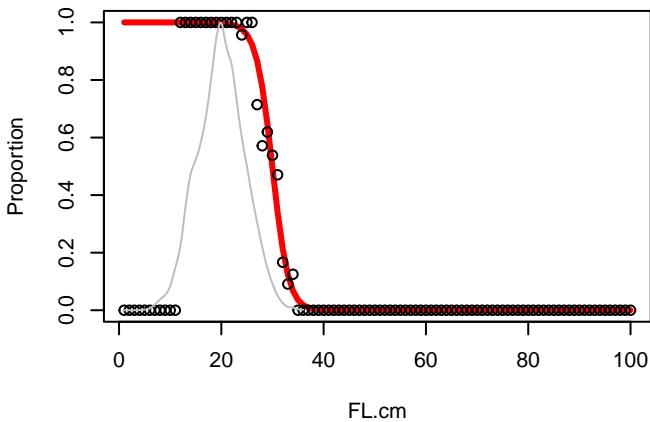
A0, 2004, fall**A1****A2****A3****A4****A5****A6**

All fall
2004 fall pred
○ 2004 fall obs

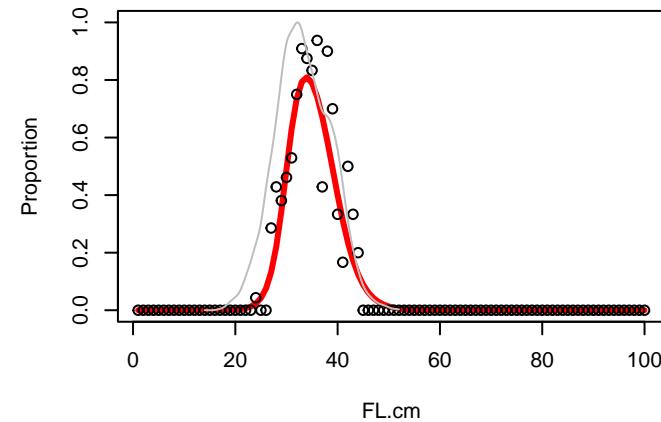
2005
fall



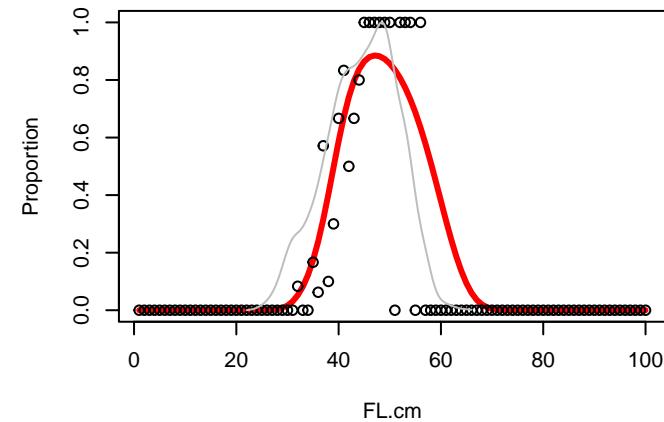
A0, 2005, fall



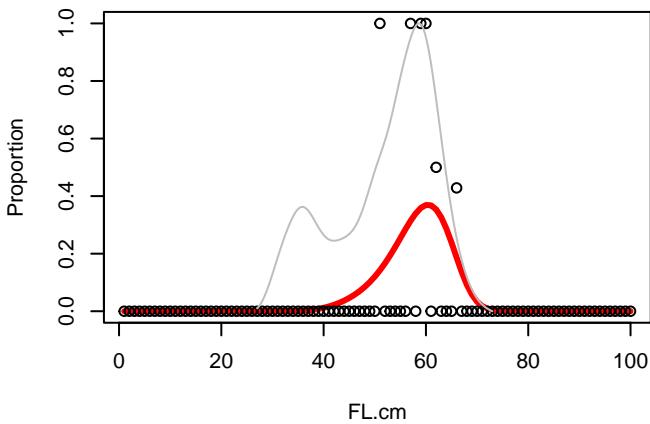
A1



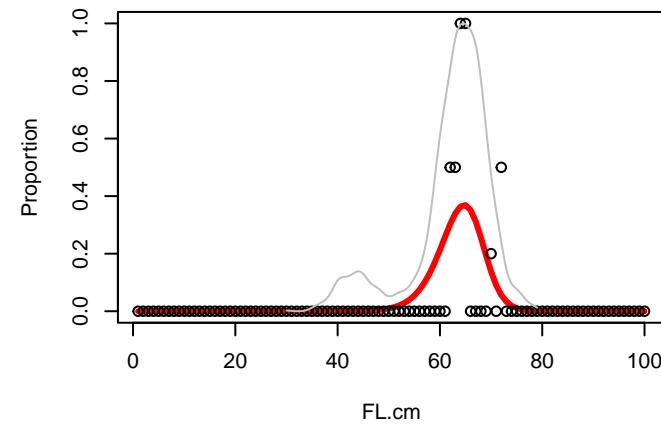
A2



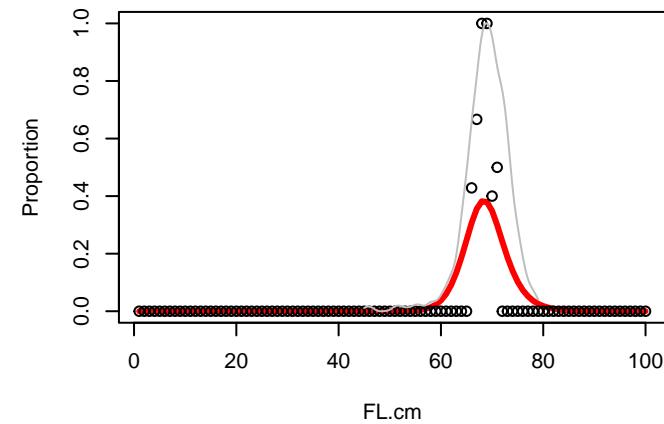
A3



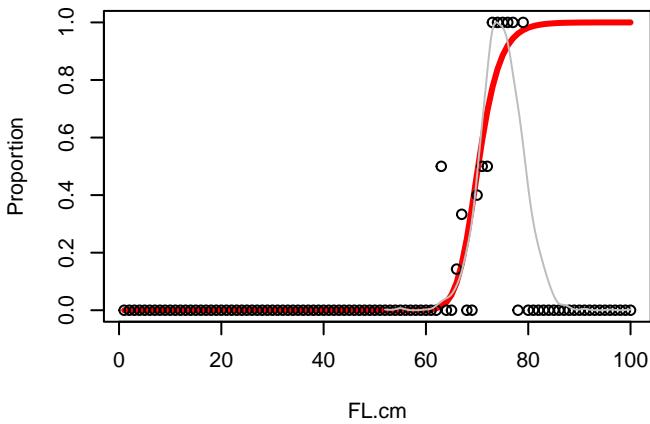
A4



A5

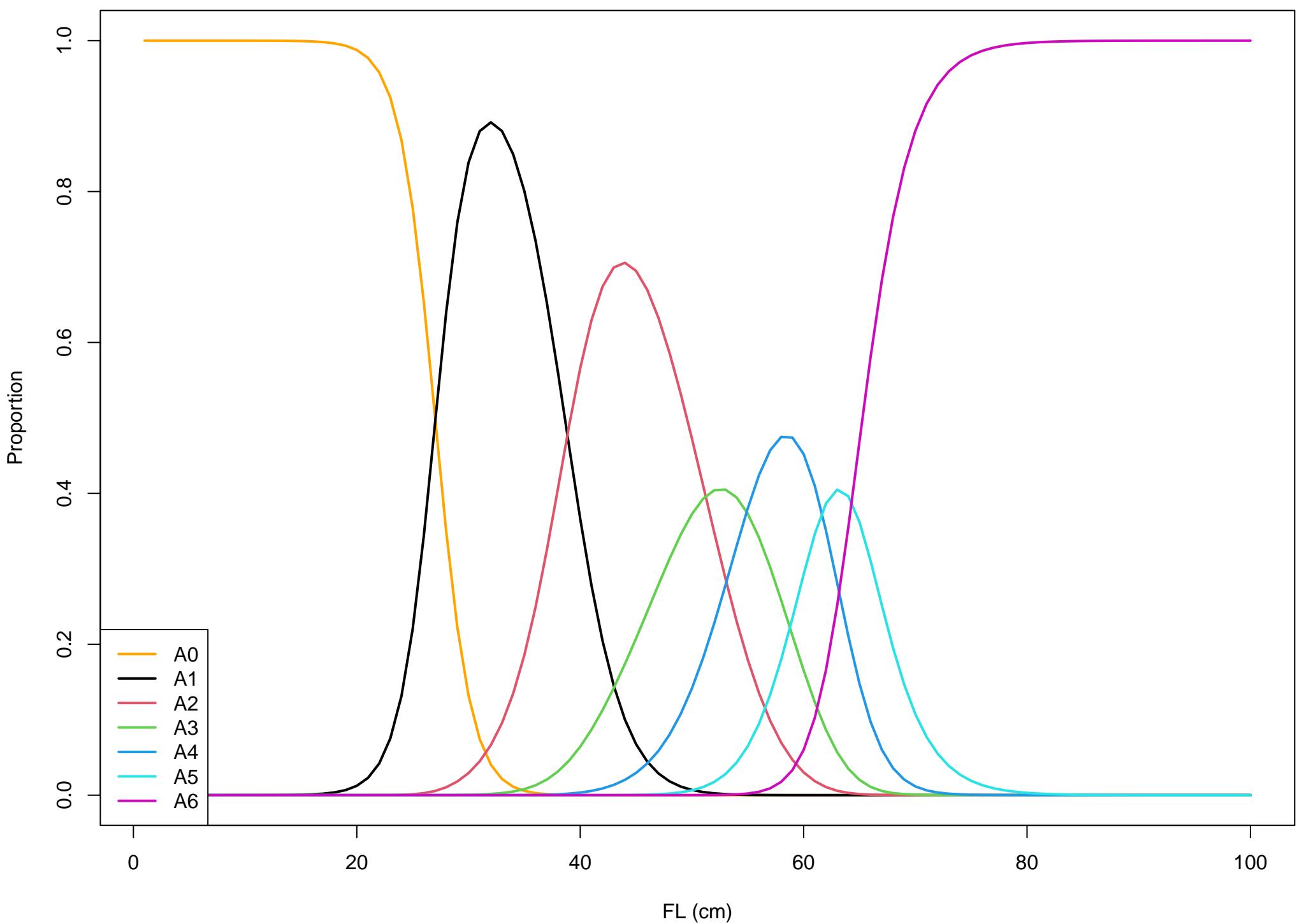


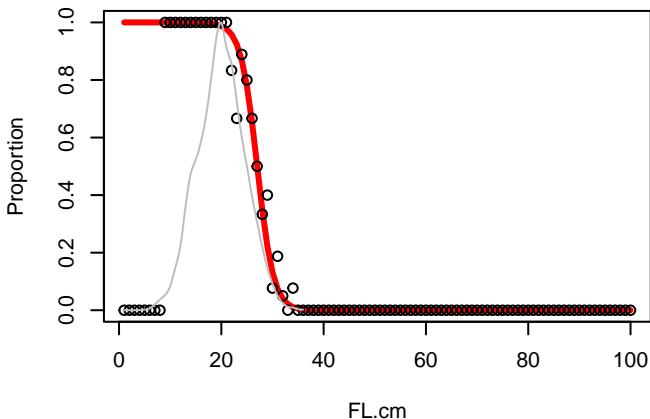
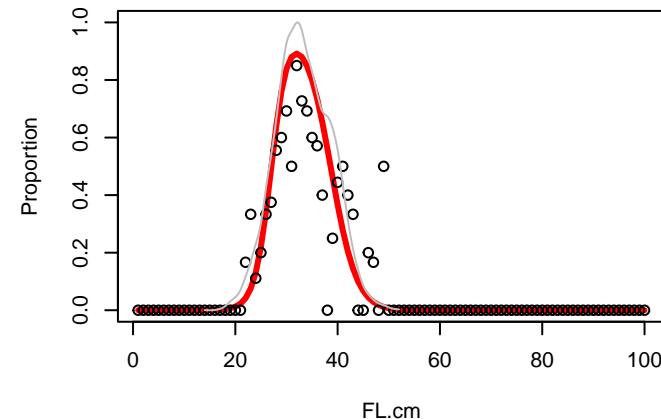
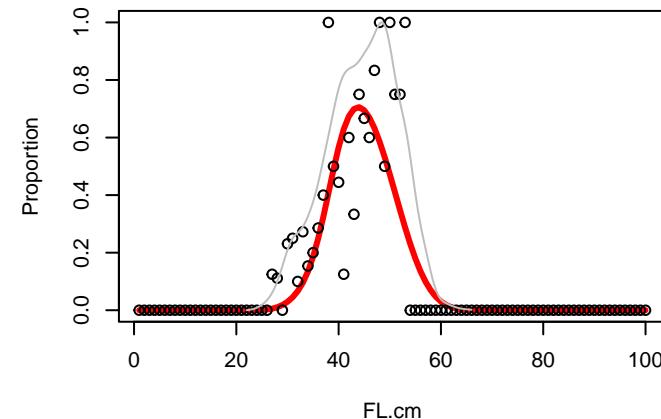
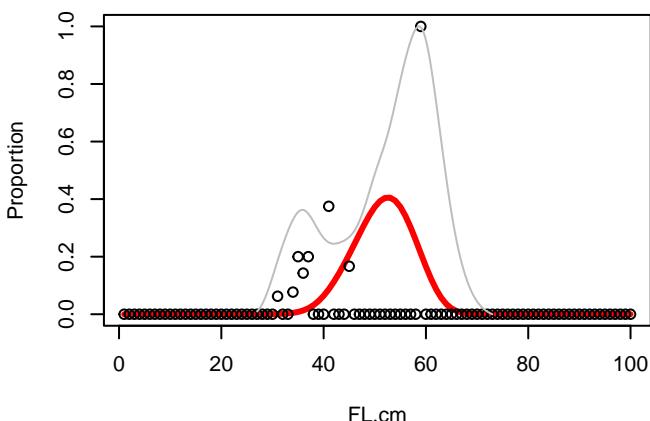
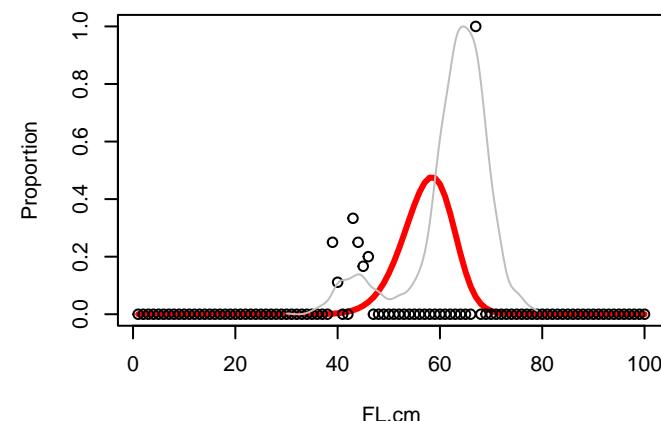
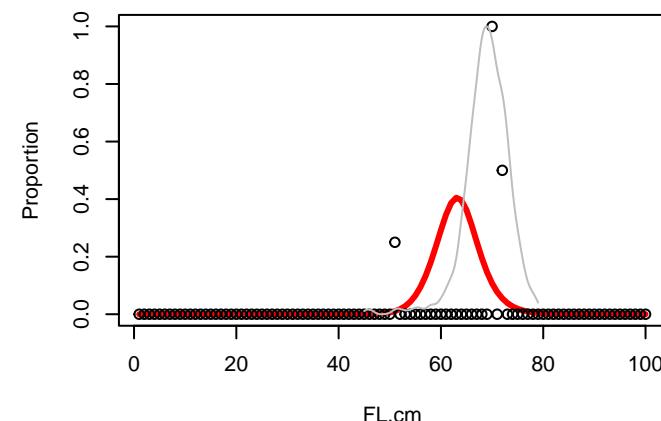
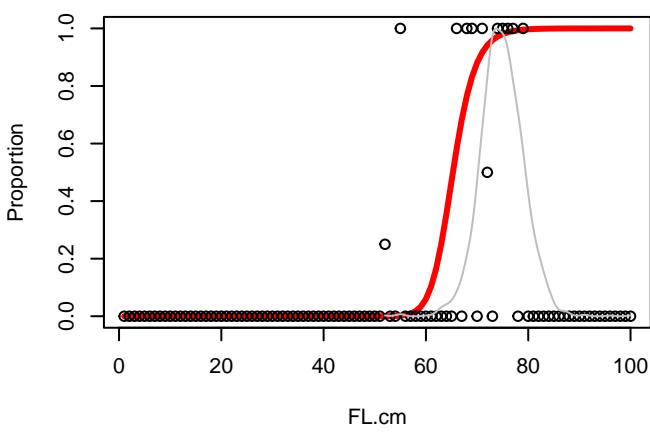
A6



All fall
2005 fall pred
2005 fall obs

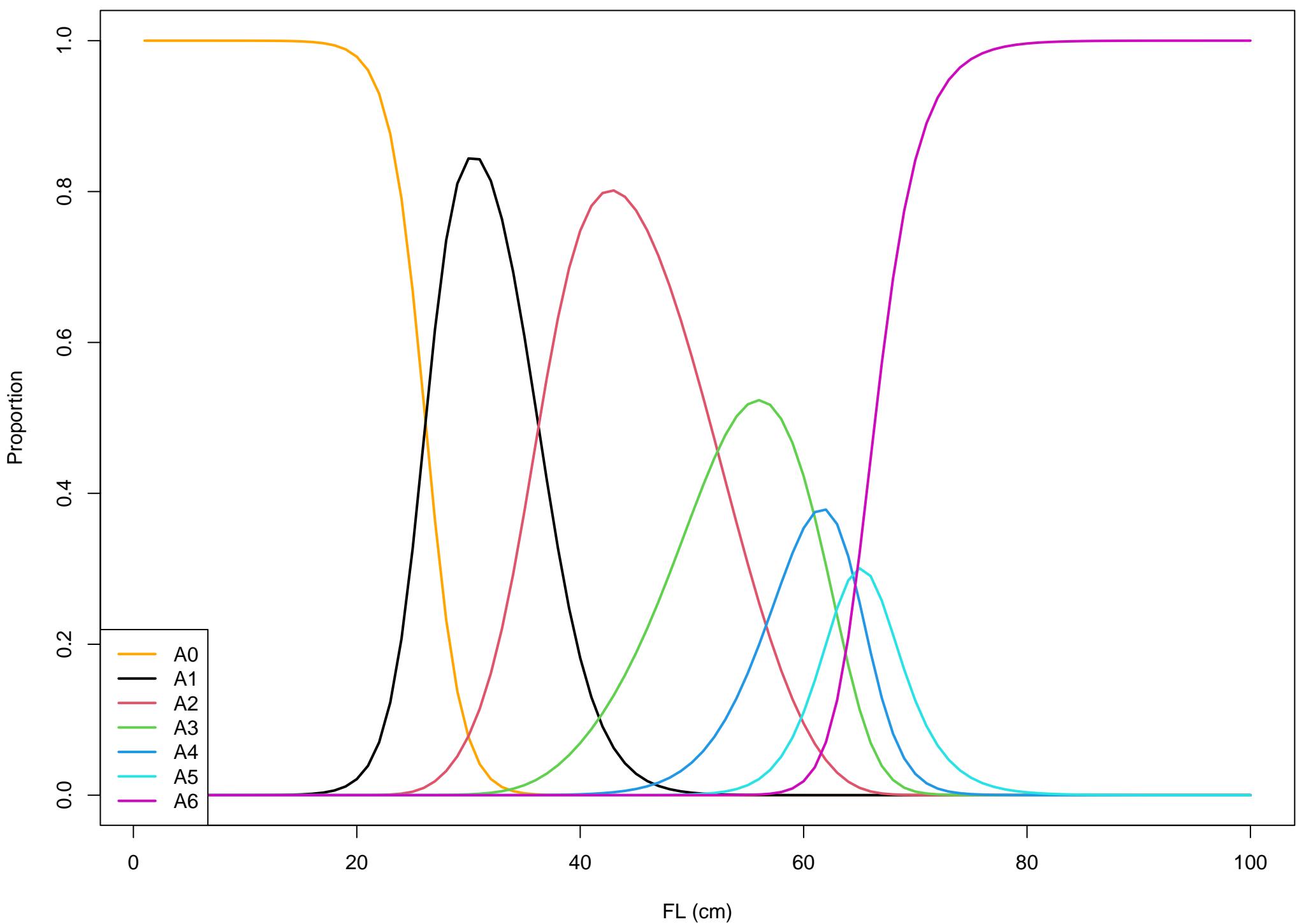
2006
fall

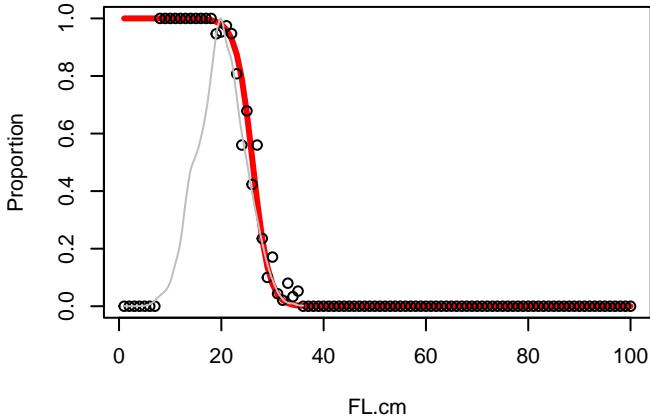
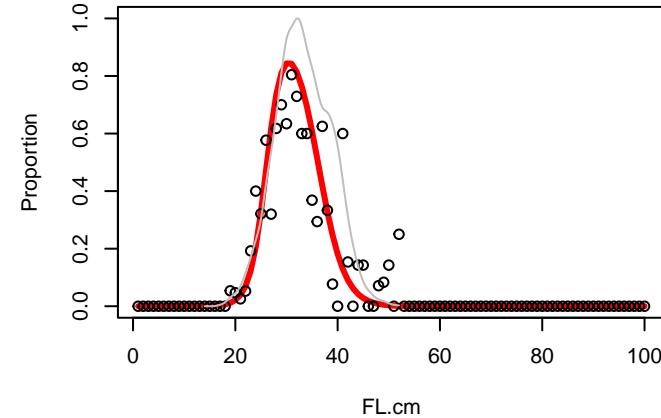
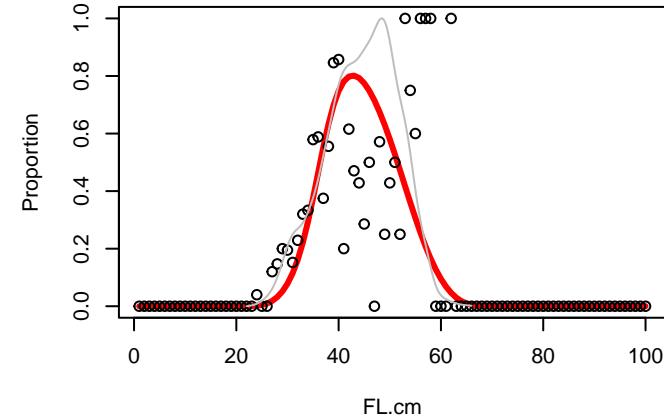
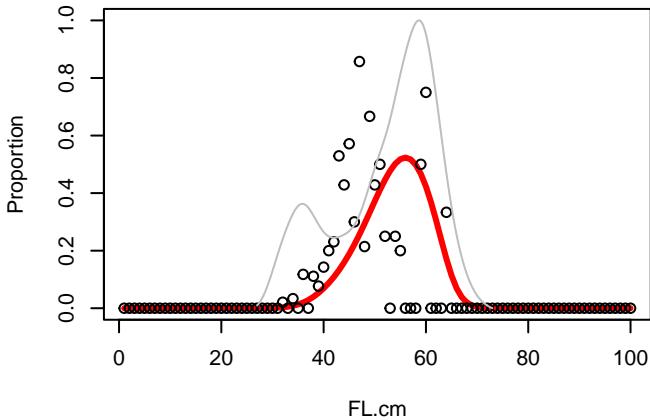
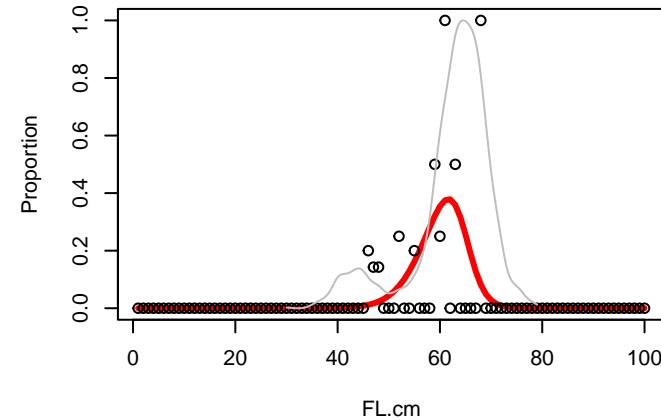
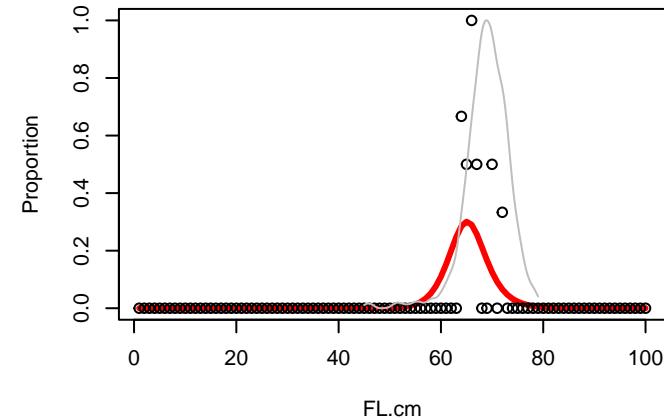
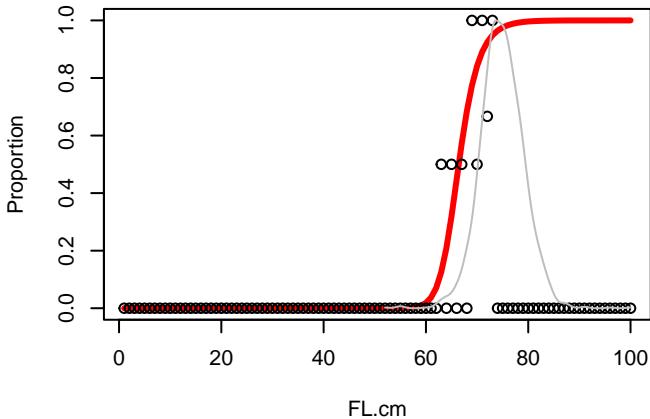


A0, 2006, fall**A1****A2****A3****A4****A5****A6**

All fall
2006 fall pred
2006 fall obs

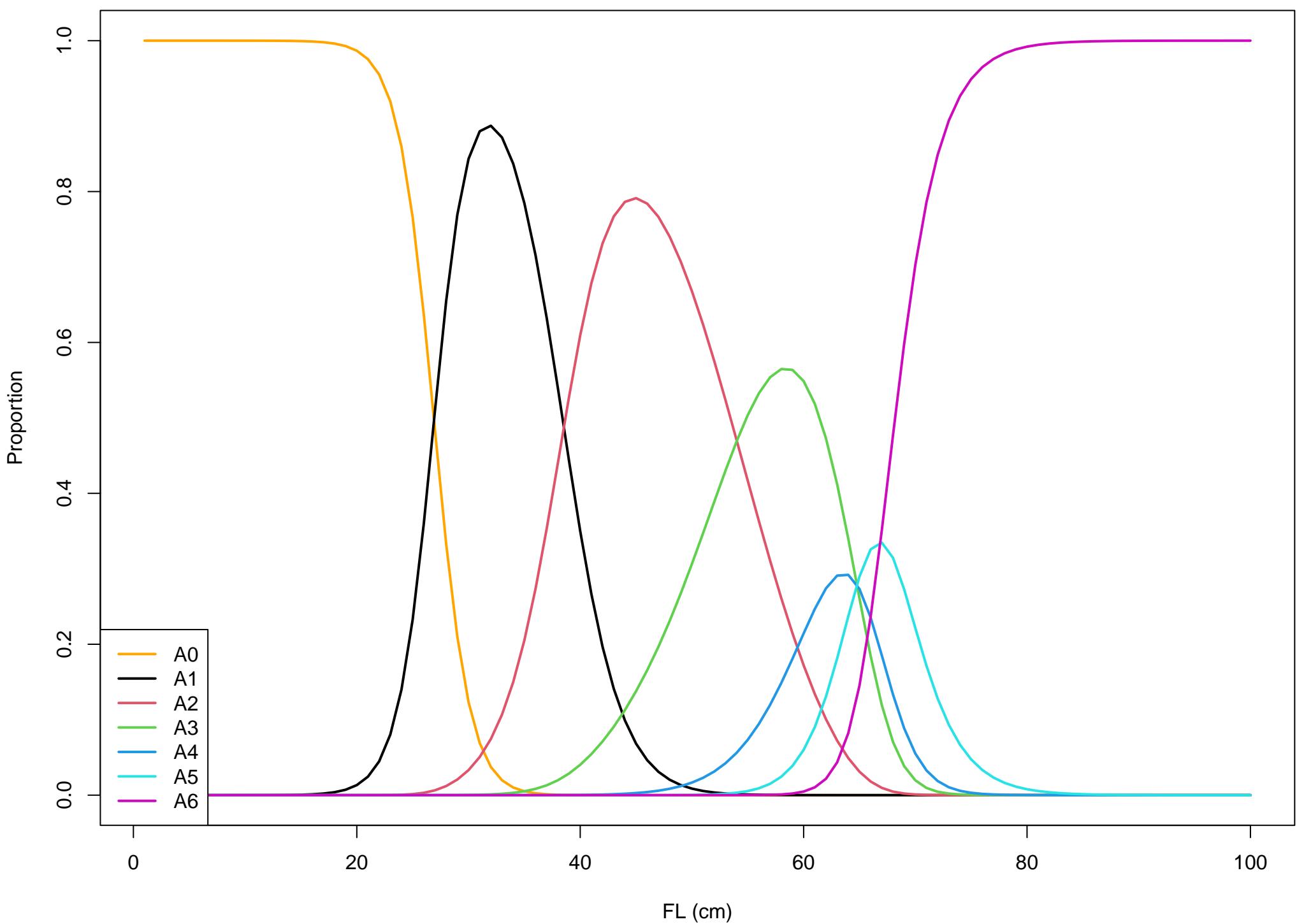
2007
fall

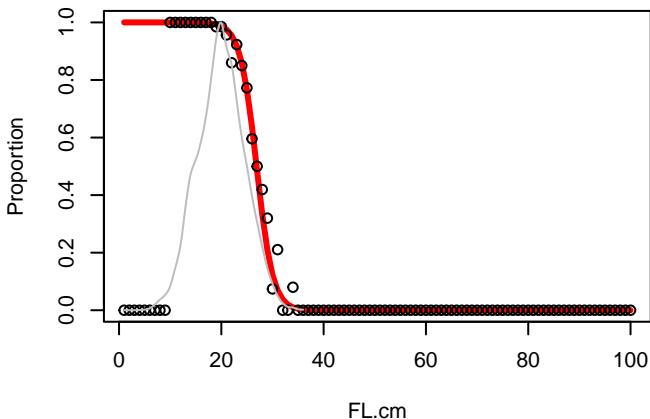
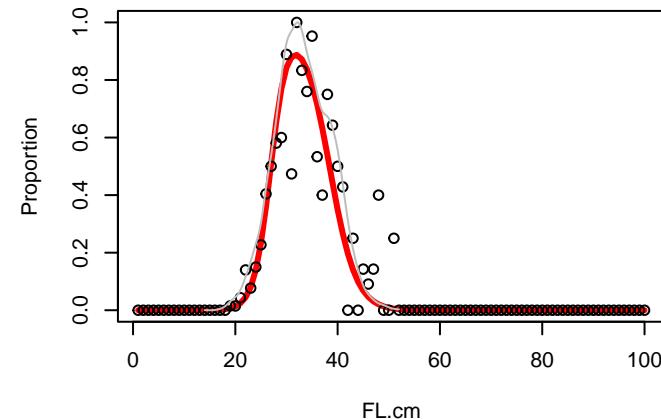
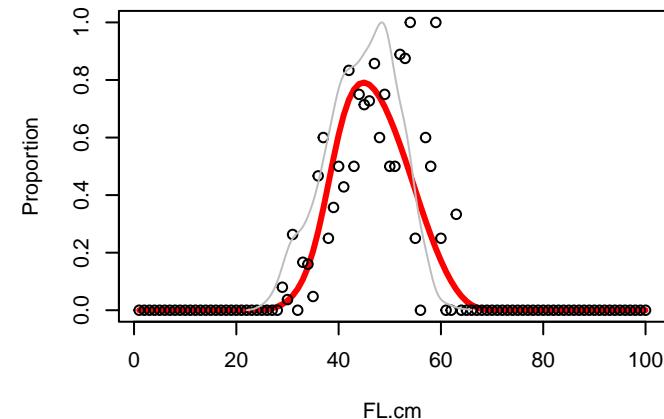
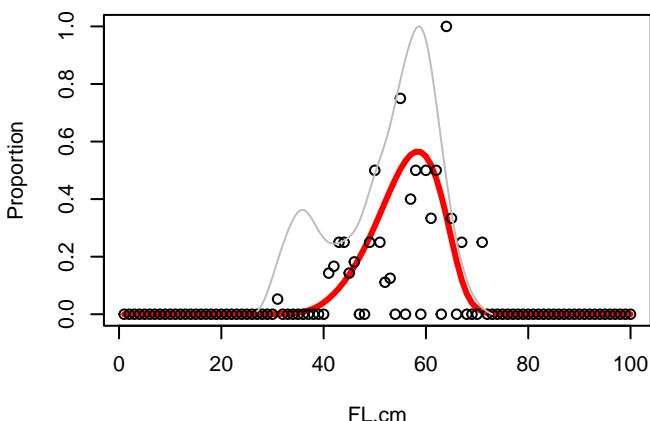
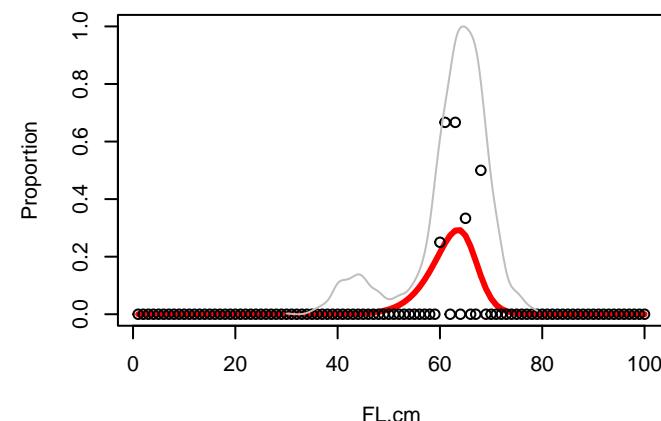
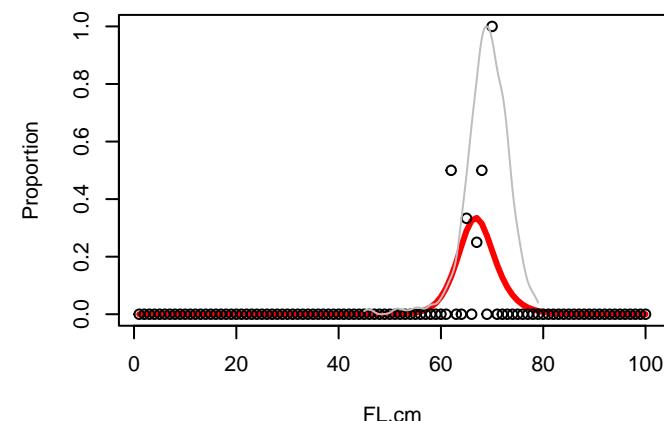
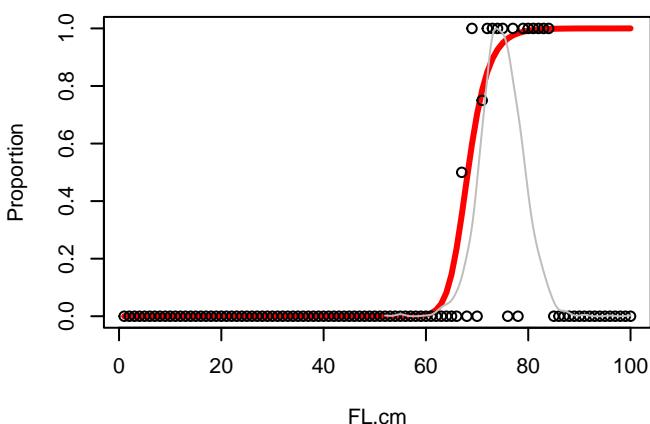


A0, 2007, fall**A1****A2****A3****A4****A5****A6**

All fall
2007 fall pred
2007 fall obs

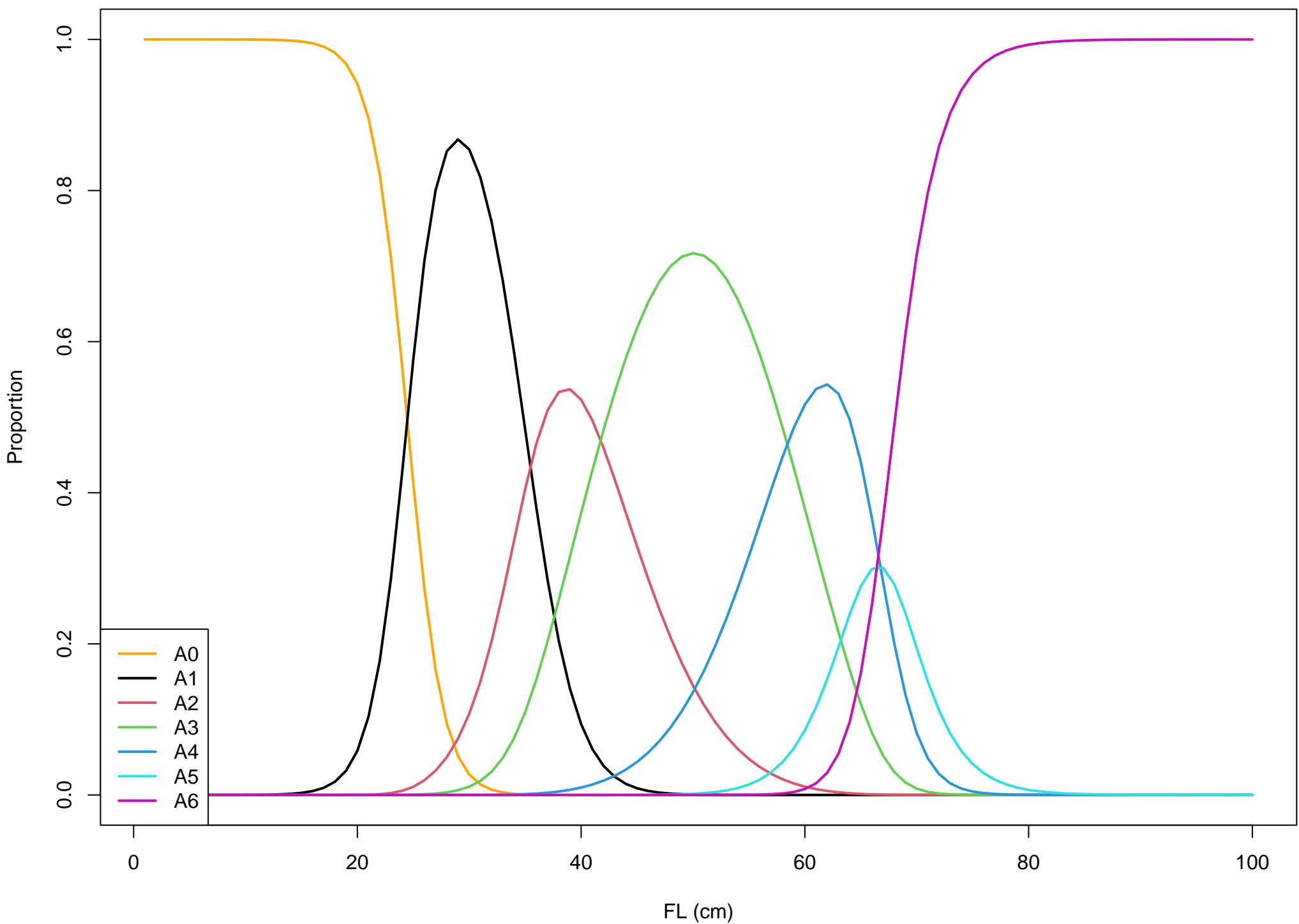
2008
fall

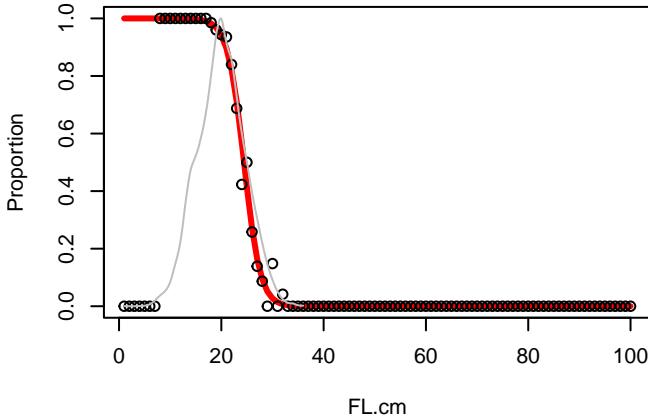
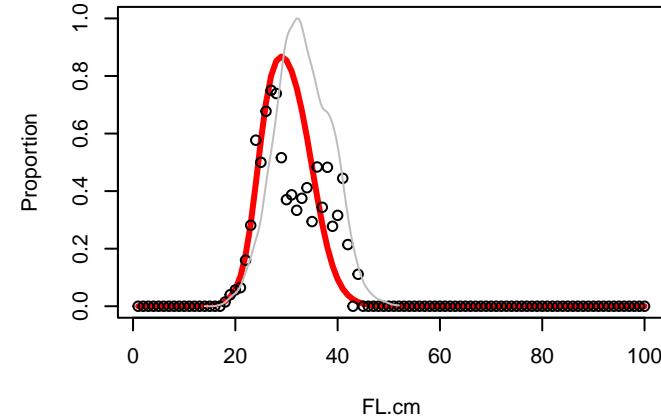
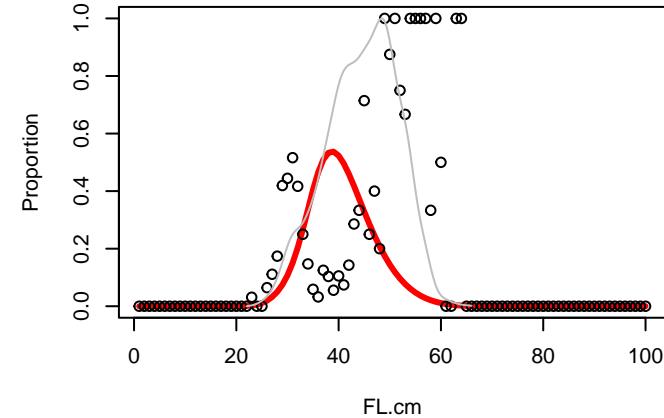
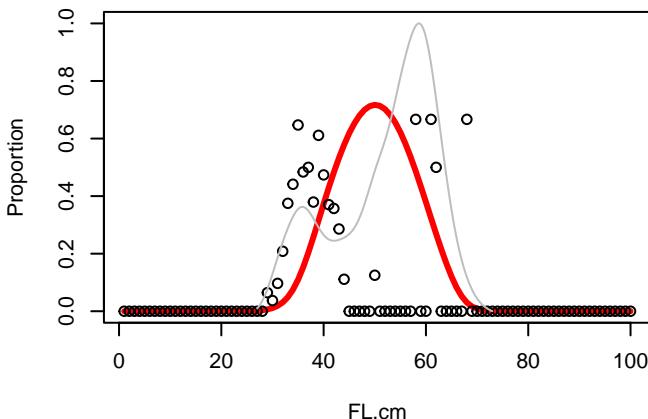
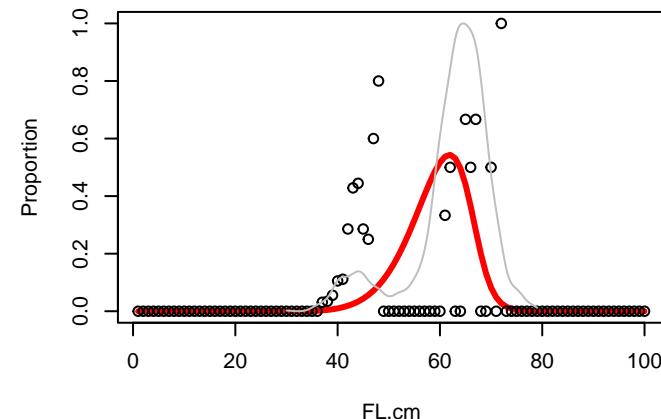
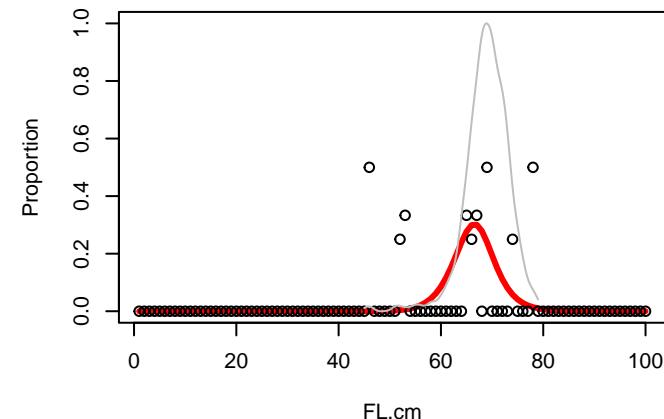
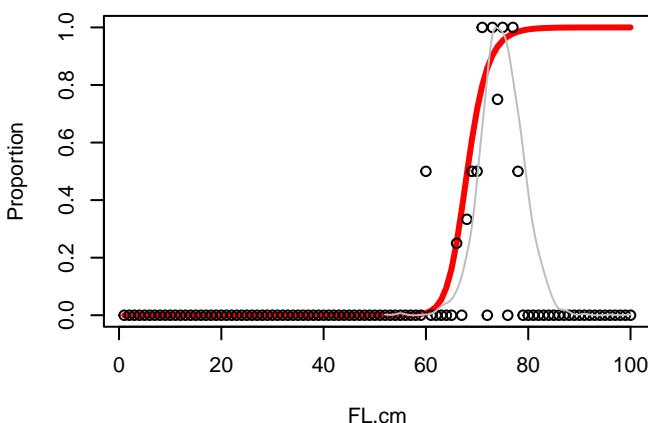


A0, 2008, fall**A1****A2****A3****A4****A5****A6**

All fall
2008 fall pred
2008 fall obs

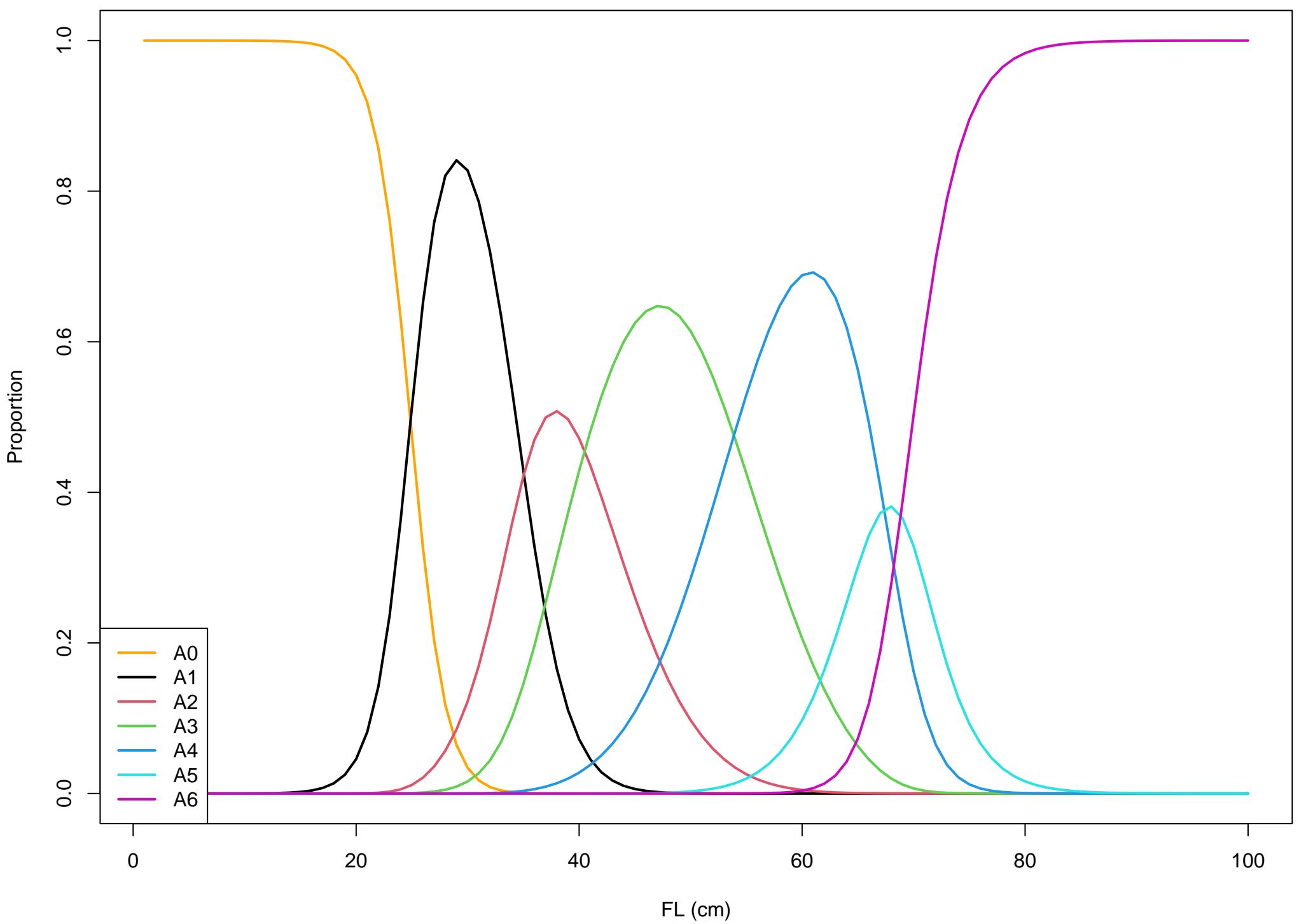
2009
fall

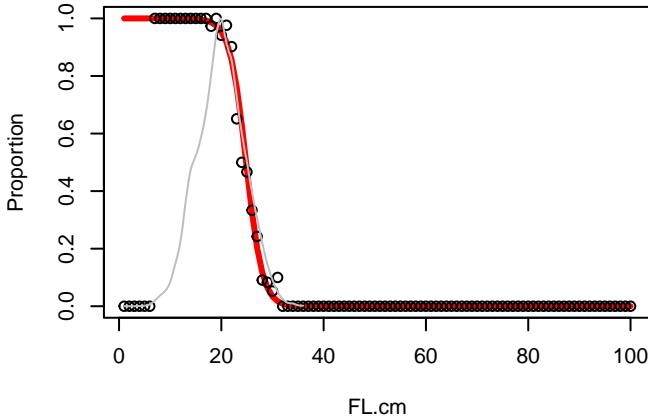
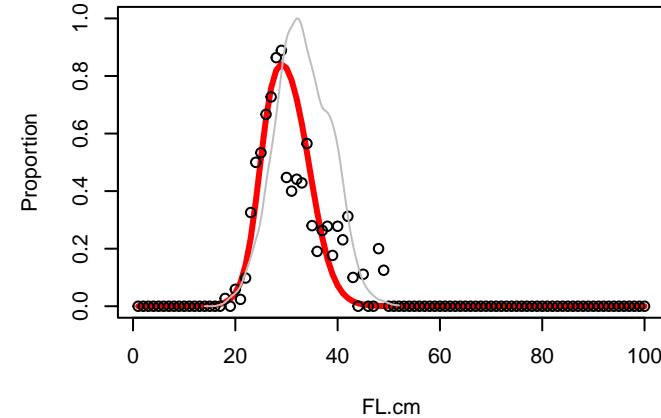
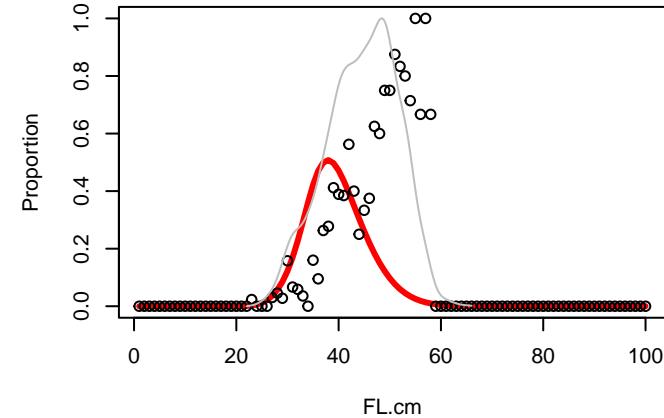
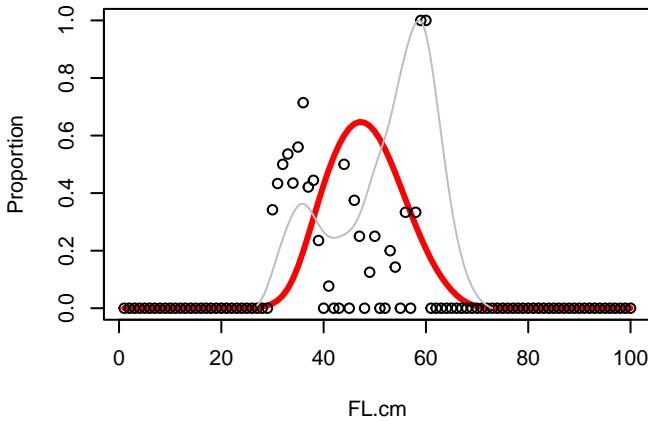
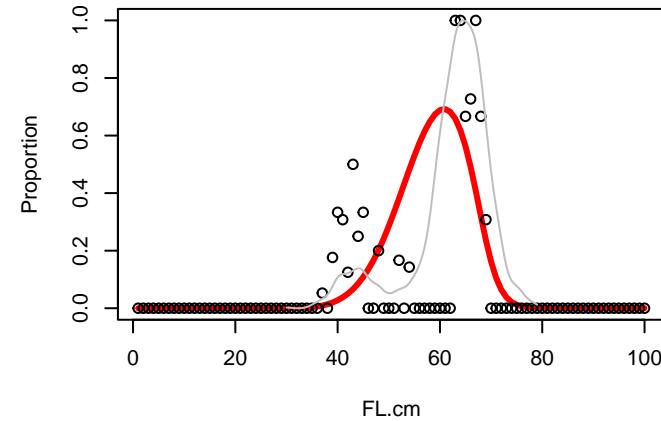
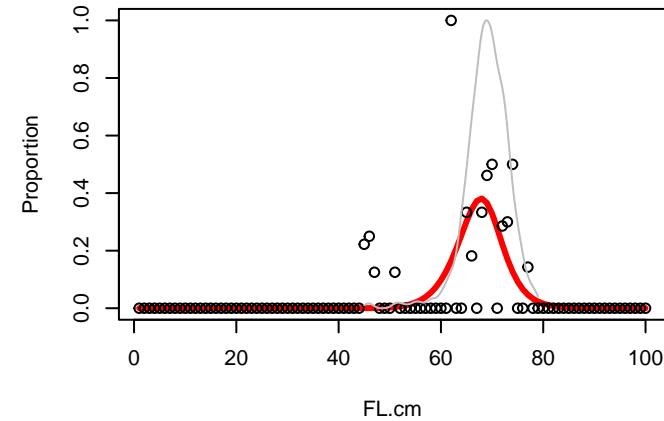
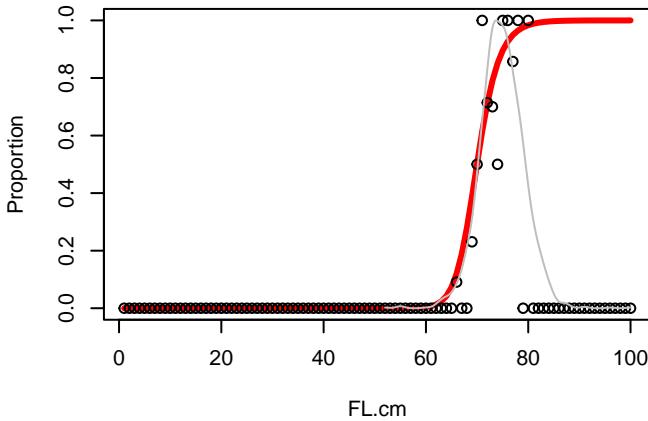


A0, 2009, fall**A1****A2****A3****A4****A5****A6**

All fall
2009 fall pred
2009 fall obs

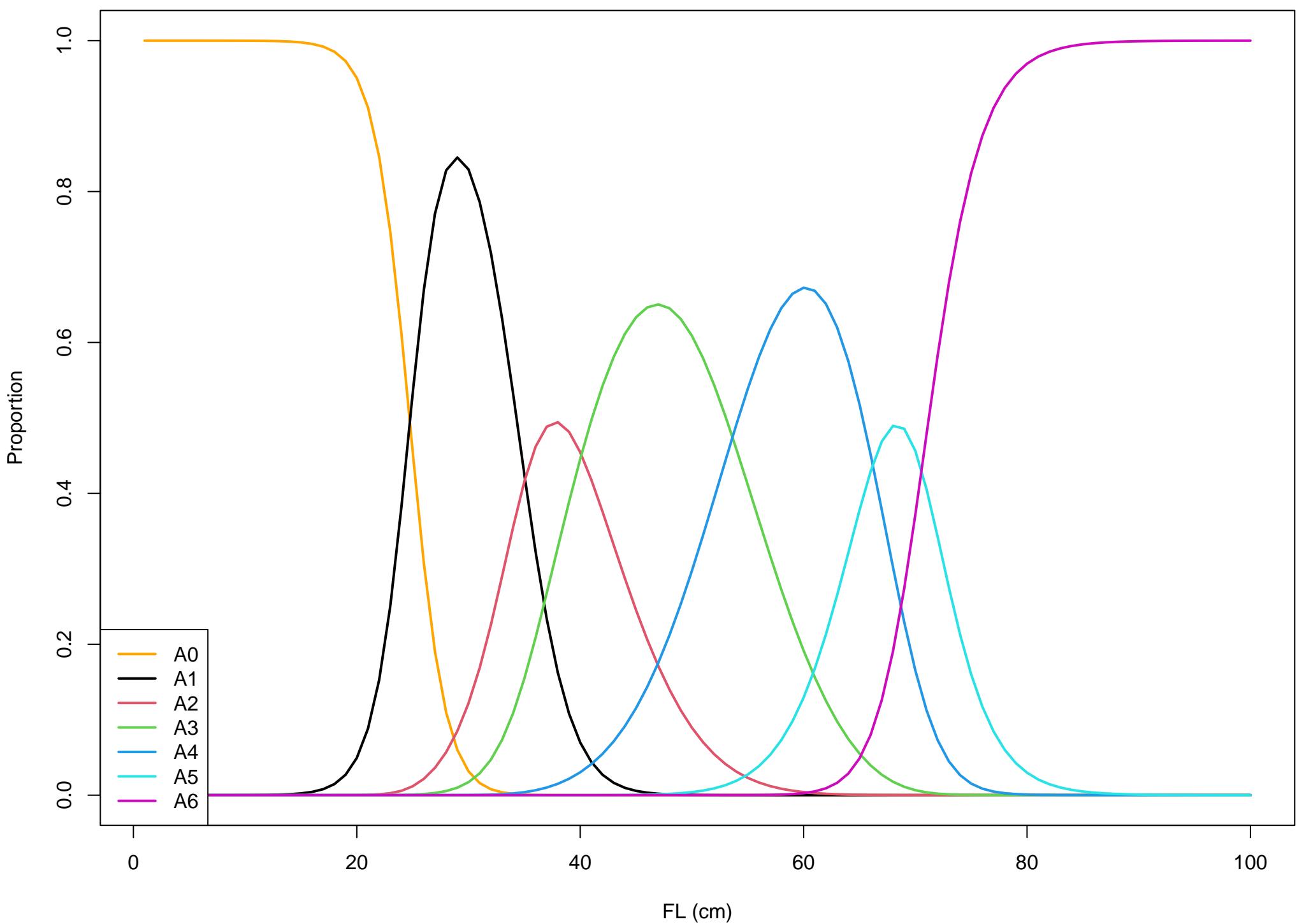
2010
fall

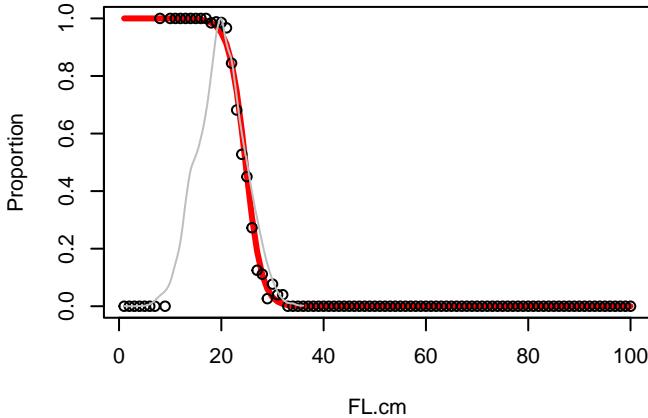
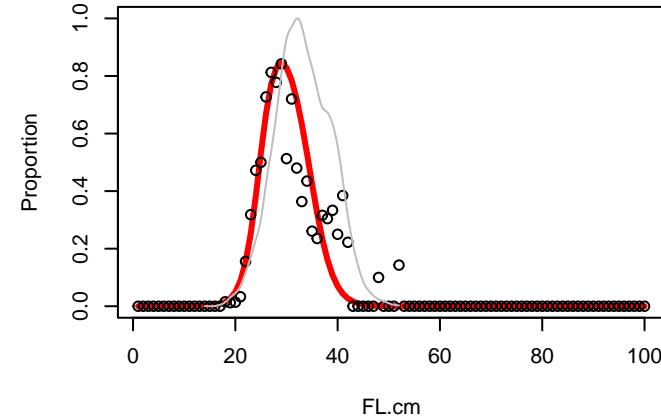
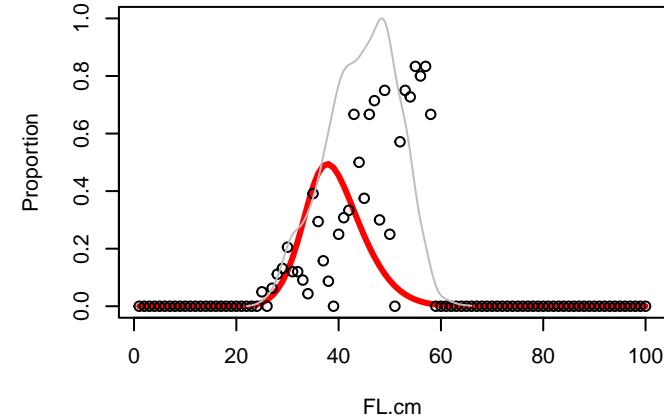
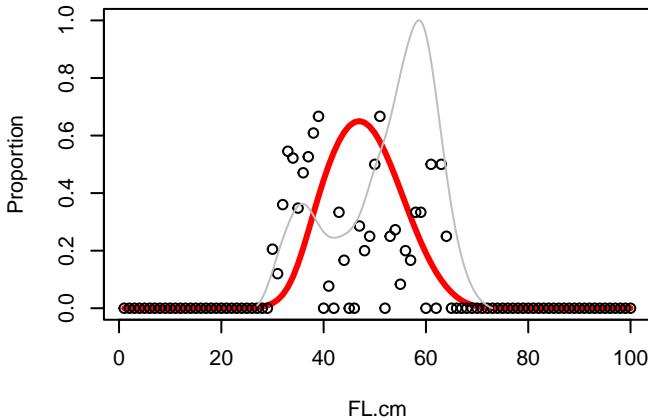
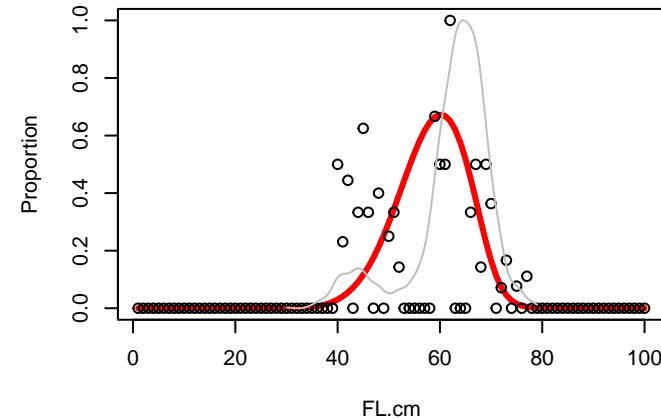
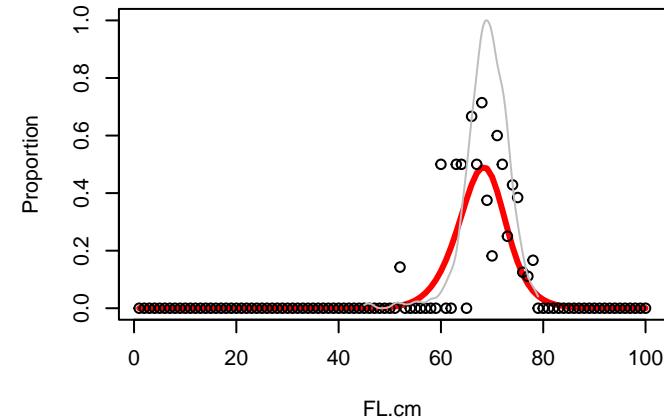
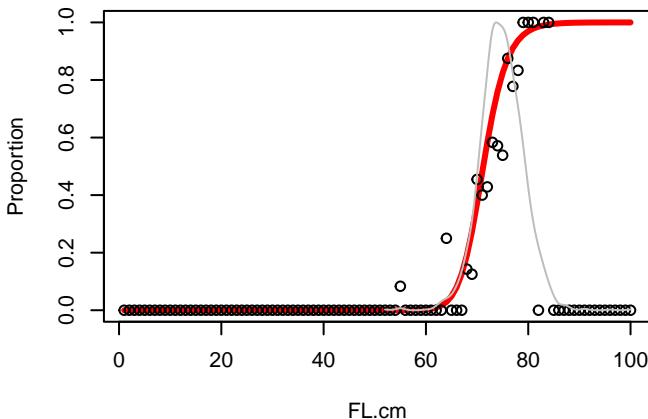


A0, 2010, fall**A1****A2****A3****A4****A5****A6**

All fall
2010 fall pred
2010 fall obs

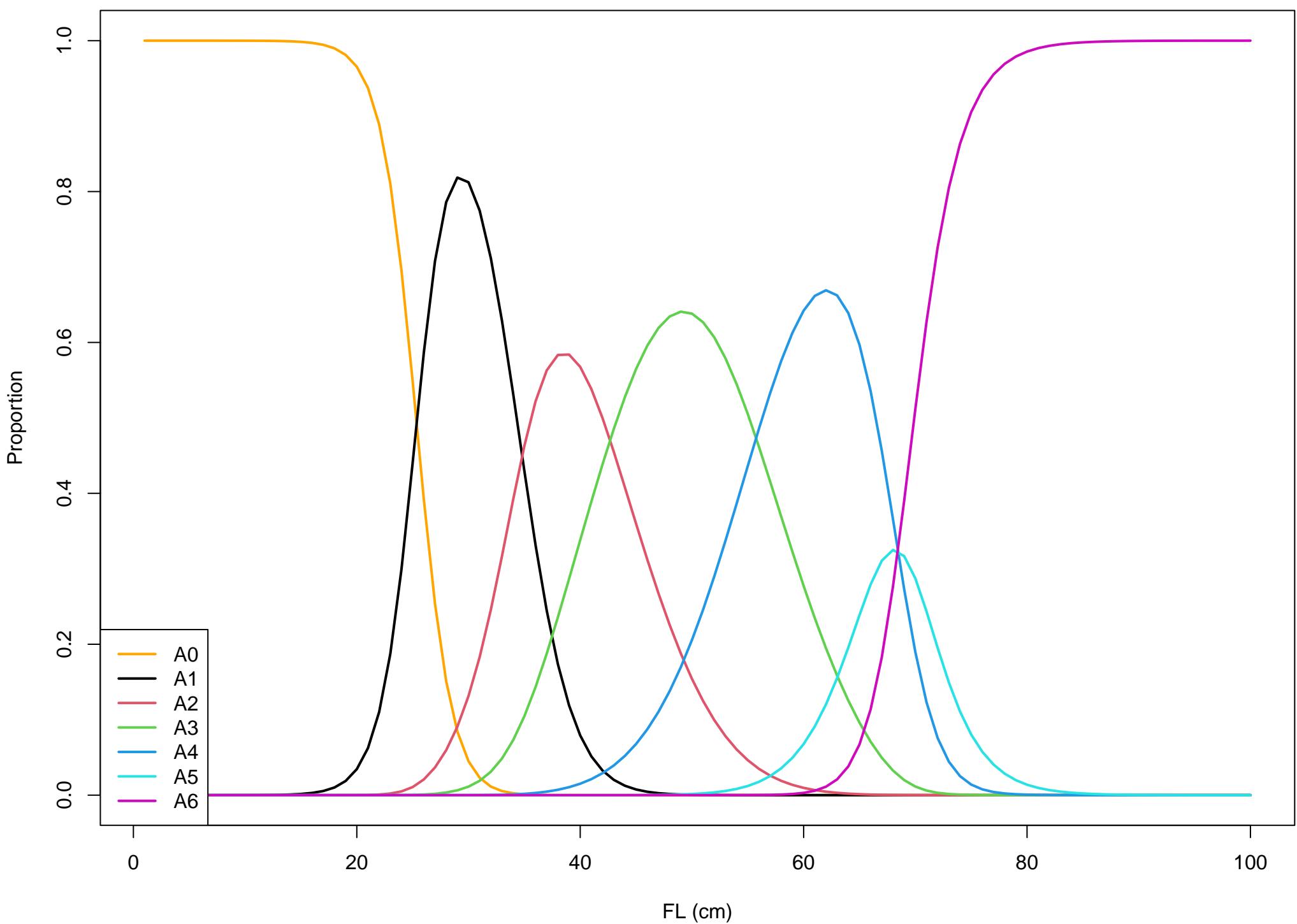
2011
fall

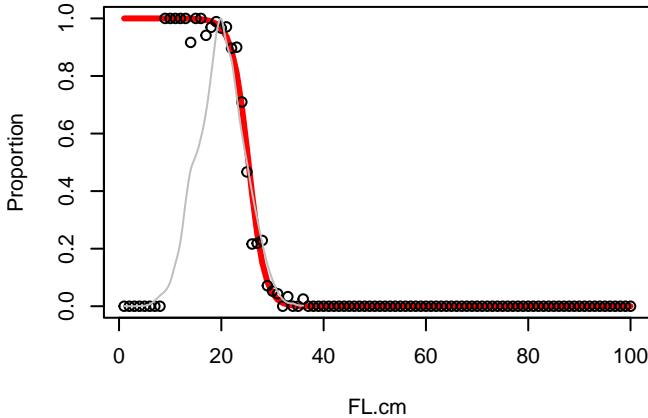
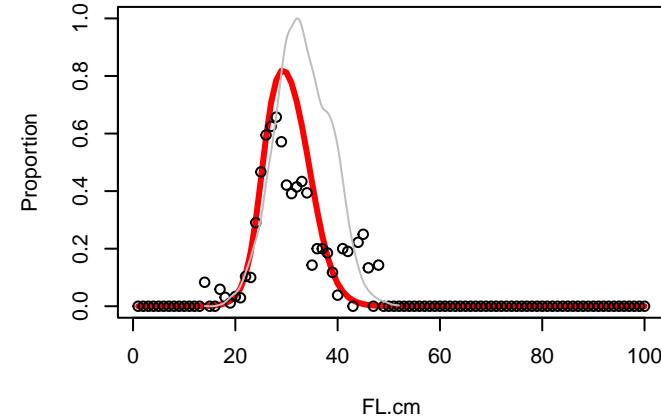
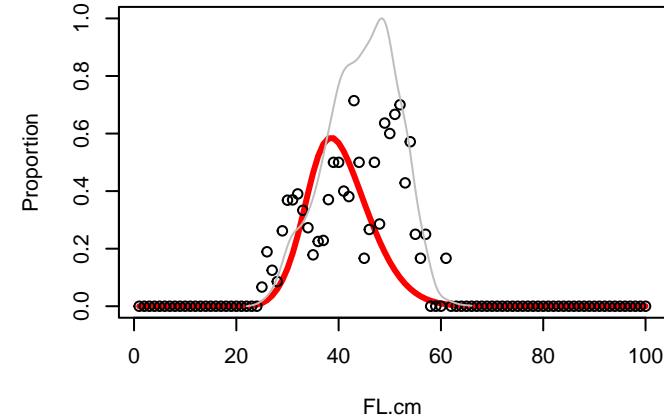
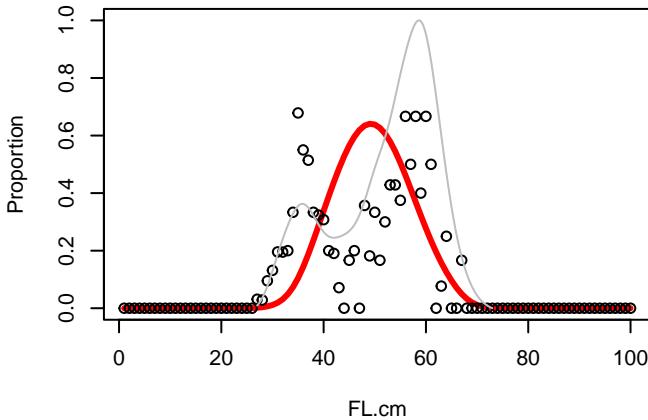
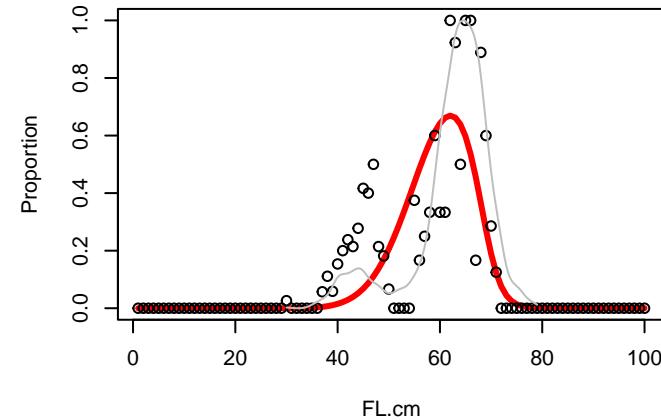
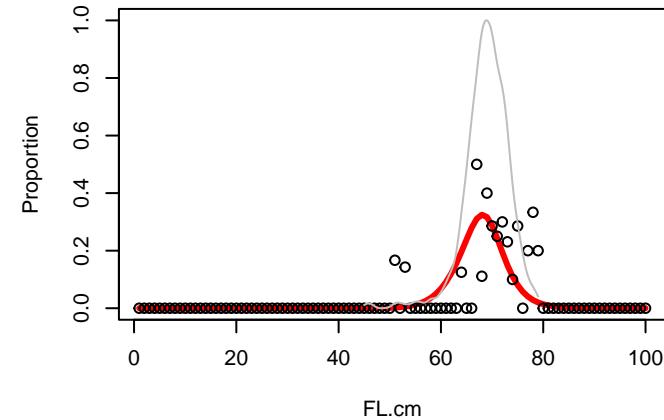
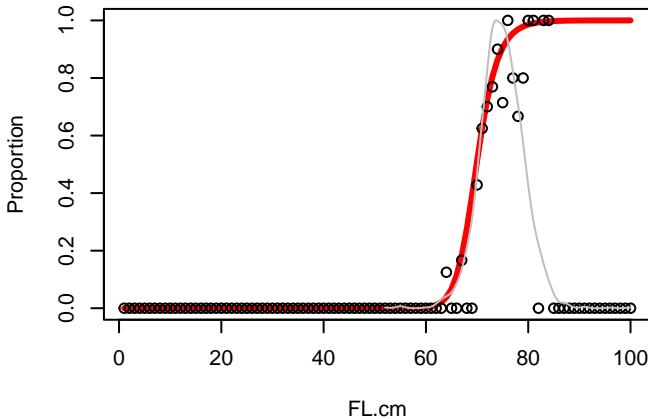


A0, 2011, fall**A1****A2****A3****A4****A5****A6**

All fall
2011 fall pred
2011 fall obs

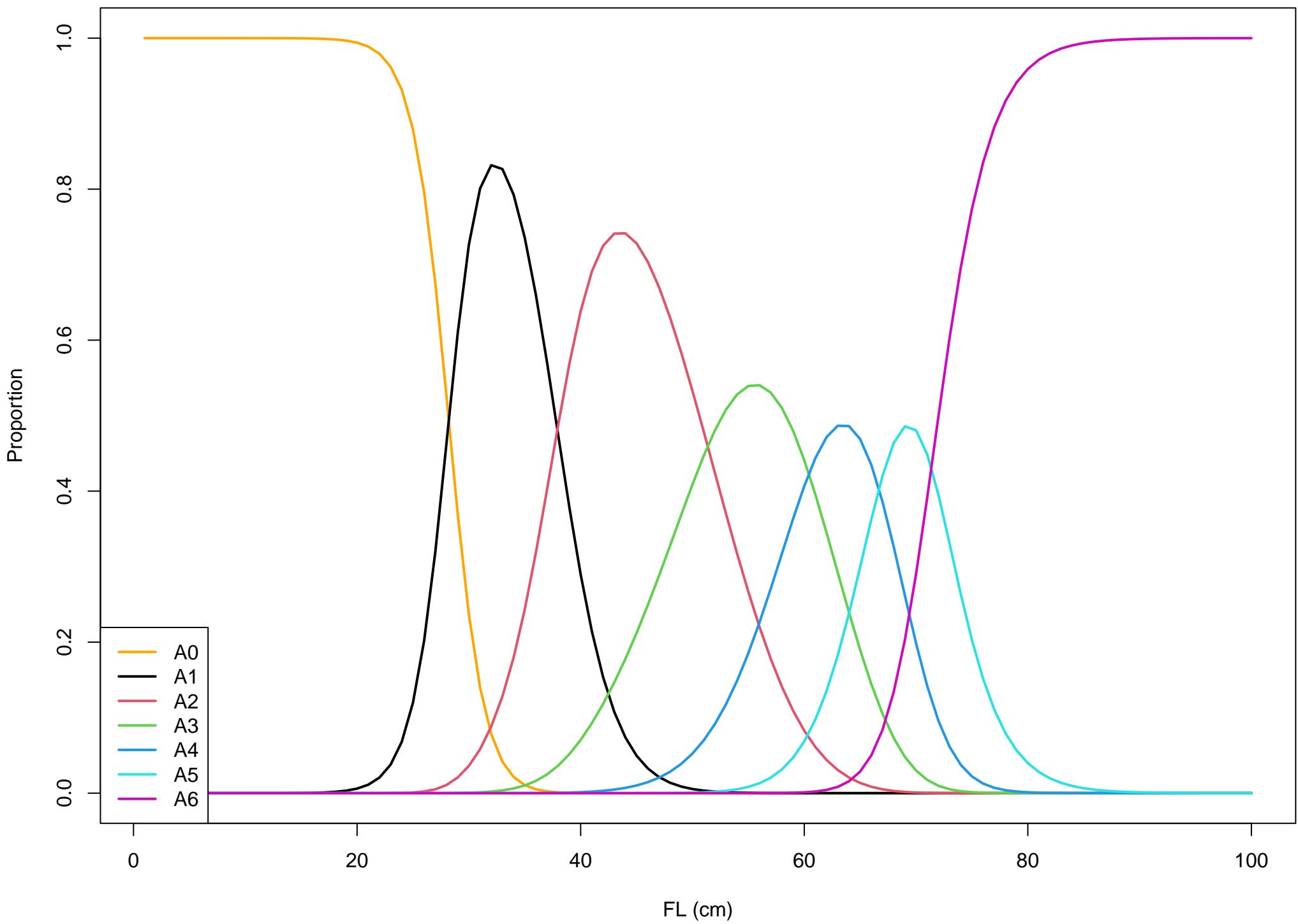
2012
fall



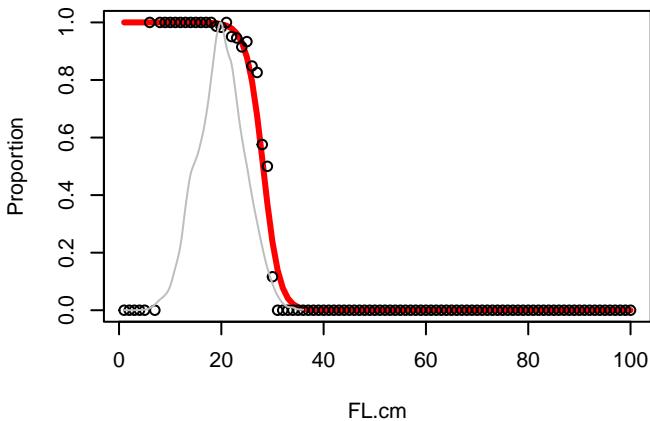
A0, 2012, fall**A1****A2****A3****A4****A5****A6**

All fall
2012 fall pred
2012 fall obs

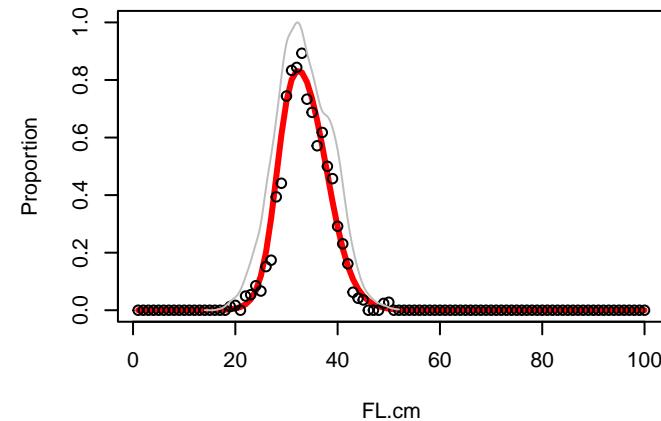
2013
fall



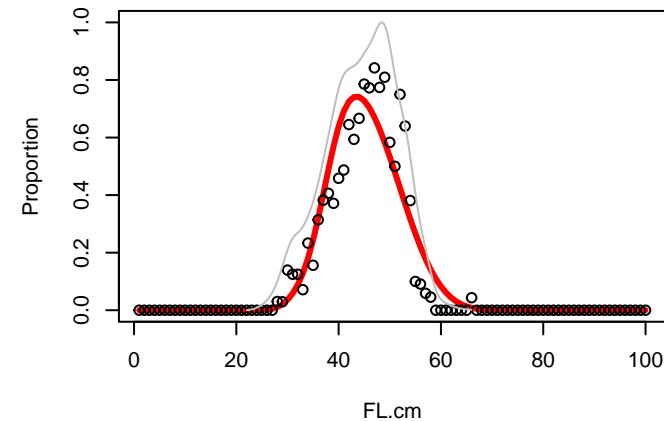
A0, 2013, fall



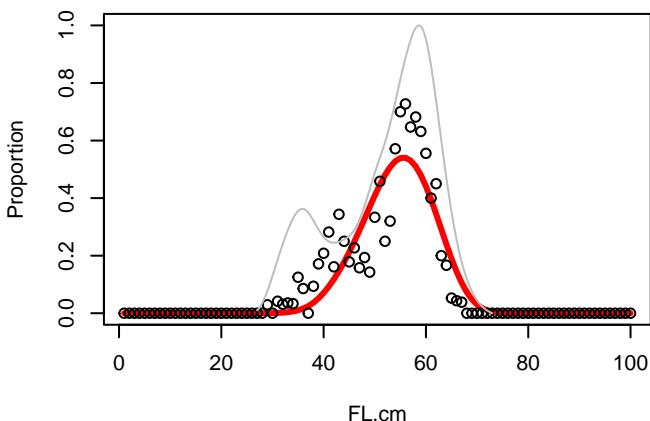
A1



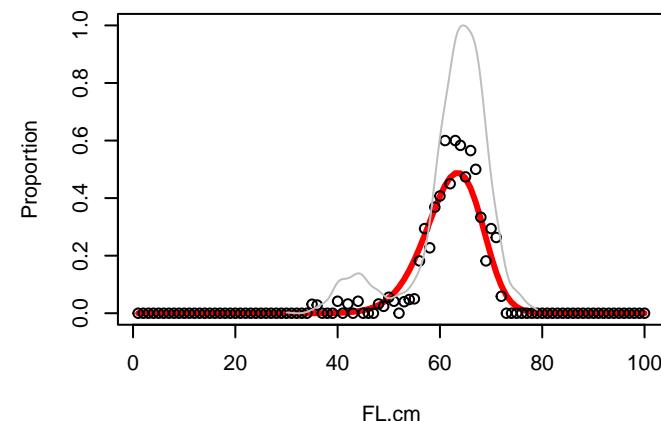
A2



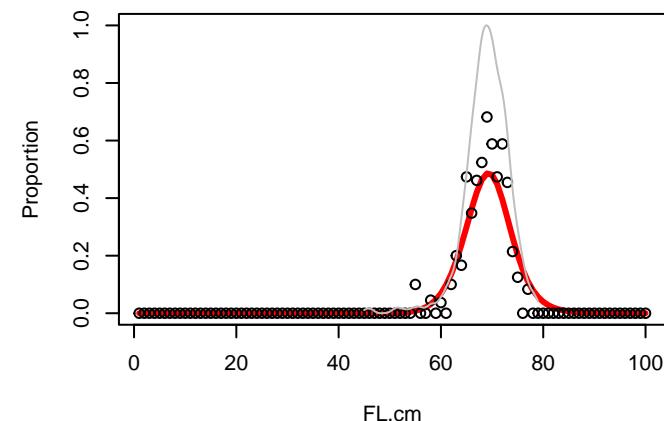
A3



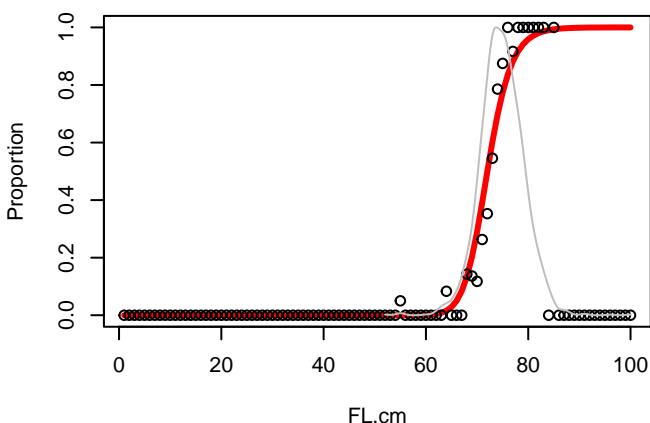
A4



A5

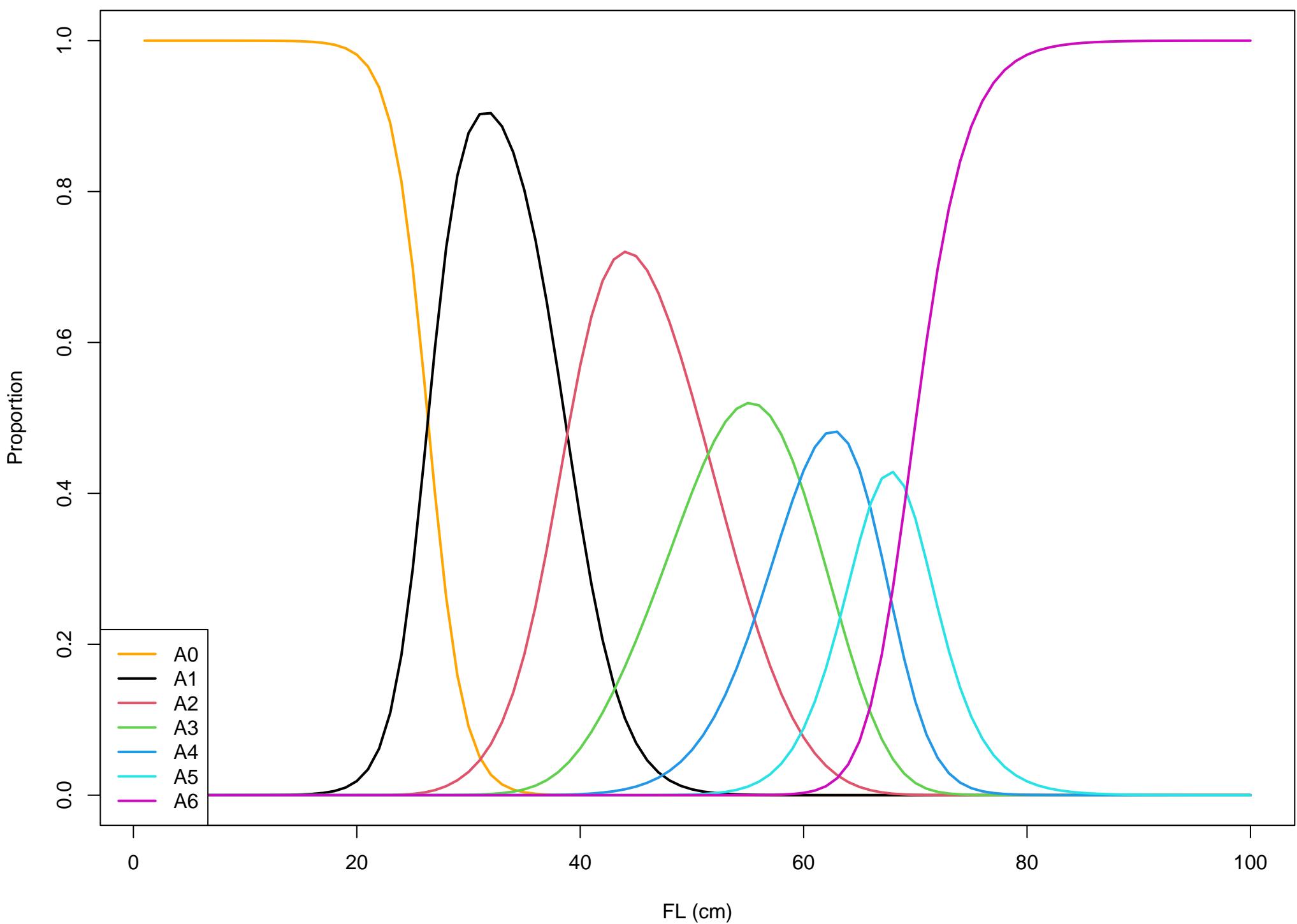


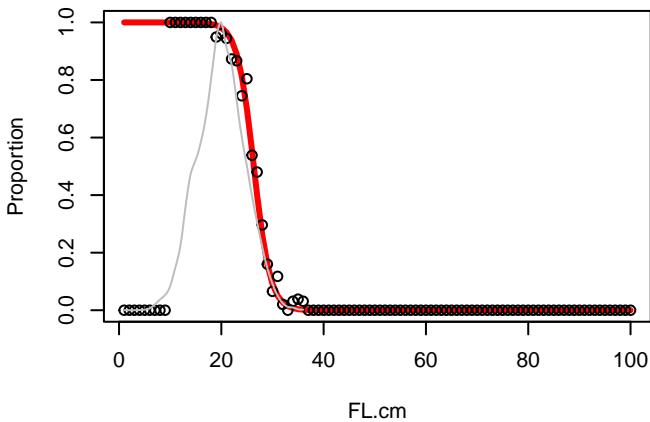
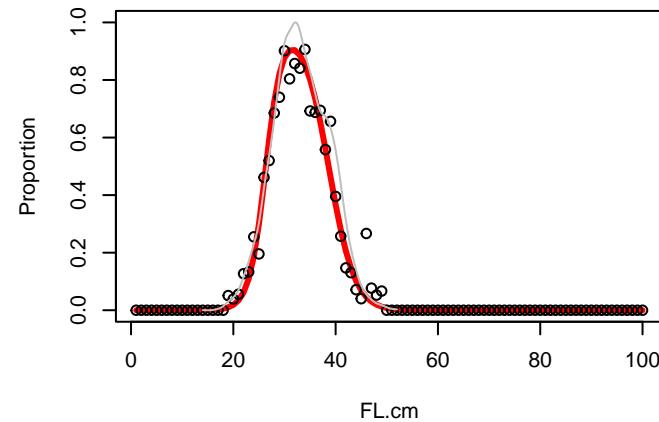
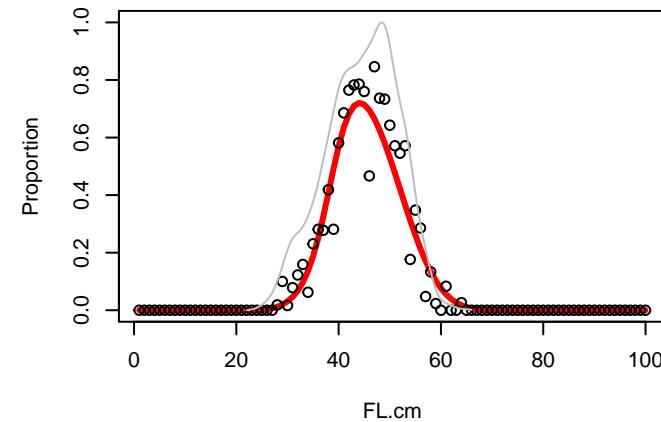
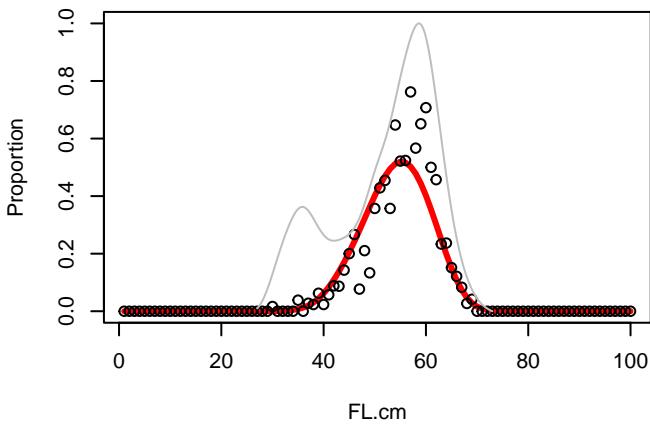
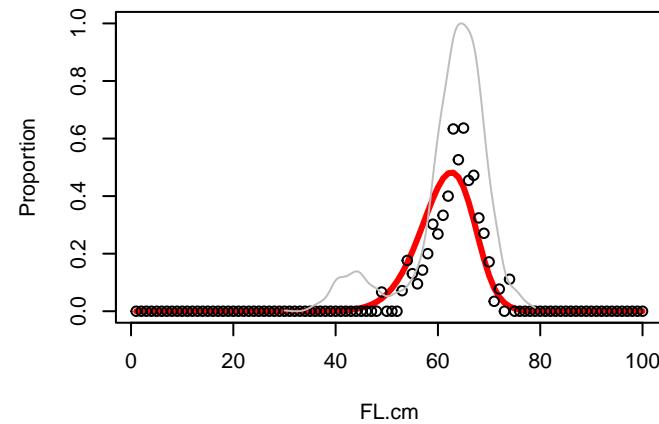
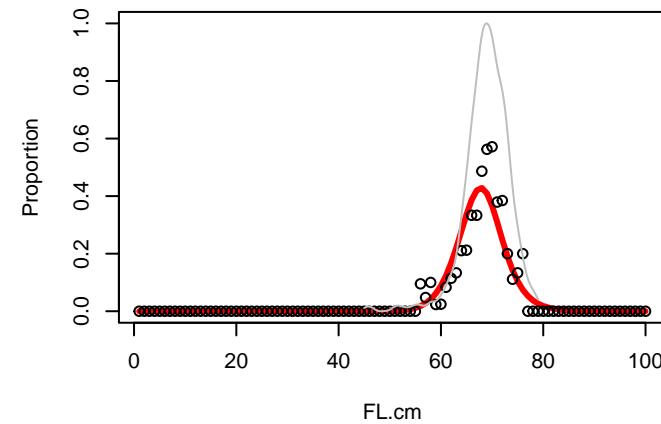
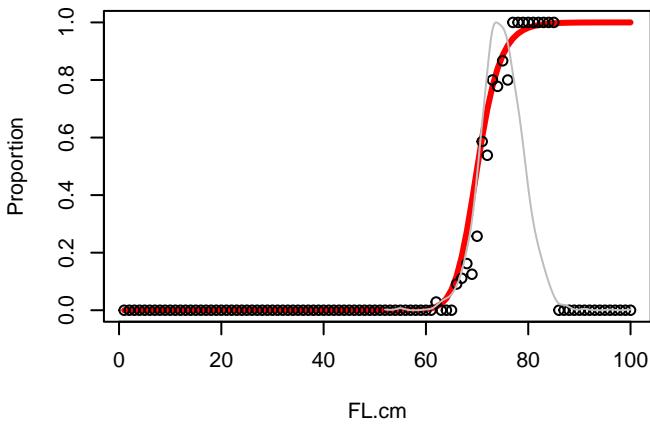
A6



All fall
2013 fall pred
○ 2013 fall obs

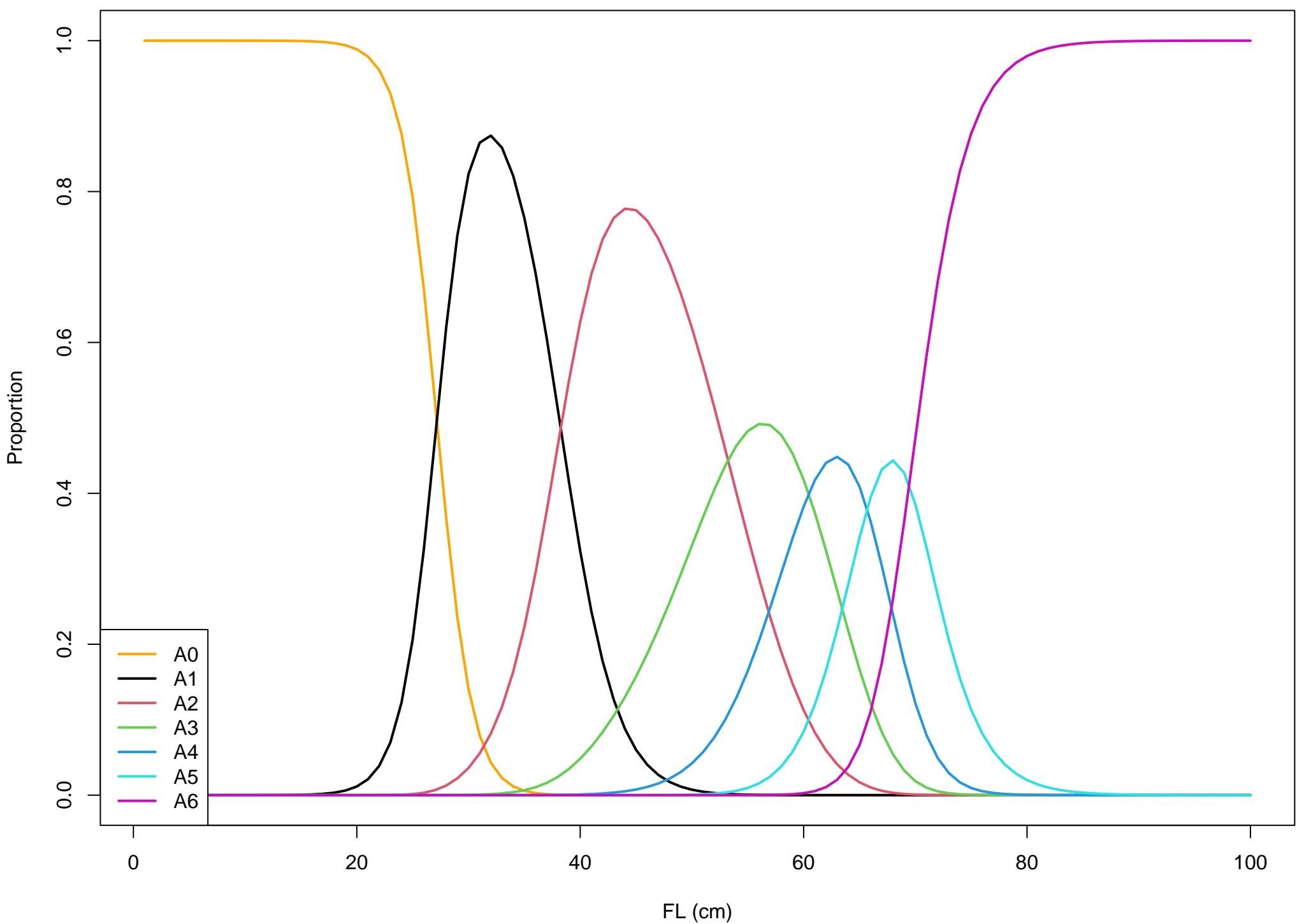
2014
fall

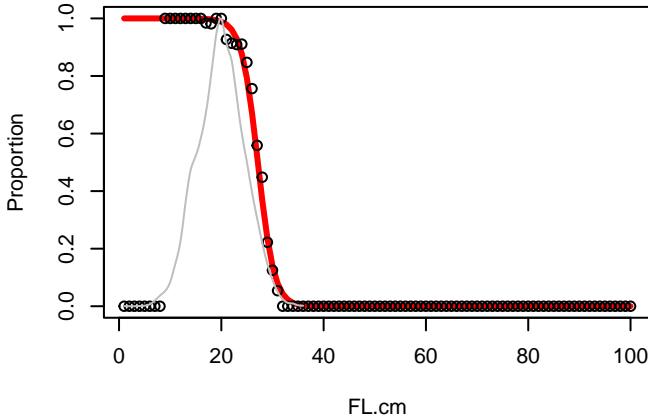
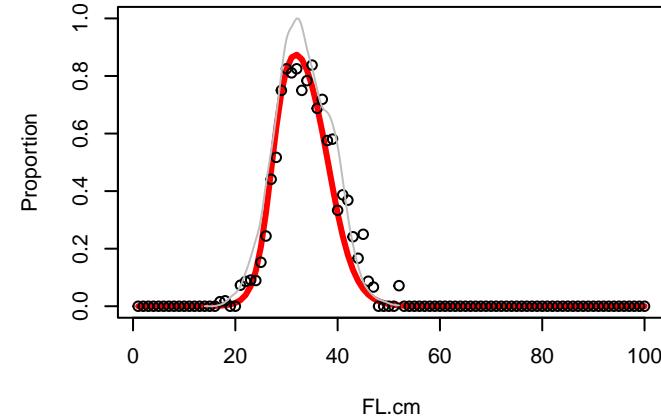
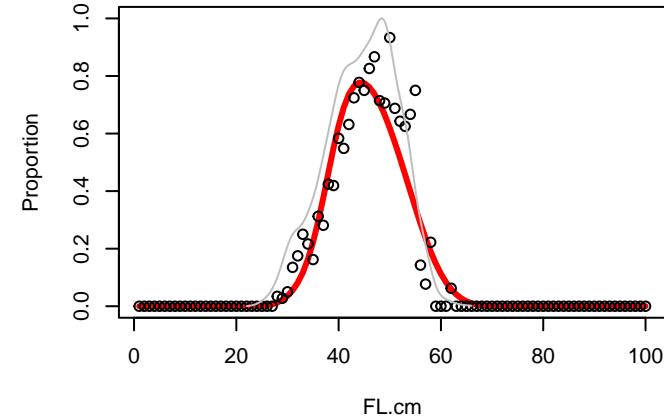
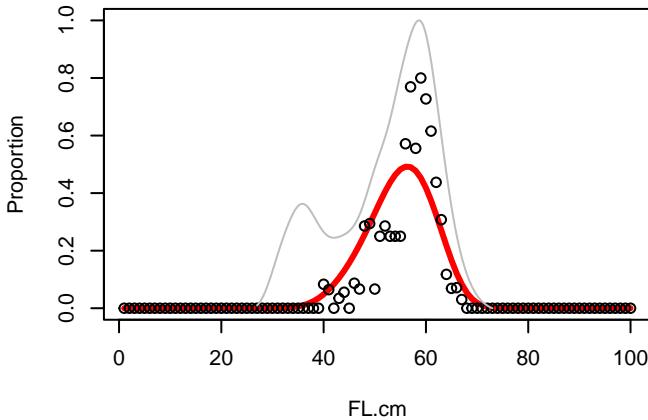
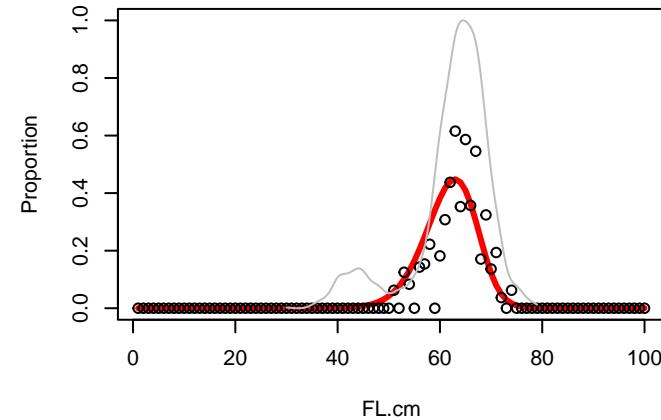
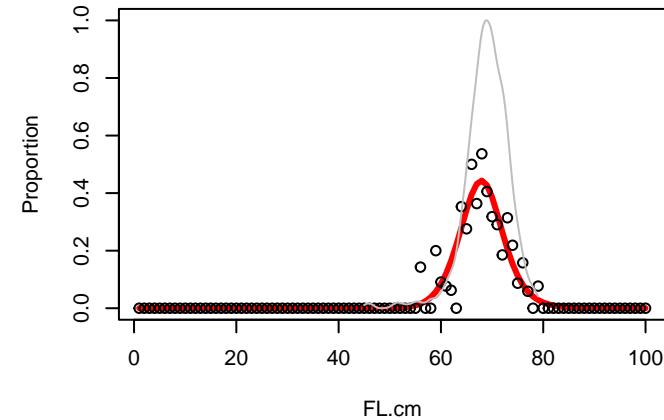
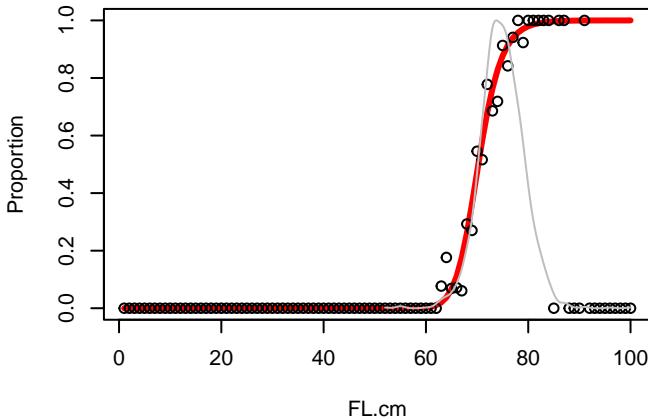


A0, 2014, fall**A1****A2****A3****A4****A5****A6**

All fall
2014 fall pred
2014 fall obs

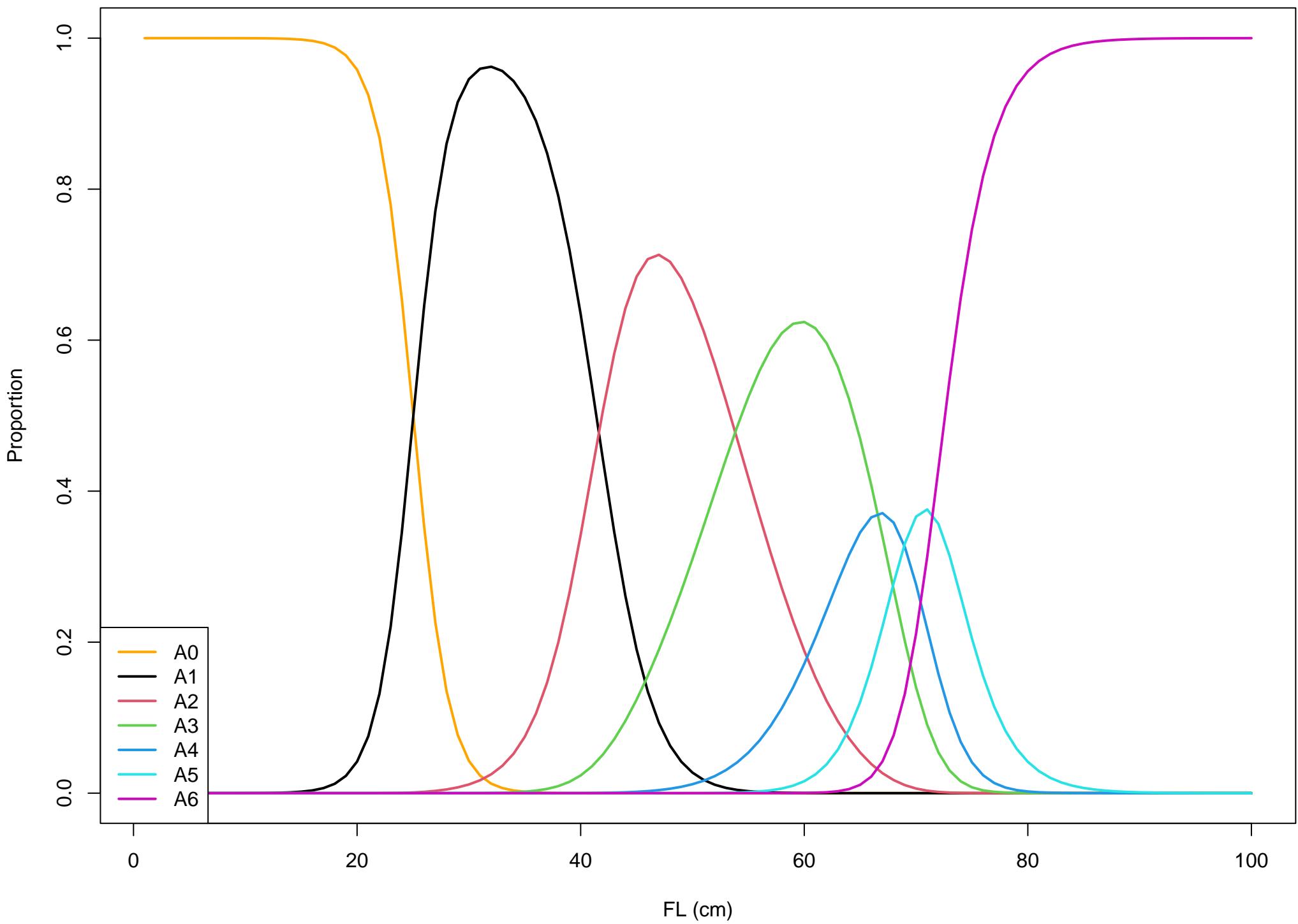
2015
fall

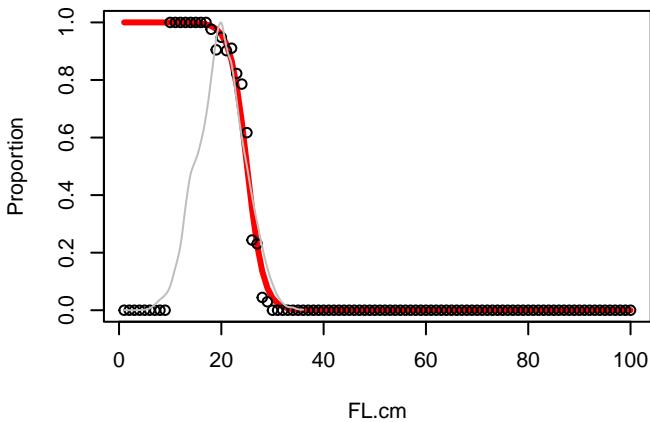
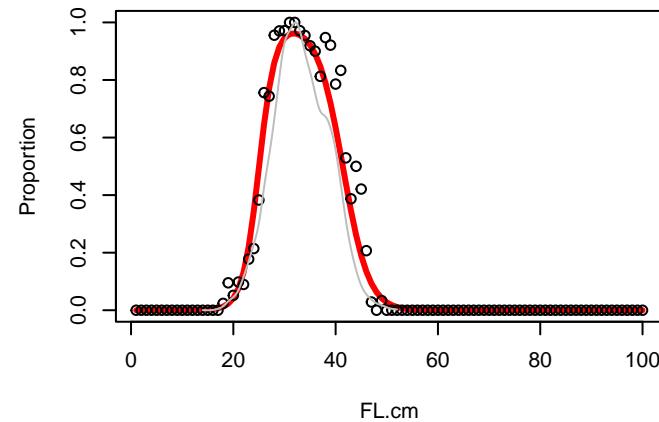
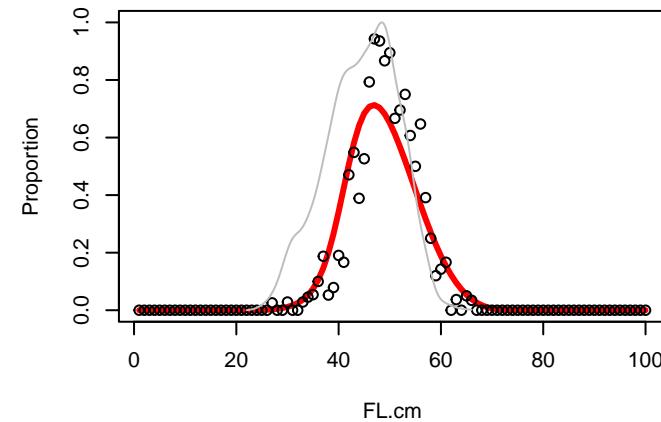
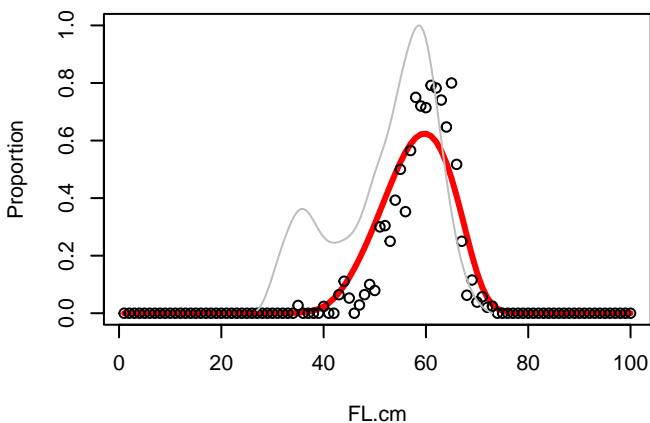
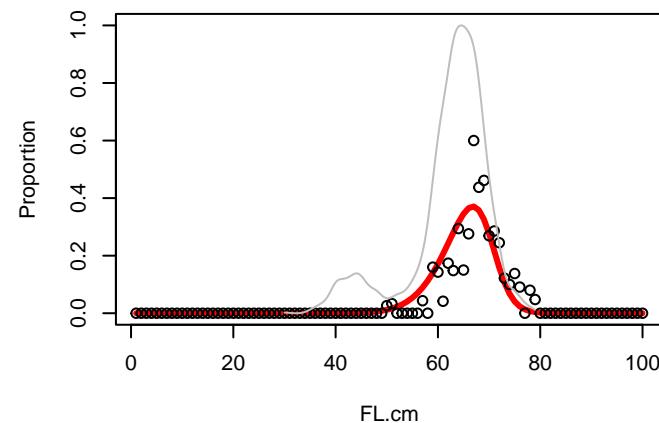
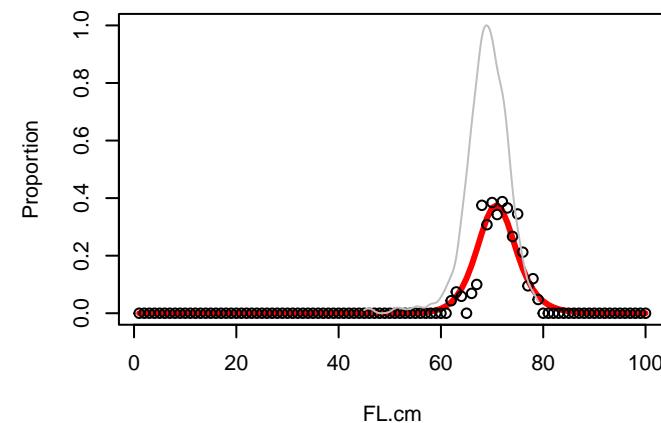
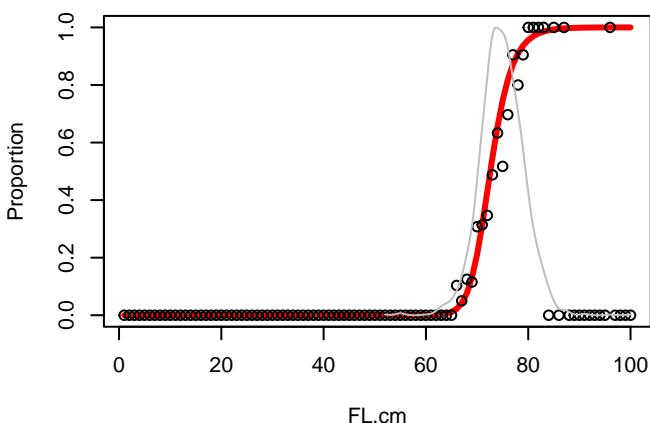


A0, 2015, fall**A1****A2****A3****A4****A5****A6**

All fall
2015 fall pred
○ 2015 fall obs

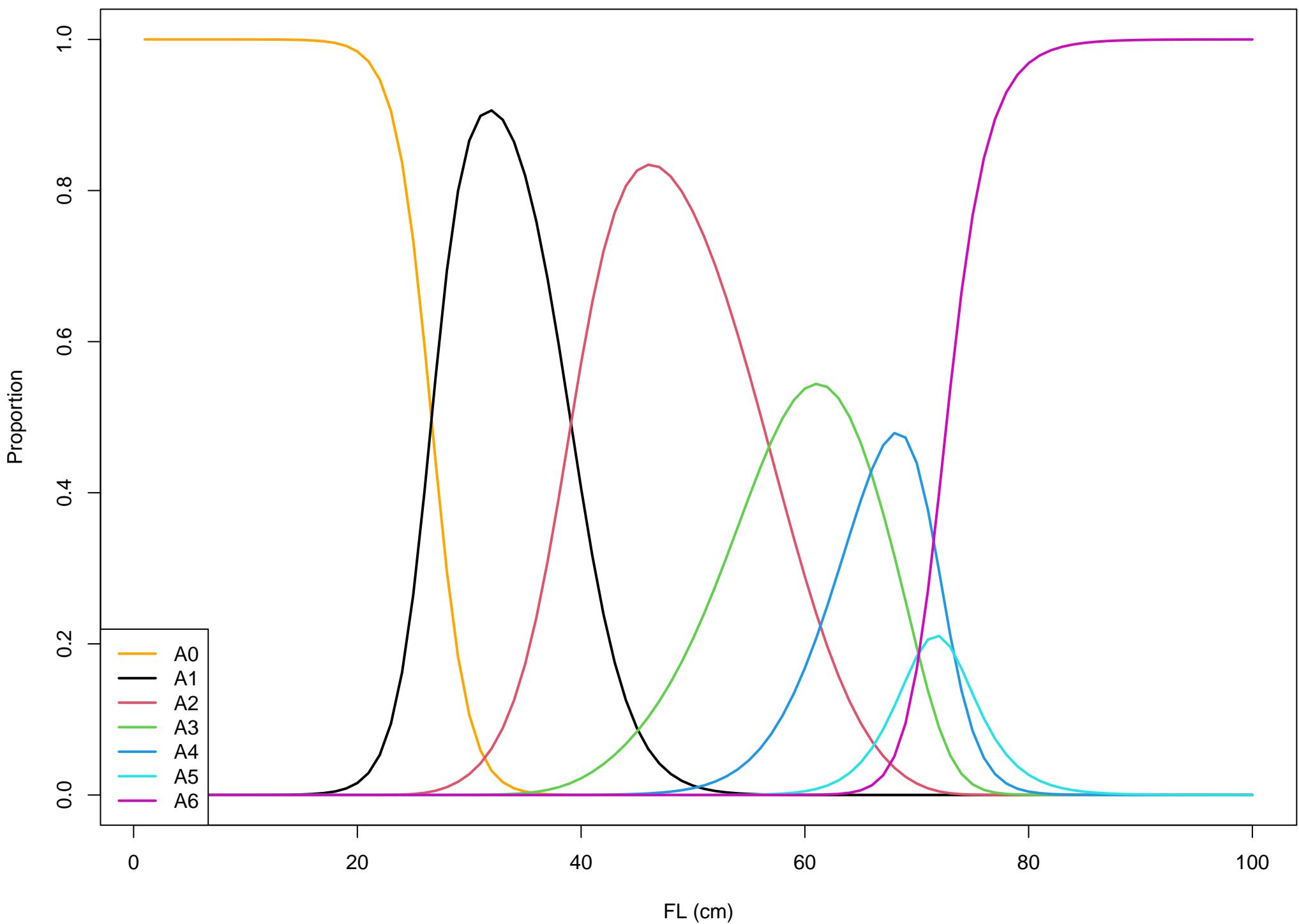
2016
fall

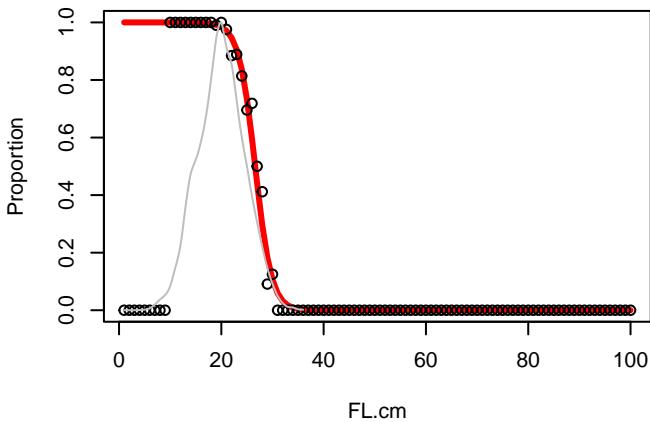
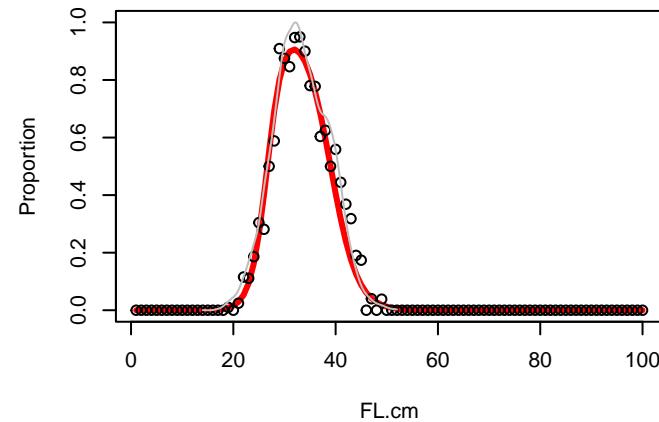
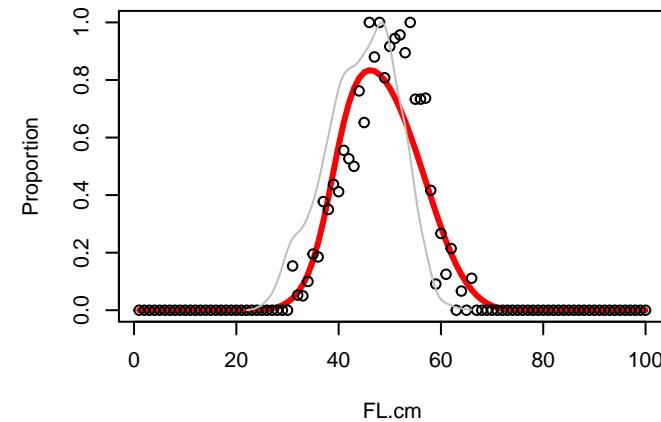
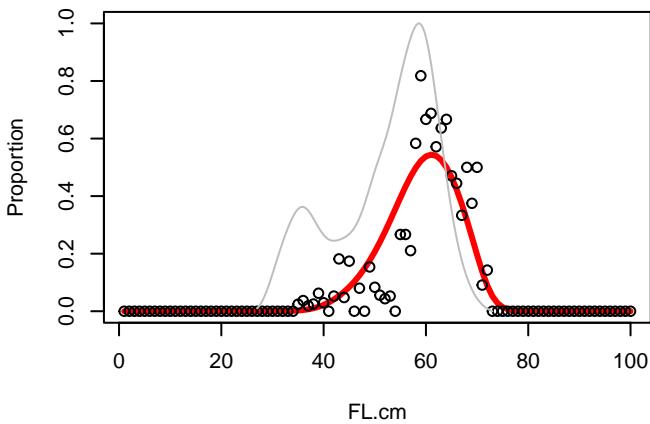
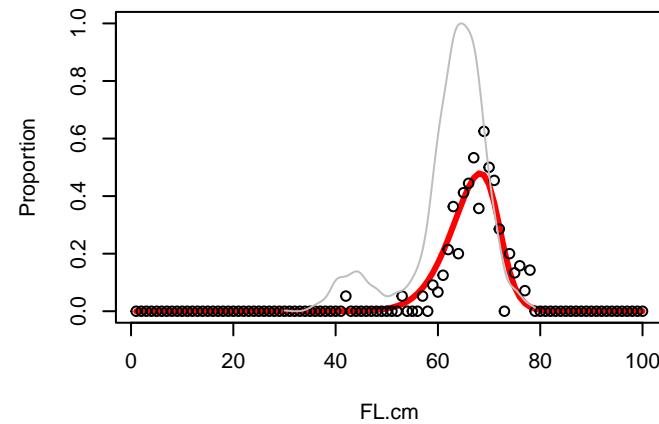
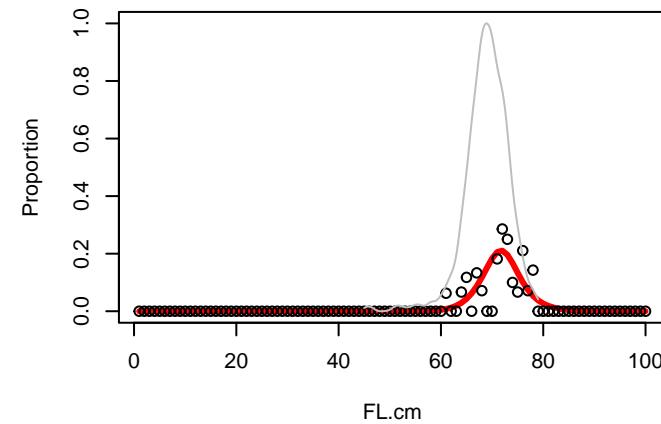
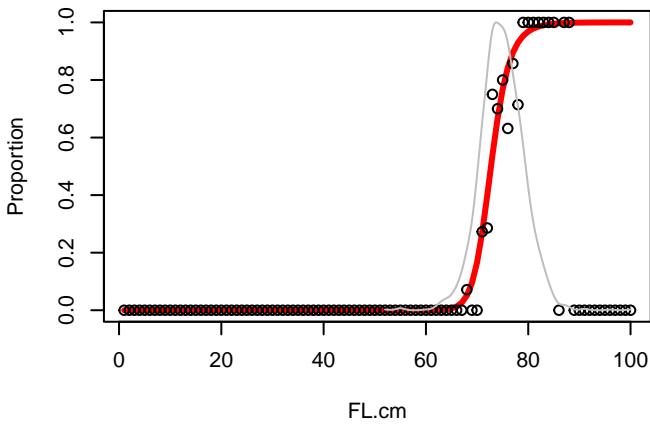


A0, 2016, fall**A1****A2****A3****A4****A5****A6**

All fall
2016 fall pred
○ 2016 fall obs

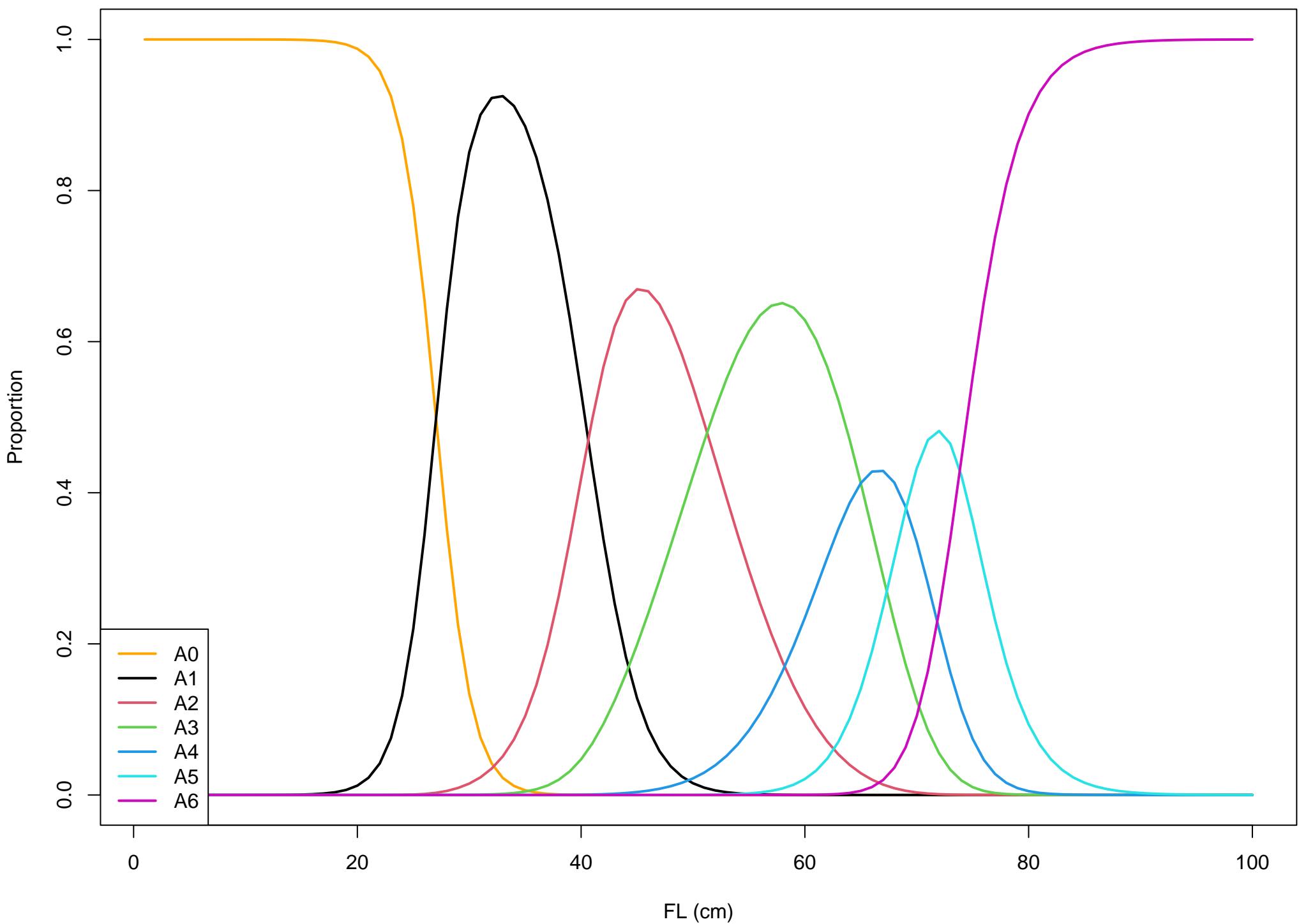
2017
fall

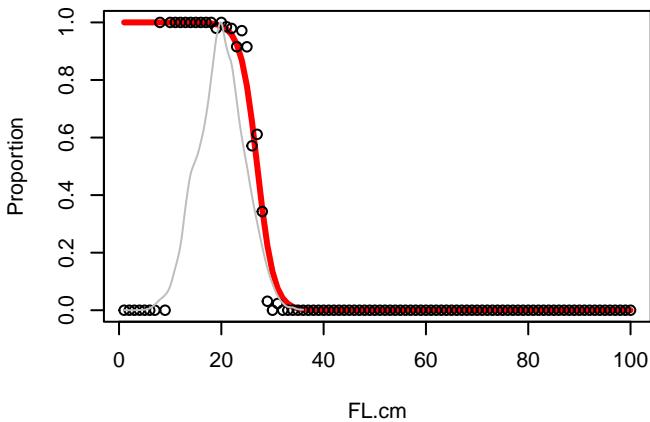
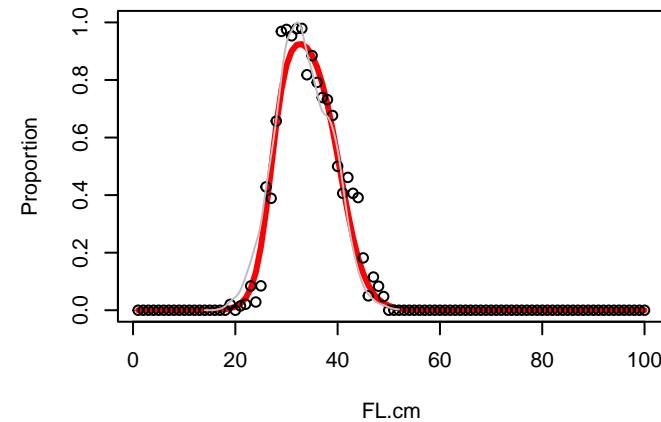
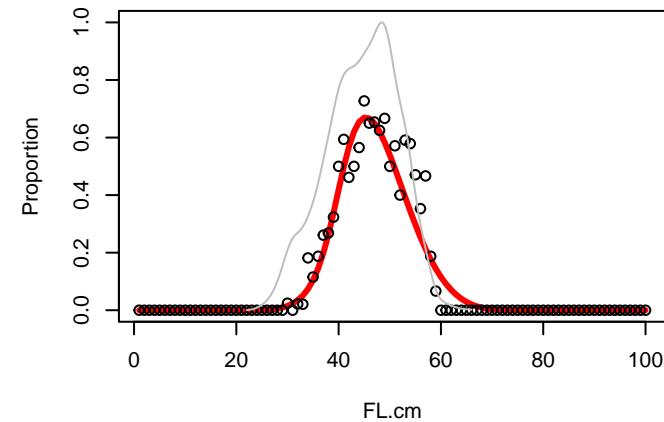
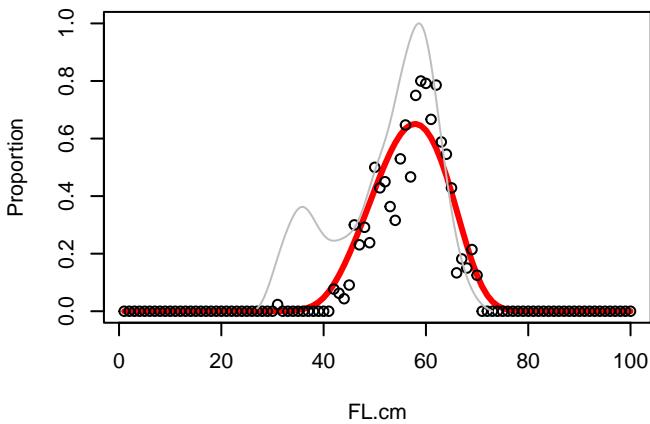
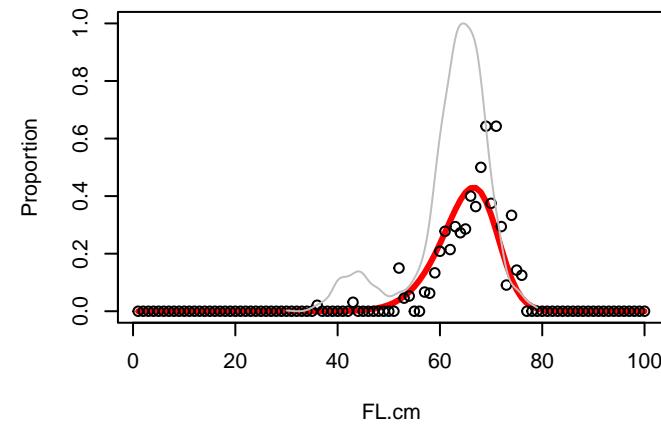
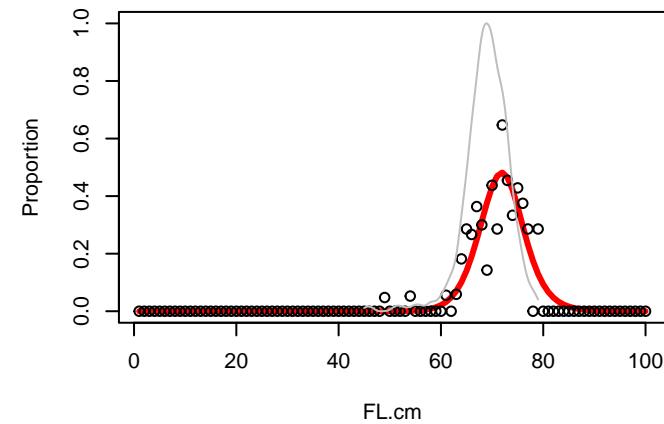
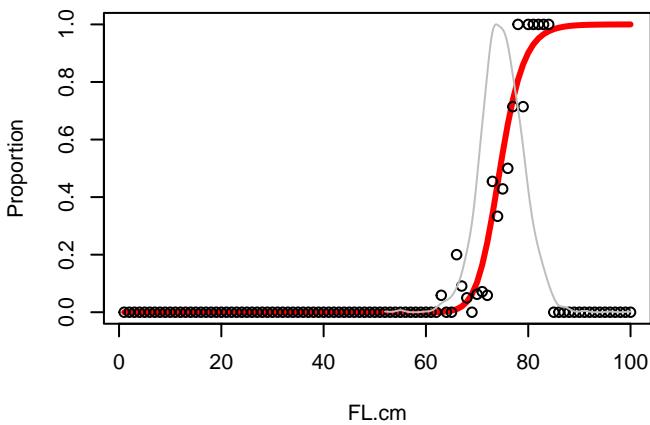


A0, 2017, fall**A1****A2****A3****A4****A5****A6**

All fall
2017 fall pred
○ 2017 fall obs

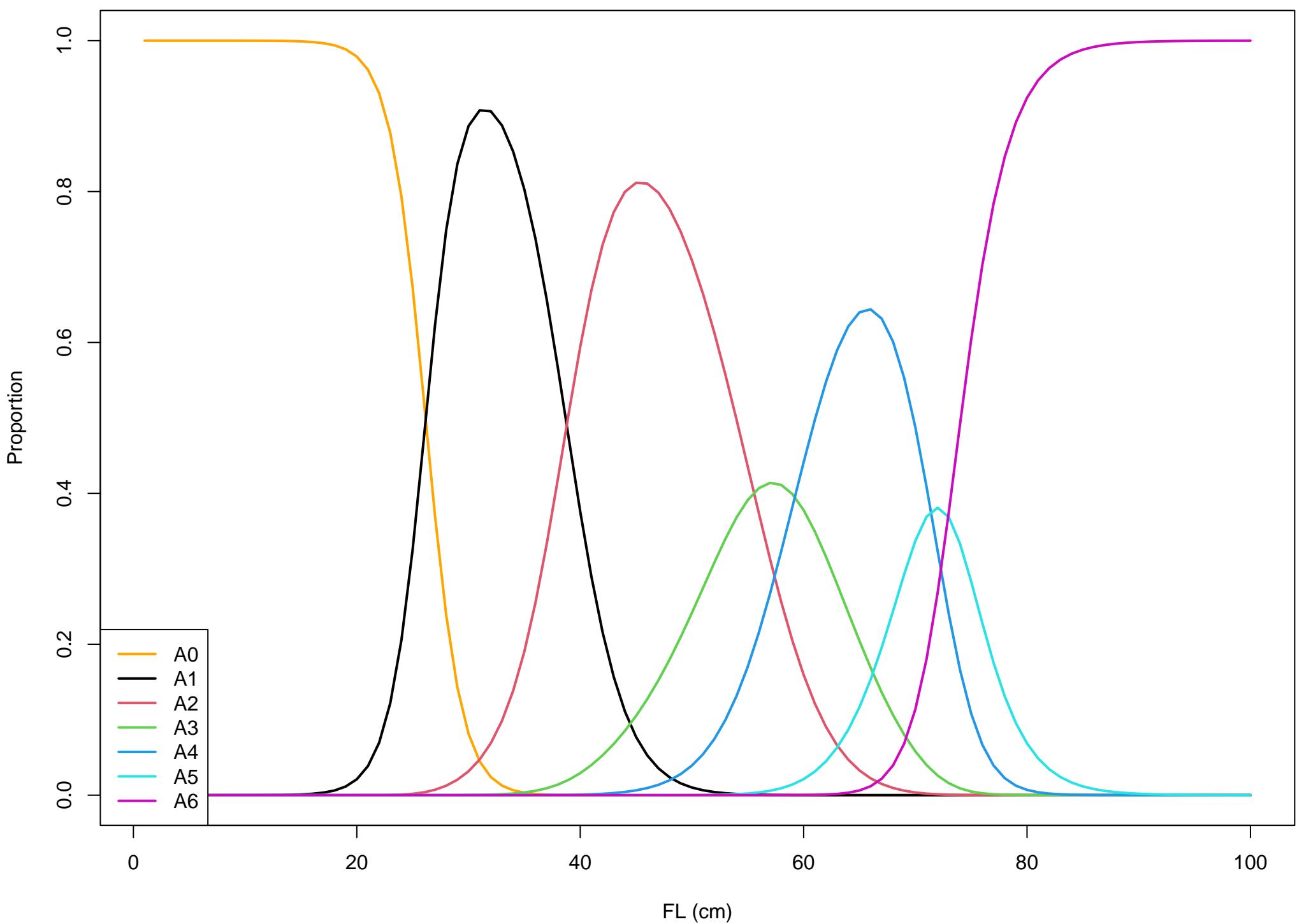
2018
fall

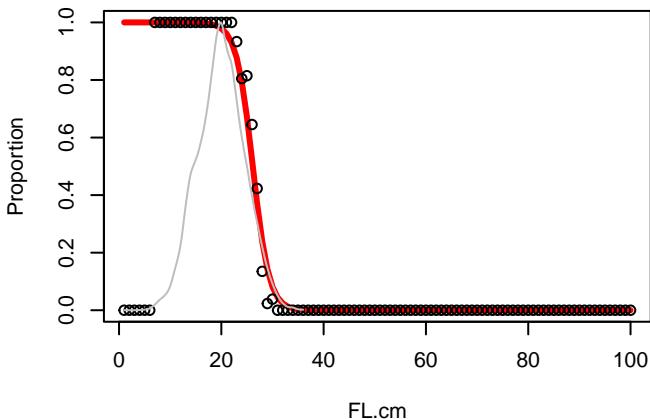
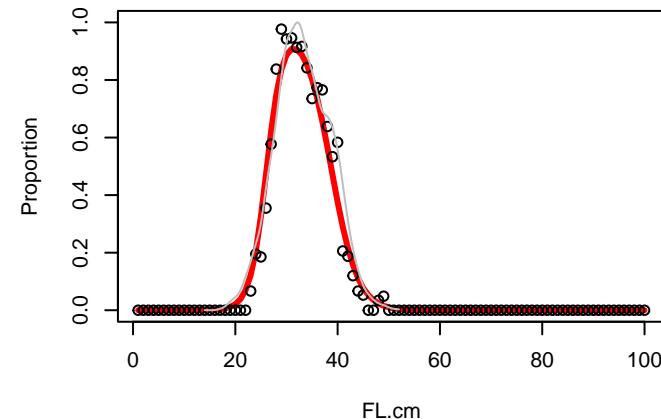
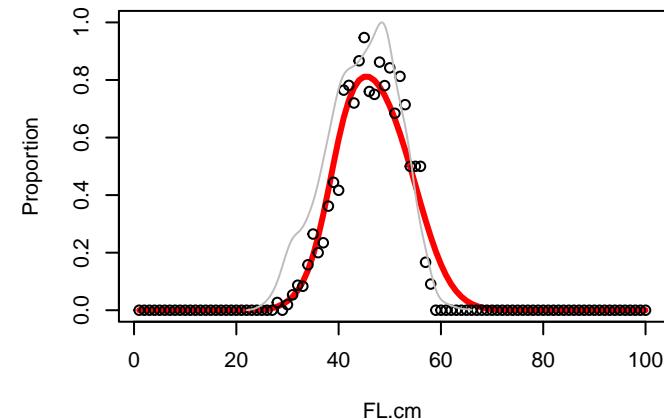
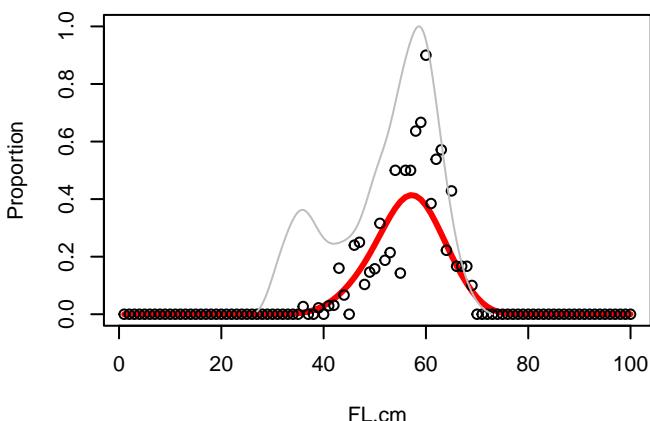
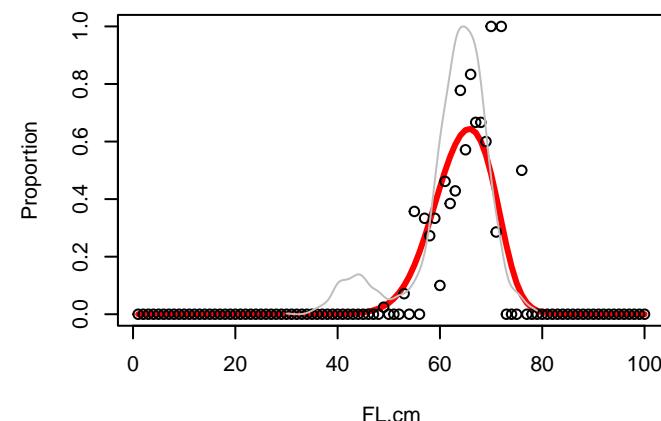
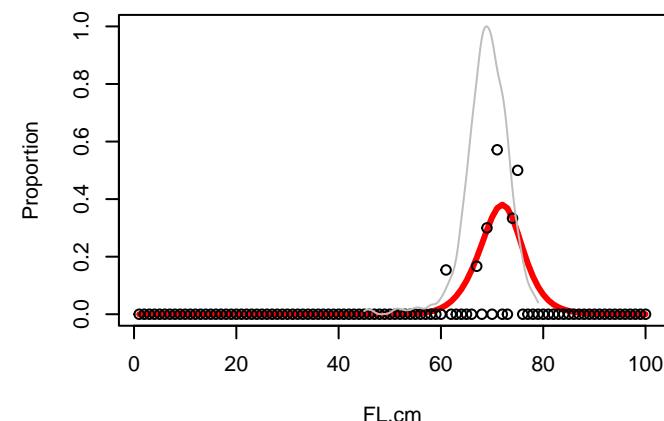
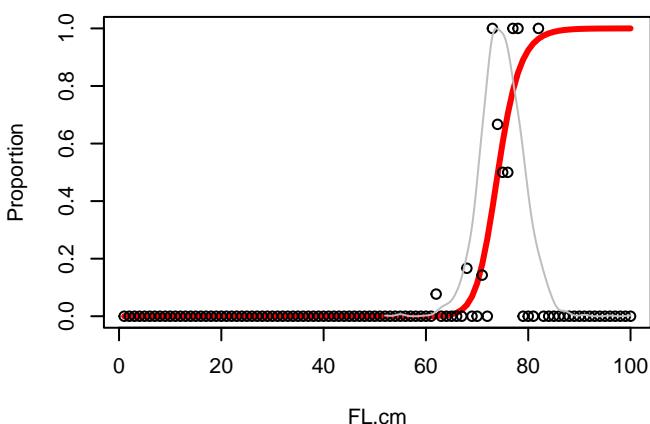


A0, 2018, fall**A1****A2****A3****A4****A5****A6**

— All fall
— 2018 fall pred
○ 2018 fall obs

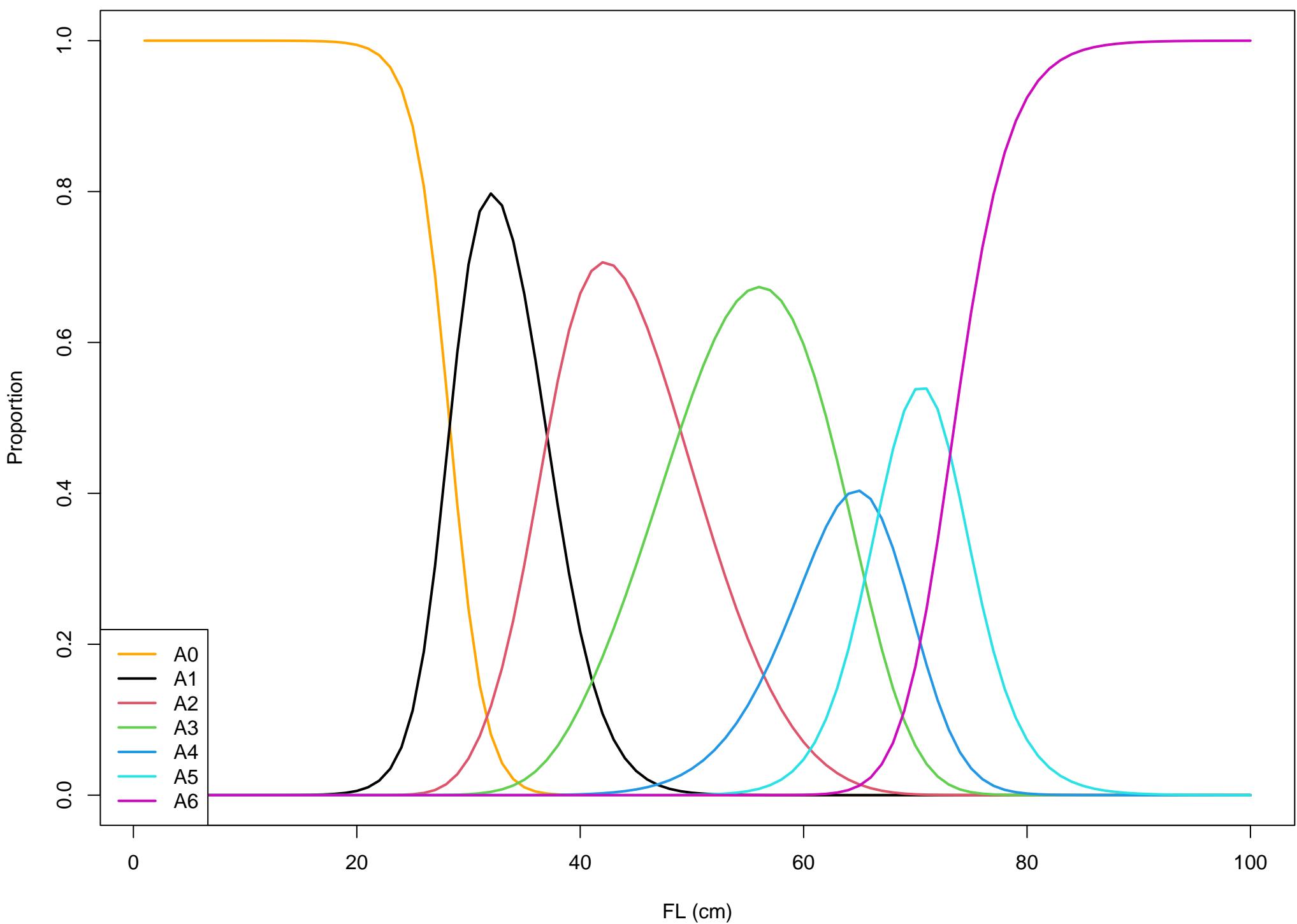
2019
fall

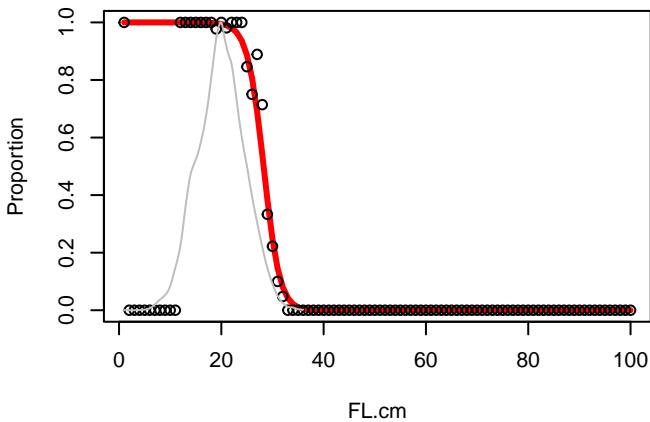
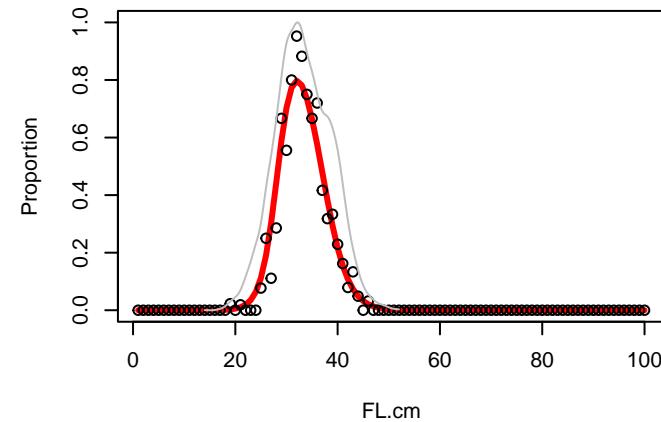
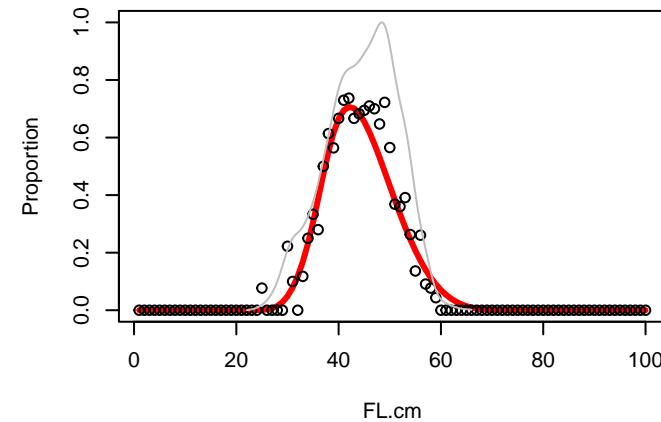
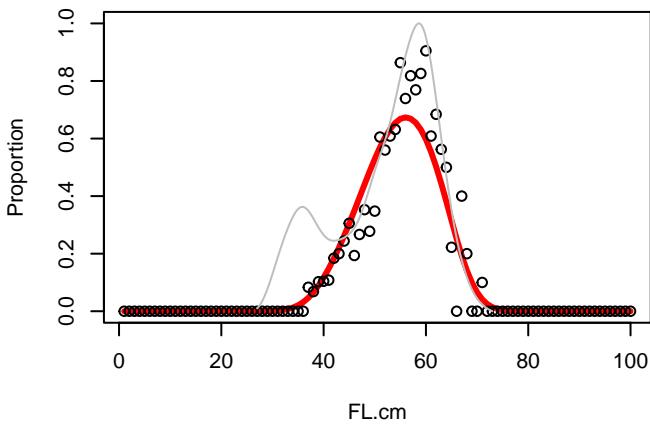
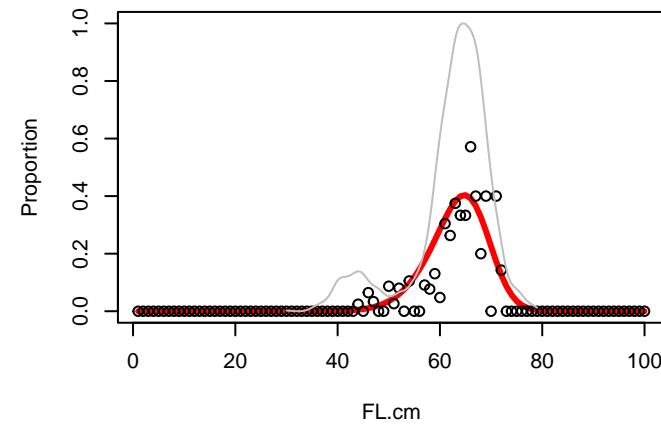
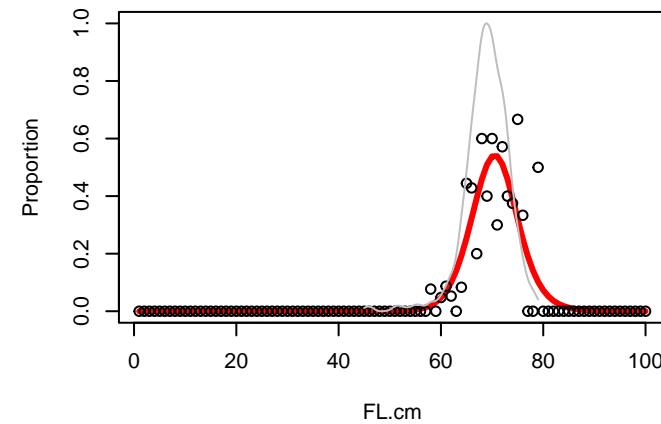
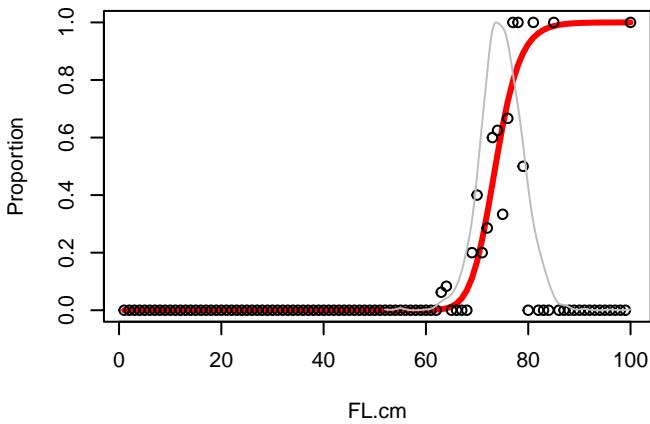


A0, 2019, fall**A1****A2****A3****A4****A5****A6**

All fall
2019 fall pred
2019 fall obs

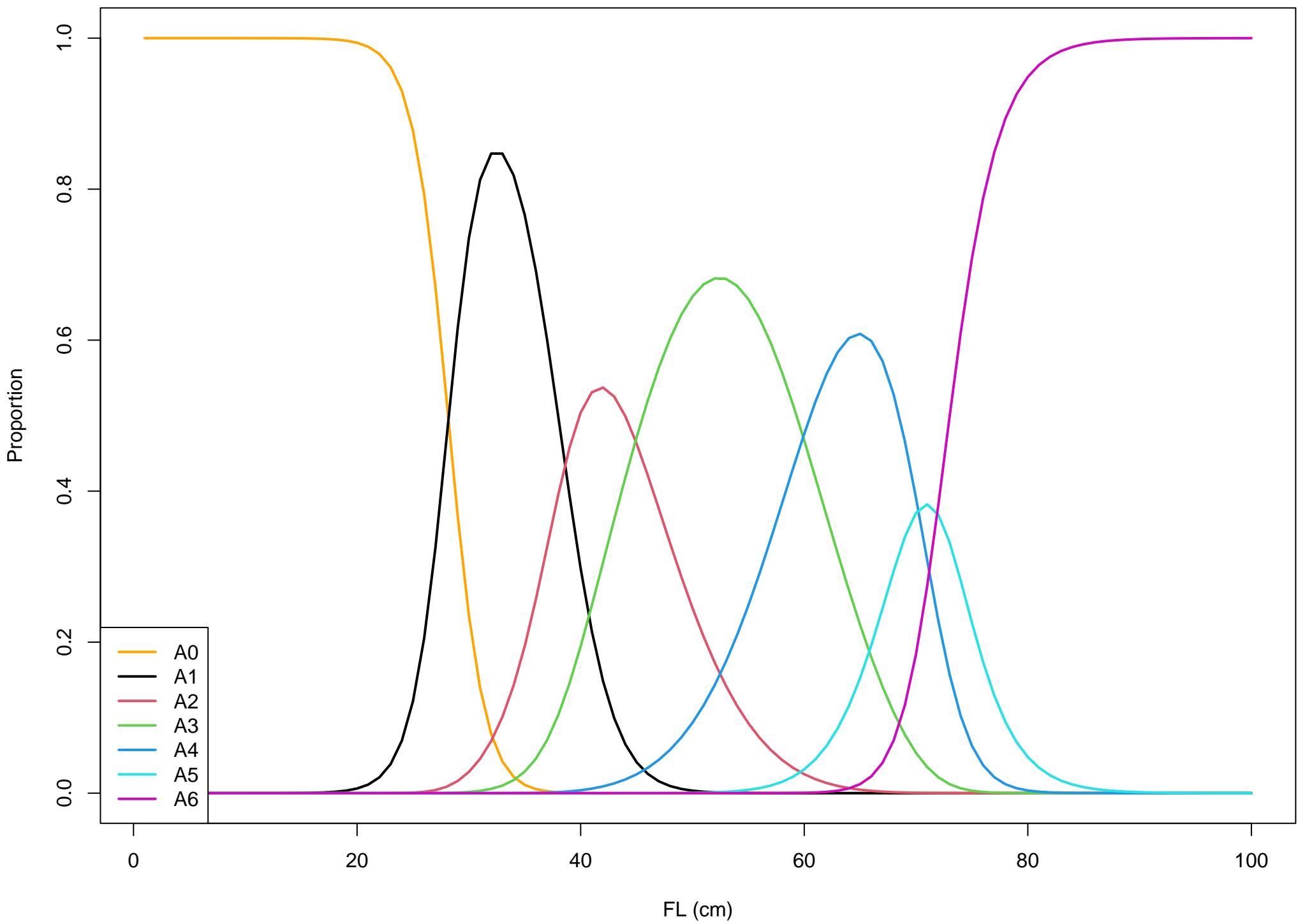
2020
fall

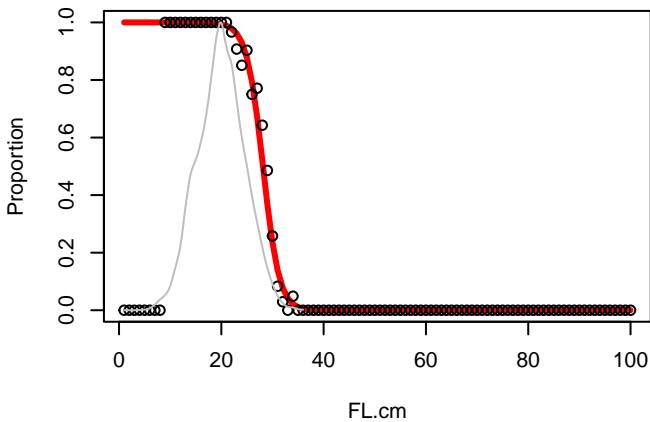
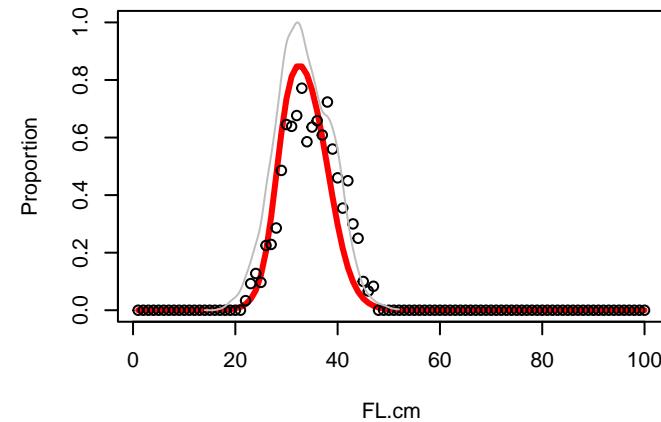
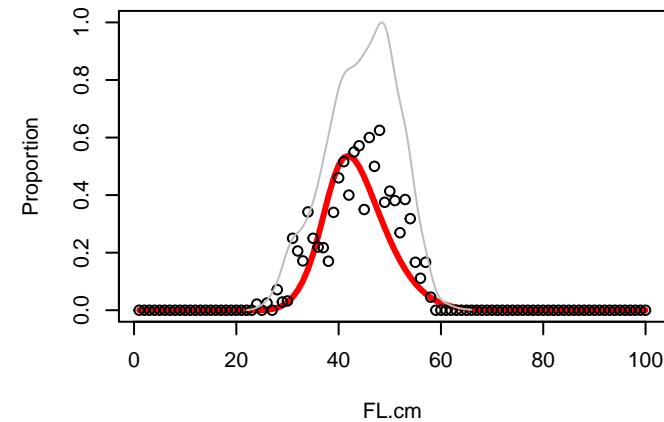
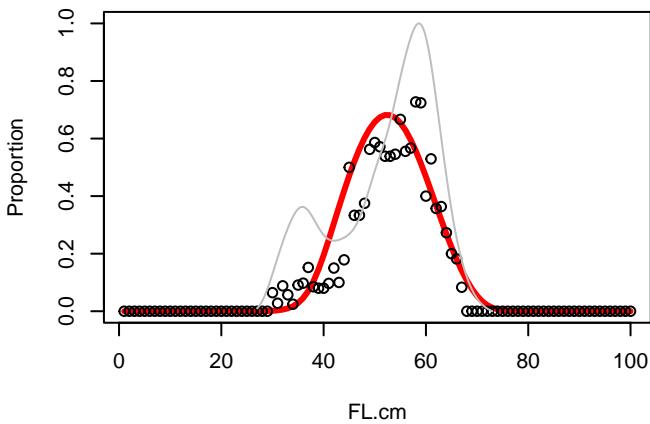
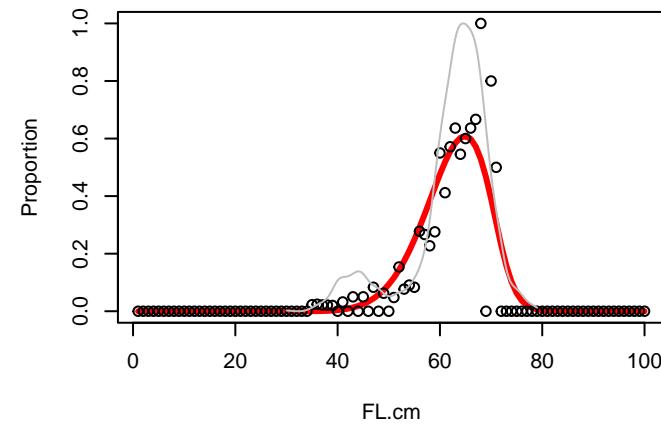
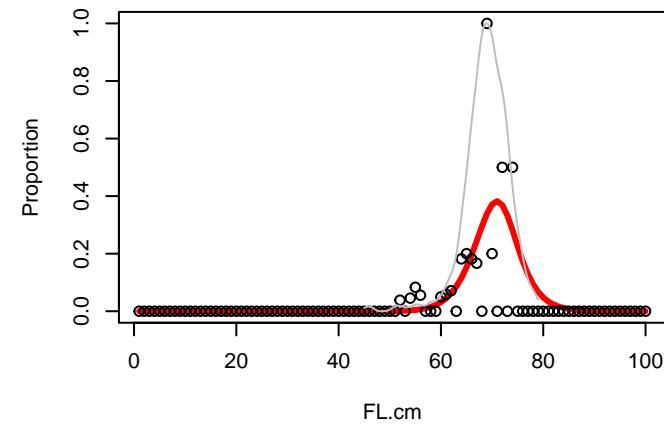
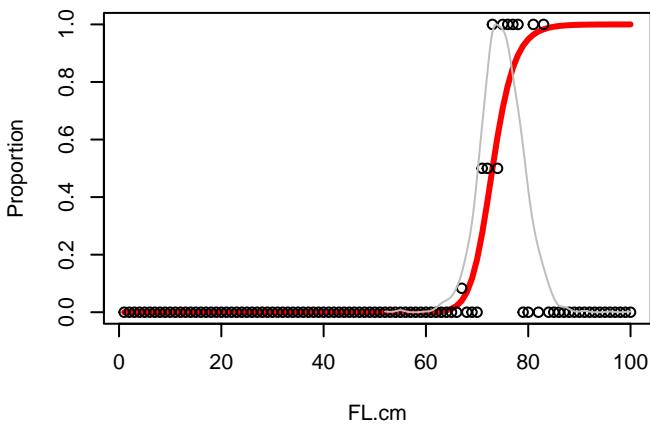


A0, 2020, fall**A1****A2****A3****A4****A5****A6**

All fall
2020 fall pred
2020 fall obs

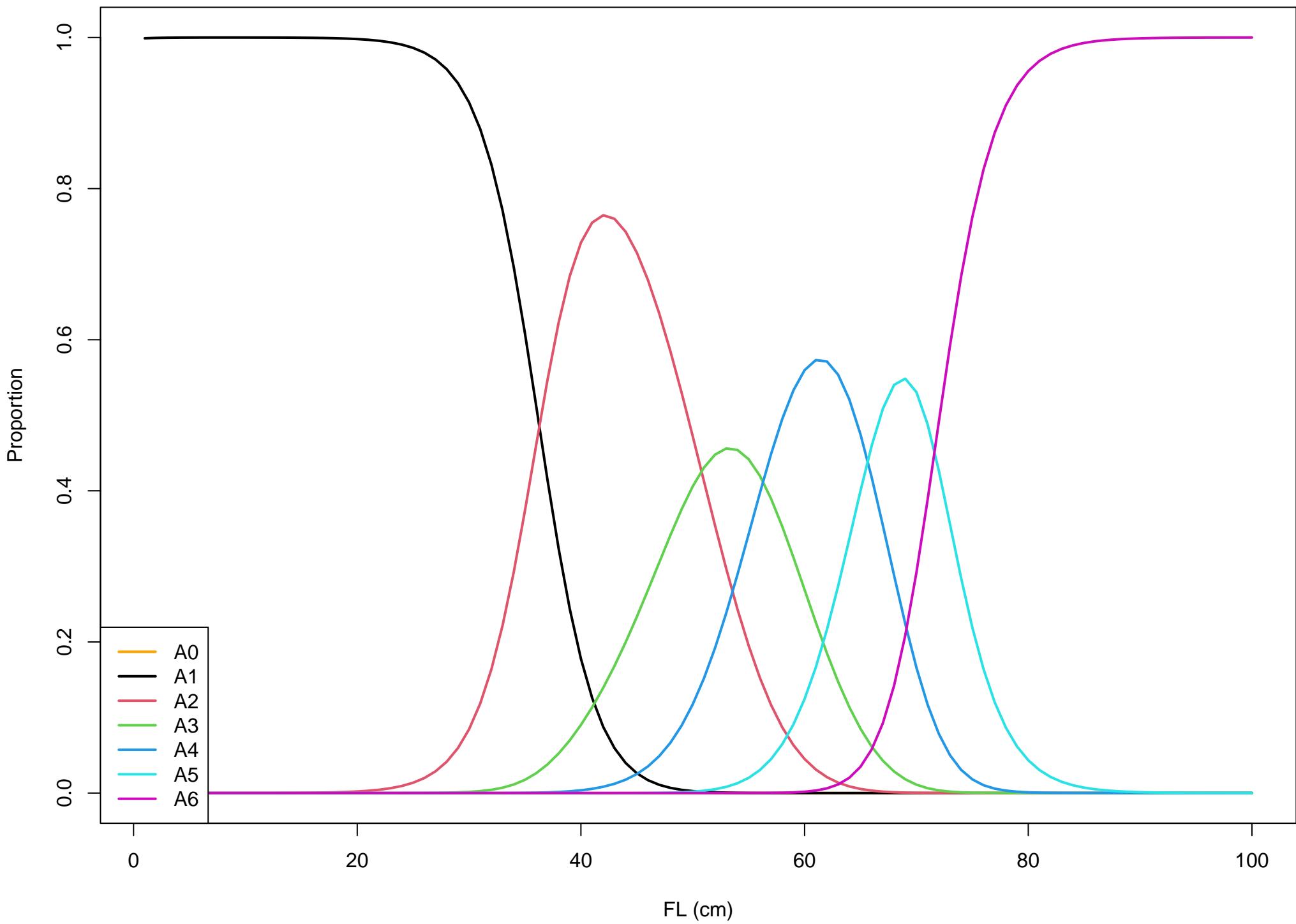
2021
fall



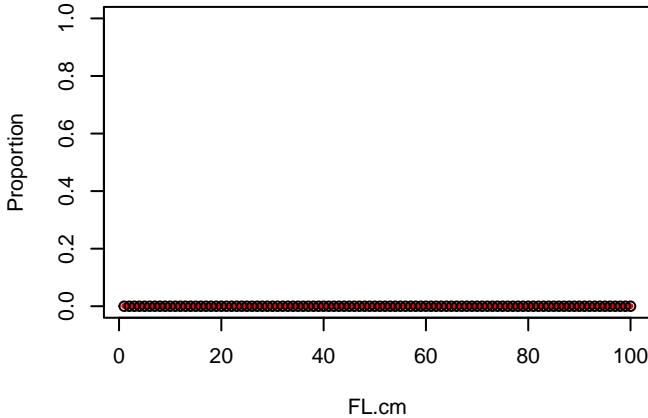
A0, 2021, fall**A1****A2****A3****A4****A5****A6**

All fall
2021 fall pred
○ 2021 fall obs

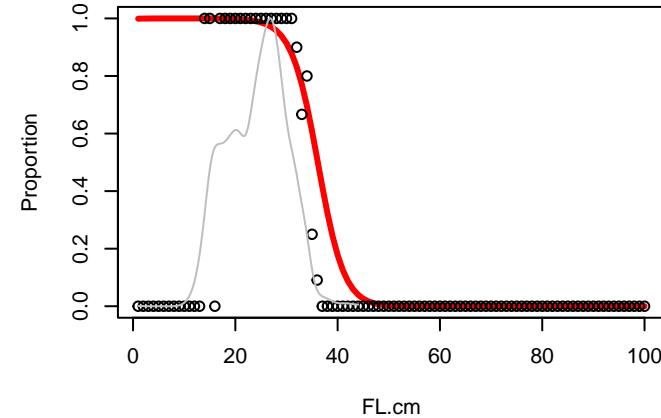
**1985
spring**



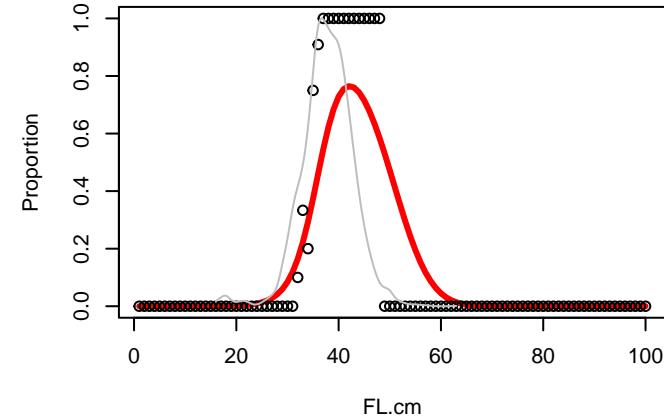
A0, 1985, spring



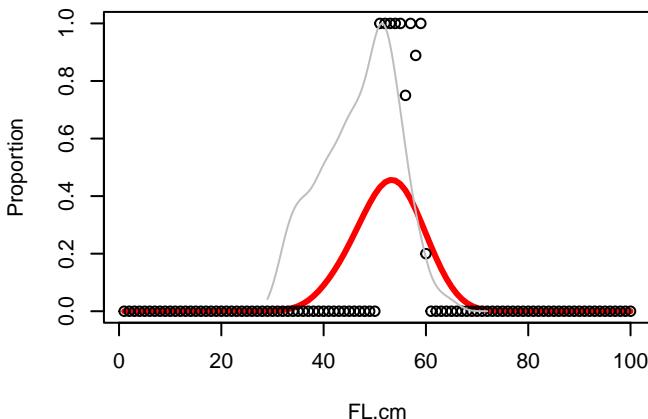
A1



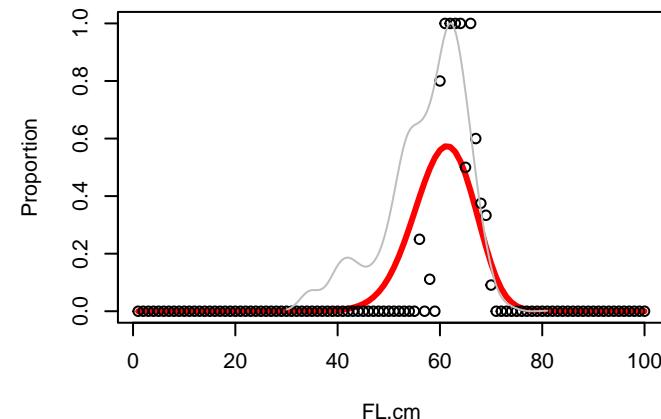
A2



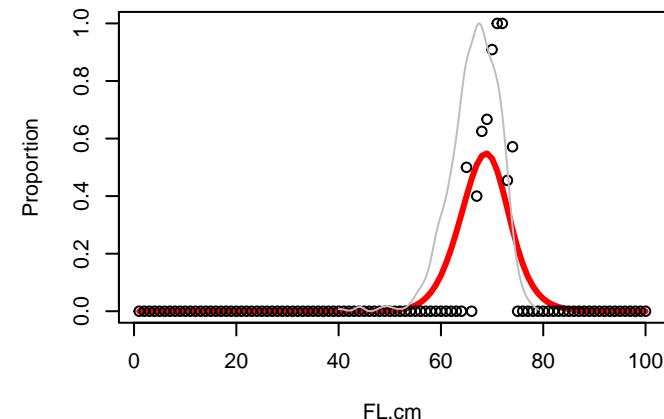
A3



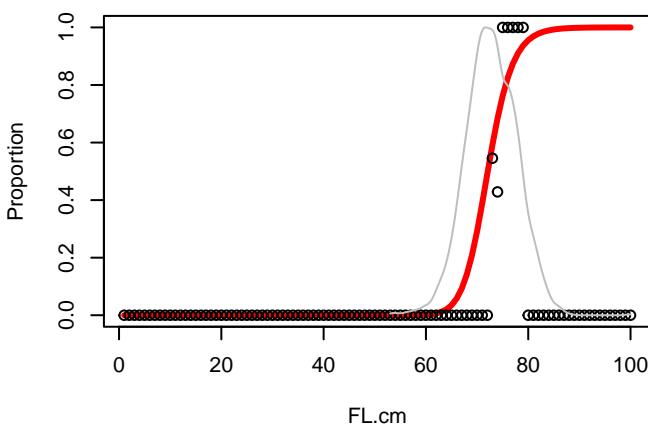
A4



A5

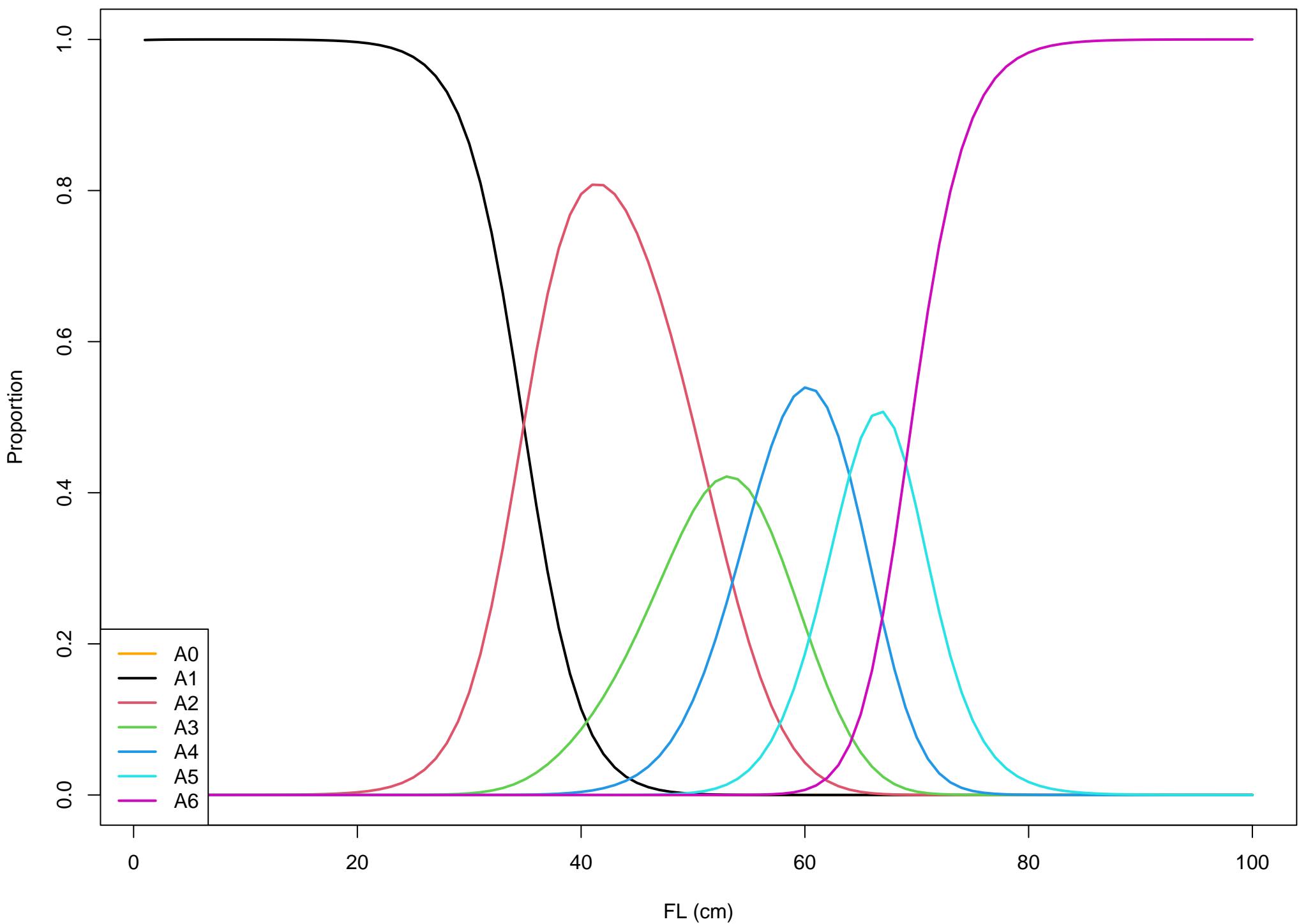


A6

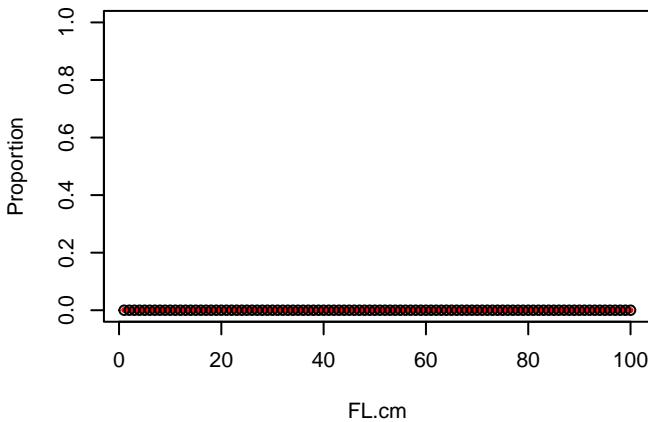


All spring
1985 spring pred
○ 1985 spring obs

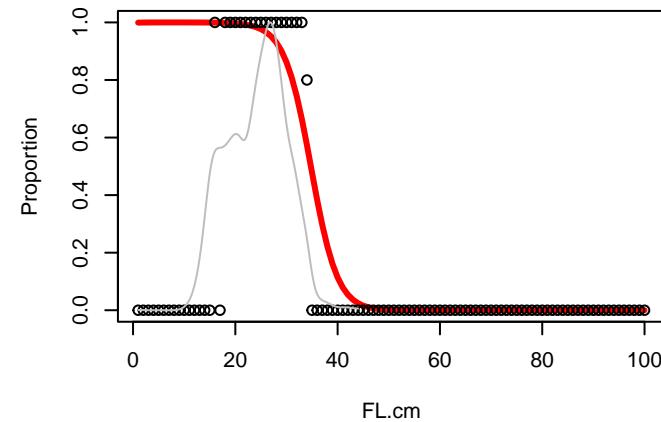
1986
spring



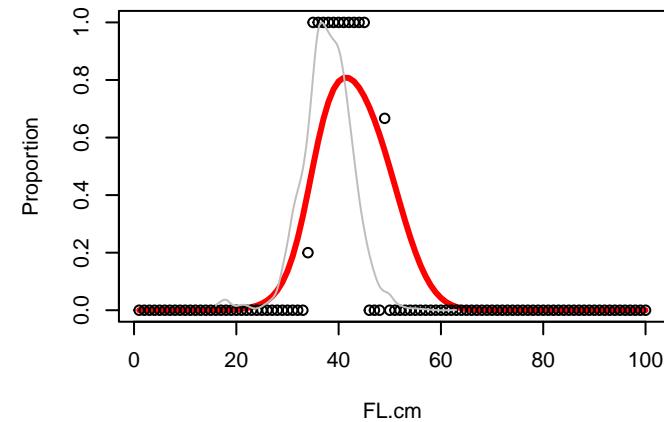
A0, 1986, spring



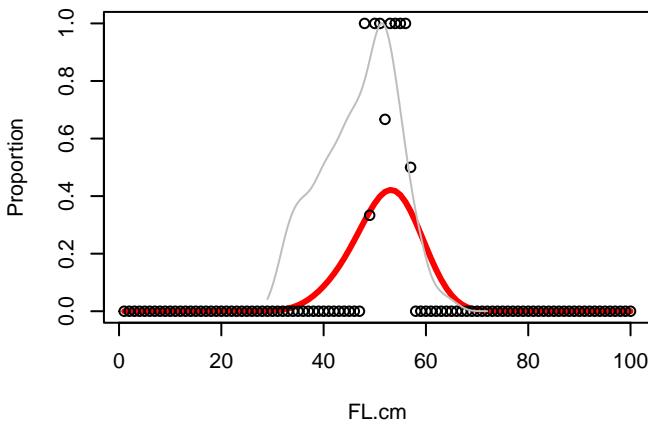
A1



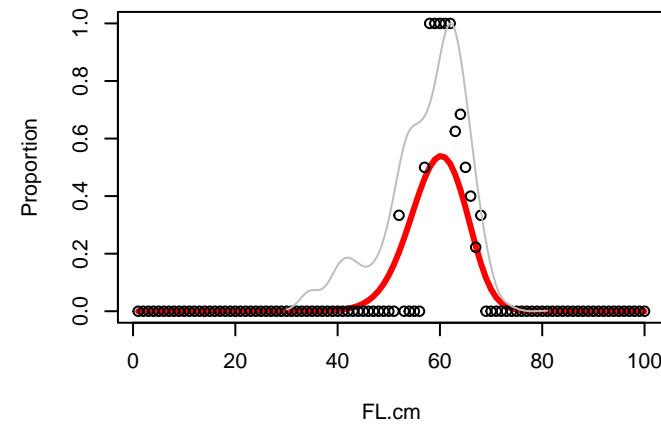
A2



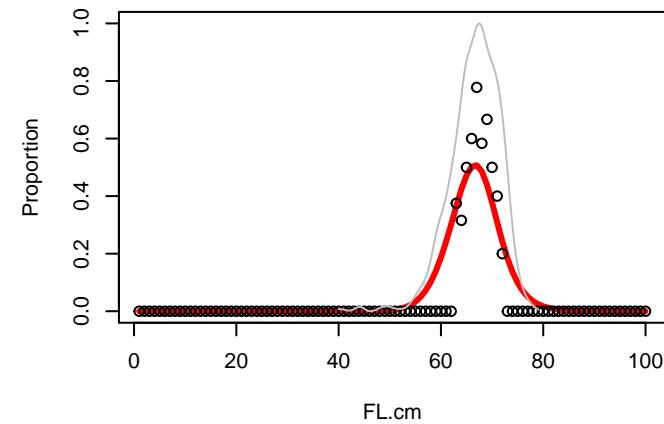
A3



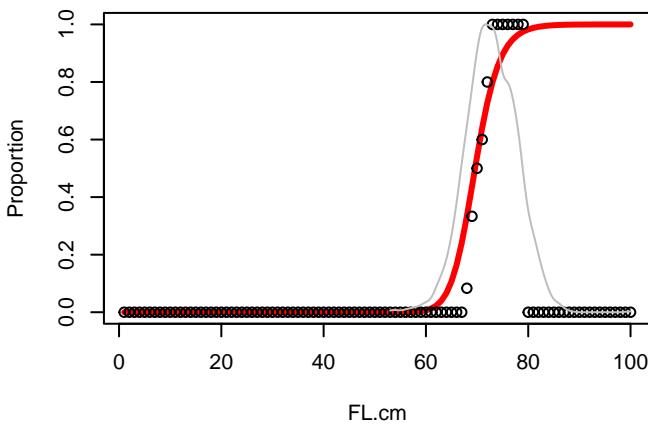
A4



A5

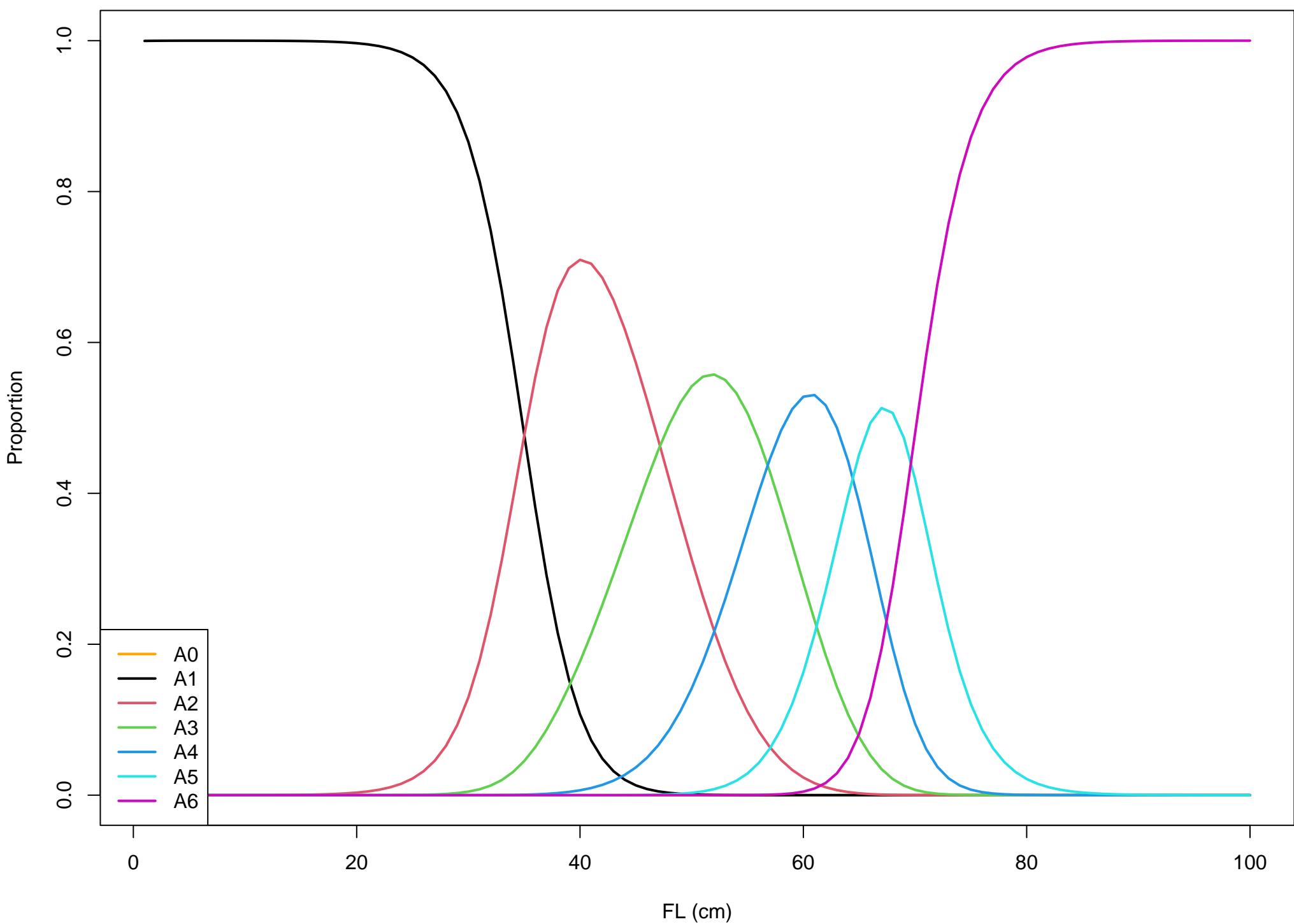


A6

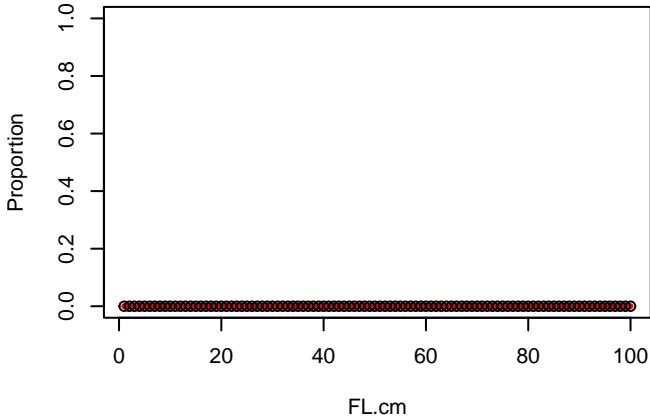


All spring
1986 spring pred
○ 1986 spring obs

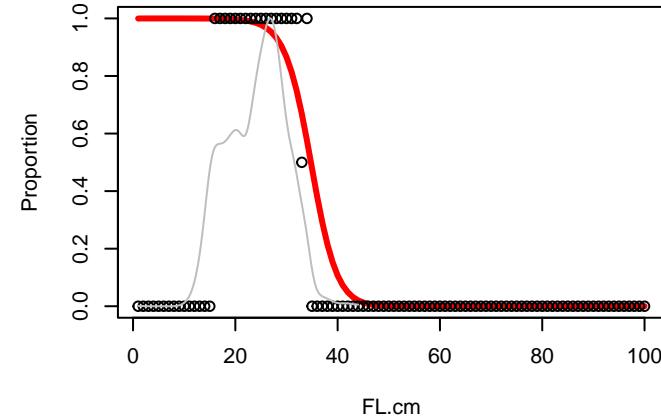
1987
spring



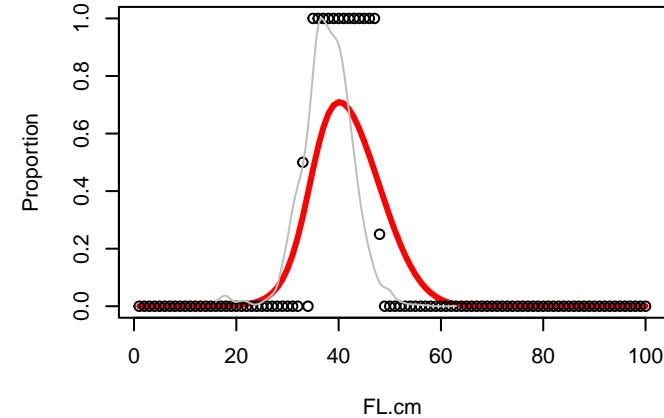
A0, 1987, spring



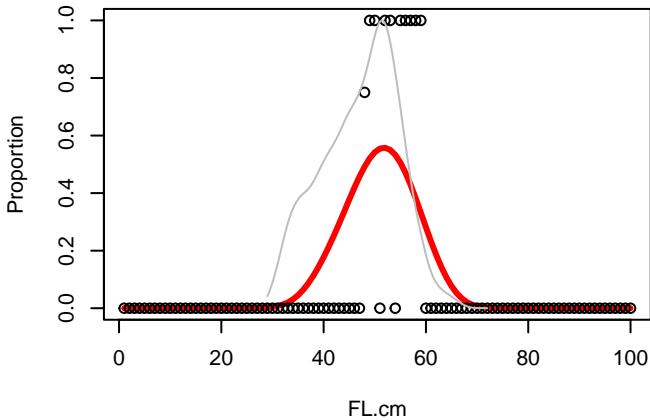
A1



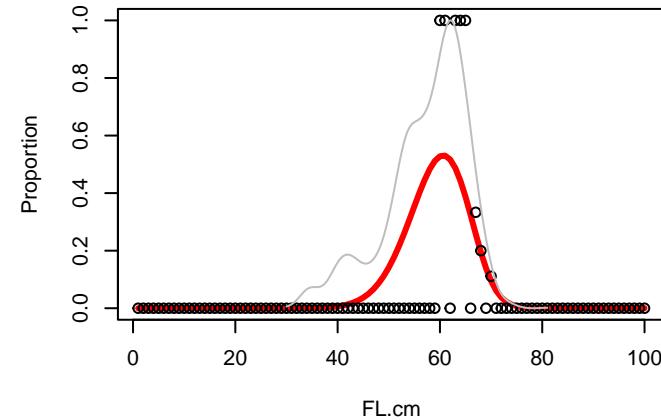
A2



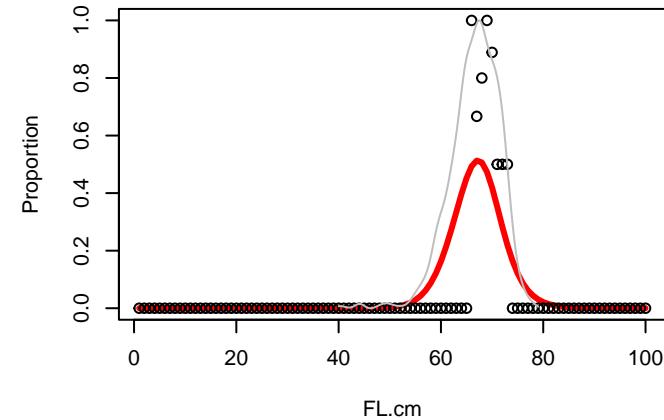
A3



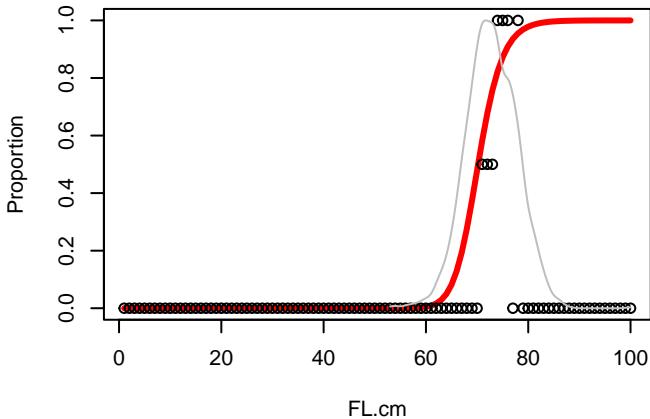
A4



A5

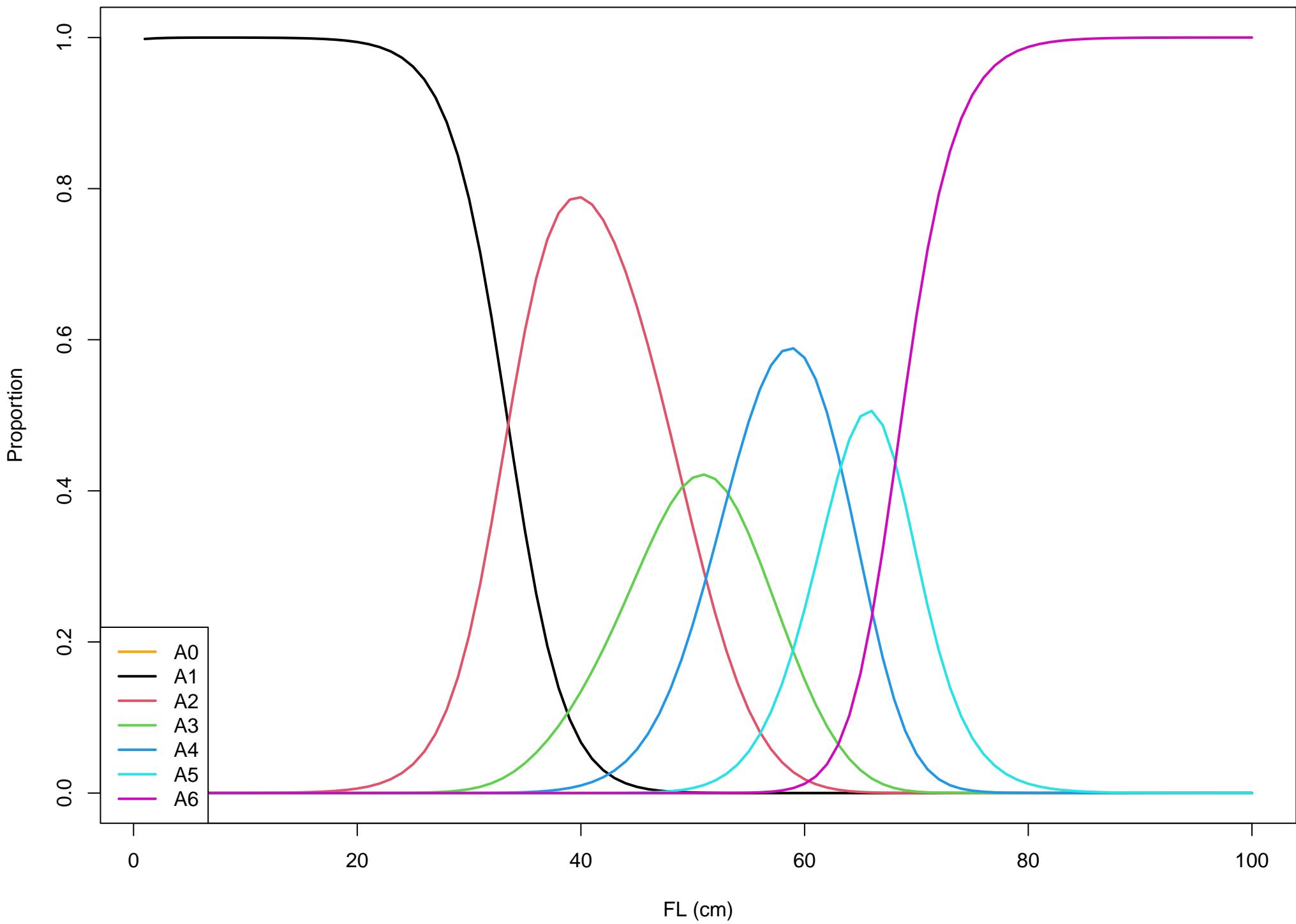


A6

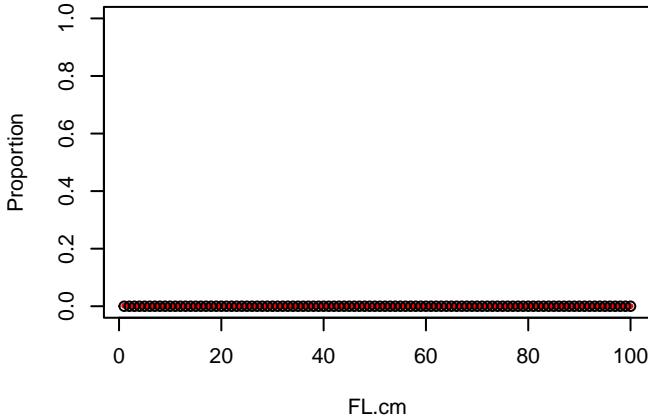


All spring
1987 spring pred
○ 1987 spring obs

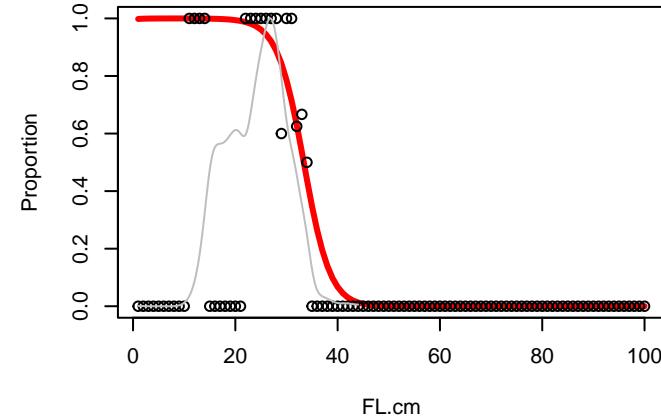
**1988
spring**



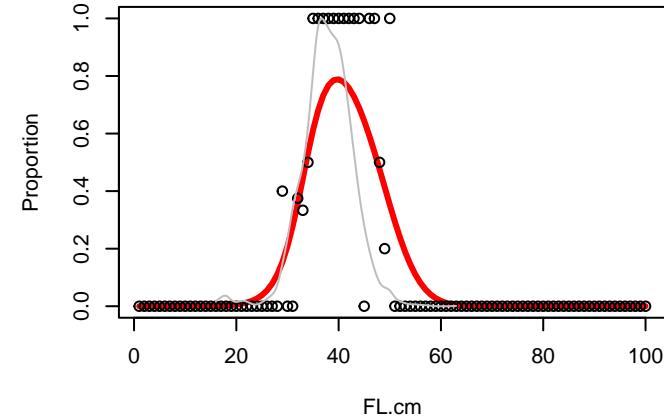
A0, 1988, spring



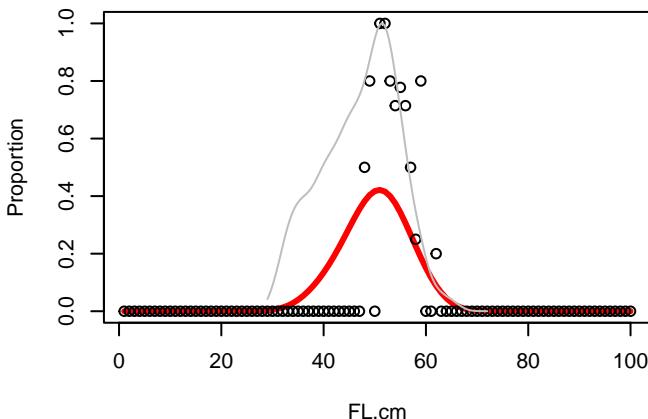
A1



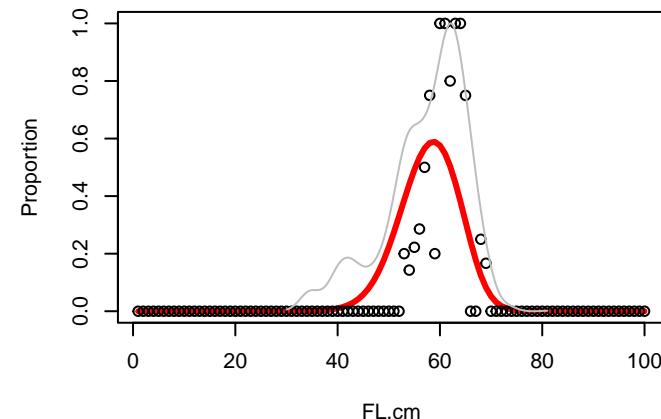
A2



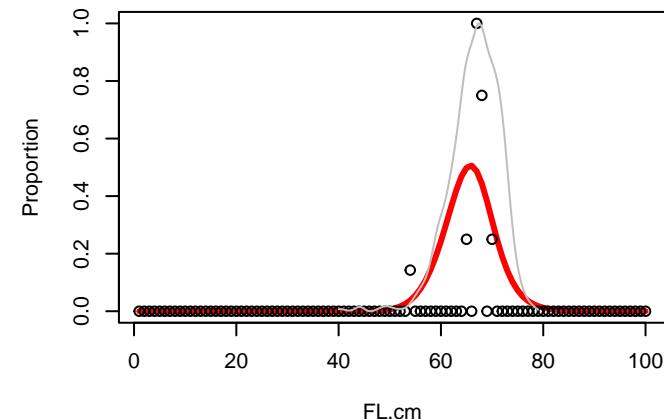
A3



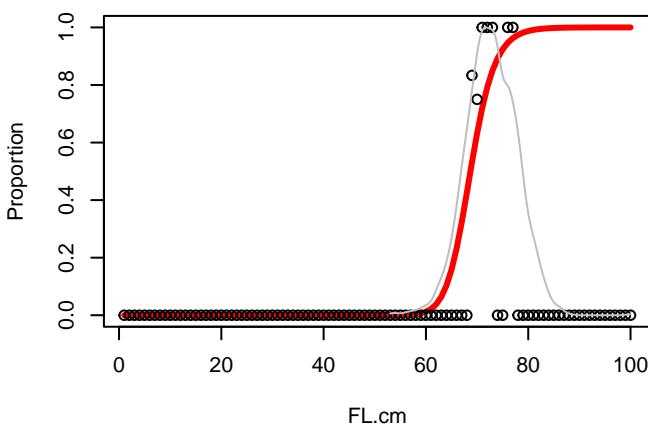
A4



A5

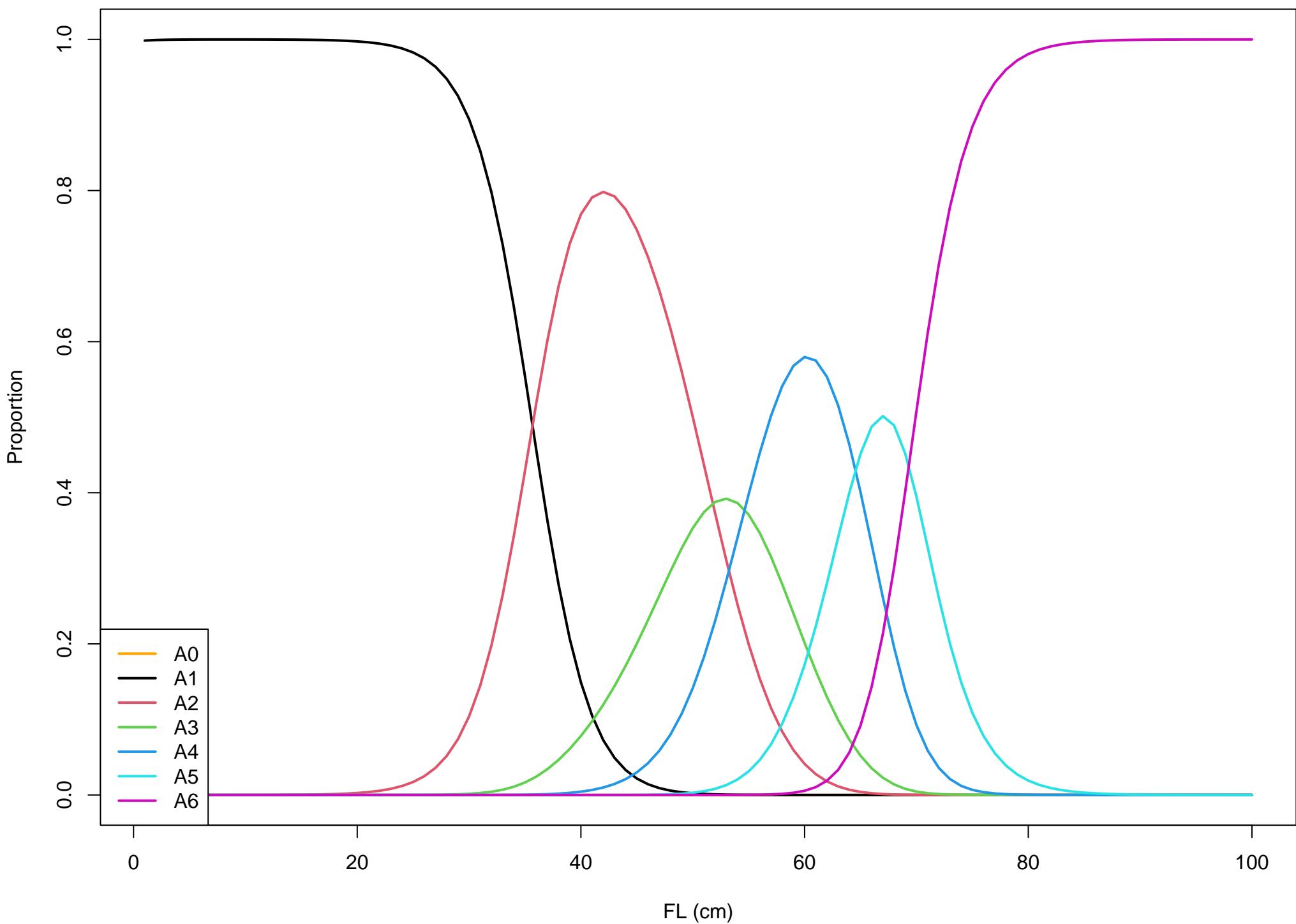


A6

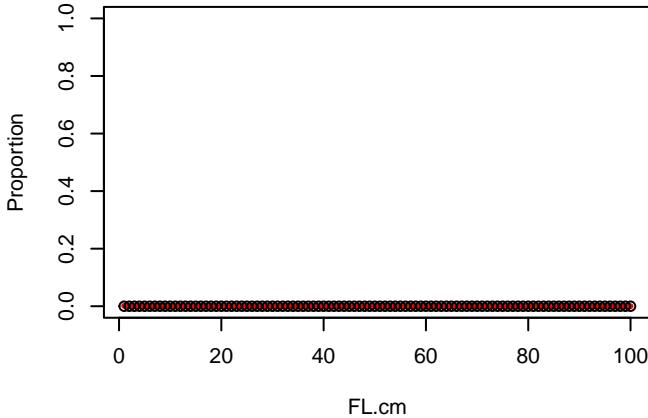


All spring
1988 spring pred
○ 1988 spring obs

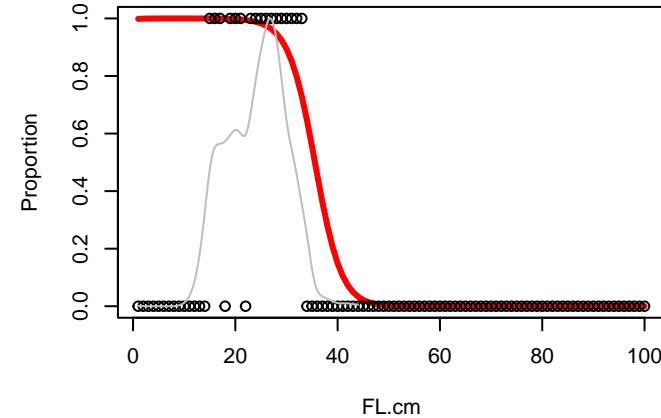
1989
spring



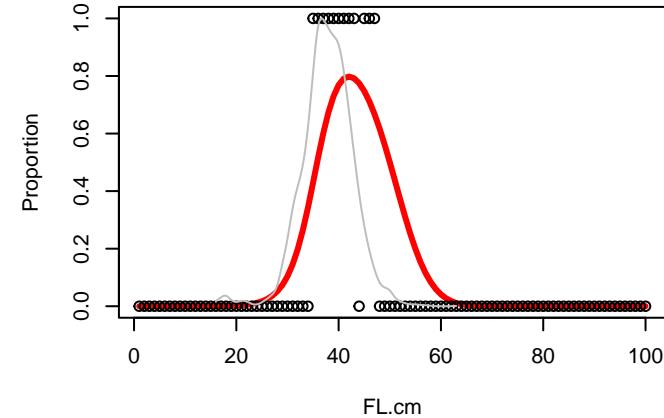
A0, 1989, spring



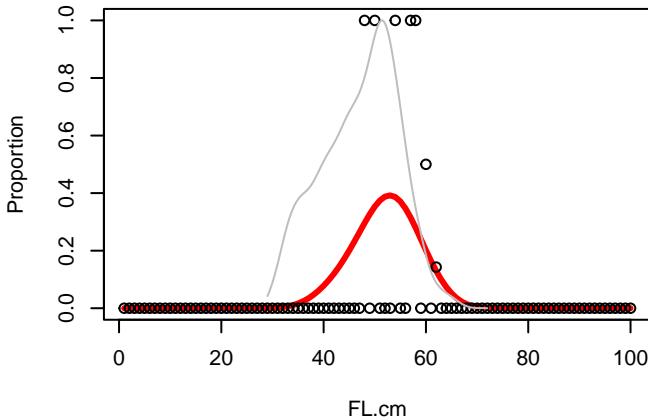
A1



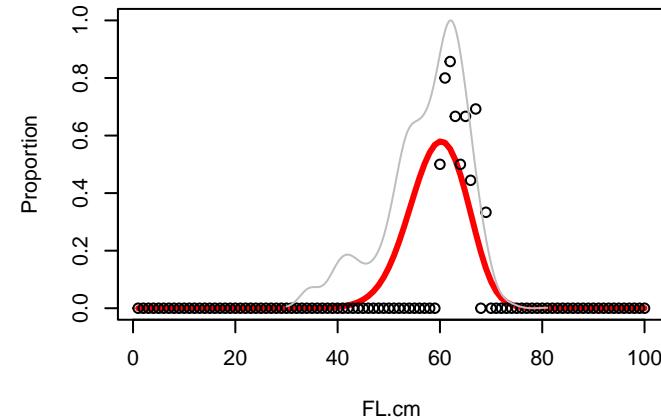
A2



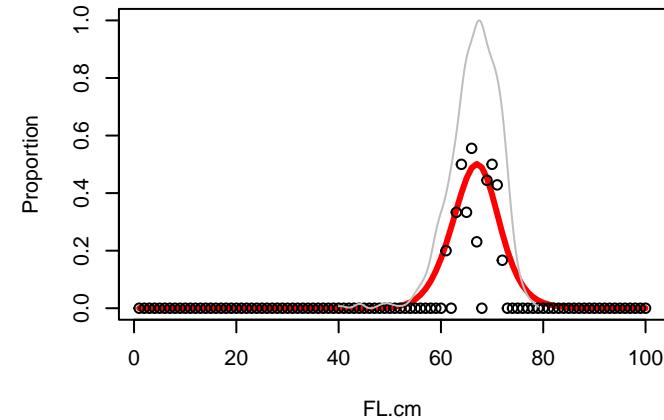
A3



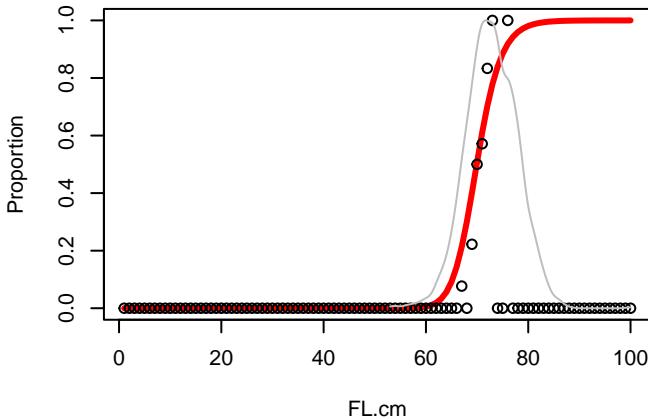
A4



A5

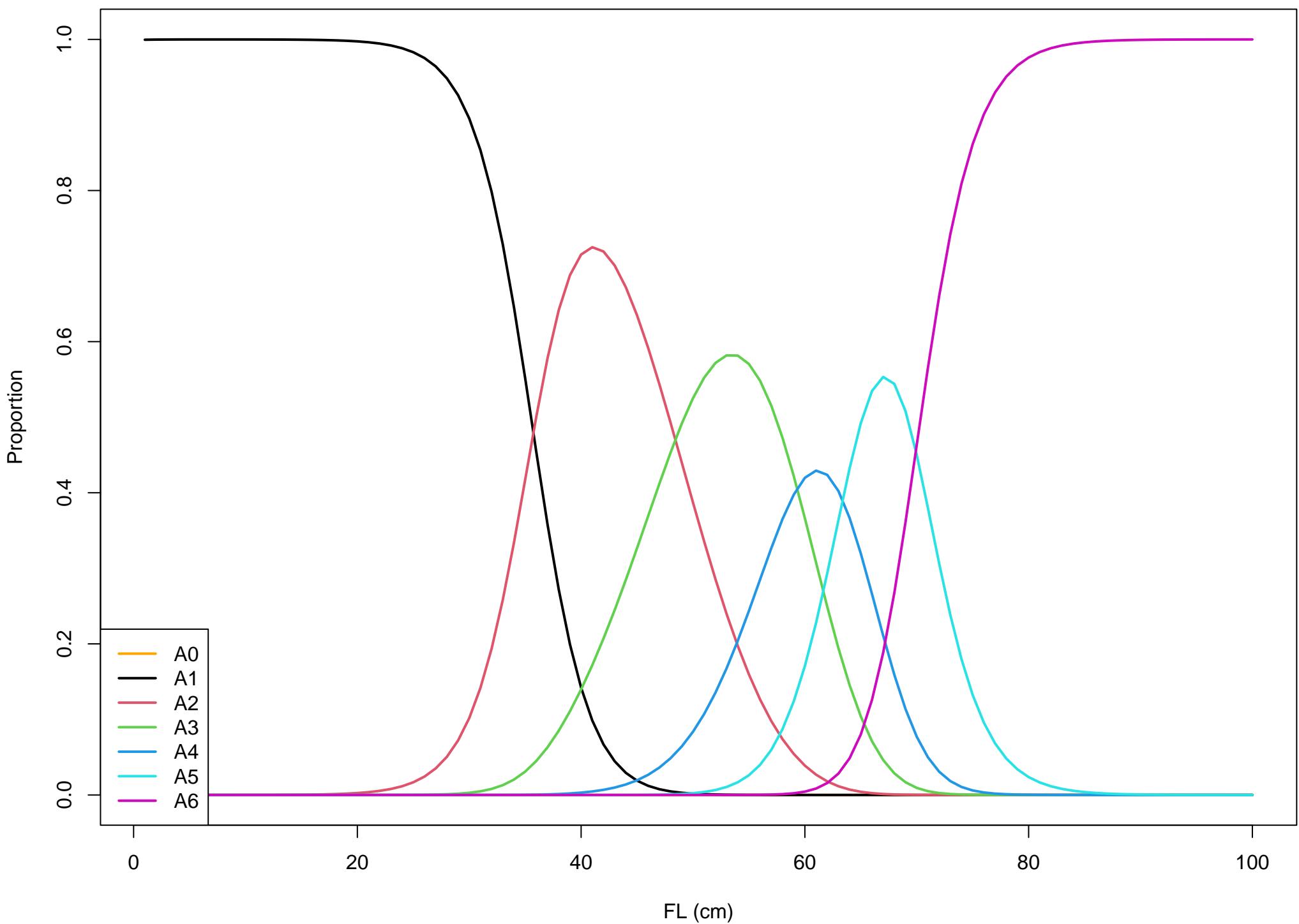


A6

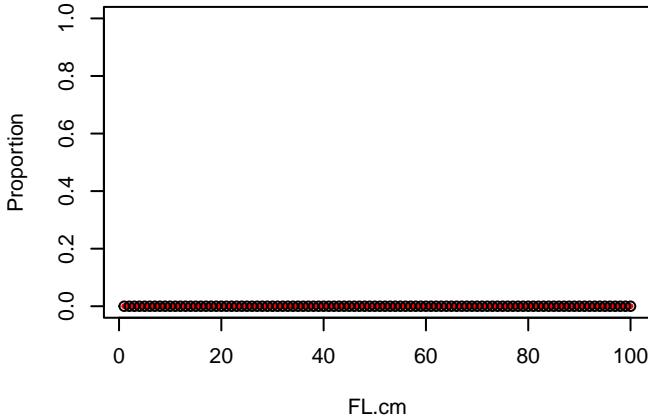


All spring
1989 spring pred
○ 1989 spring obs

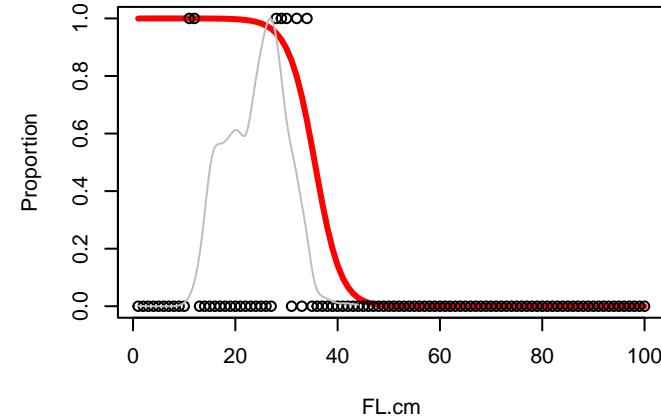
1990
spring



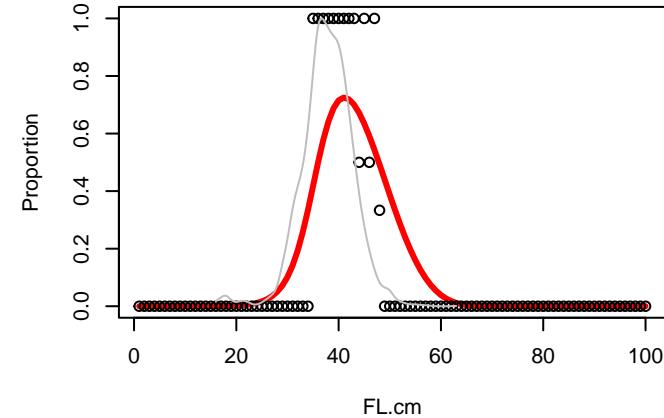
A0, 1990, spring



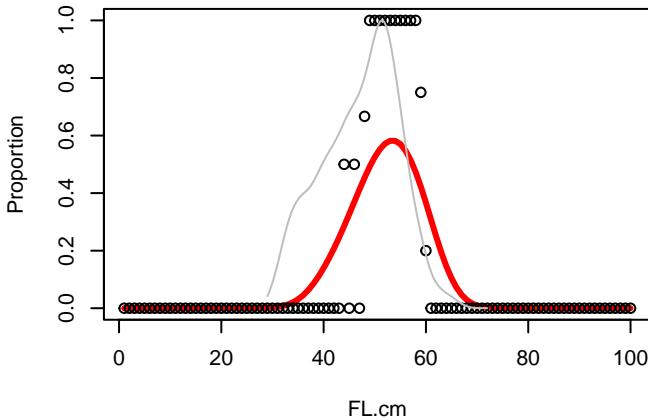
A1



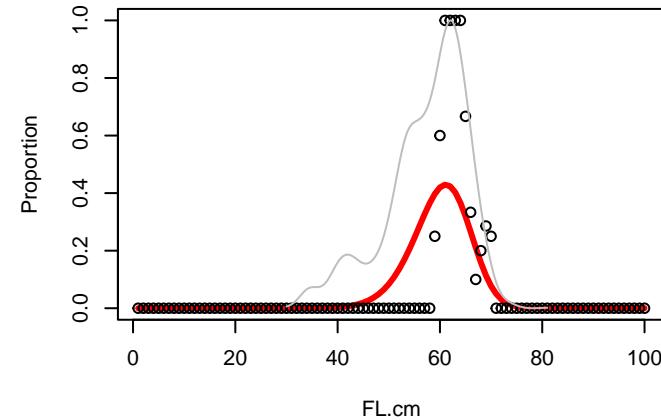
A2



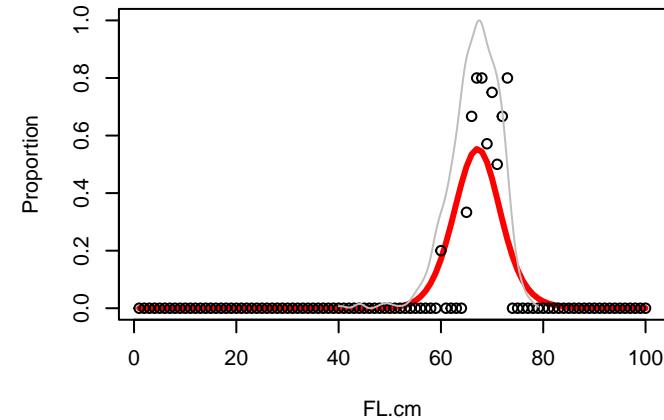
A3



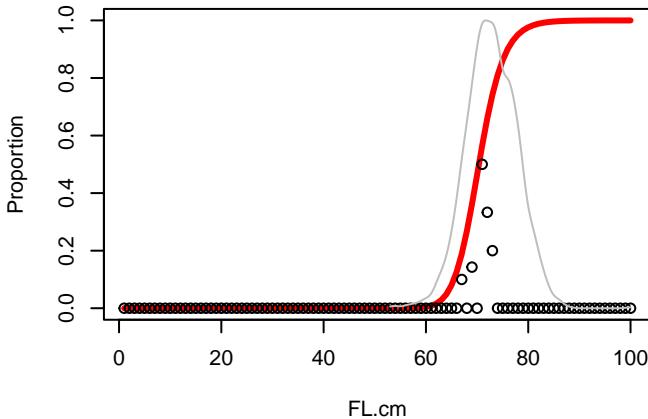
A4



A5

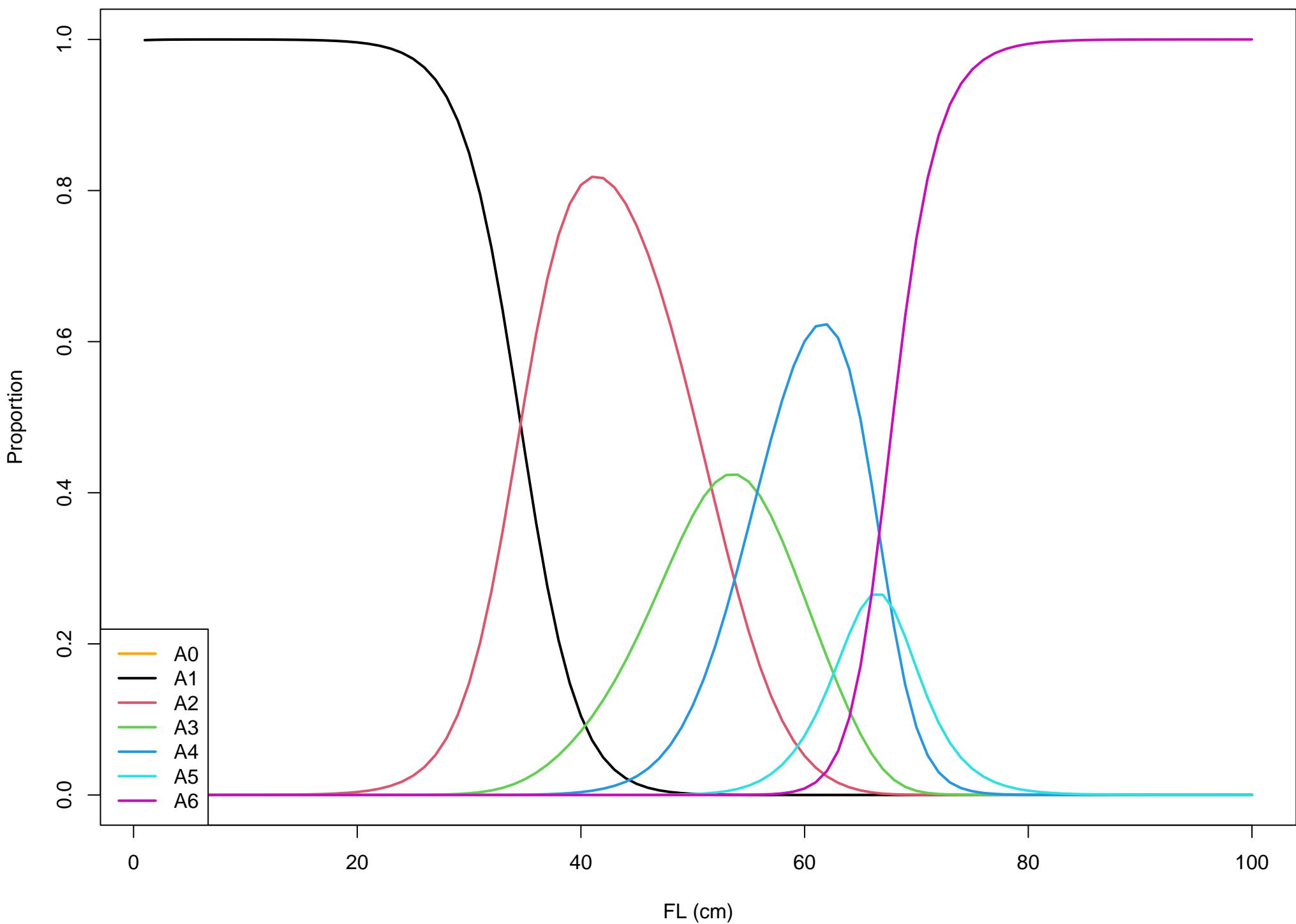


A6

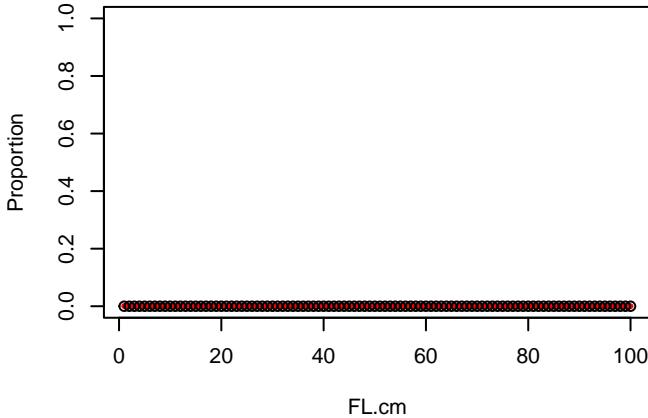


All spring
1990 spring pred
○ 1990 spring obs

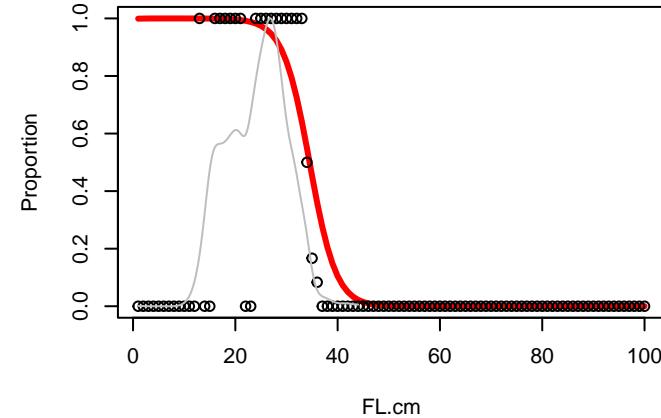
1991
spring



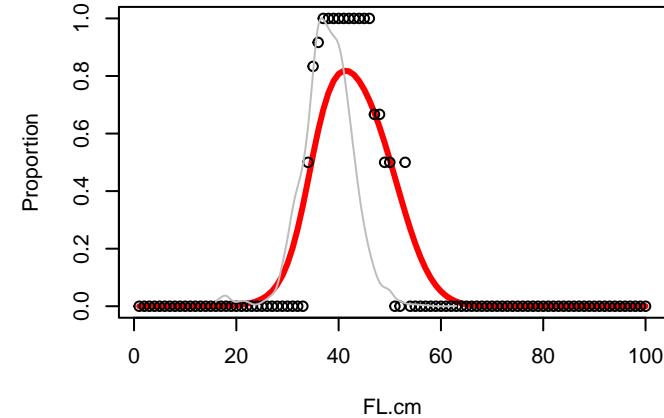
A0, 1991, spring



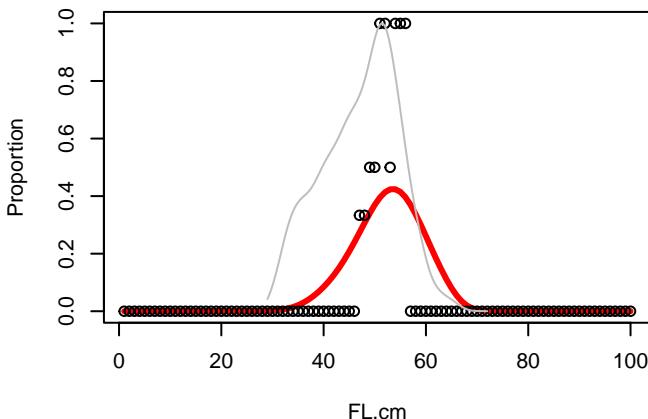
A1



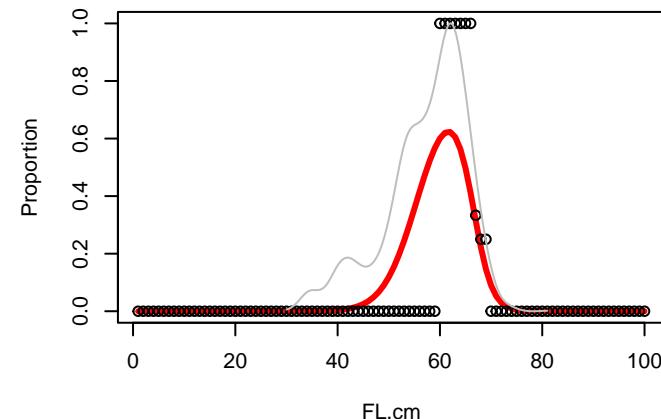
A2



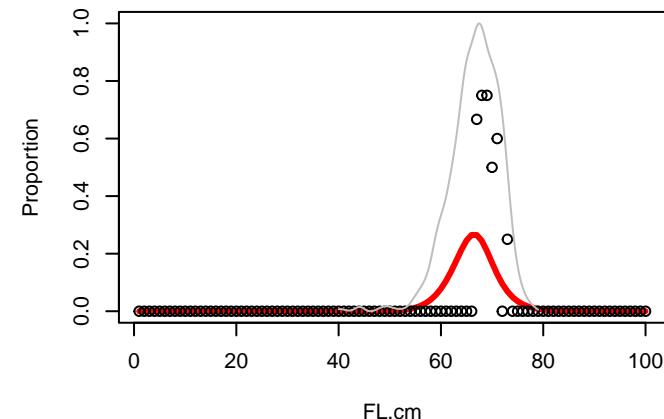
A3



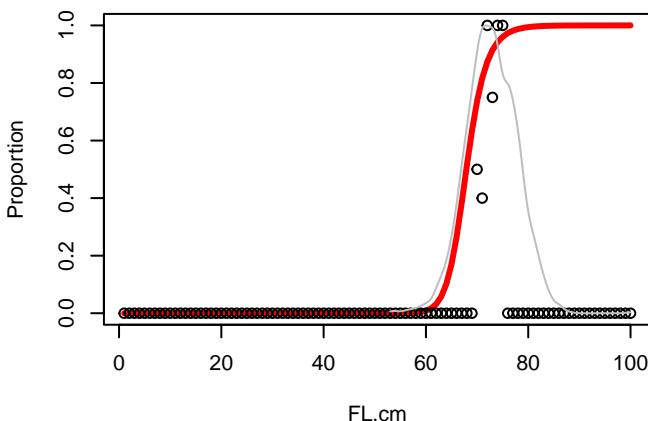
A4



A5

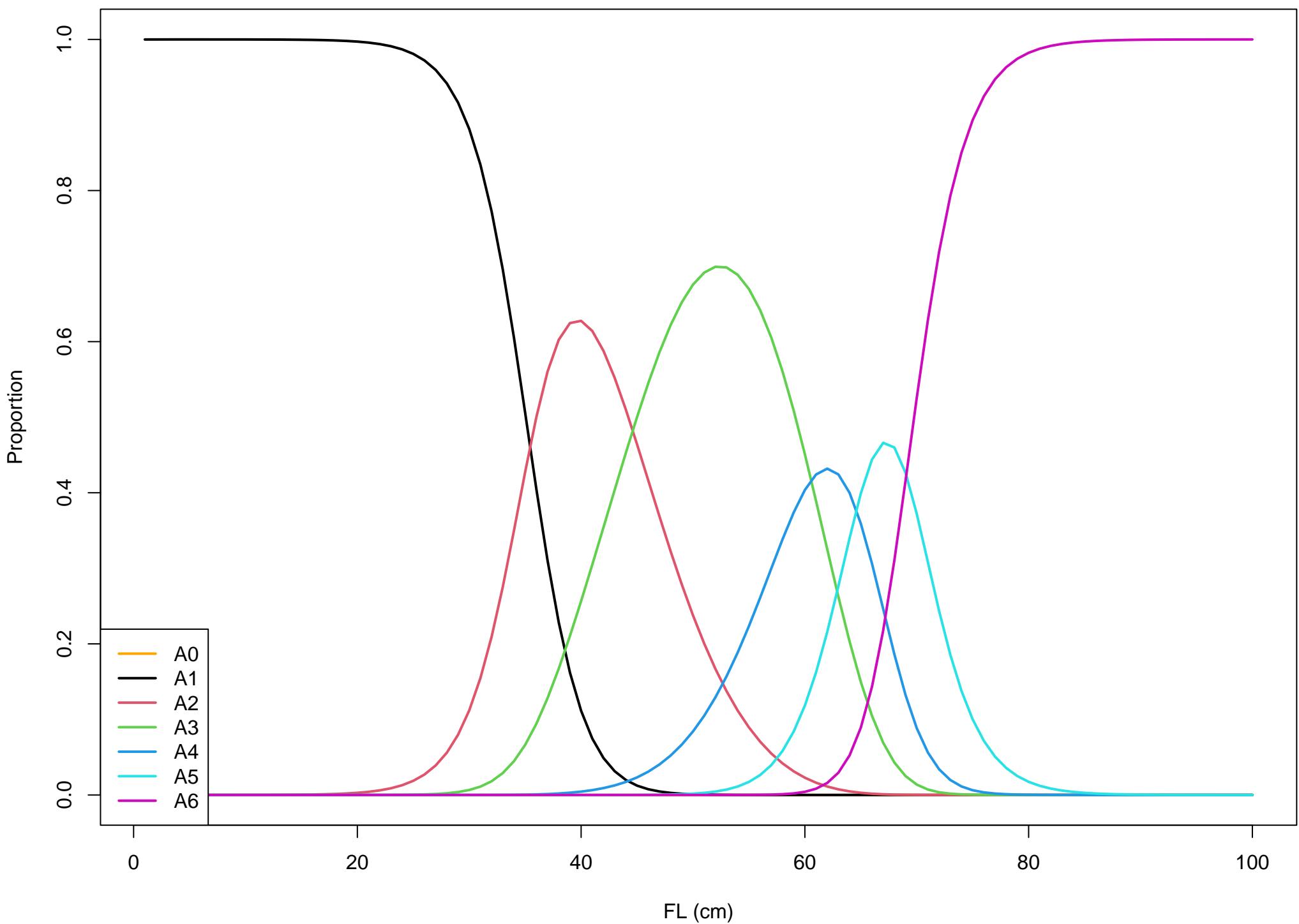


A6

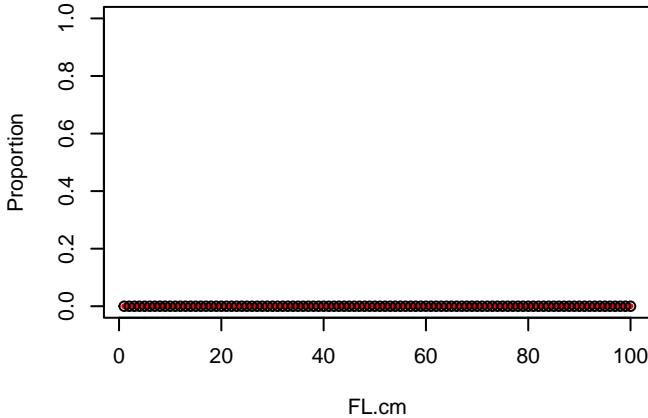


All spring
1991 spring pred
○ 1991 spring obs

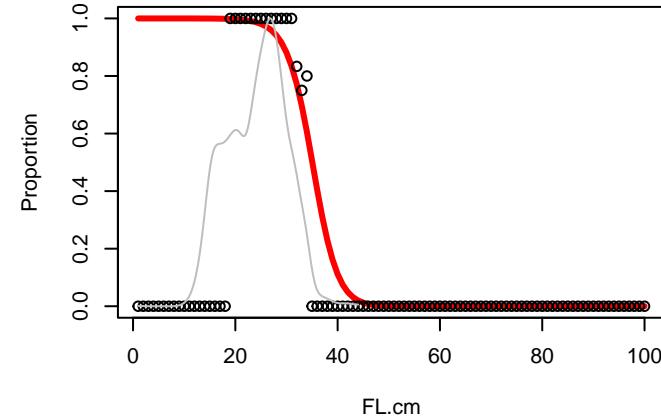
1992
spring



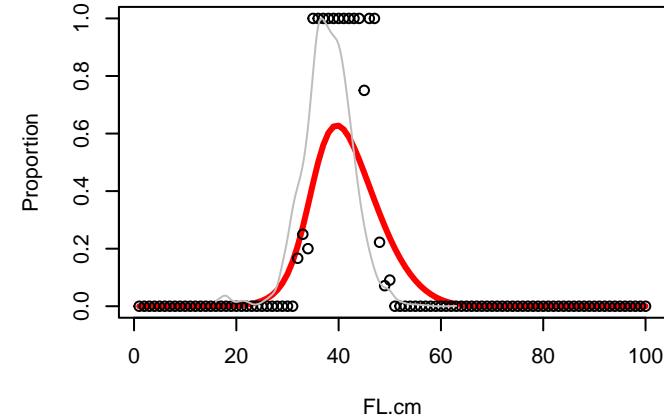
A0, 1992, spring



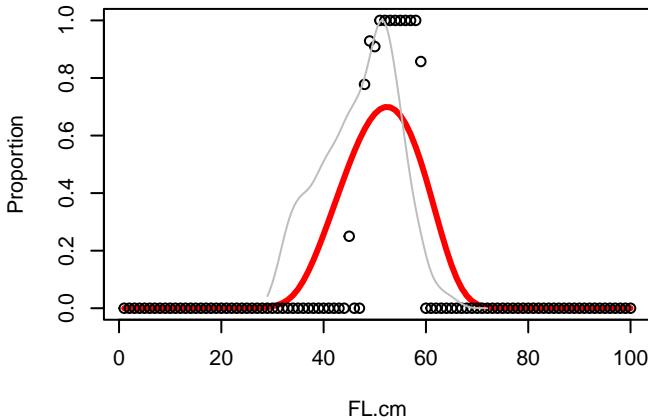
A1



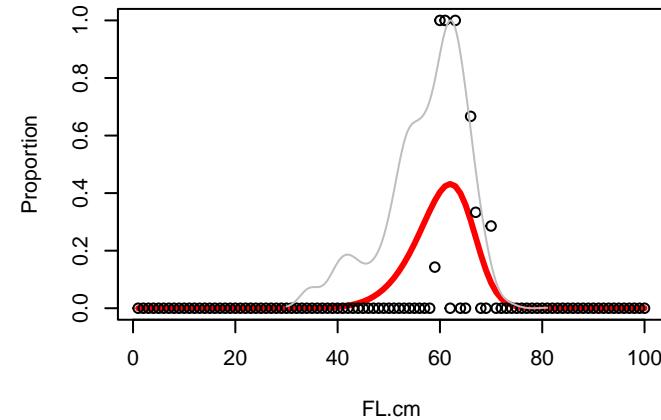
A2



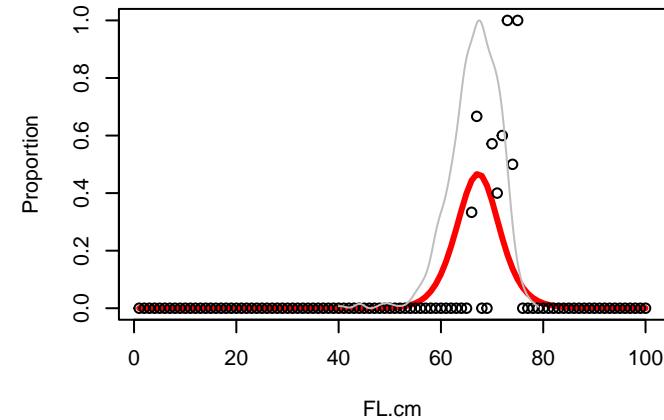
A3



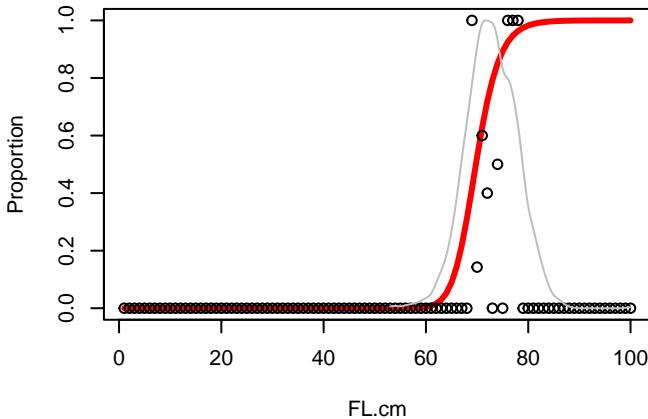
A4



A5

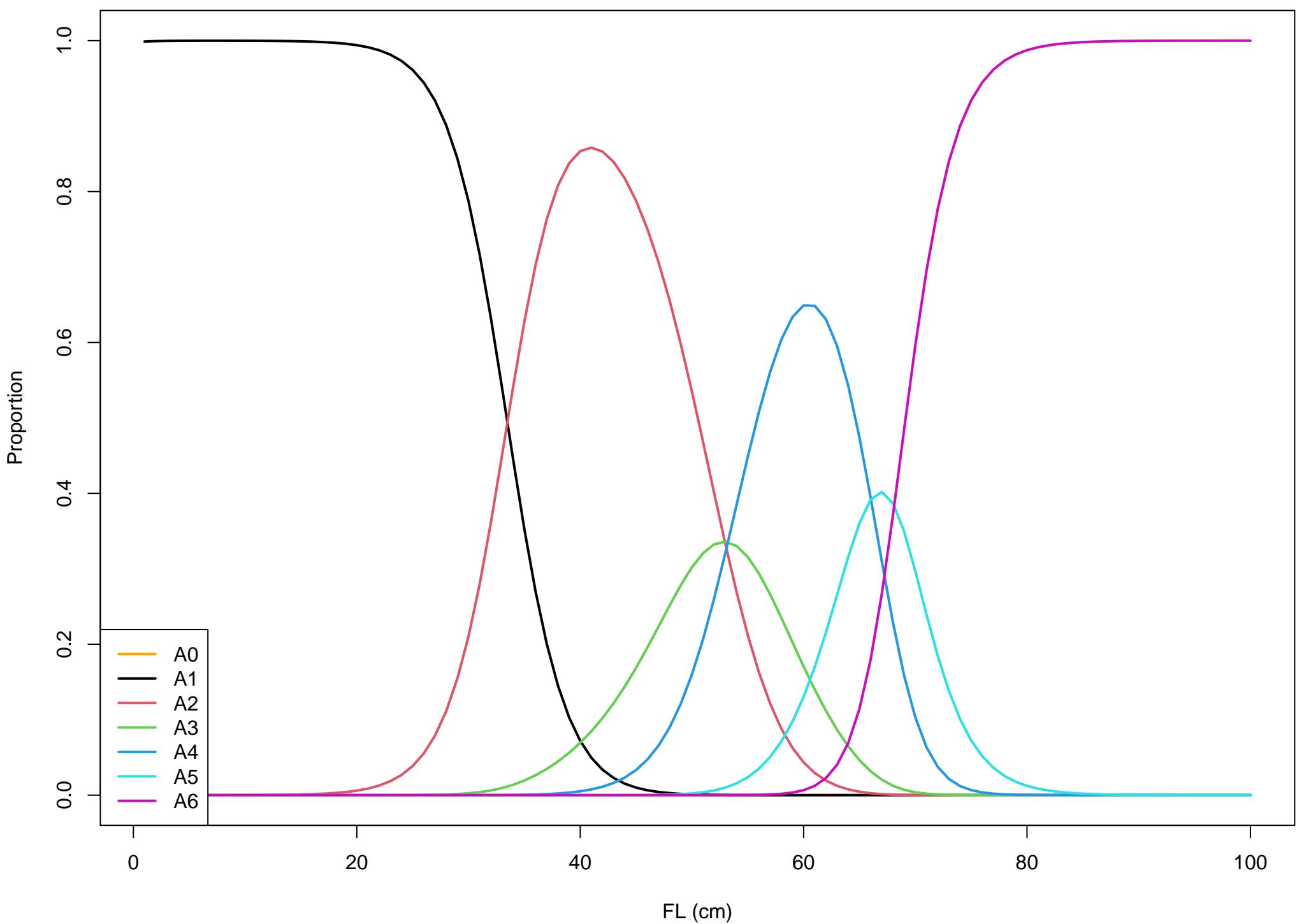


A6

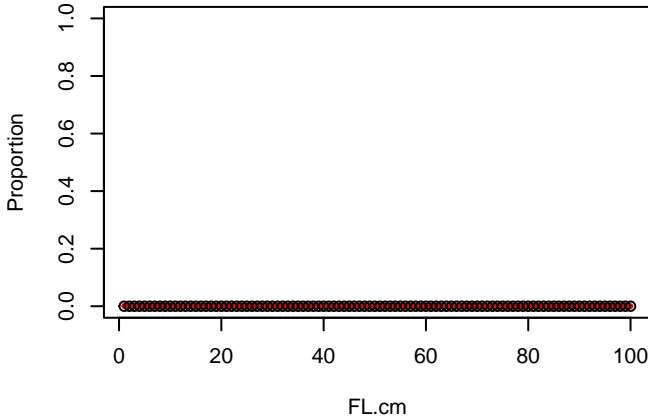


All spring
1992 spring pred
○ 1992 spring obs

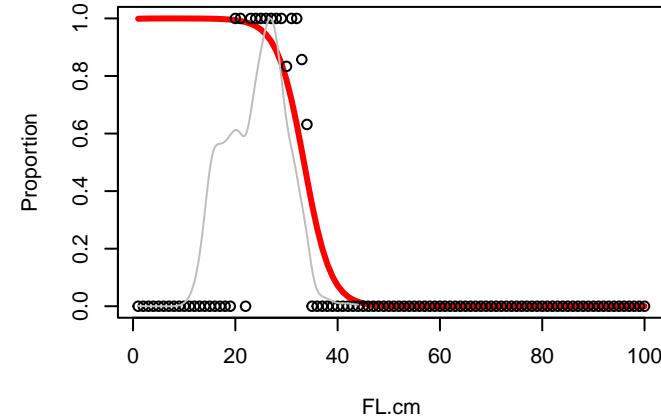
1993
spring



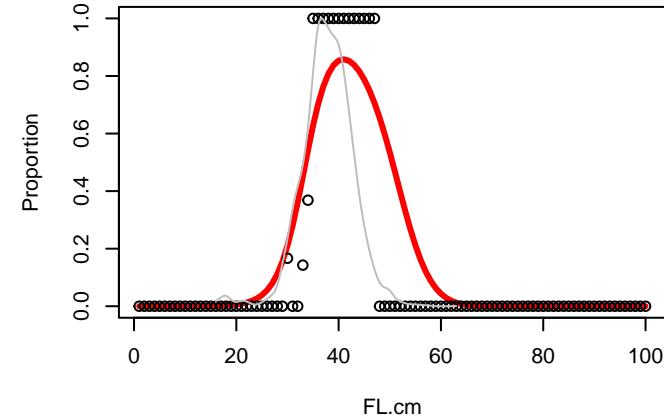
A0, 1993, spring



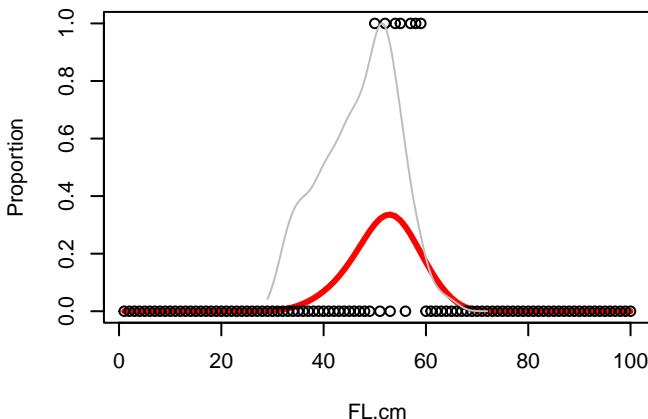
A1



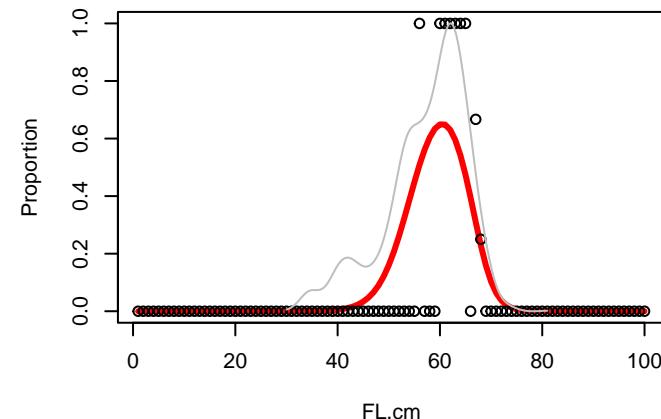
A2



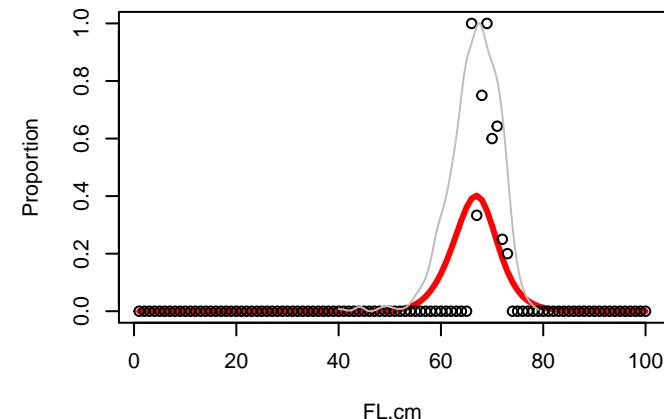
A3



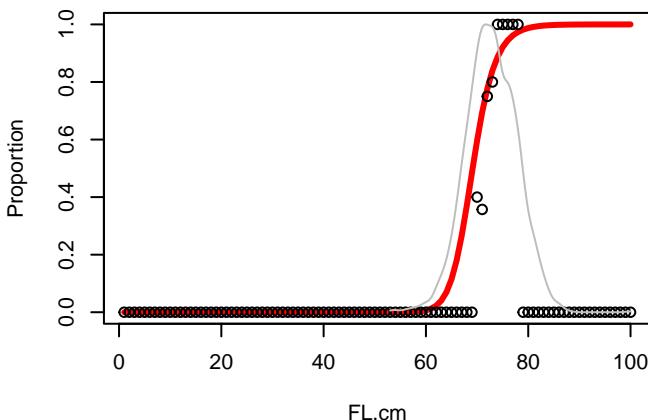
A4



A5

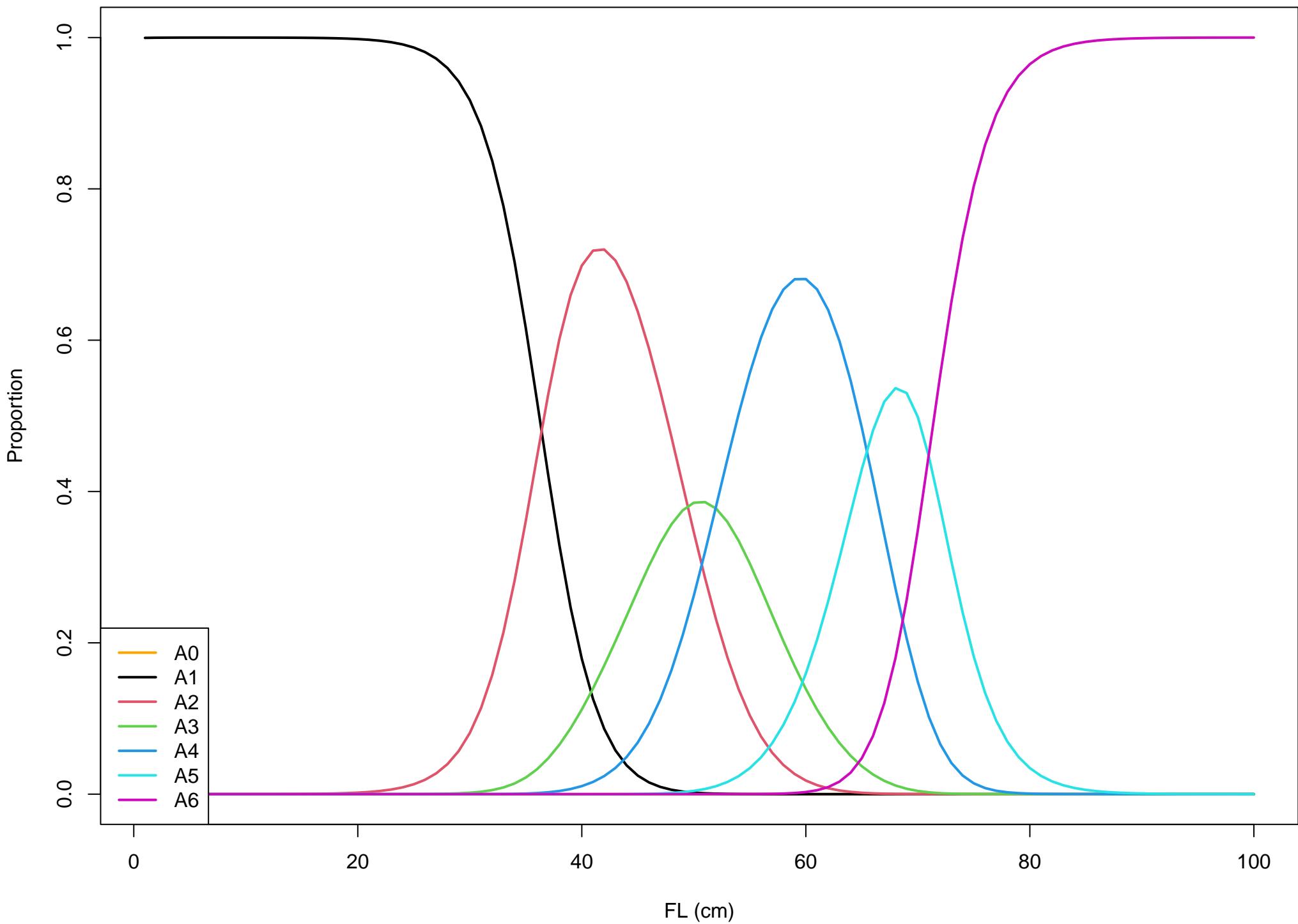


A6

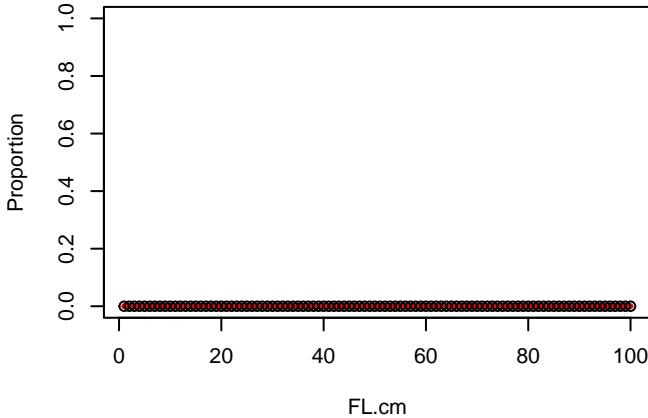


All spring
1993 spring pred
○ 1993 spring obs

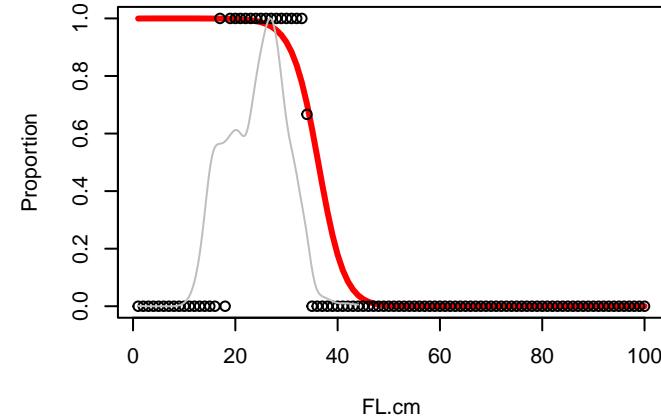
**1994
spring**



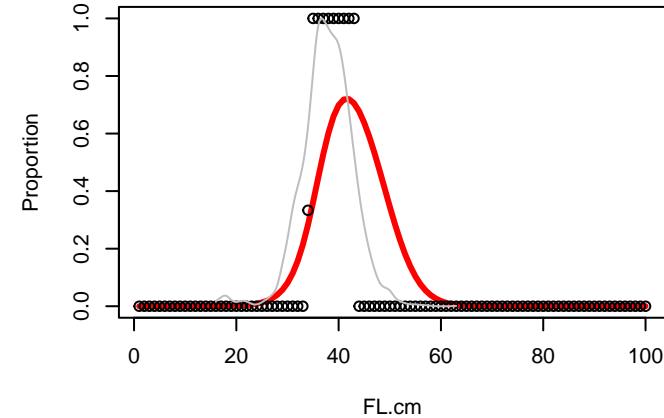
A0, 1994, spring



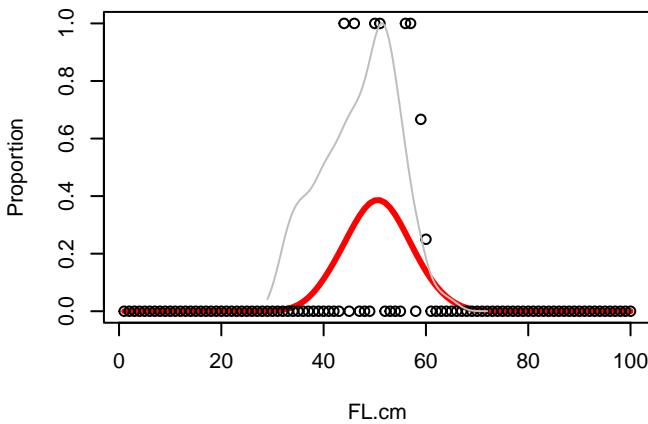
A1



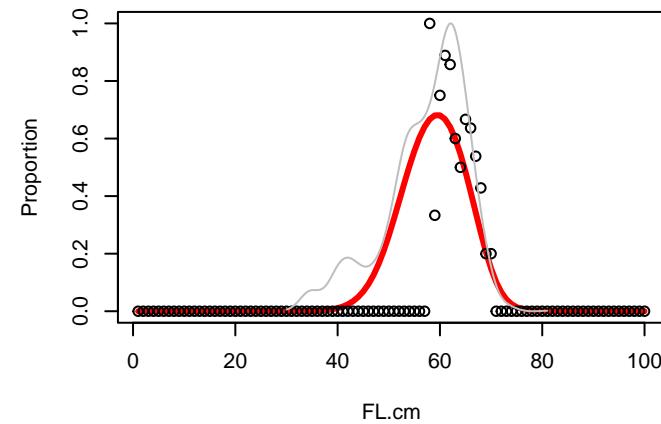
A2



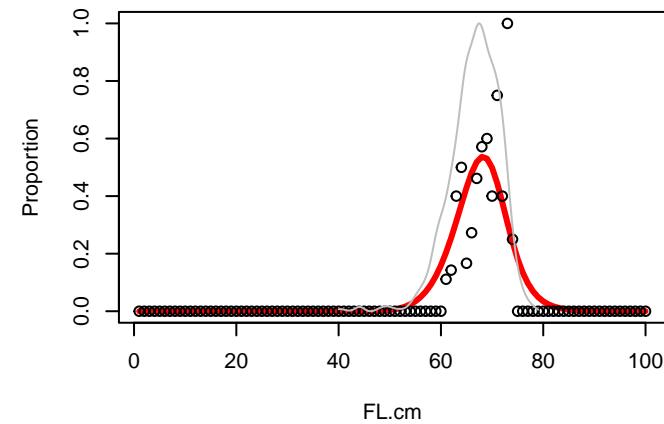
A3



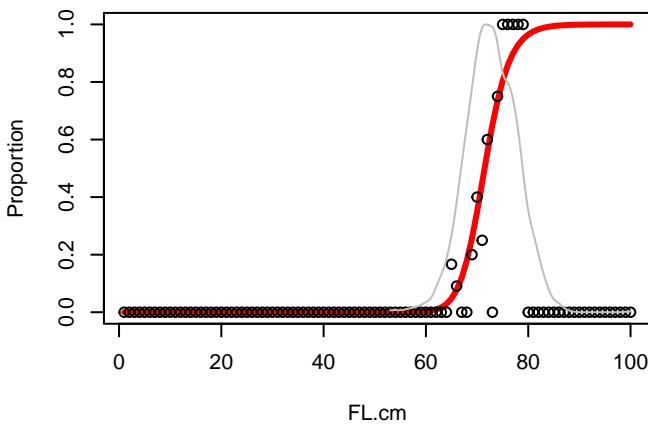
A4



A5

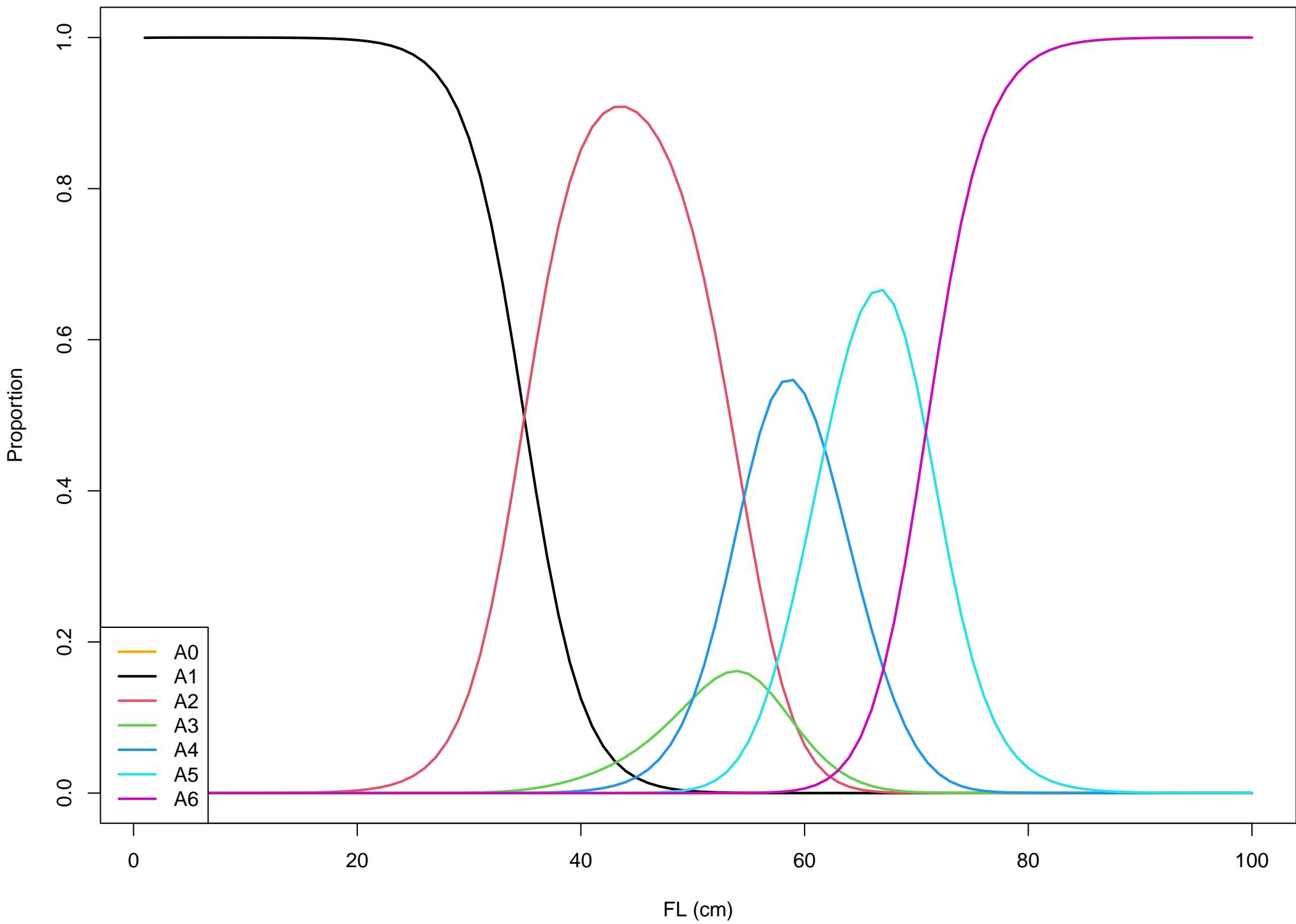


A6

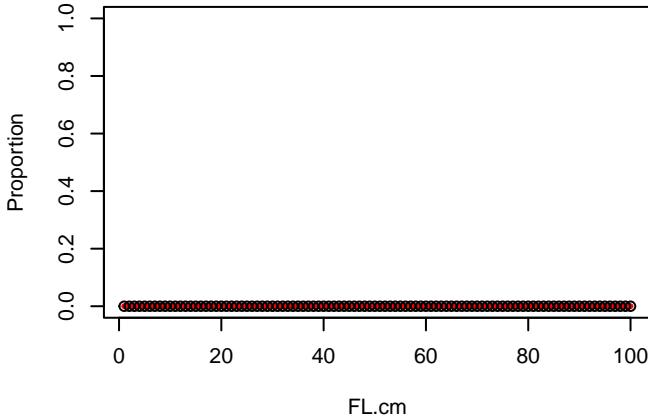


All spring
1994 spring pred
○ 1994 spring obs

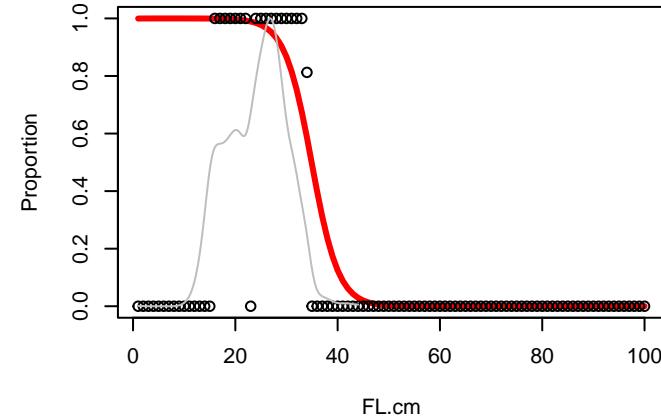
**1995
spring**



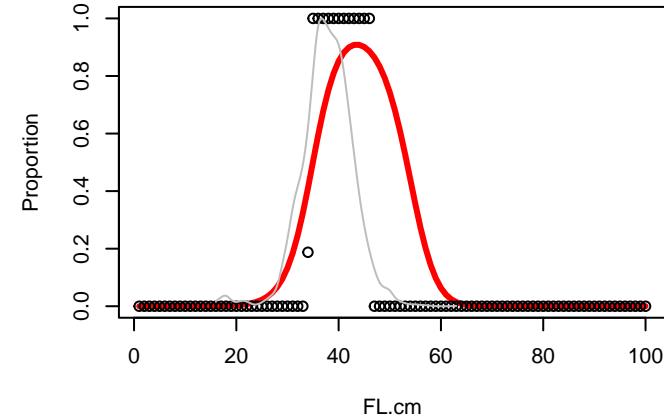
A0, 1995, spring



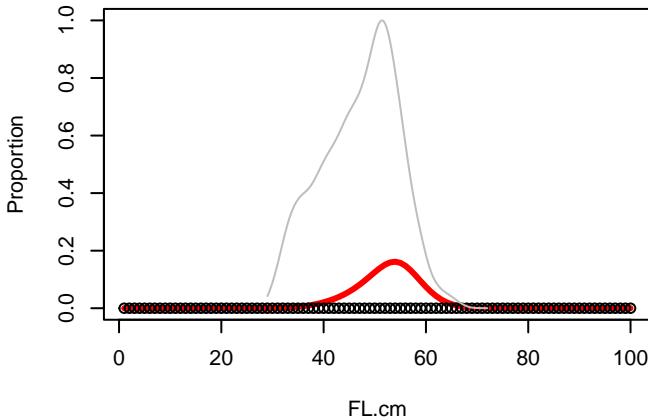
A1



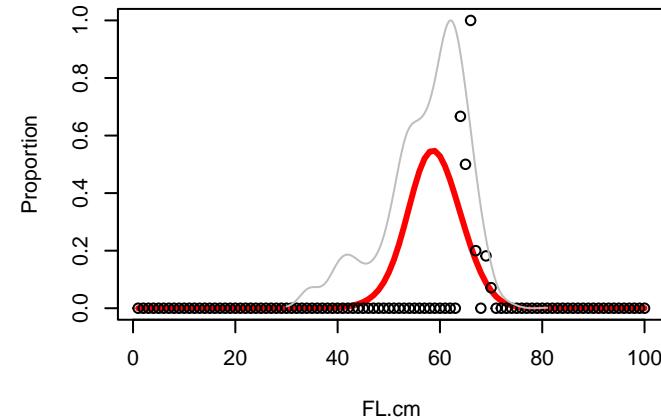
A2



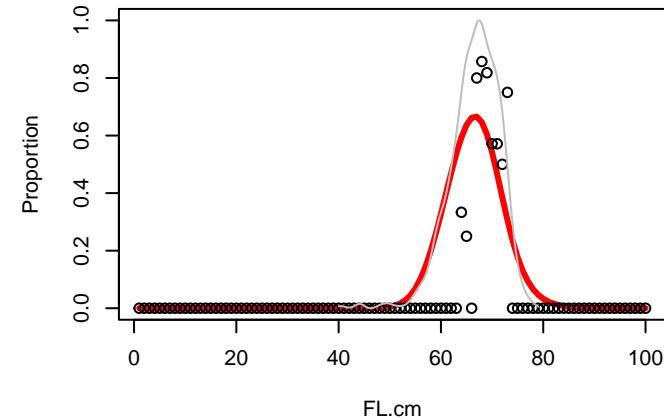
A3



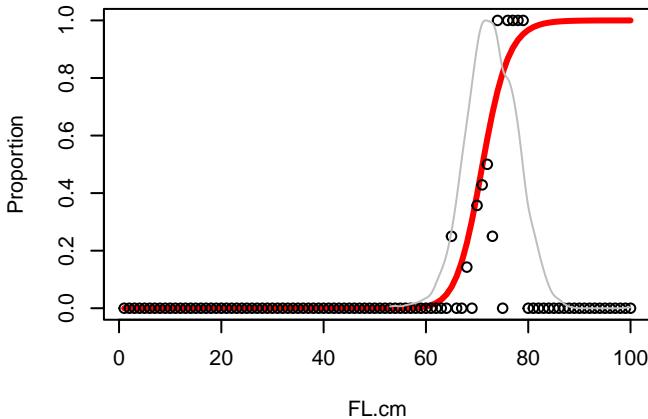
A4



A5

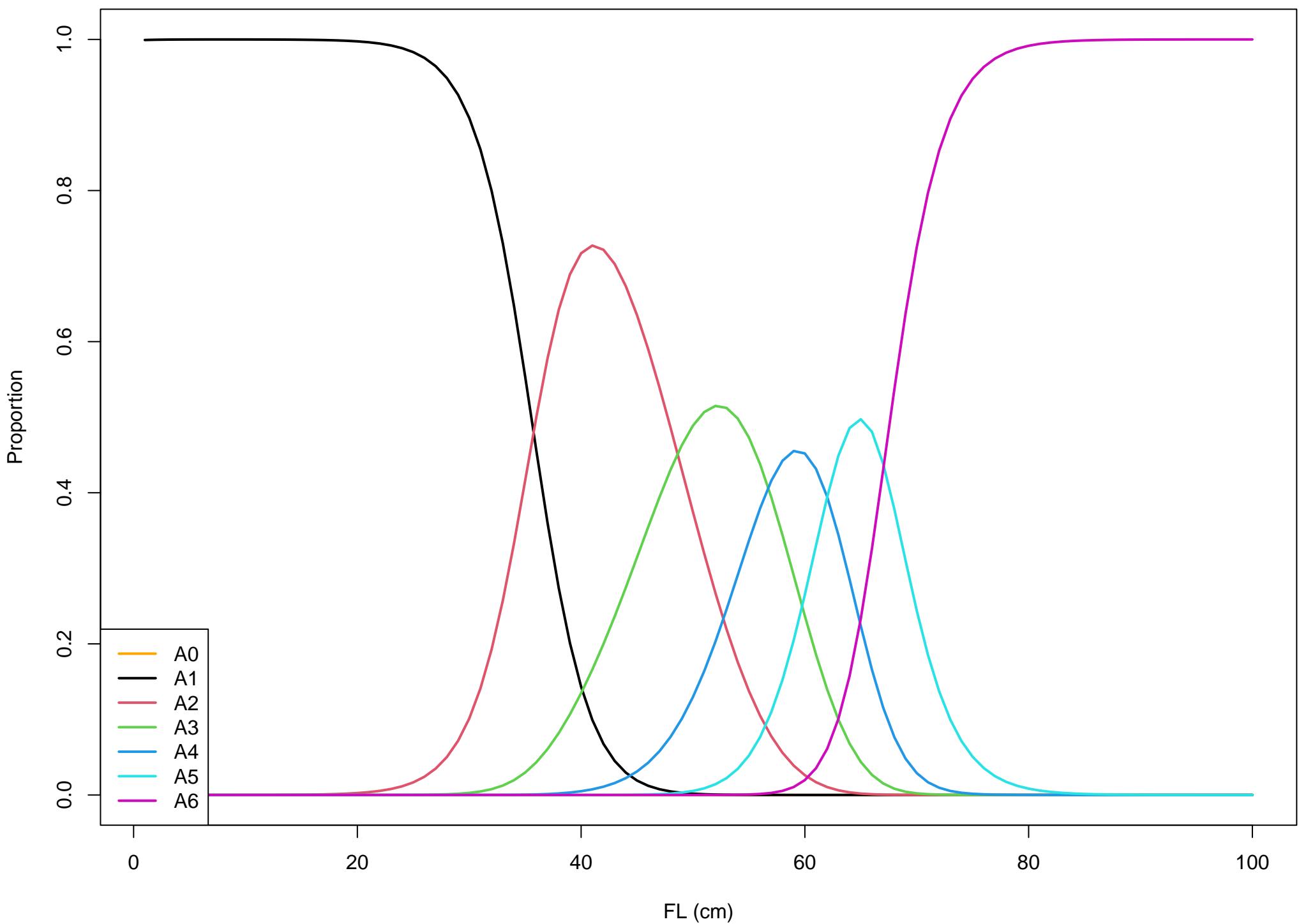


A6

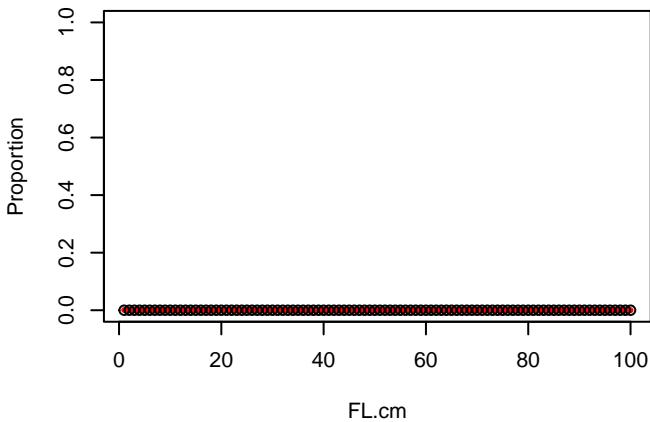


All spring
1995 spring pred
○ 1995 spring obs

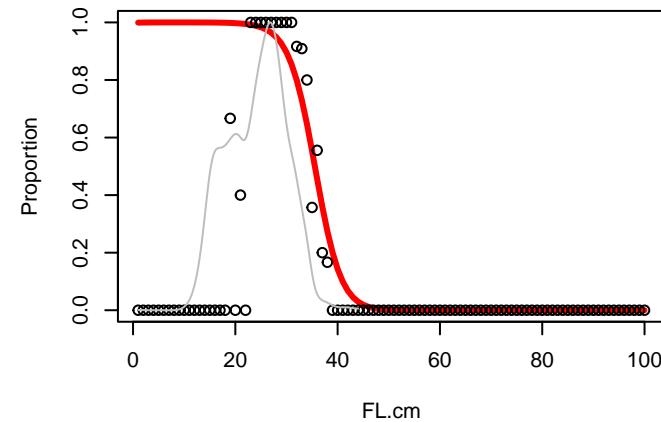
1996
spring



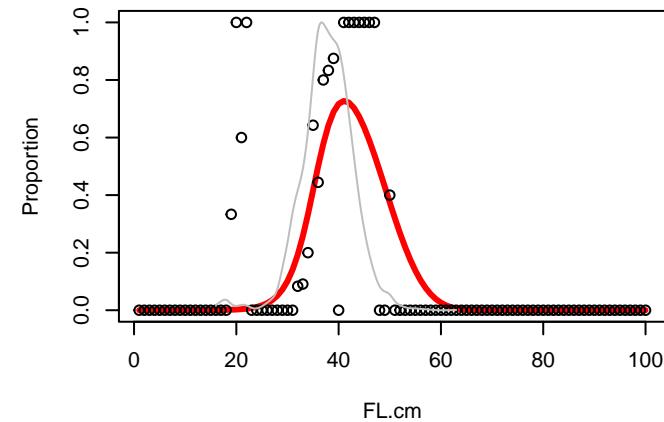
A0, 1996, spring



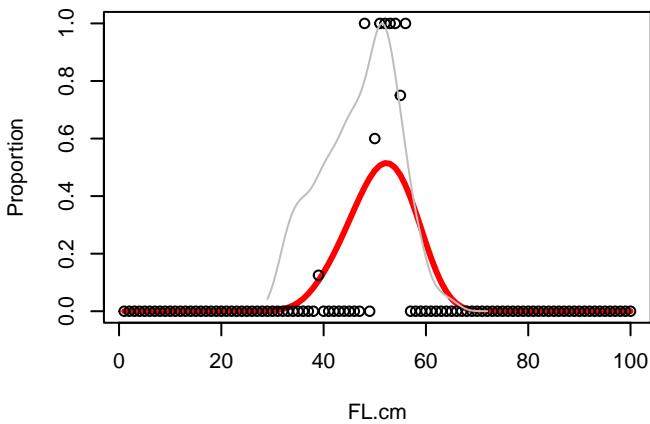
A1



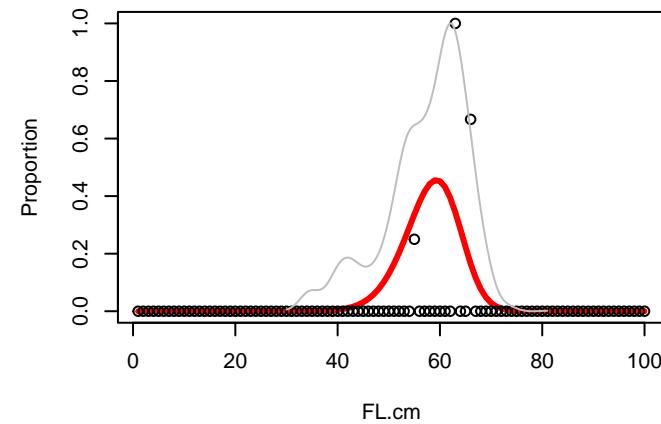
A2



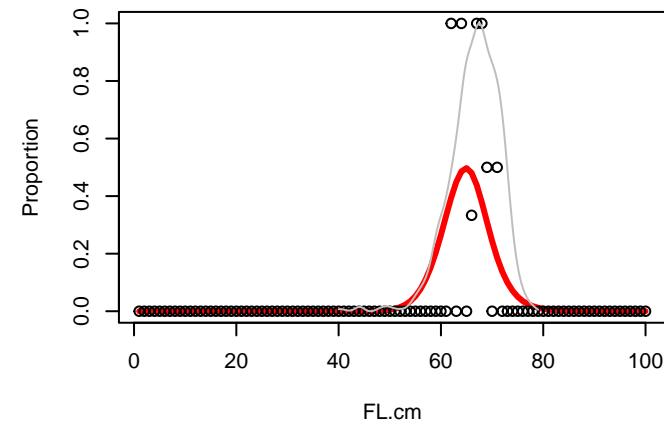
A3



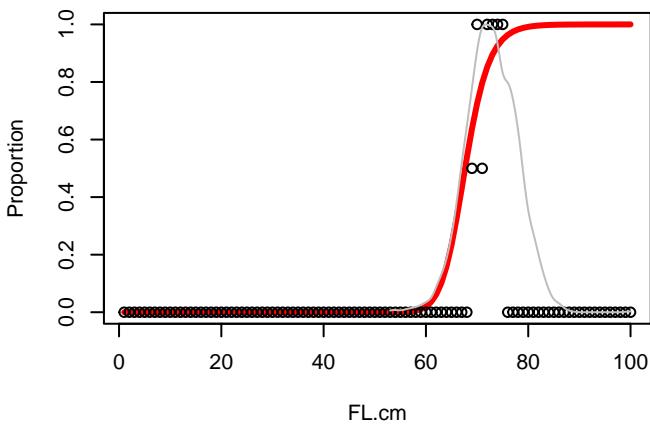
A4



A5

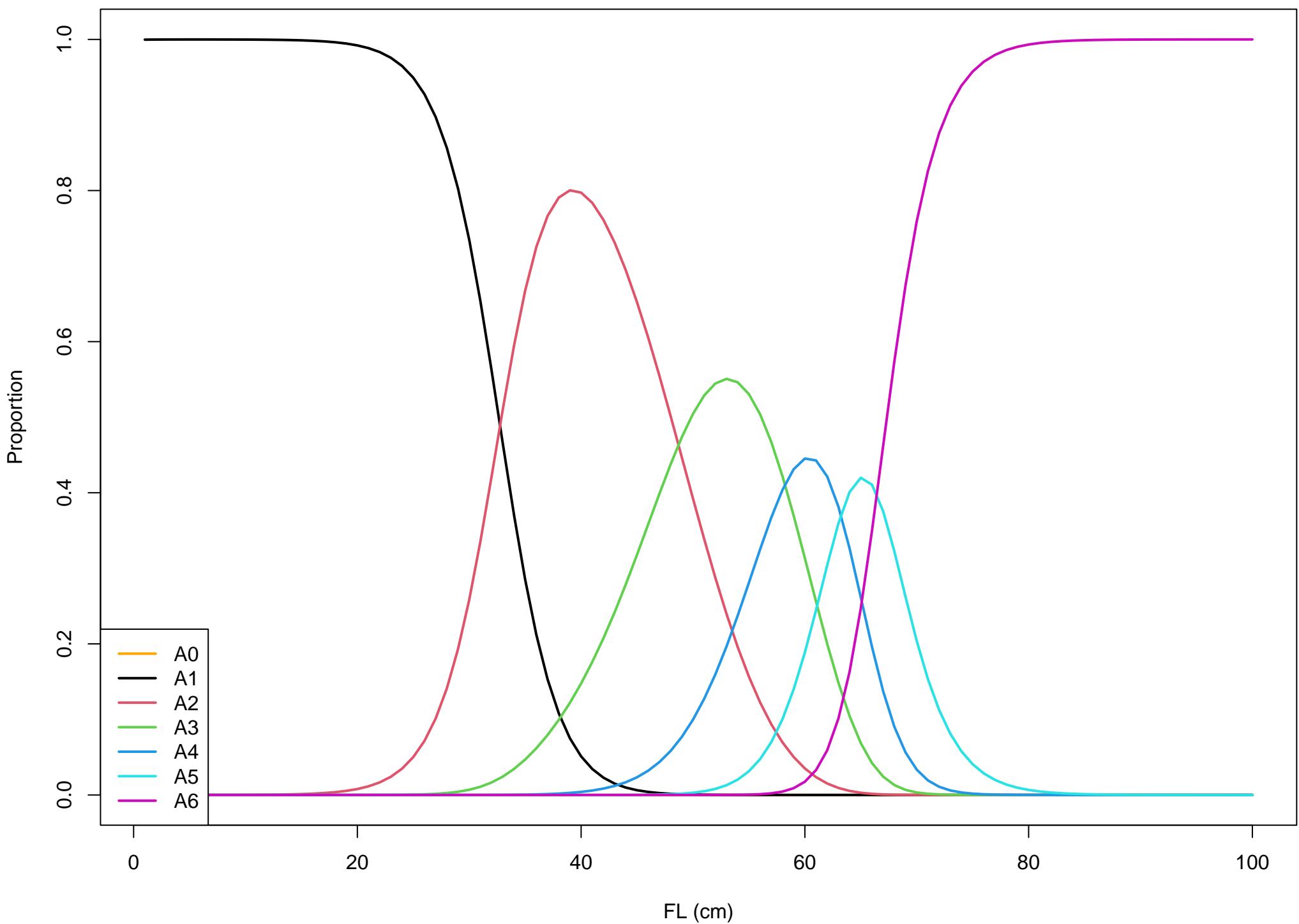


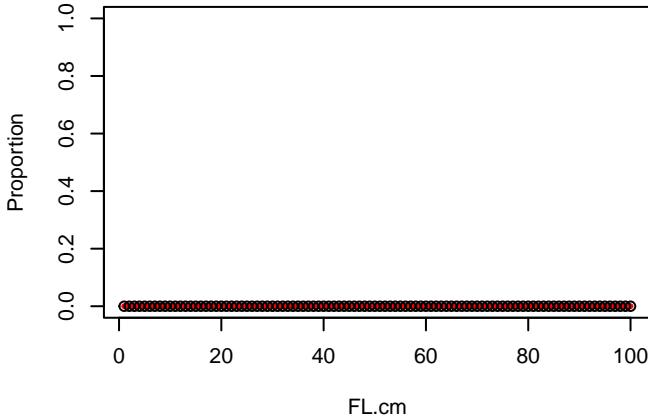
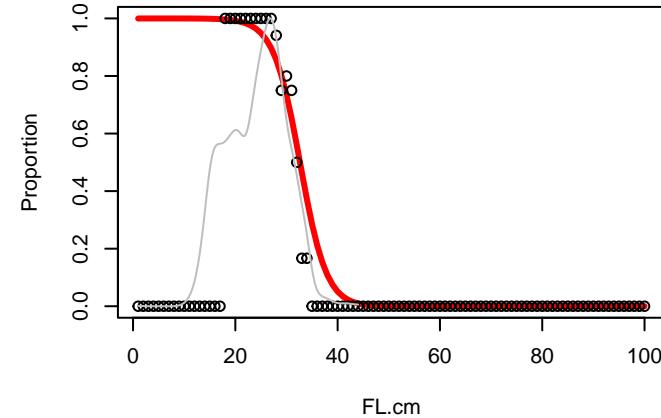
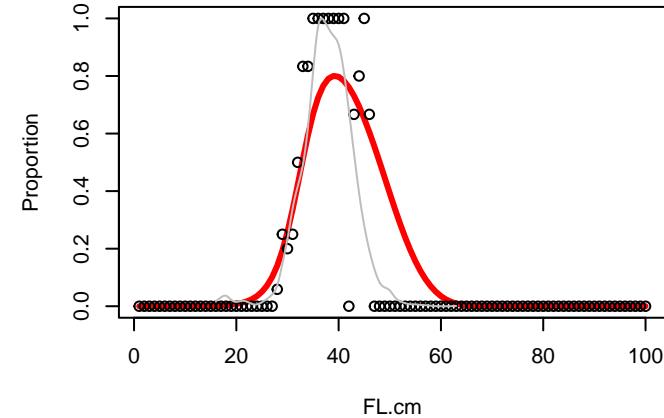
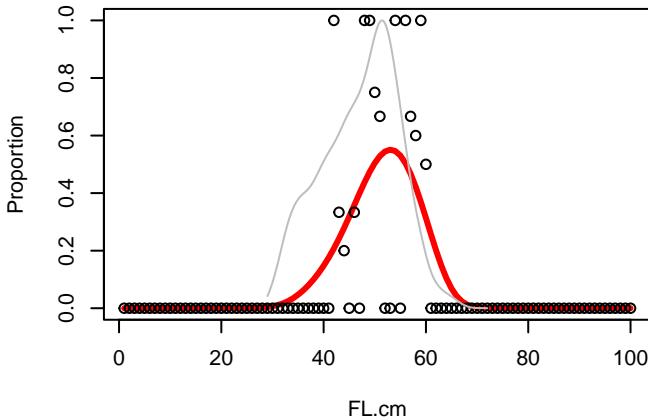
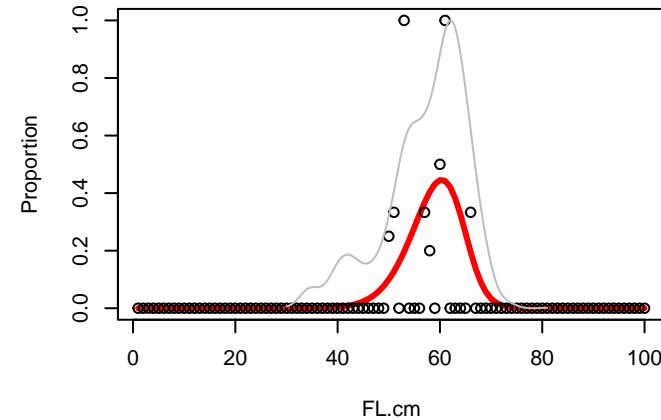
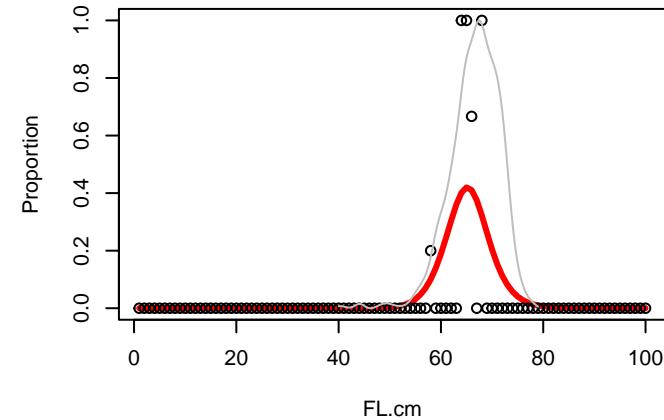
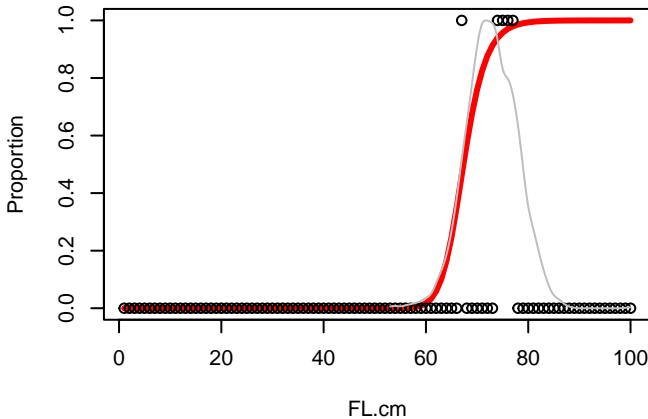
A6



All spring
1996 spring pred
○ 1996 spring obs

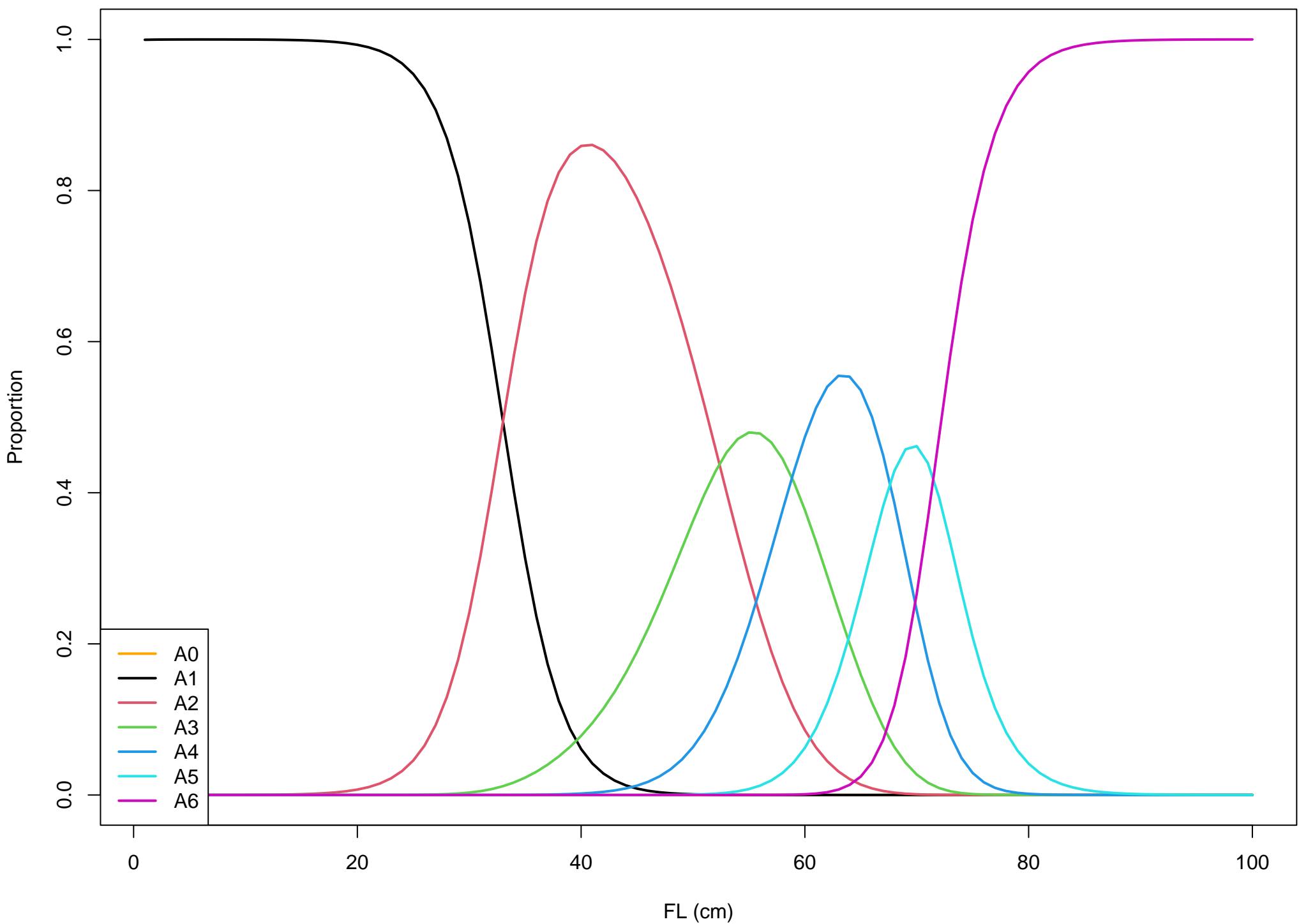
1997
spring



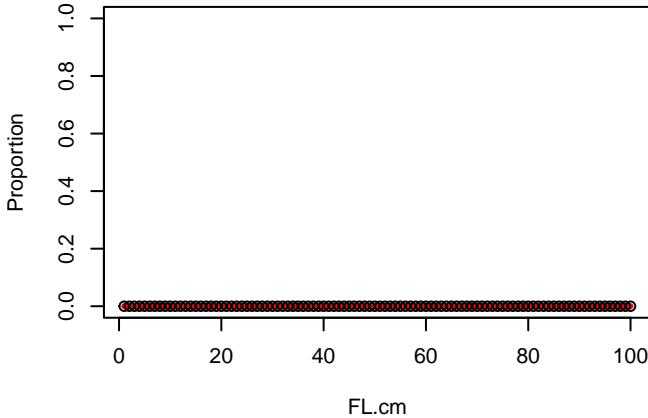
A0, 1997, spring**A1****A2****A3****A4****A5****A6**

— All spring
— 1997 spring pred
○ 1997 spring obs

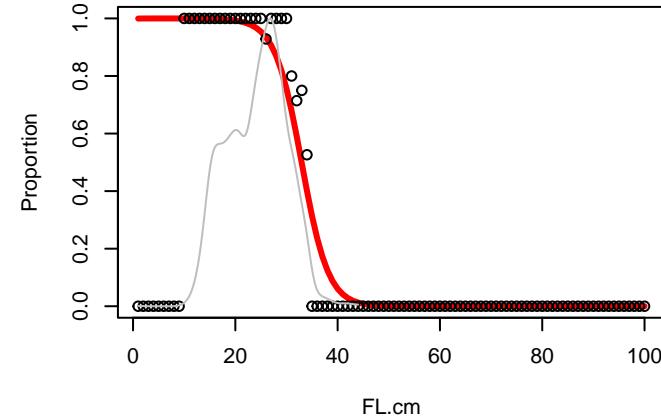
1998
spring



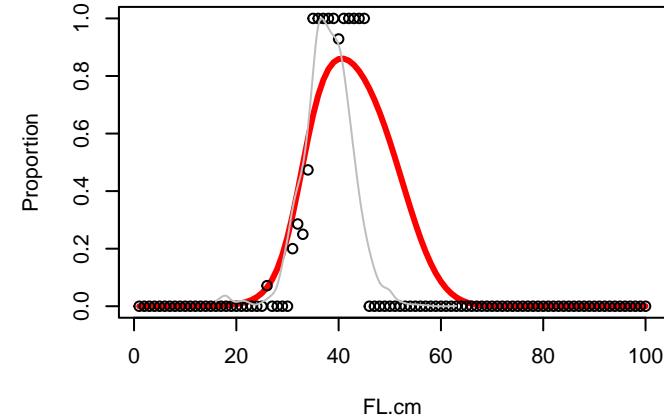
A0, 1998, spring



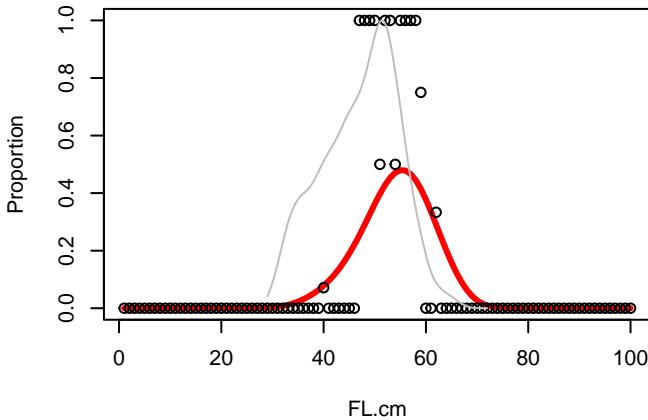
A1



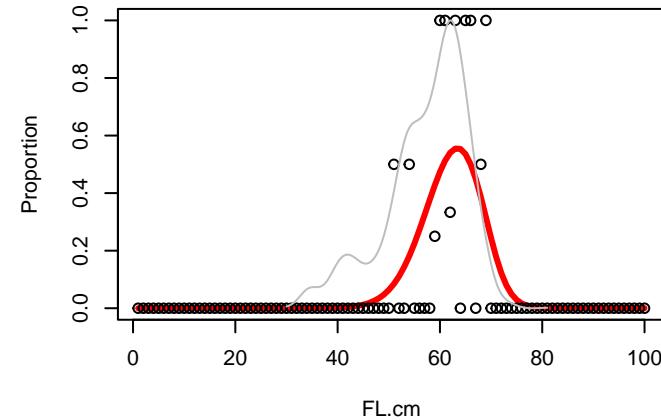
A2



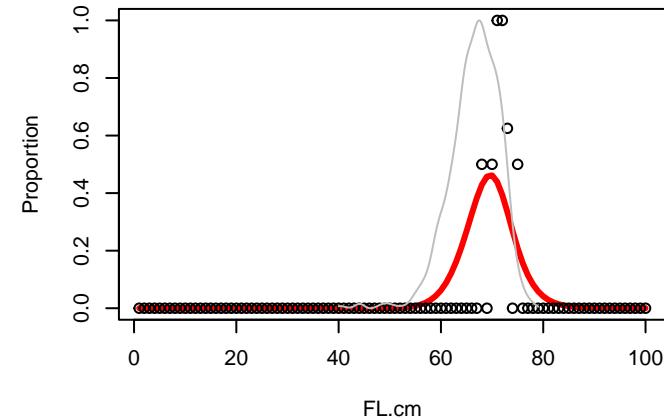
A3



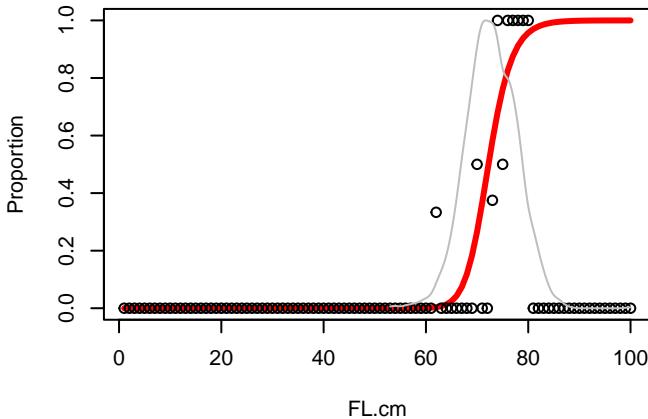
A4



A5

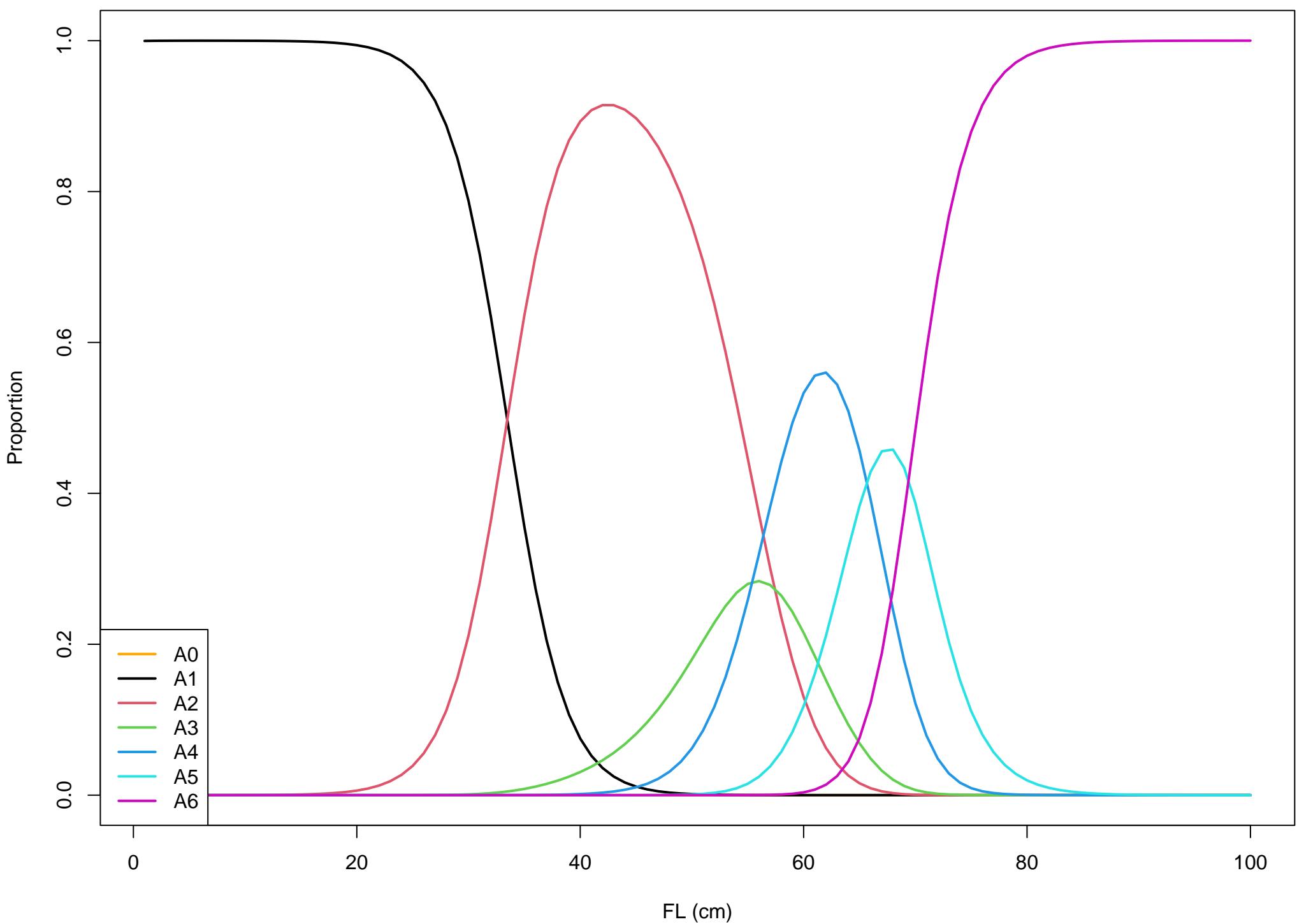


A6

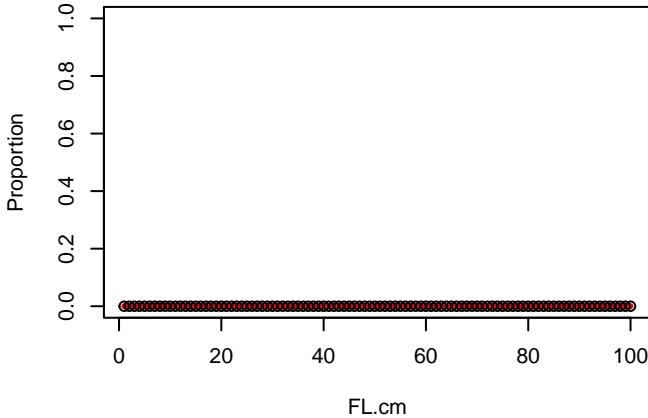


All spring
1998 spring pred
○ 1998 spring obs

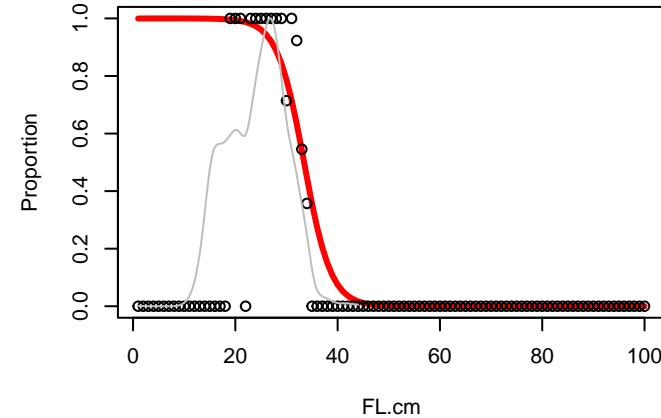
1999
spring



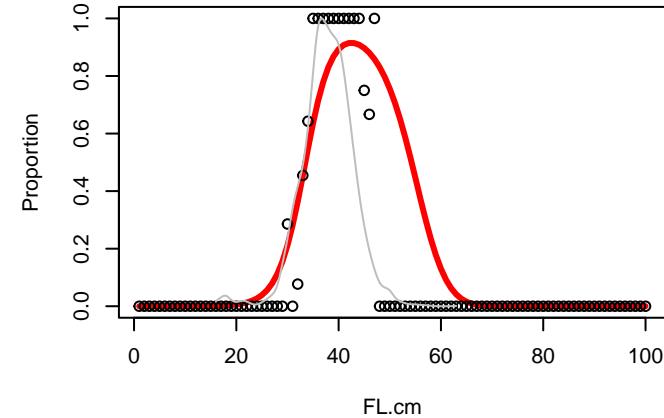
A0, 1999, spring



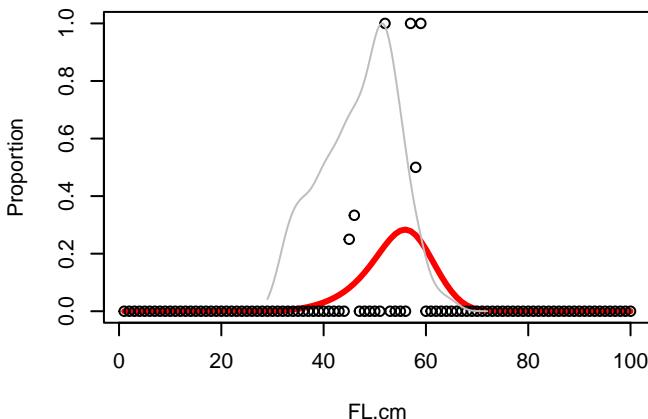
A1



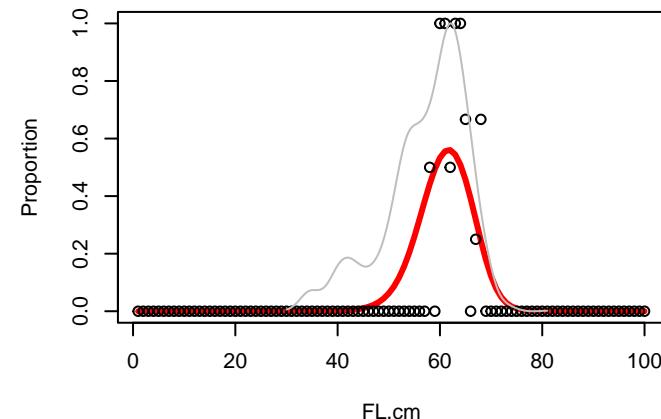
A2



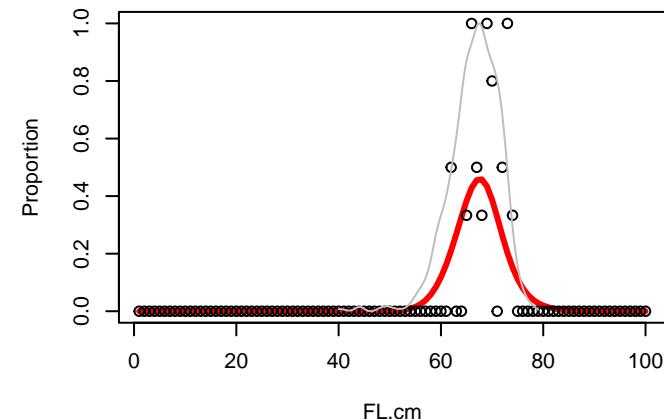
A3



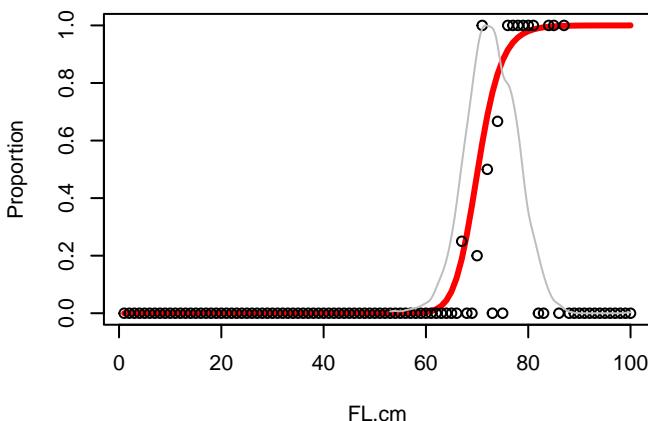
A4



A5

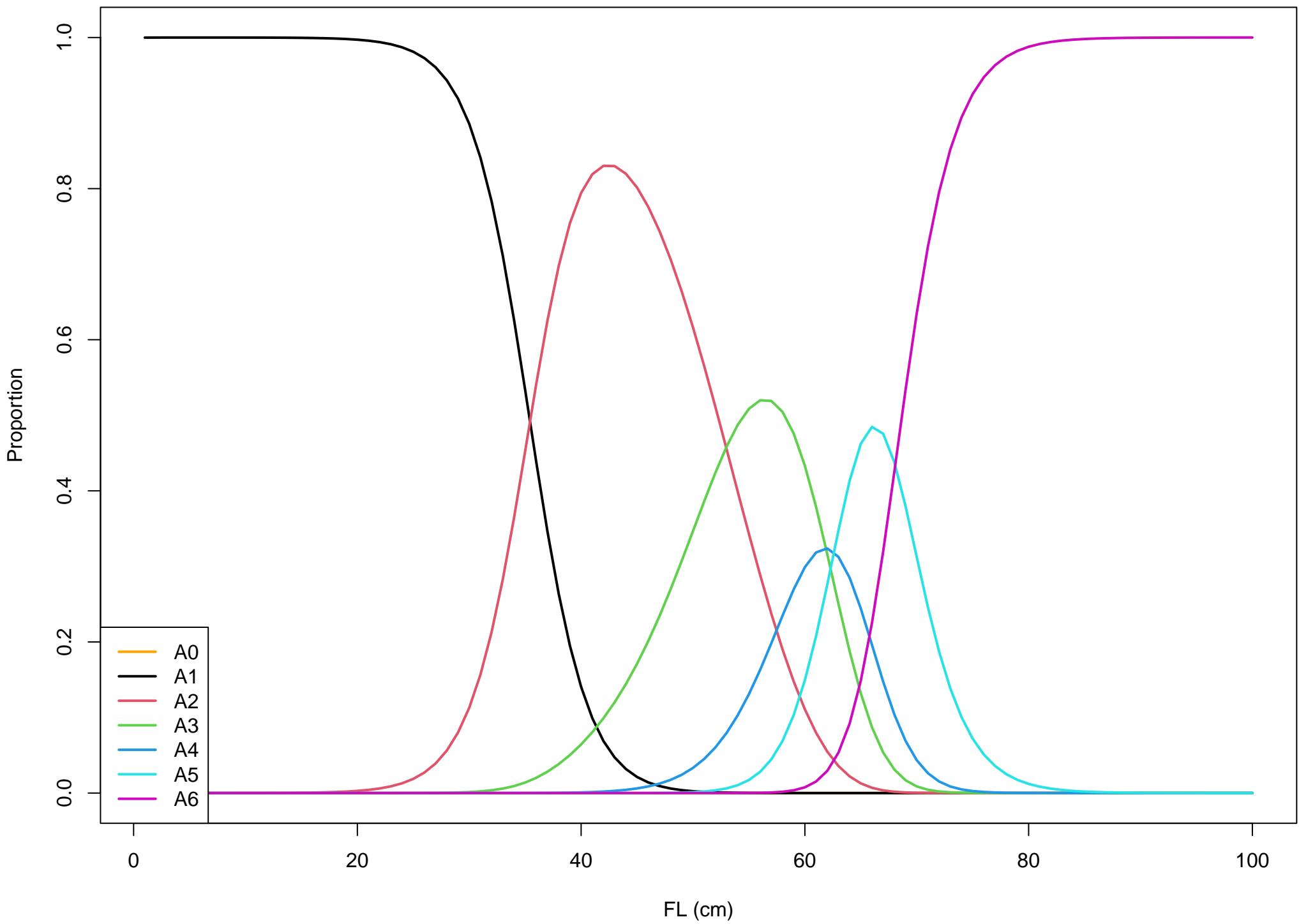


A6

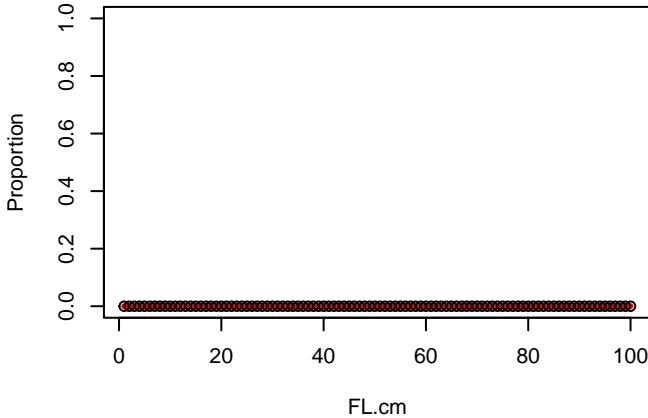


All spring
1999 spring pred
○ 1999 spring obs

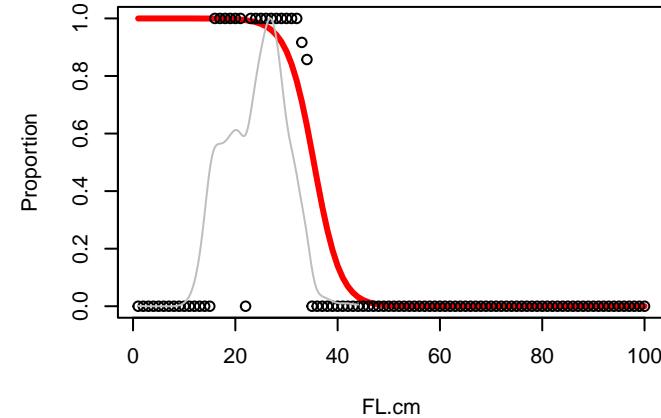
2000
spring



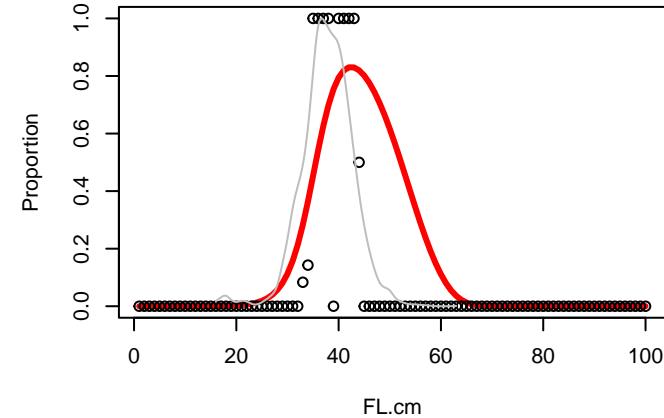
A0, 2000, spring



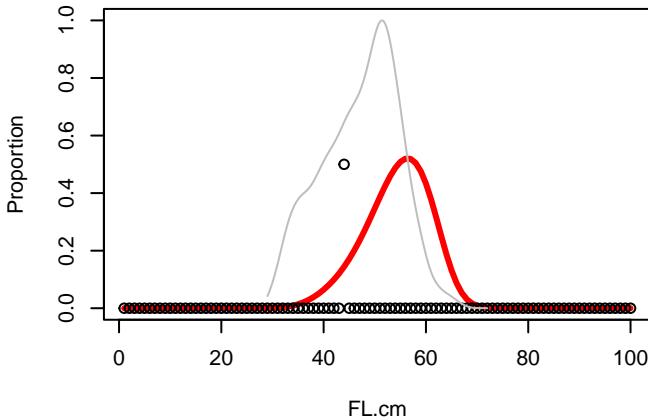
A1



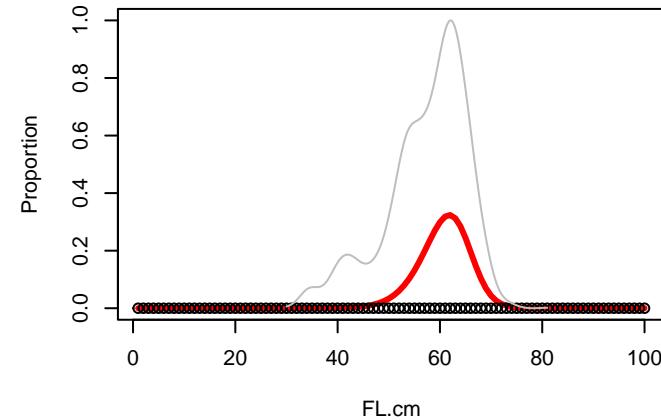
A2



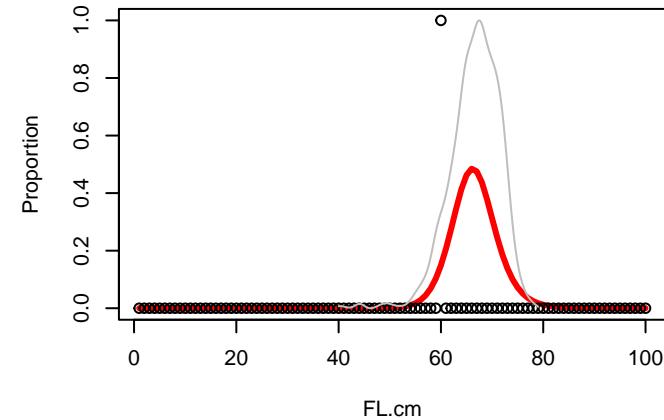
A3



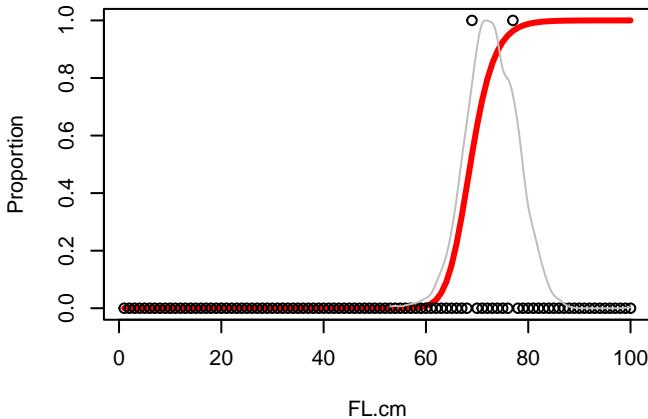
A4



A5

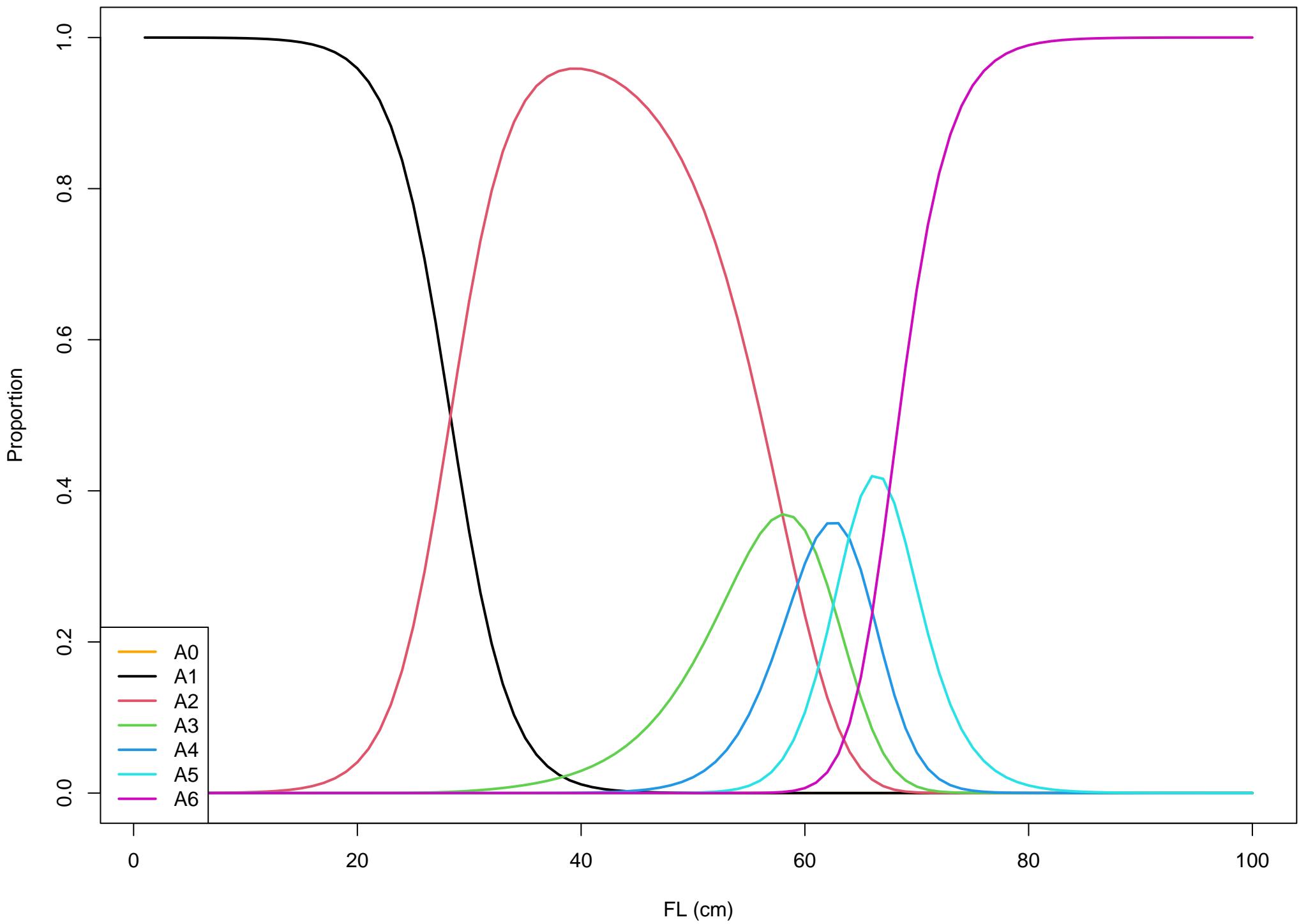


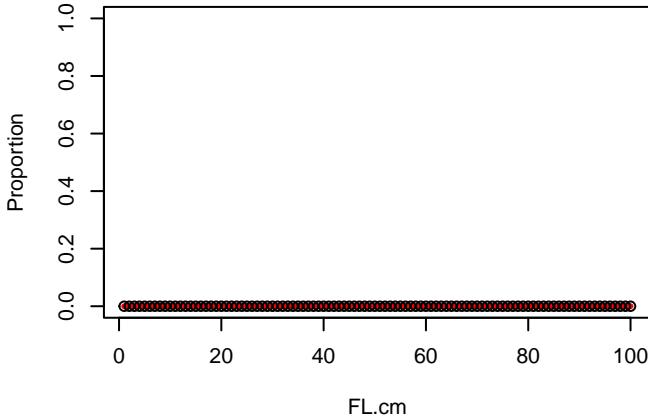
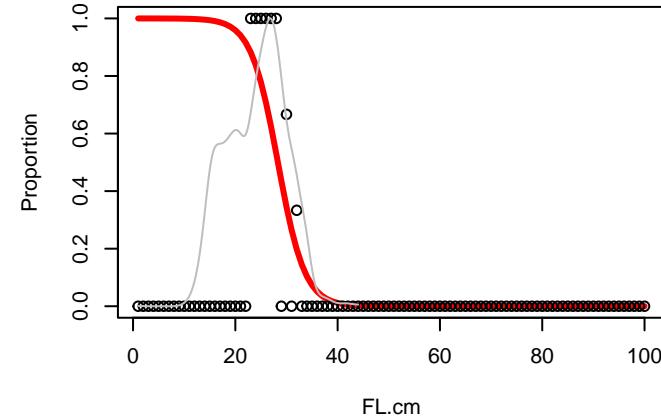
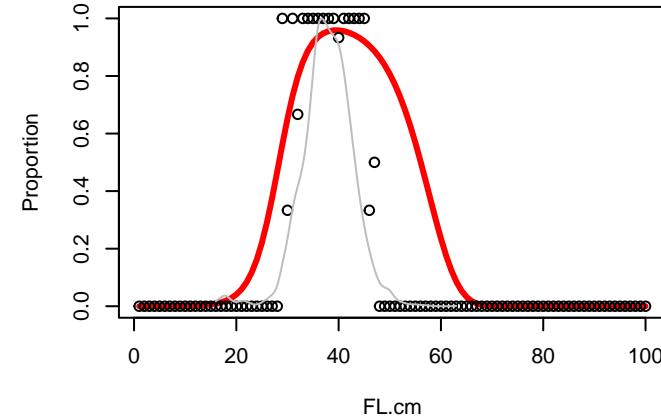
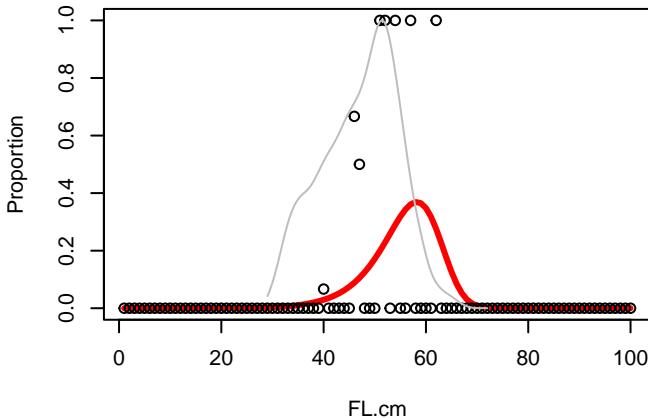
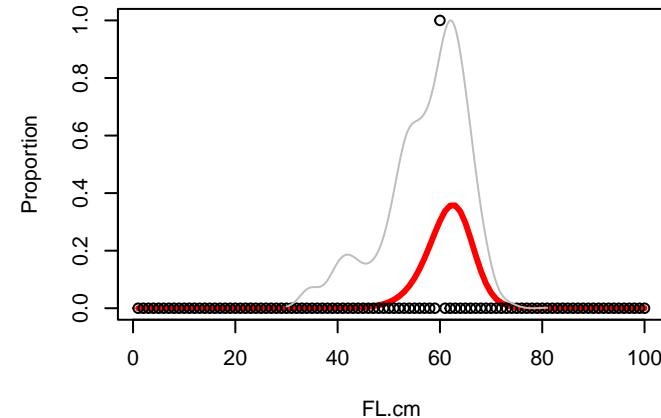
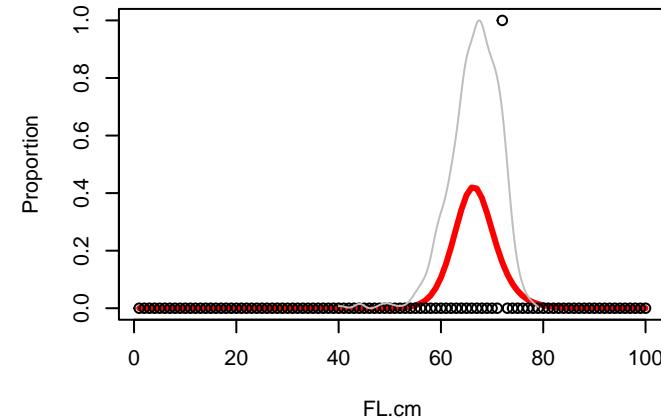
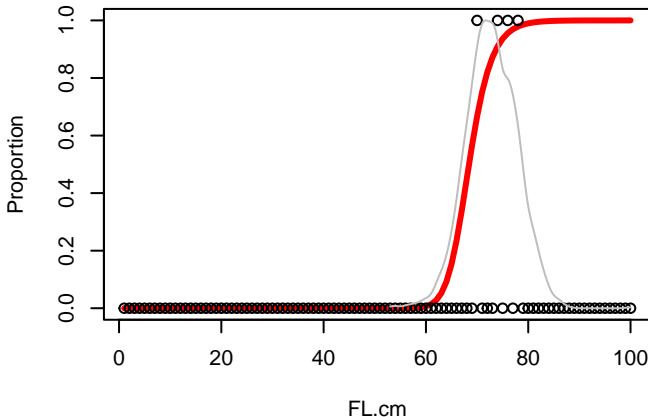
A6



All spring
2000 spring pred
○ 2000 spring obs

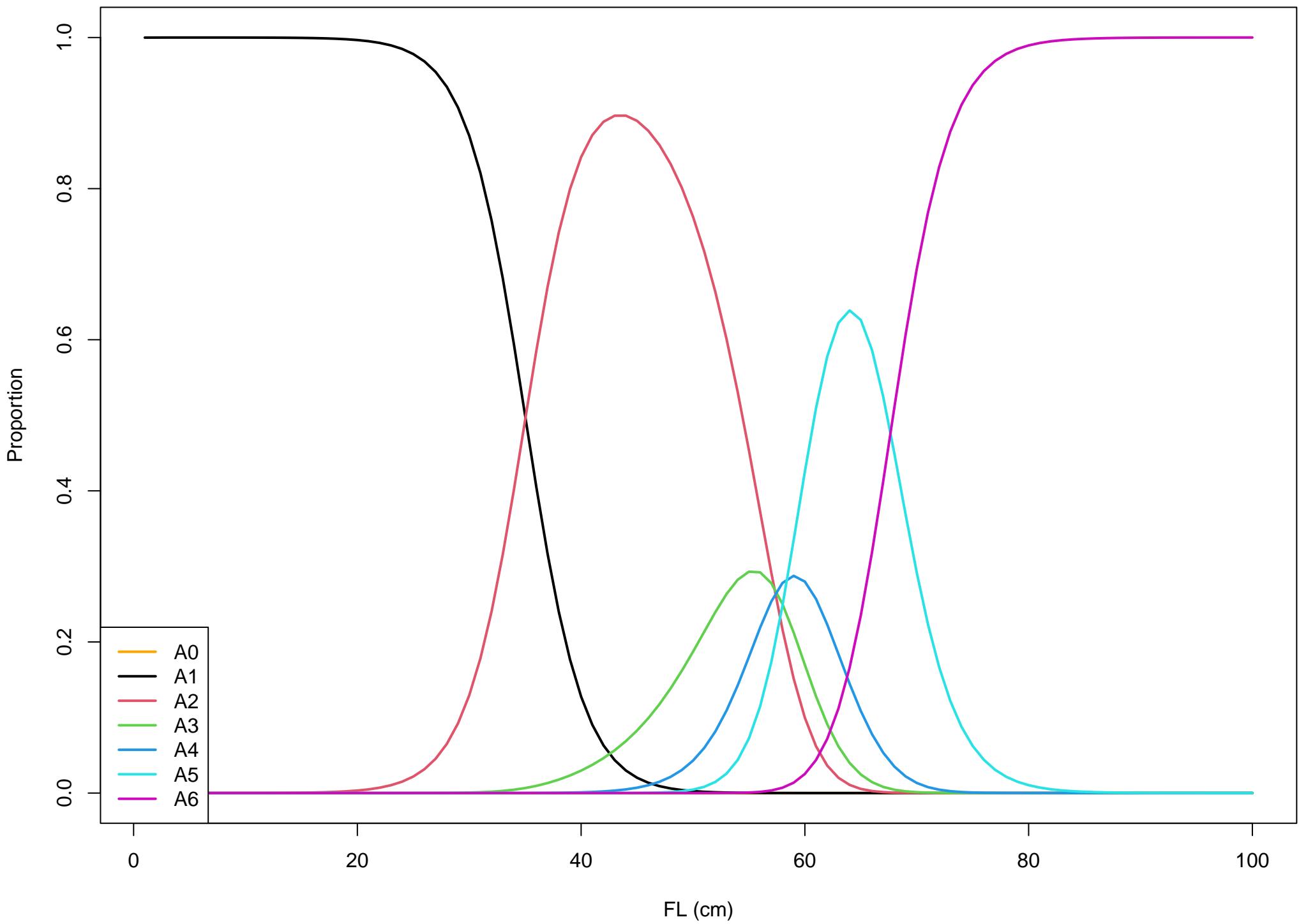
2001
spring

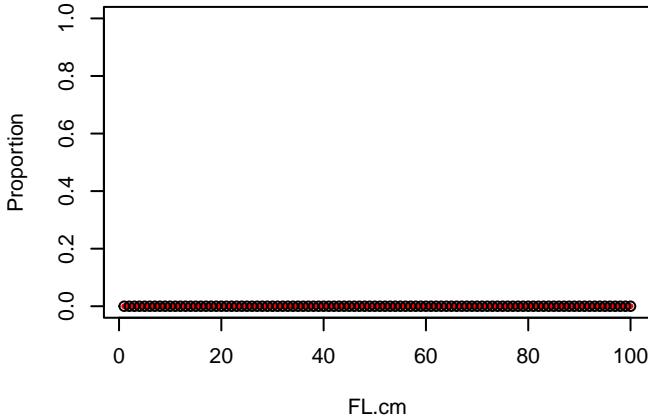
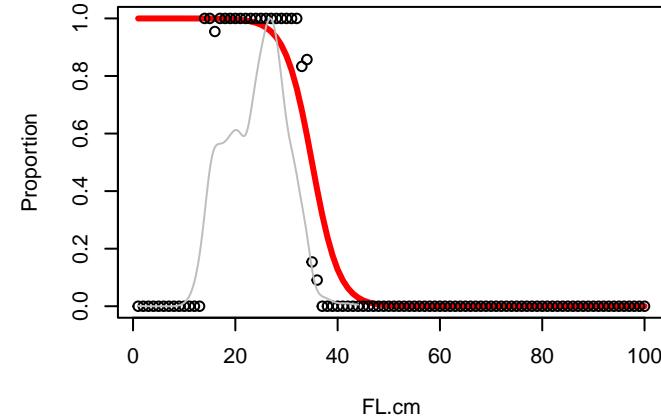
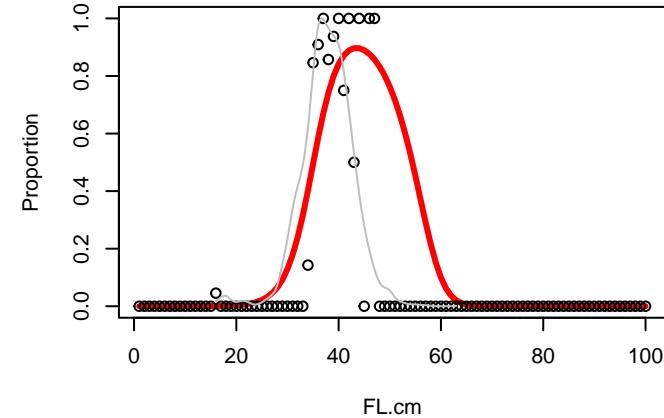
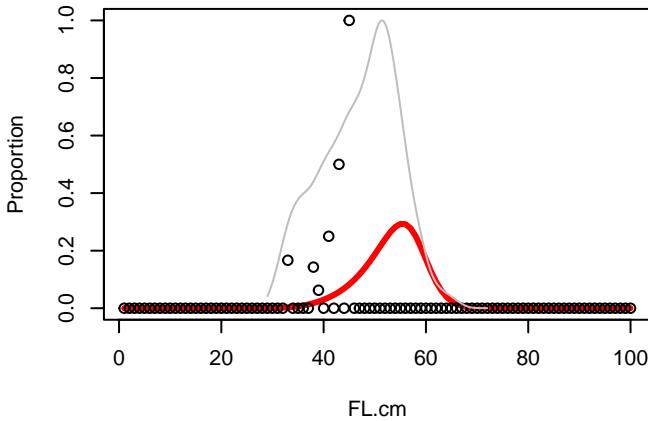
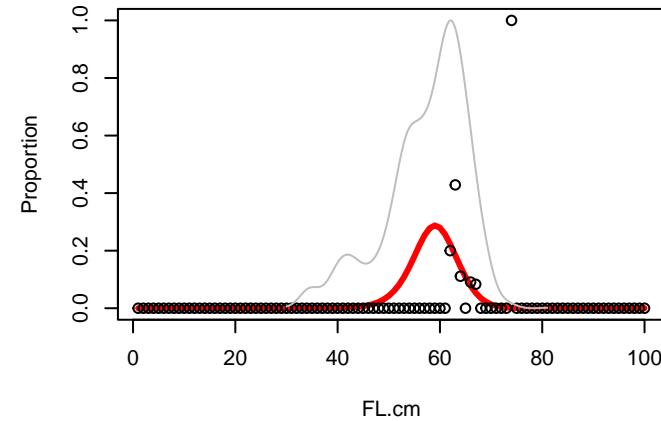
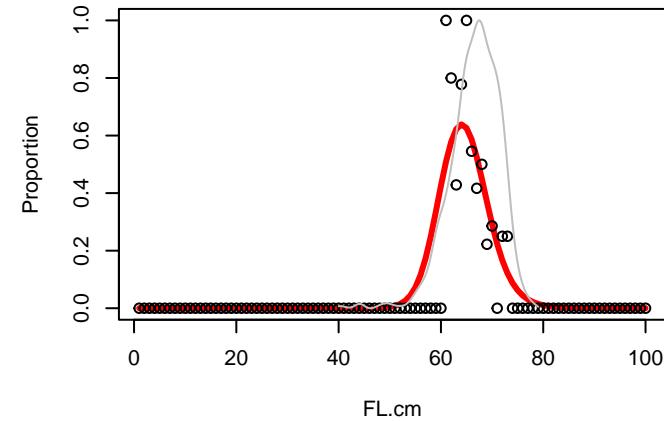
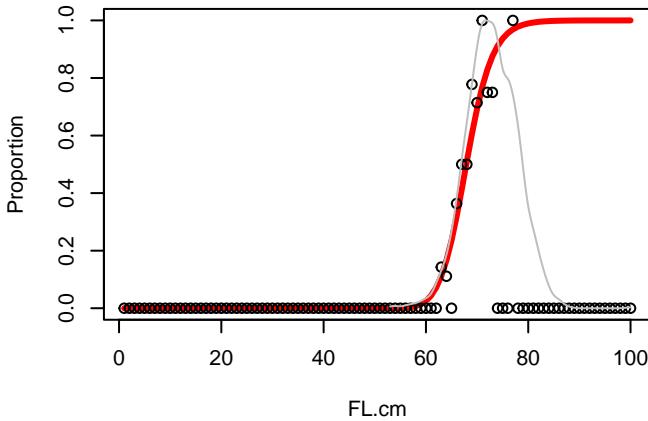


A0, 2001, spring**A1****A2****A3****A4****A5****A6**

— All spring
— 2001 spring pred
○ 2001 spring obs

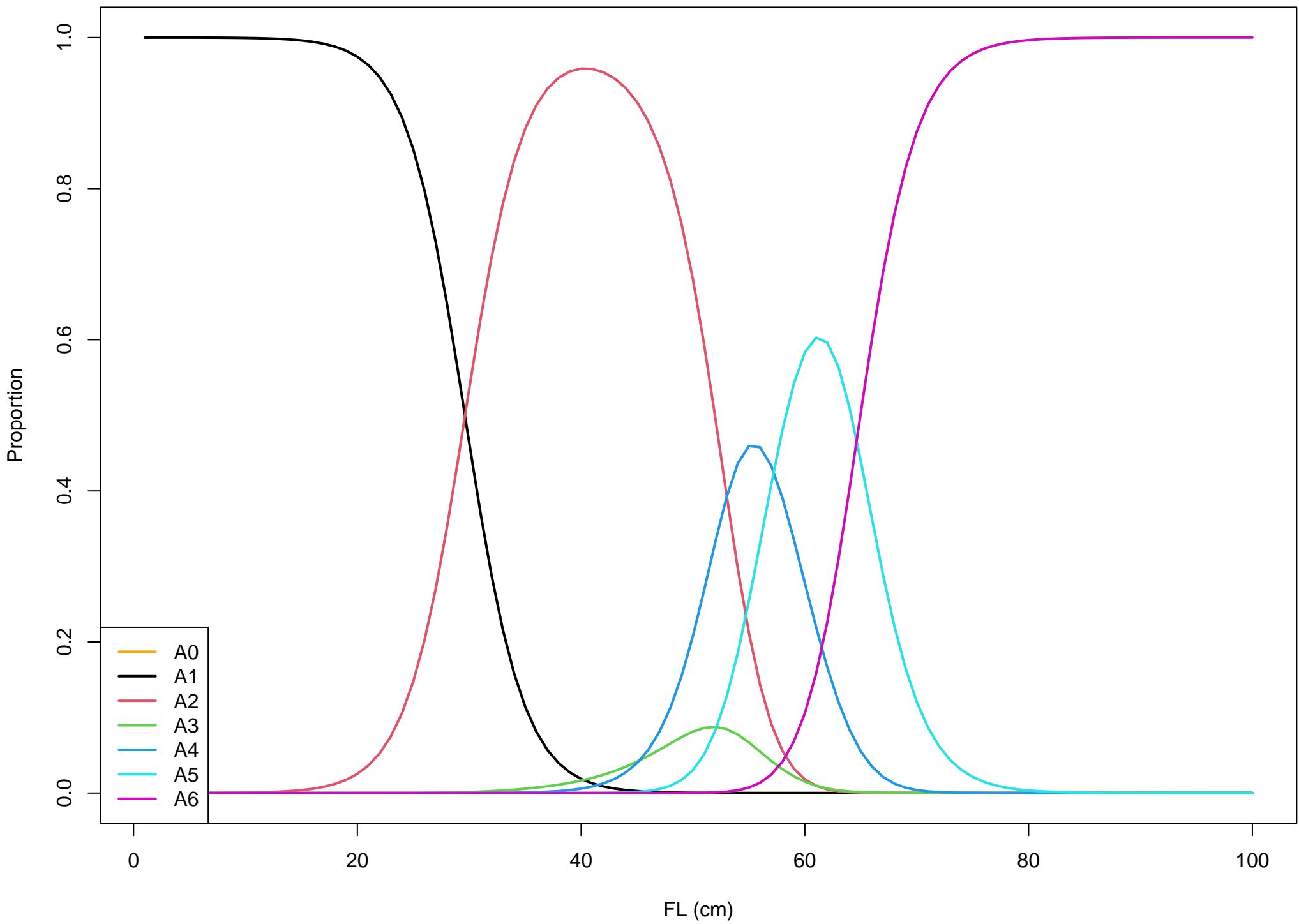
2002
spring

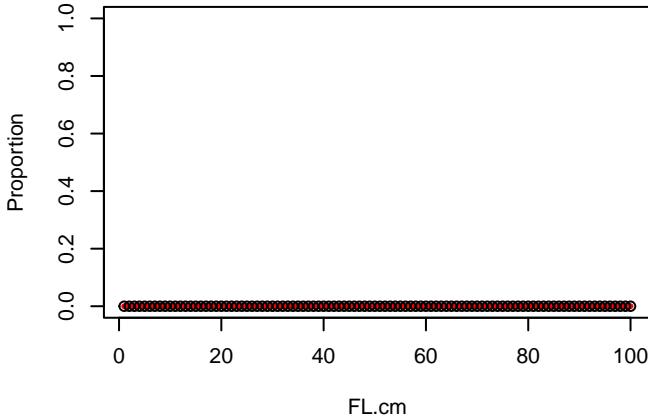
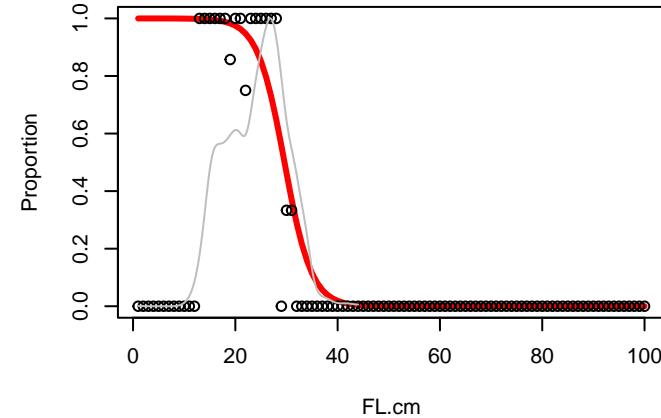
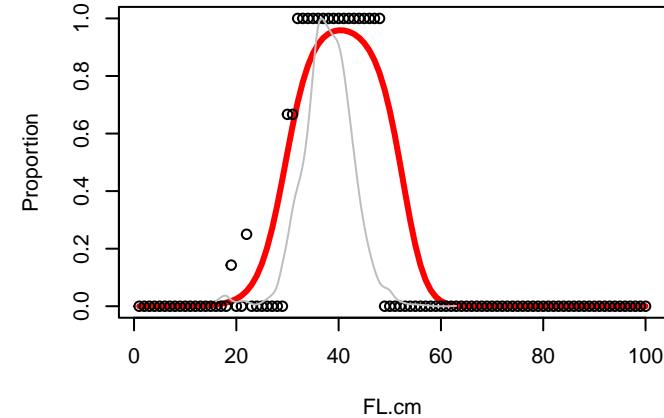
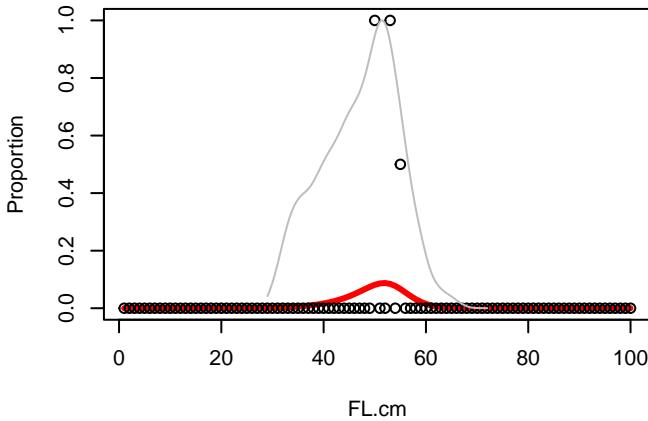
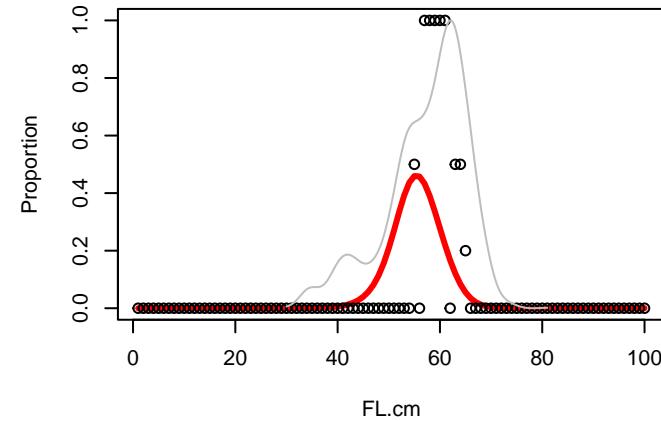
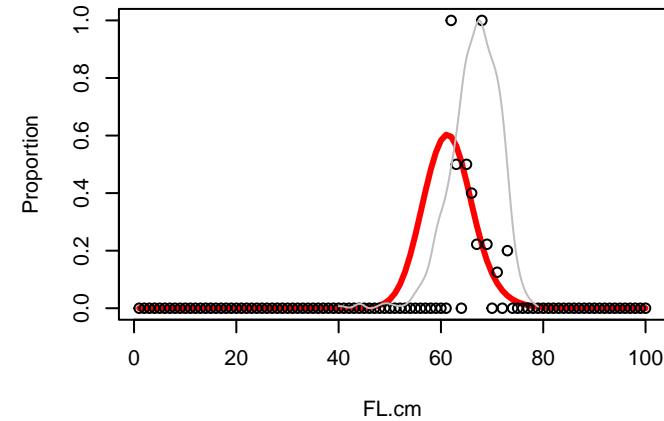
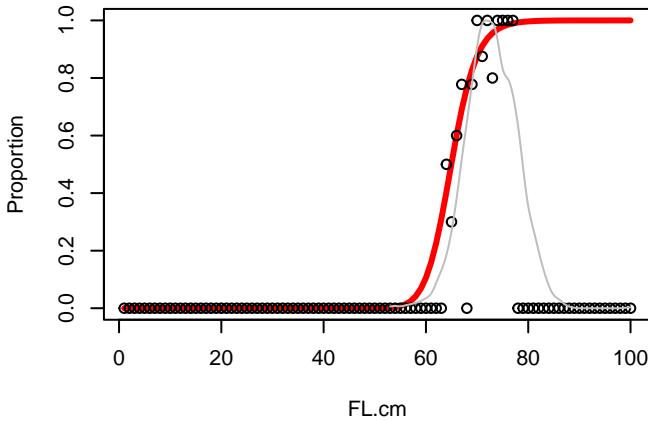


A0, 2002, spring**A1****A2****A3****A4****A5****A6**

All spring
2002 spring pred
○ 2002 spring obs

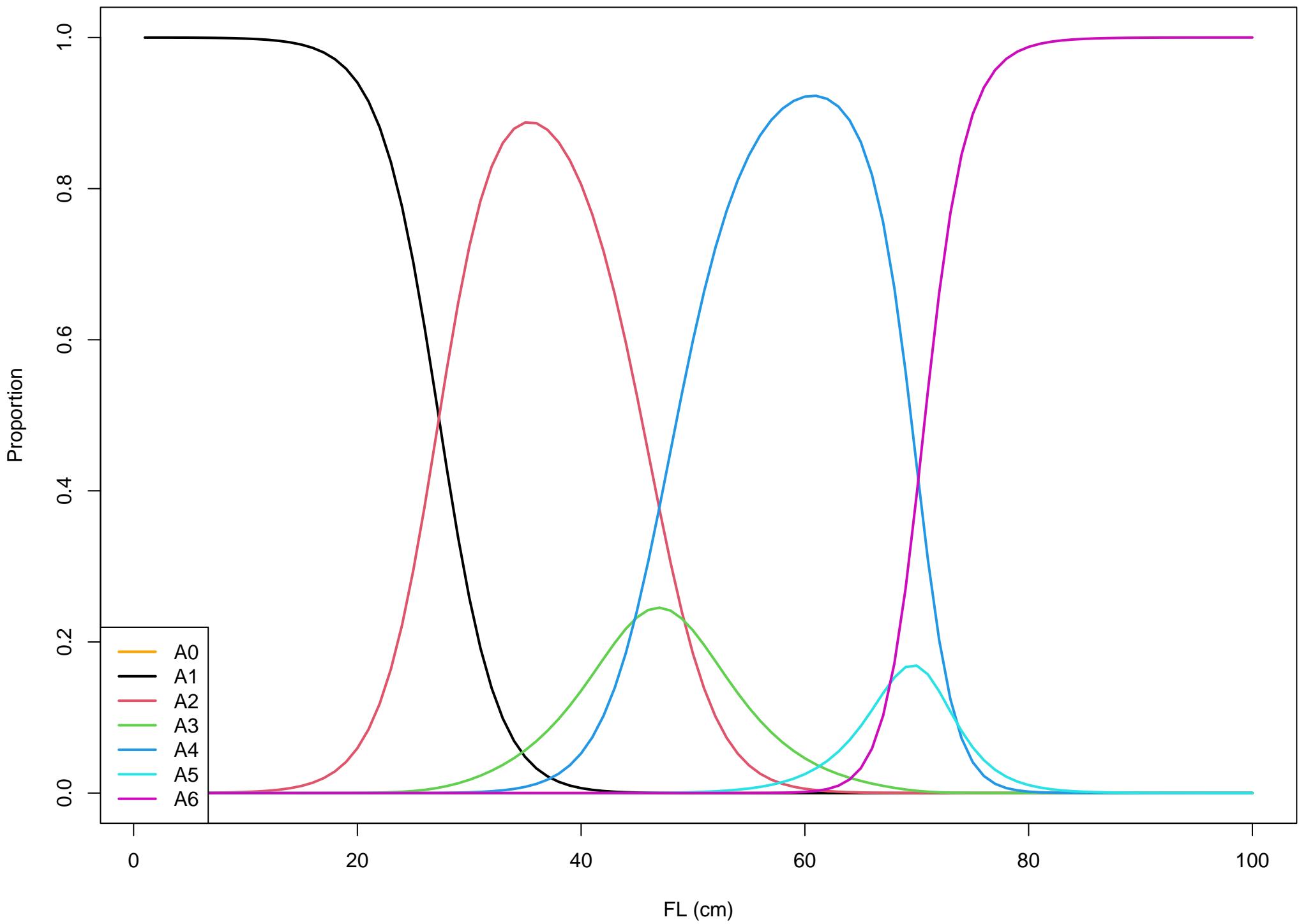
2003
spring



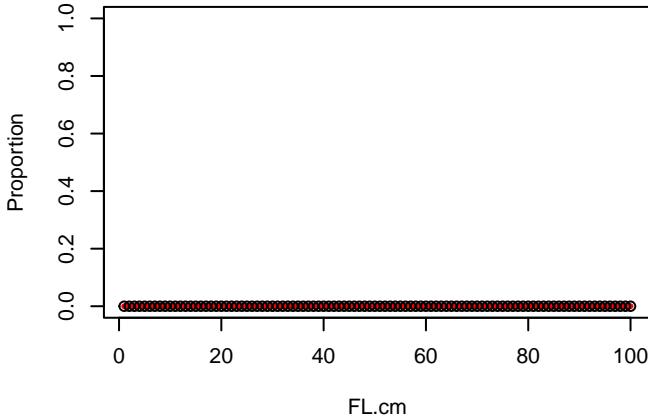
A0, 2003, spring**A1****A2****A3****A4****A5****A6**

— All spring
— 2003 spring pred
○ 2003 spring obs

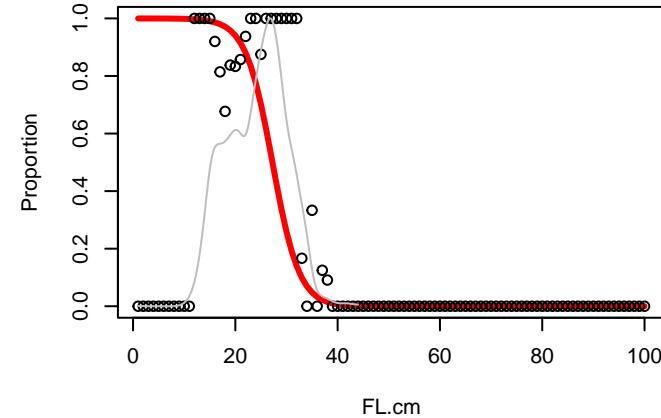
2004
spring



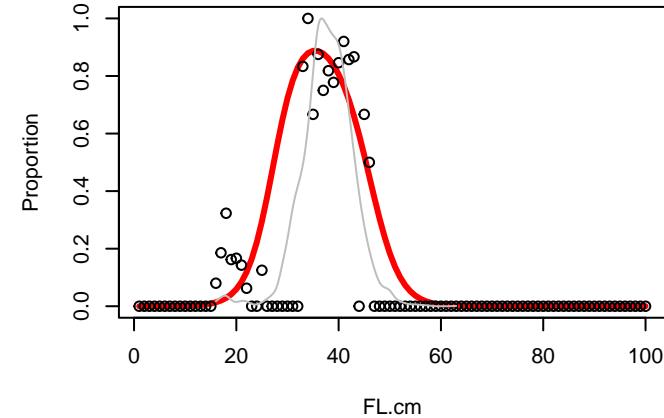
A0, 2004, spring



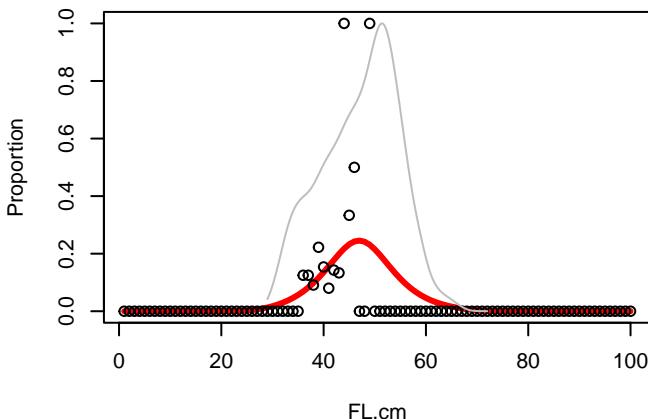
A1



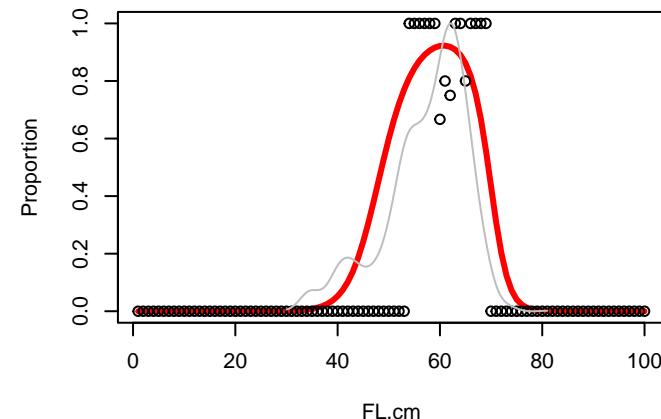
A2



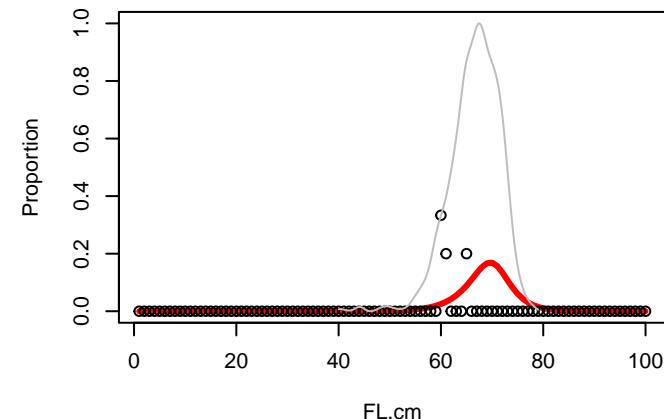
A3



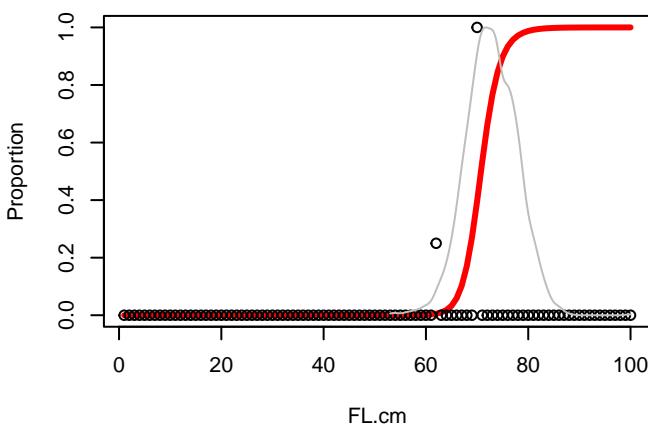
A4



A5

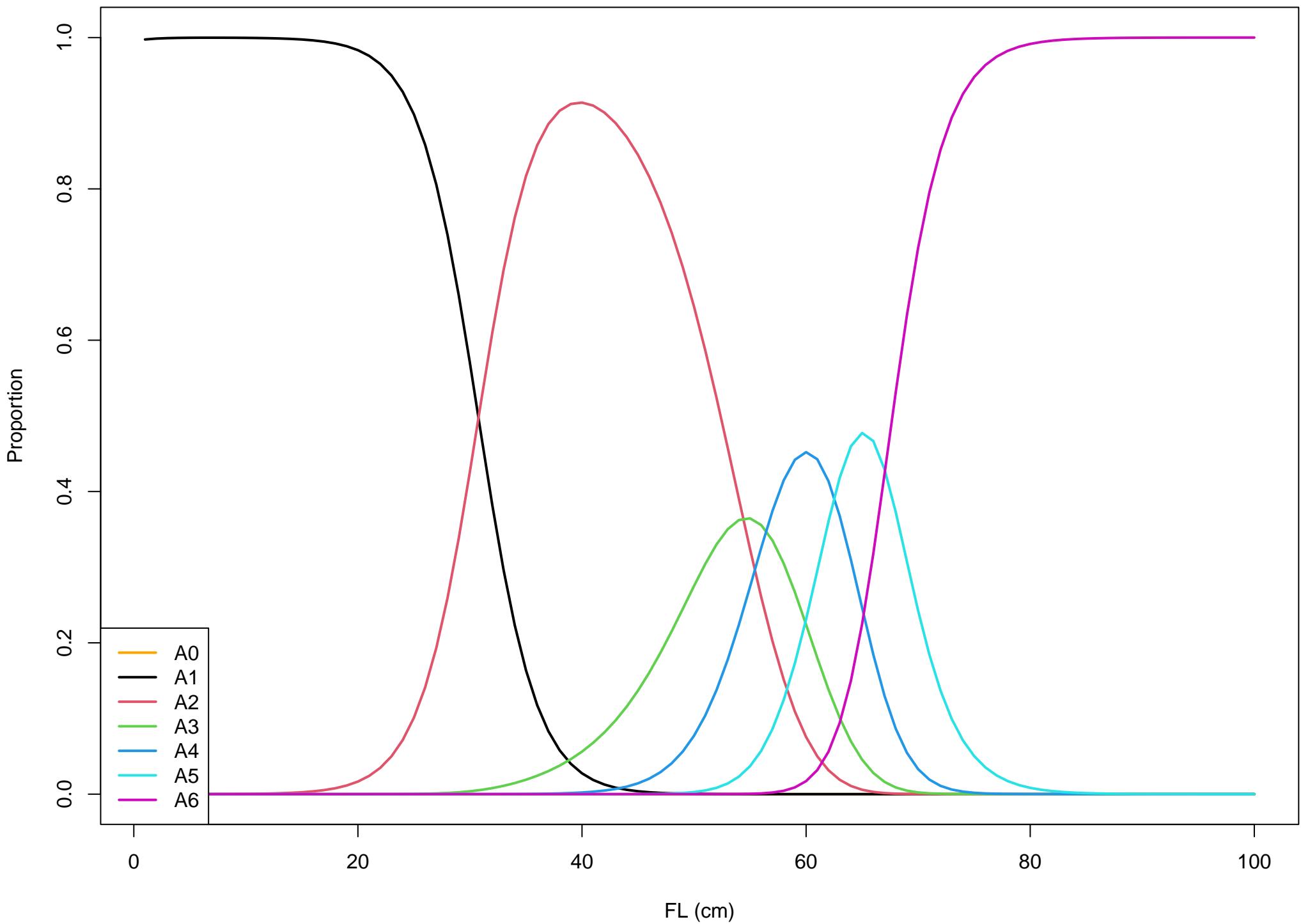


A6

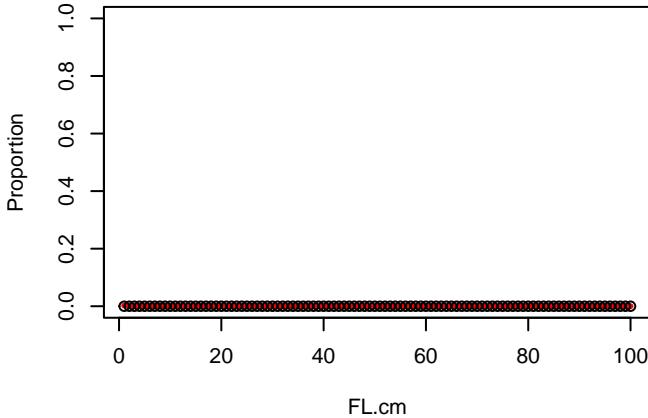


All spring
2004 spring pred
○ 2004 spring obs

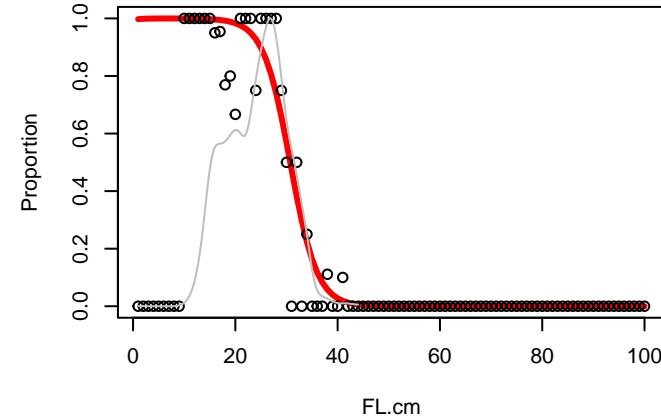
2005
spring



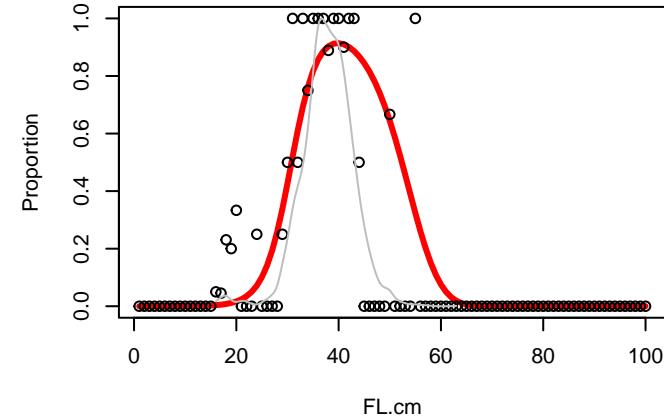
A0, 2005, spring



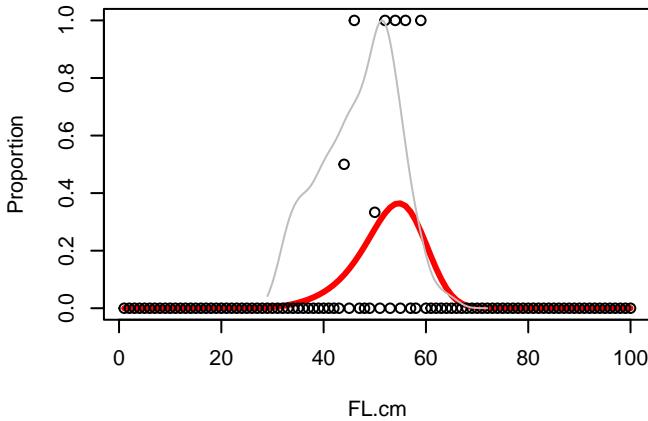
A1



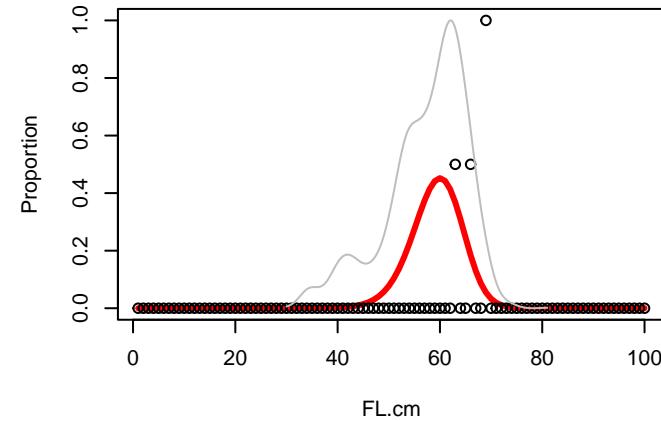
A2



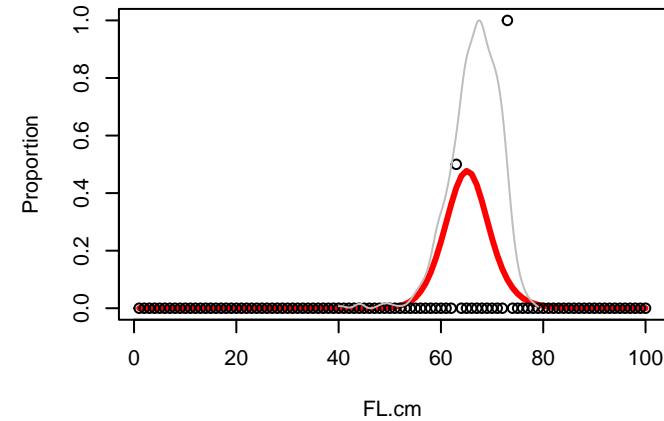
A3



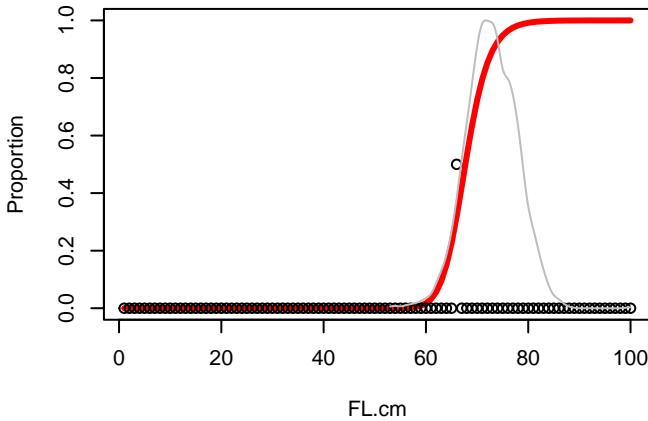
A4



A5

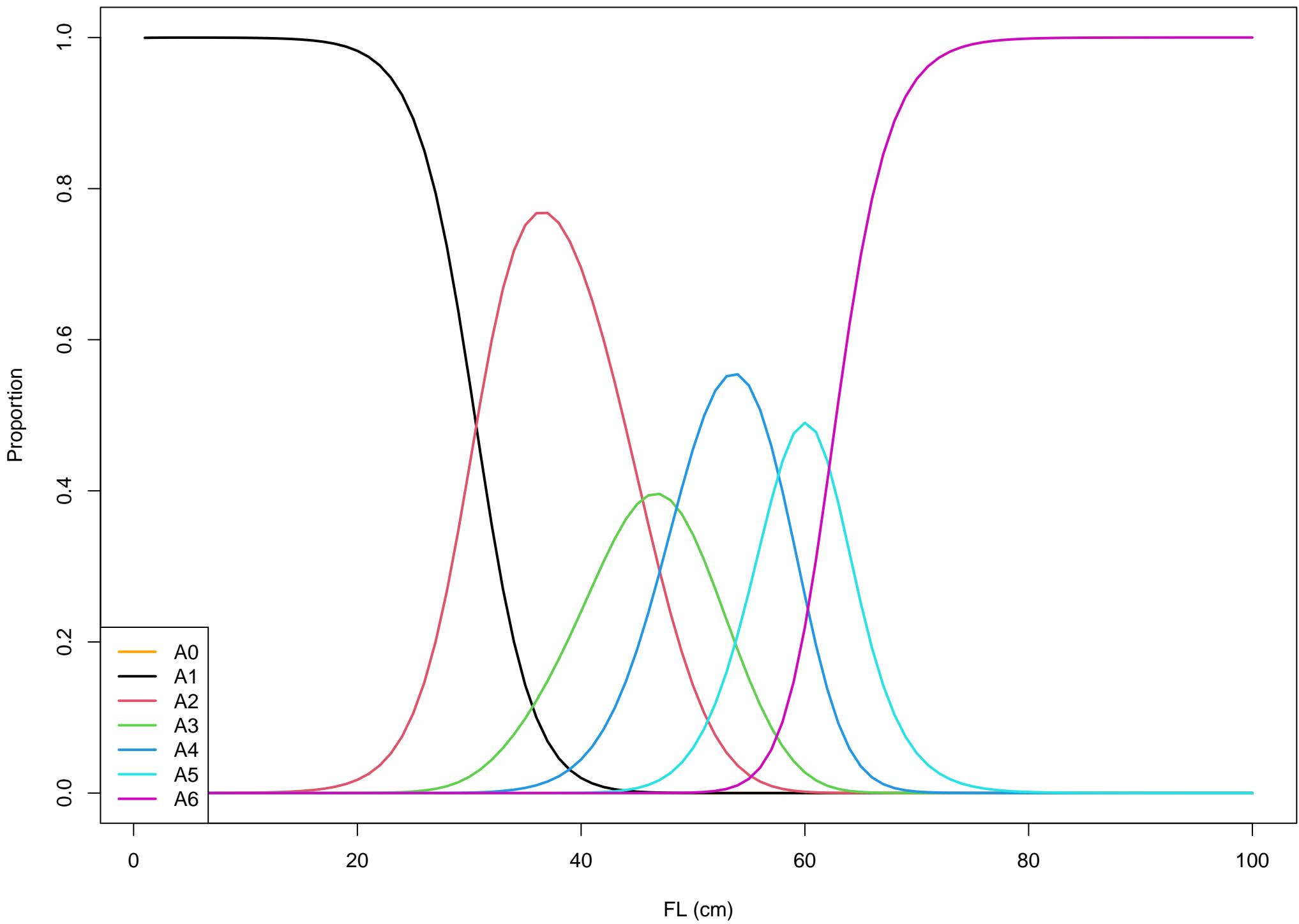


A6

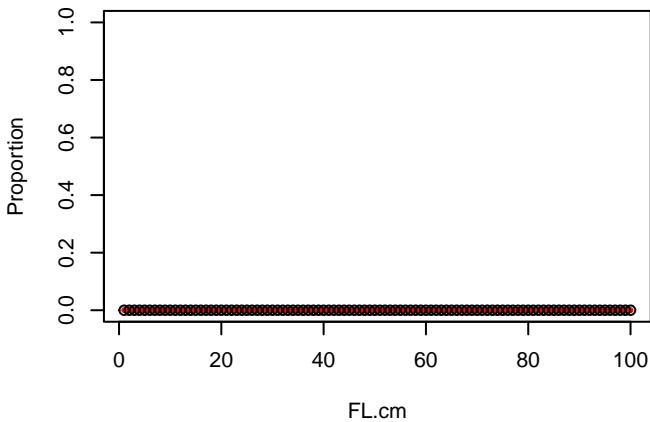


All spring
2005 spring pred
○ 2005 spring obs

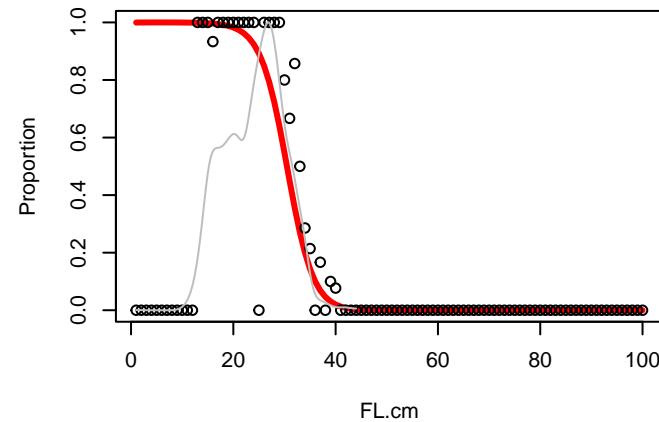
2006
spring



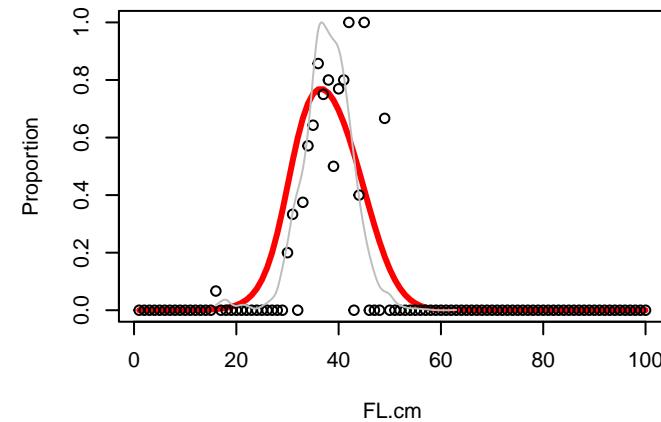
A0, 2006, spring



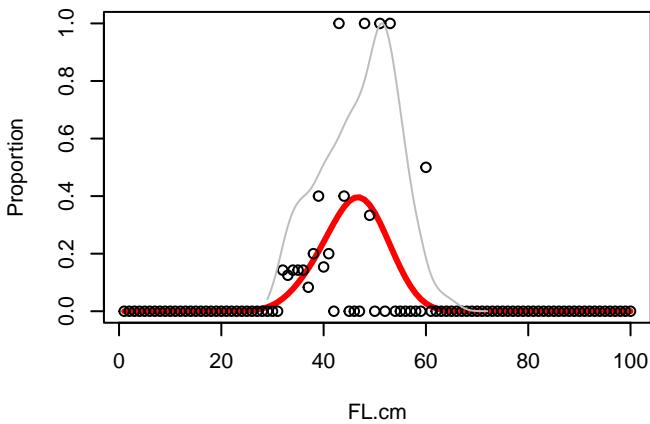
A1



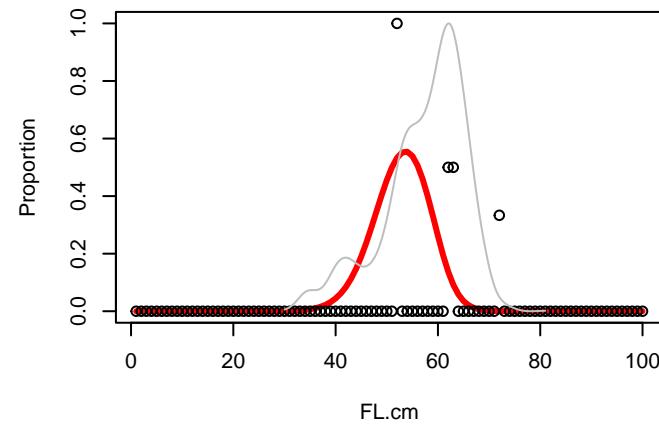
A2



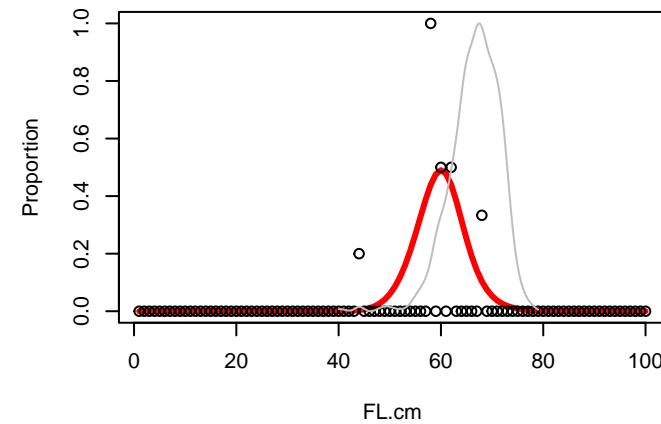
A3



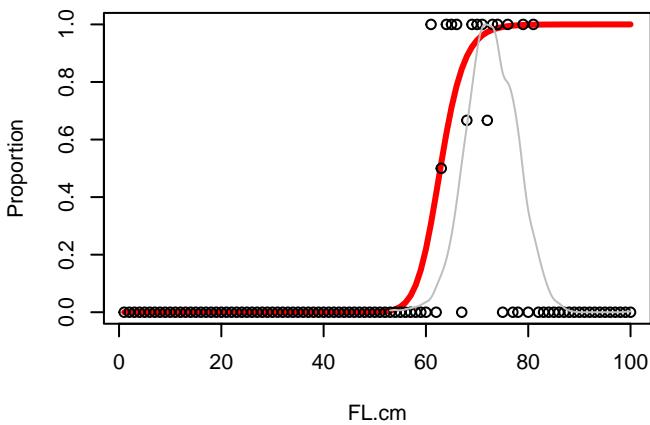
A4



A5

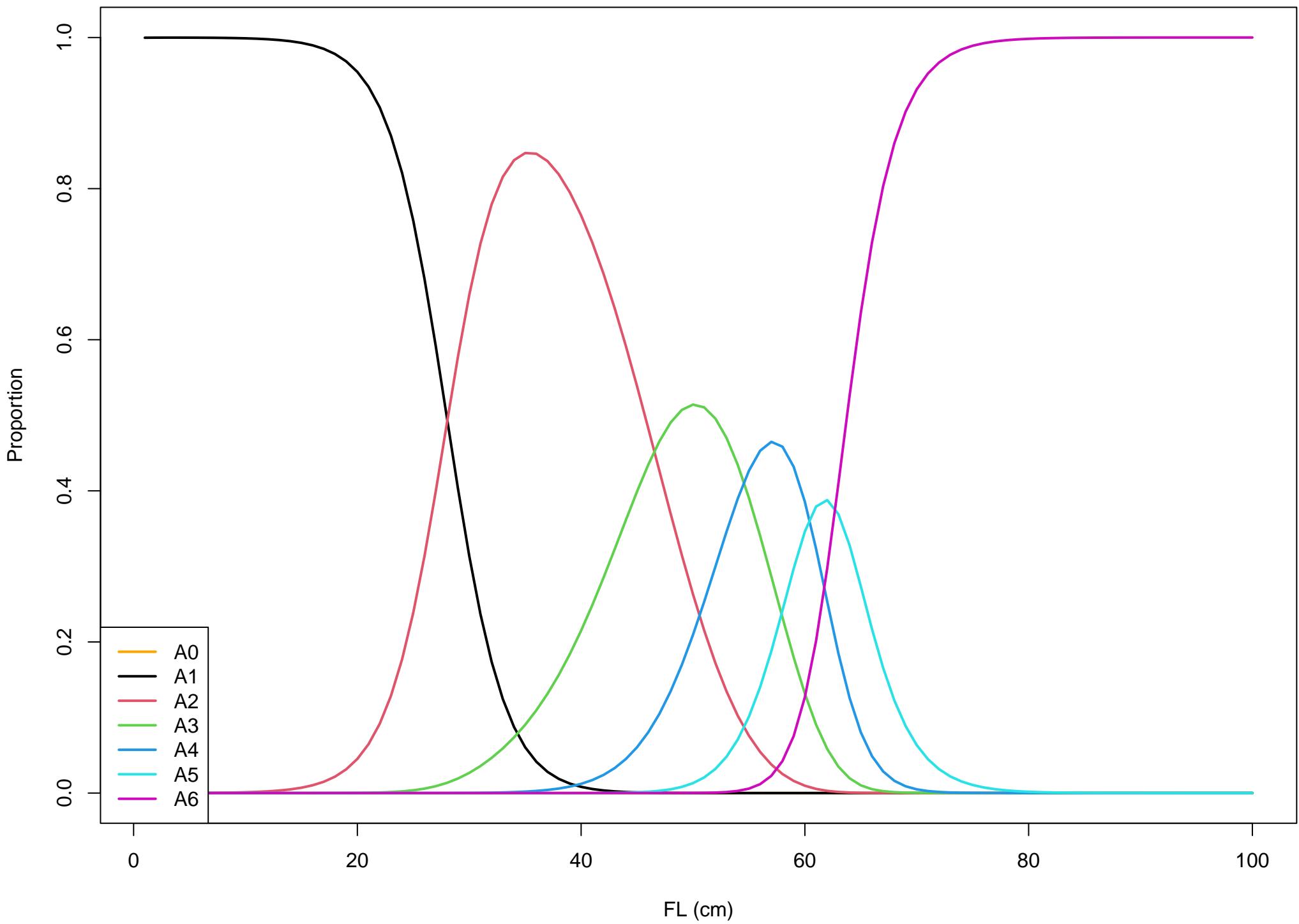


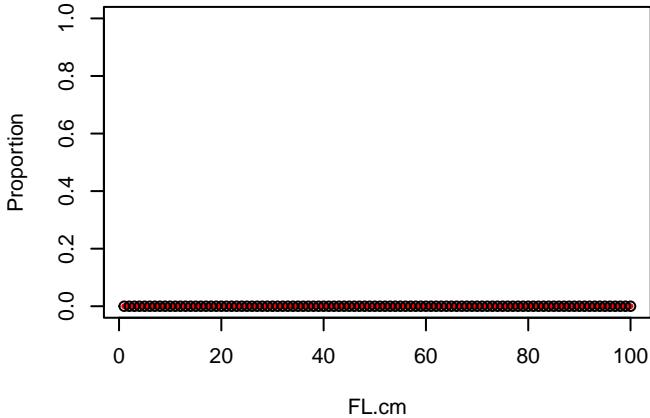
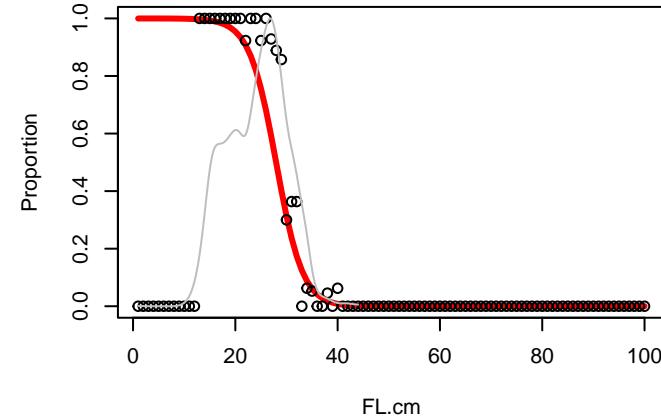
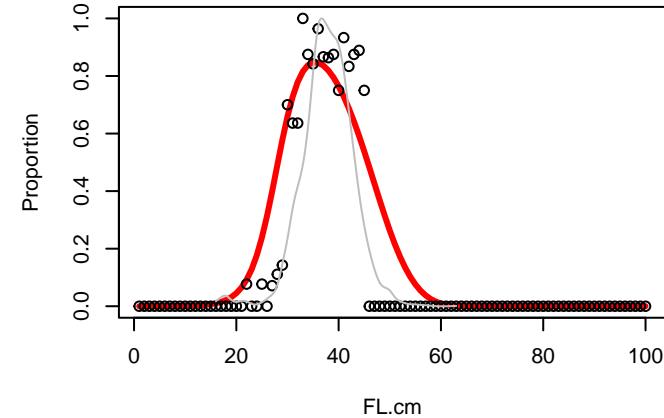
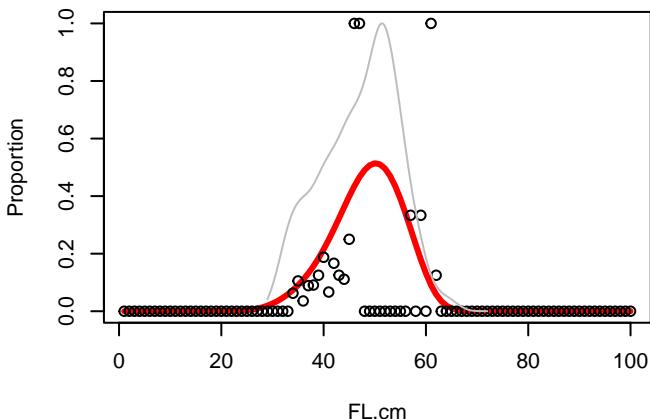
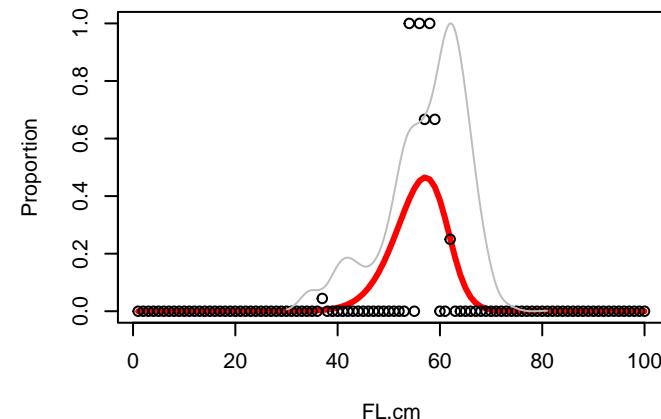
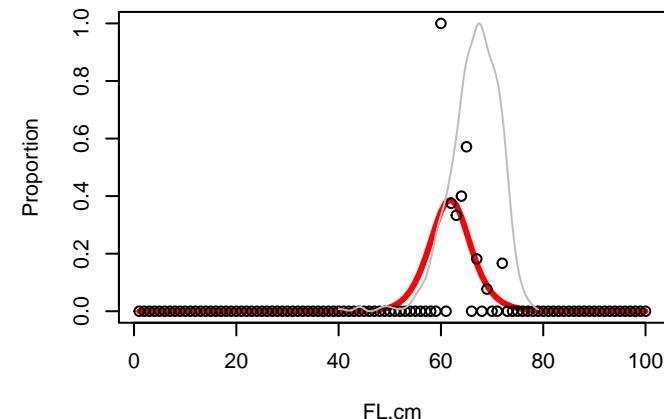
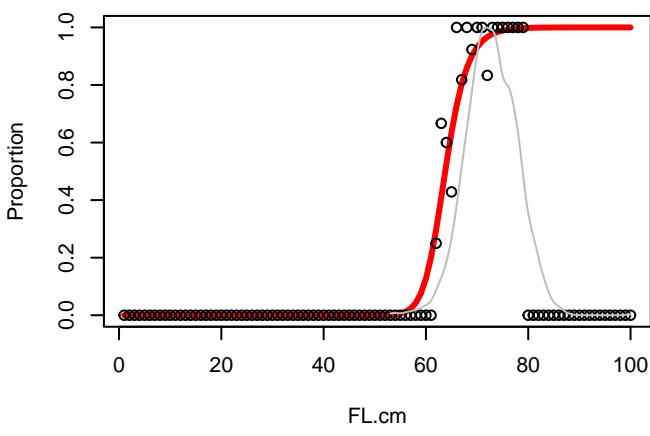
A6



All spring
2006 spring pred
○ 2006 spring obs

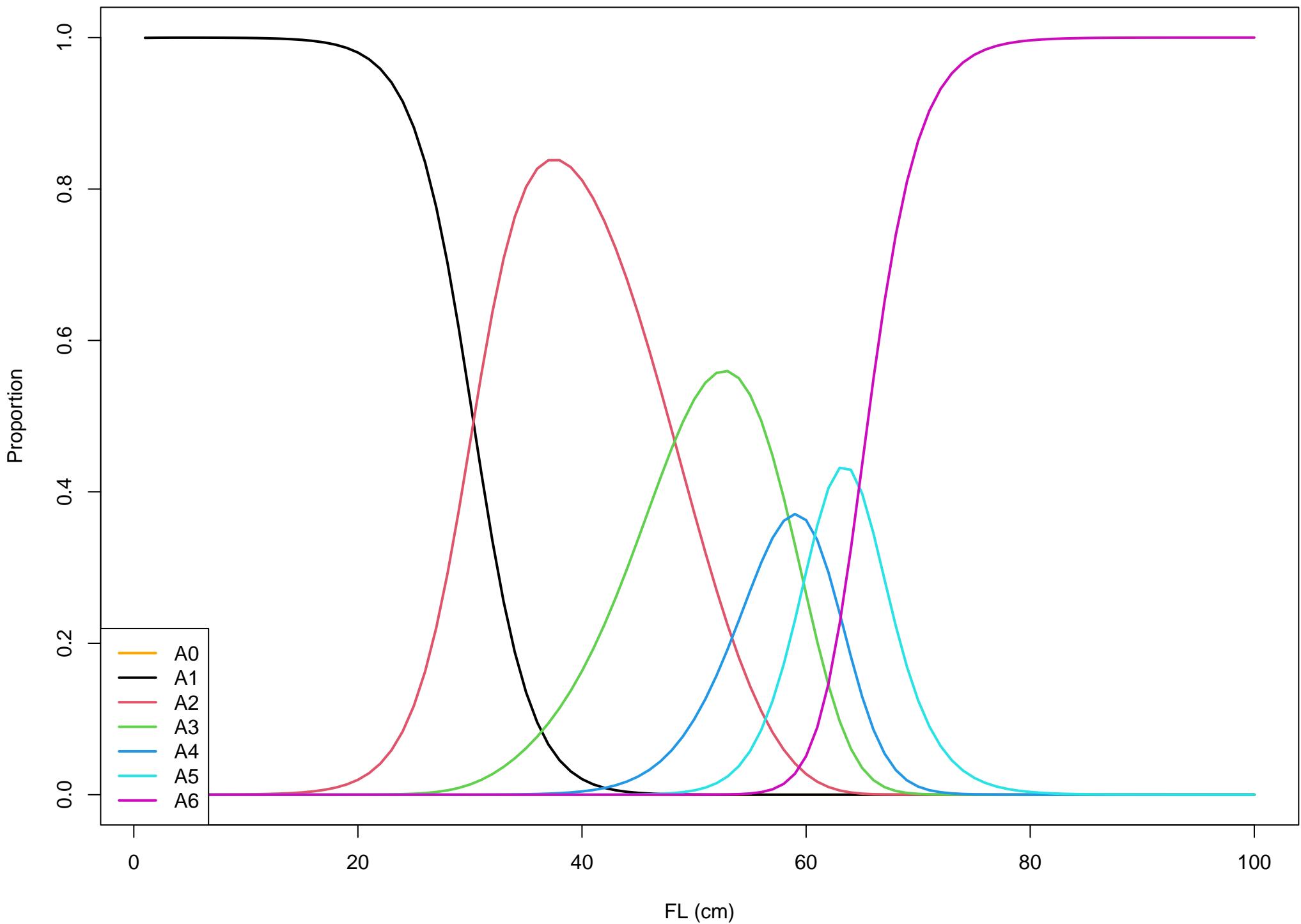
2007
spring

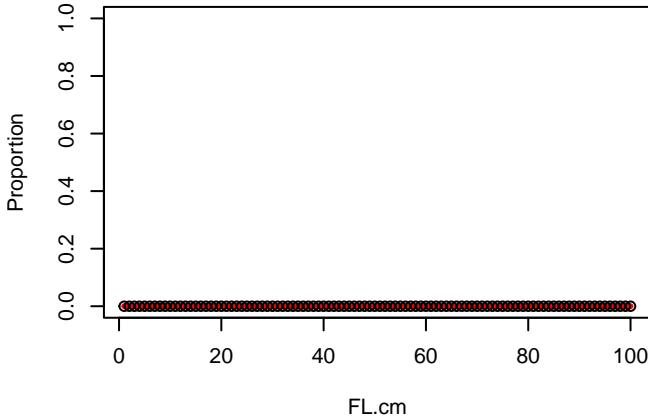
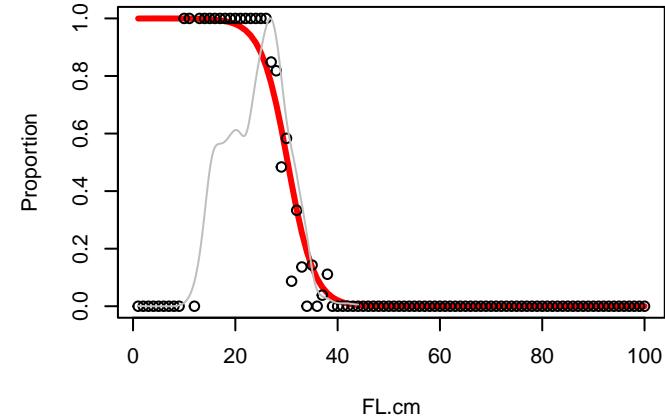
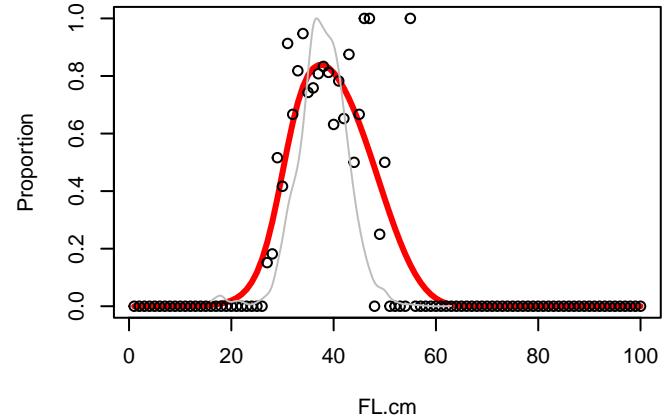
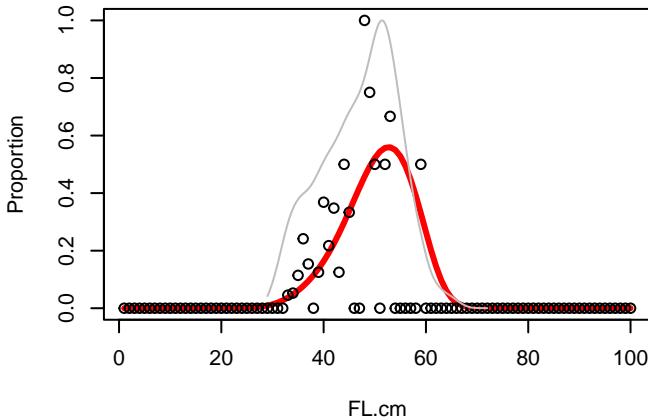
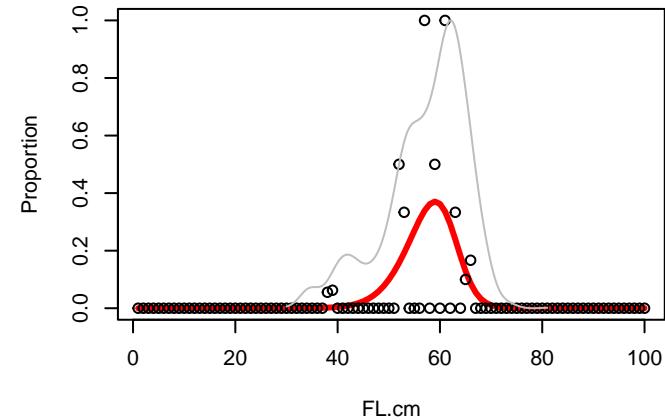
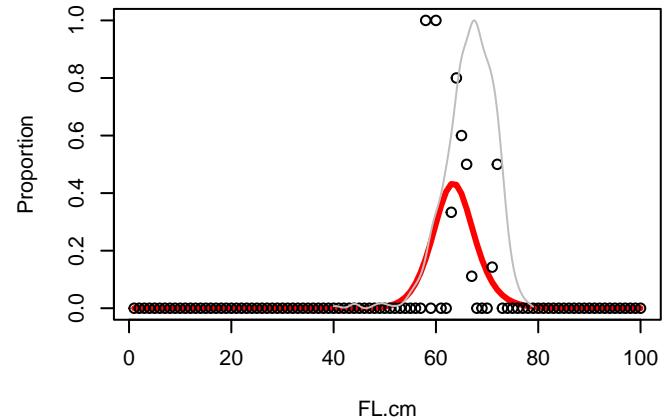
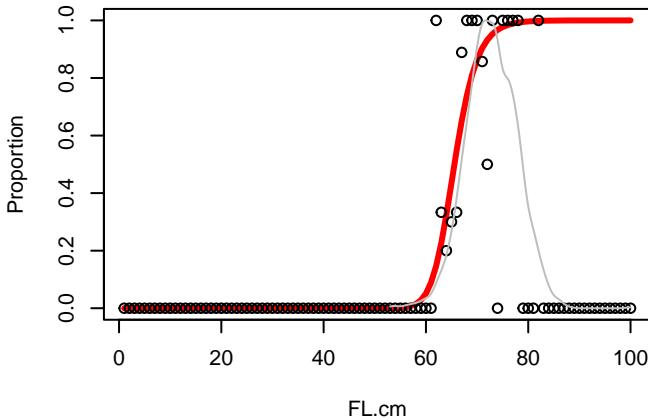


A0, 2007, spring**A1****A2****A3****A4****A5****A6**

All spring
2007 spring pred
○ 2007 spring obs

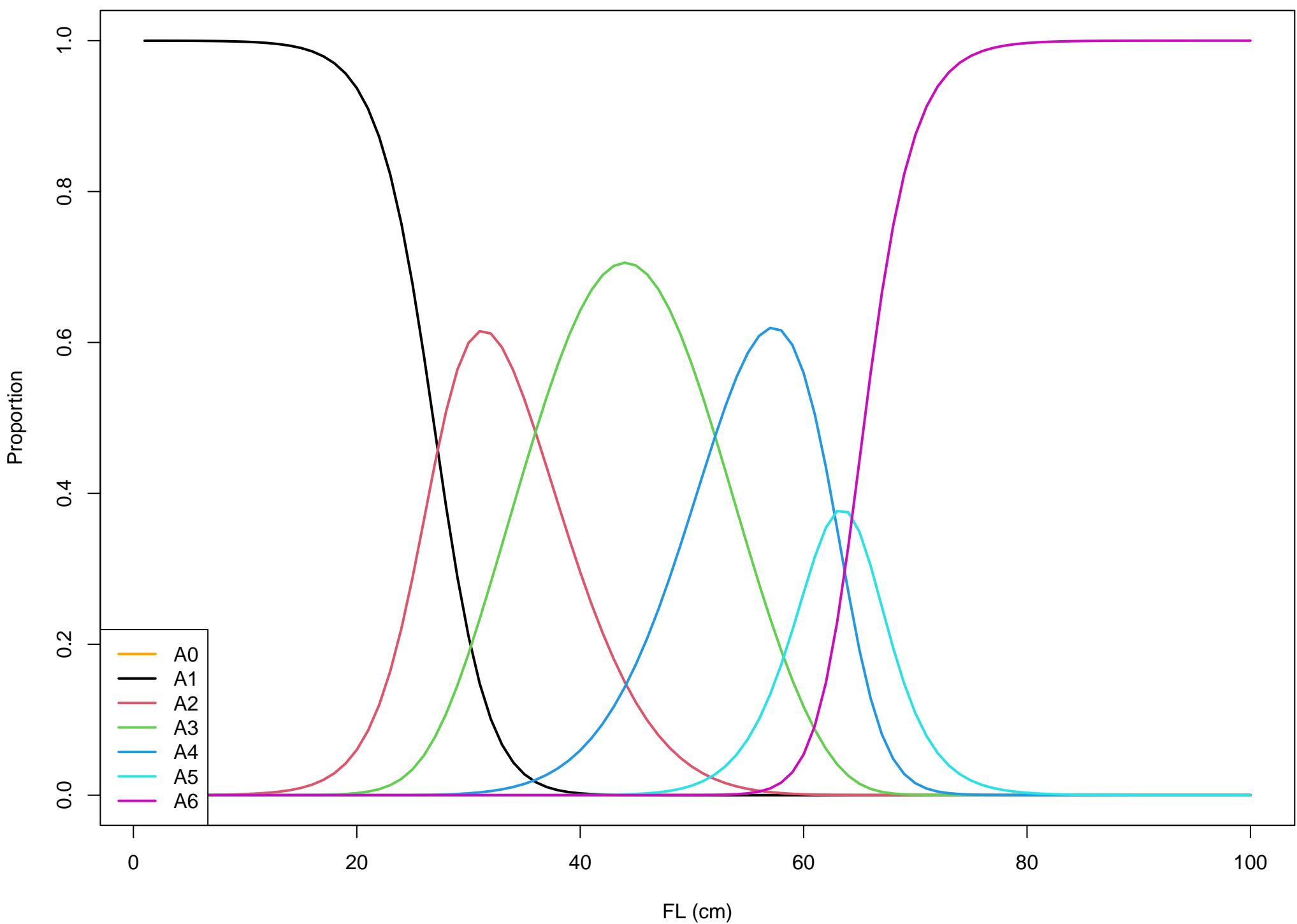
2008
spring



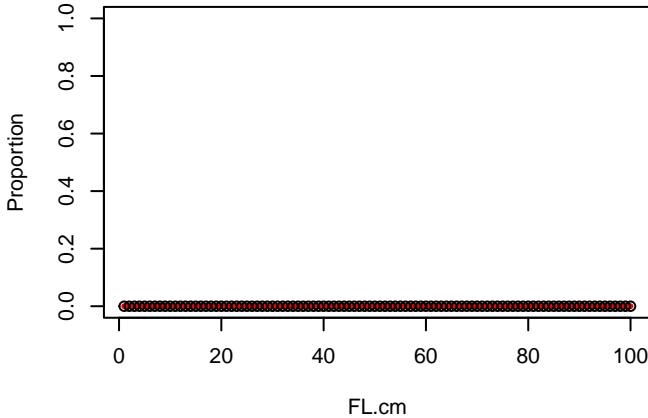
A0, 2008, spring**A1****A2****A3****A4****A5****A6**

All spring
2008 spring pred
2008 spring obs

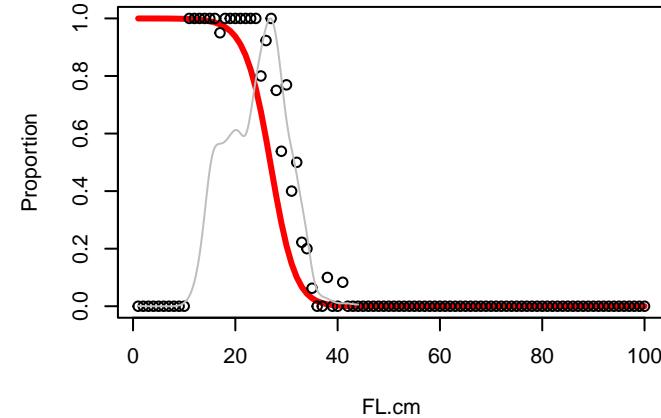
2009
spring



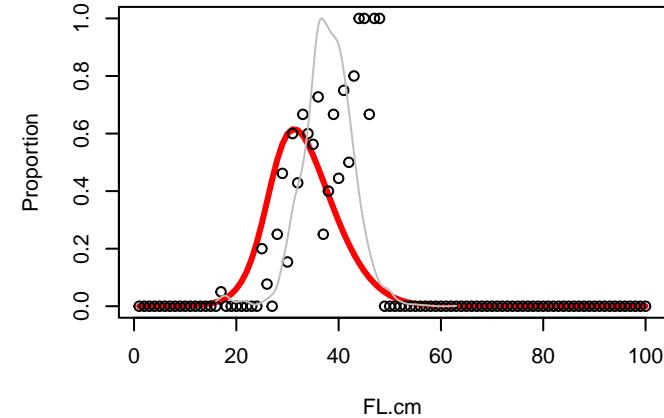
A0, 2009, spring



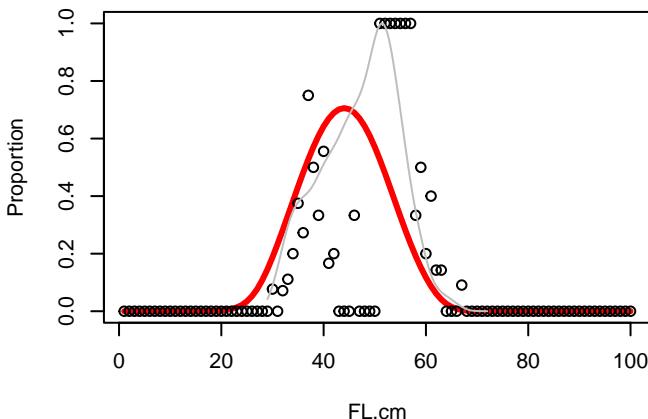
A1



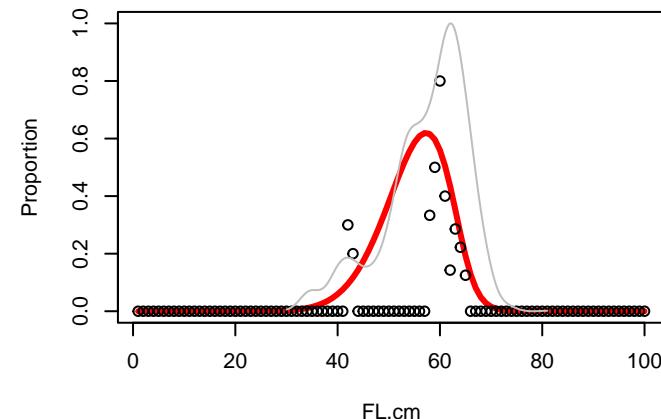
A2



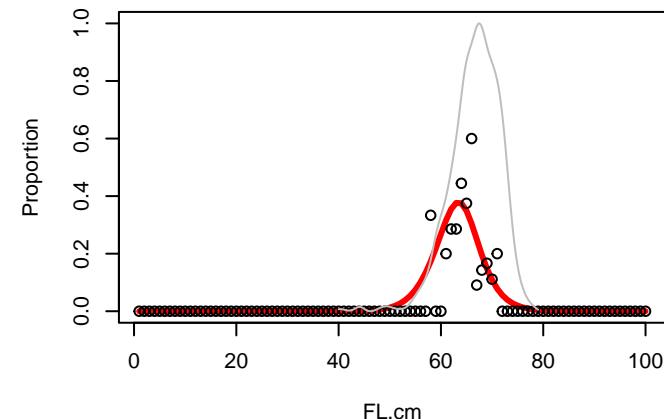
A3



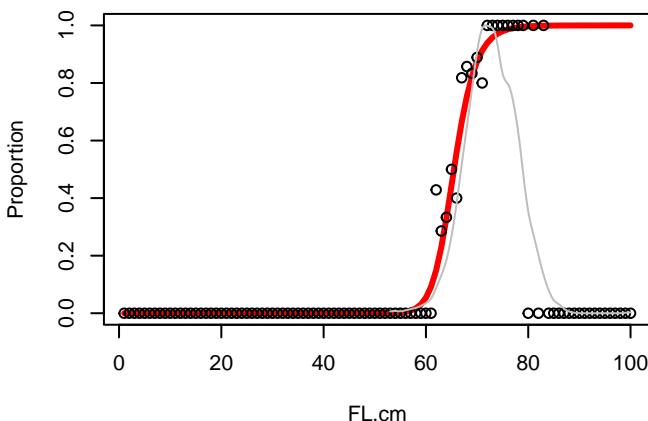
A4



A5

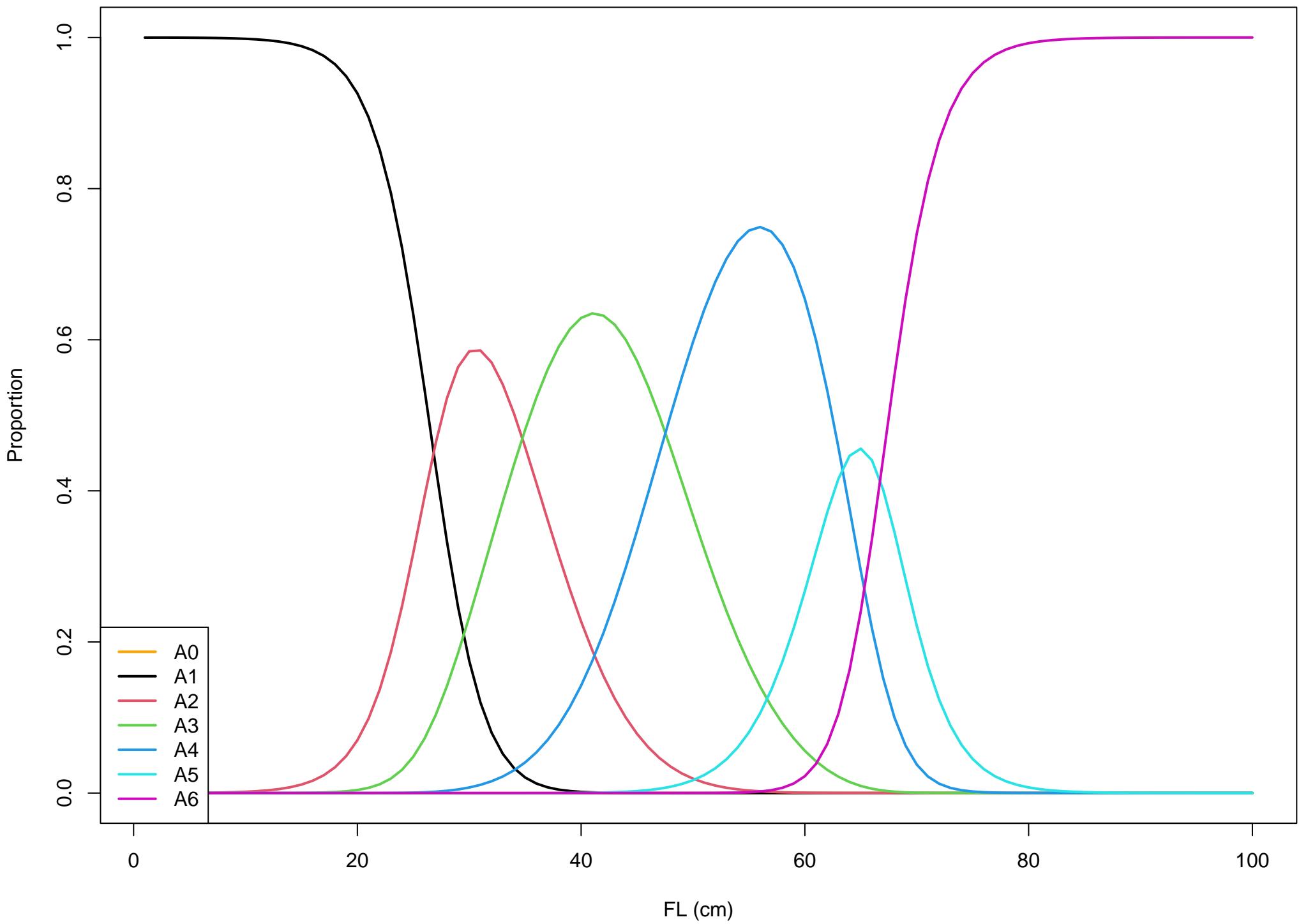


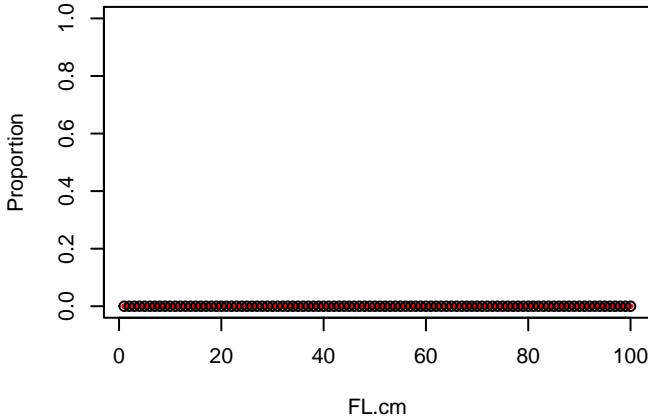
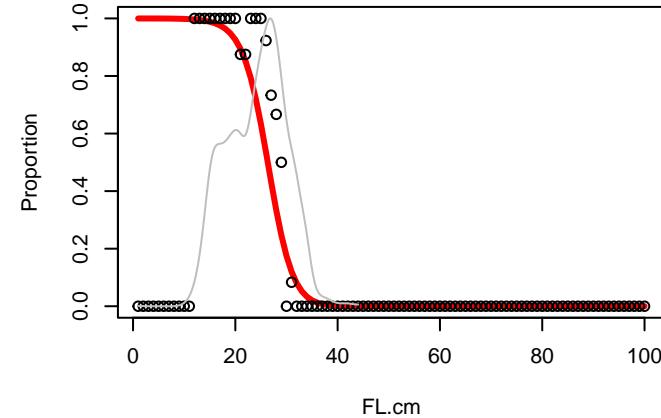
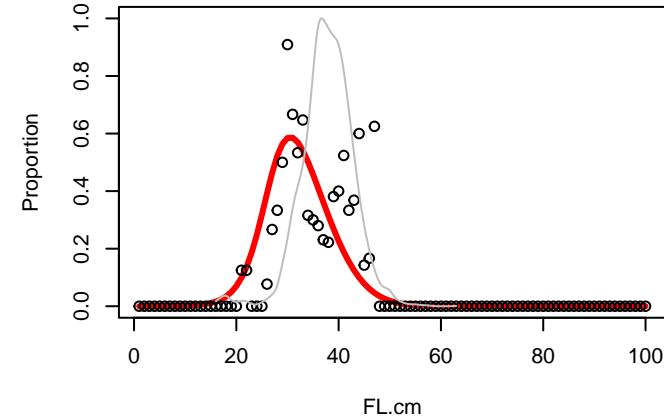
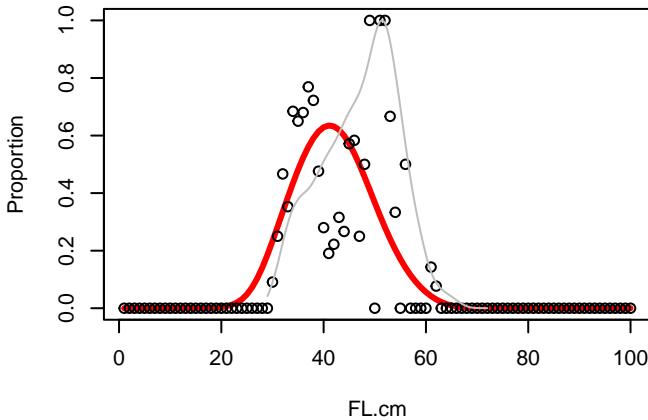
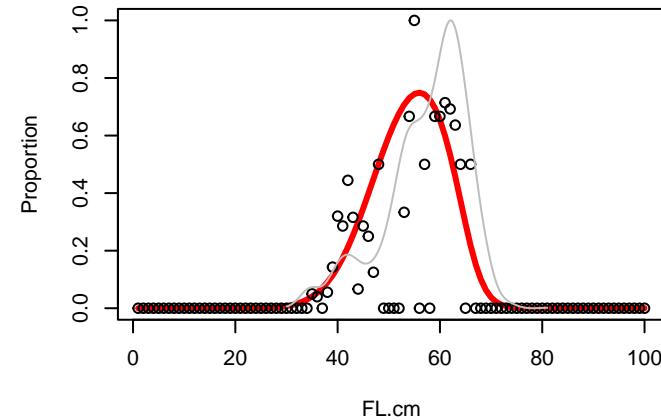
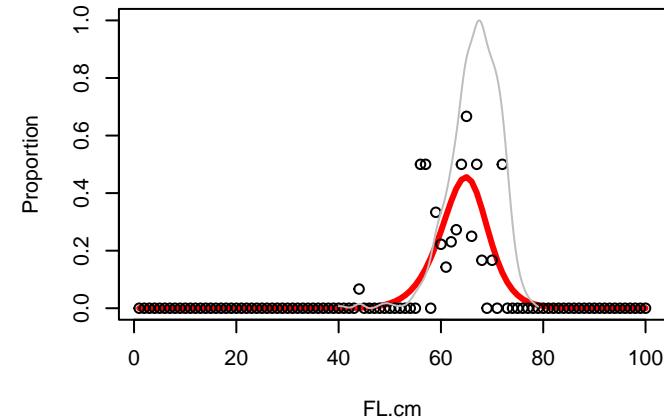
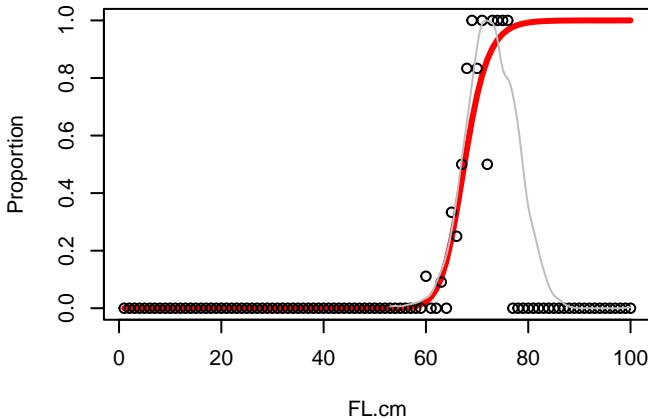
A6



All spring
2009 spring pred
○ 2009 spring obs

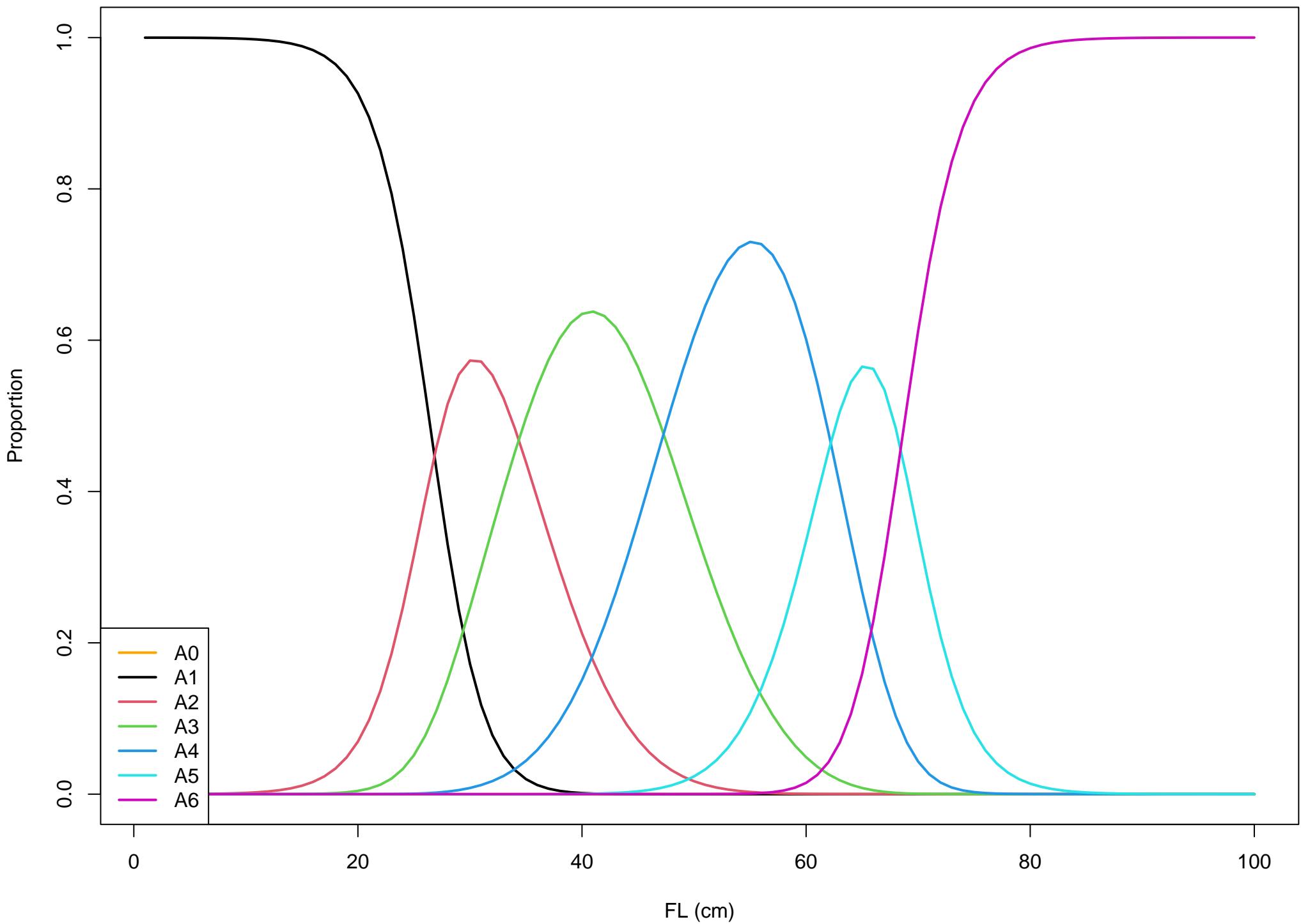
2010
spring

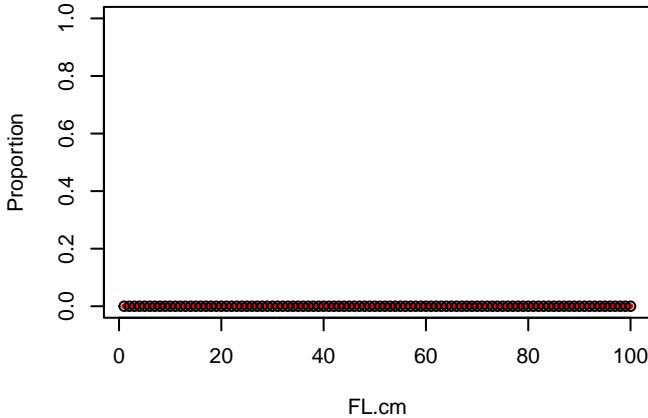
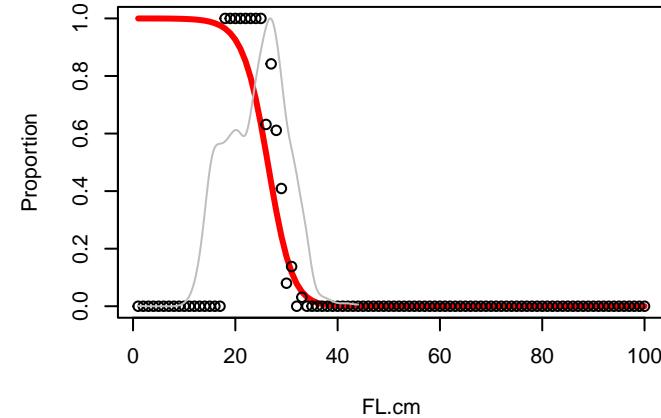
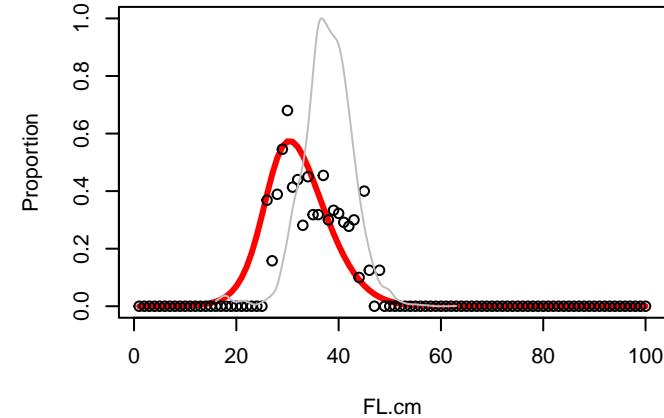
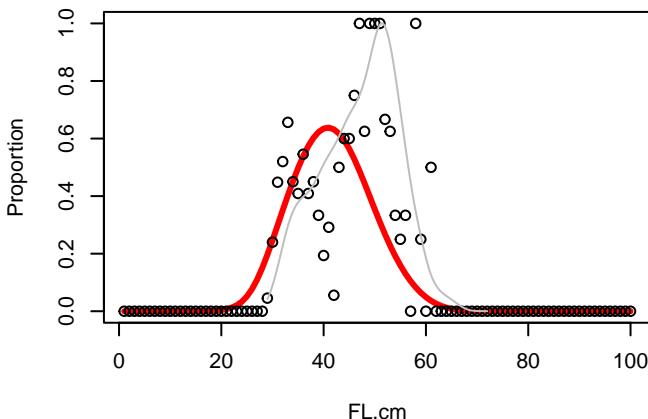
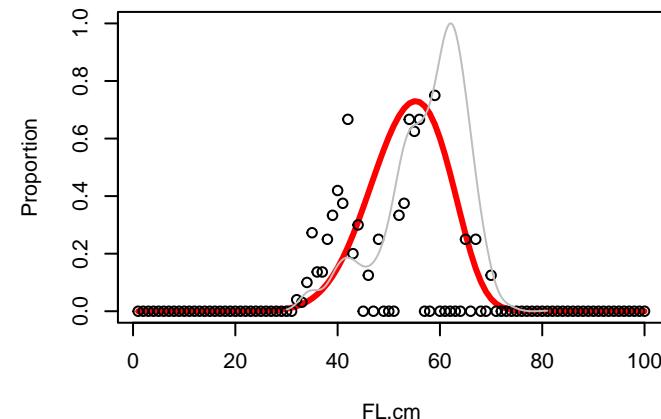
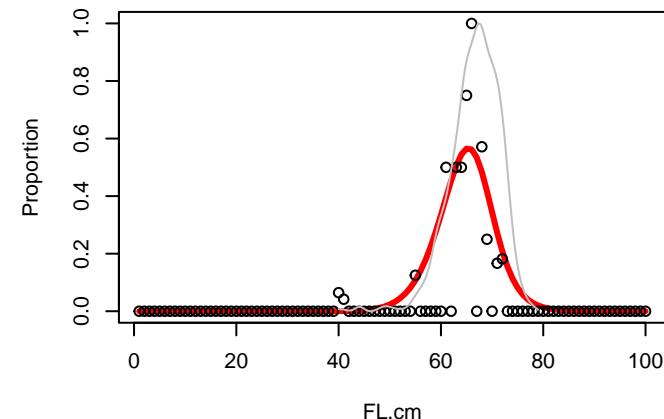
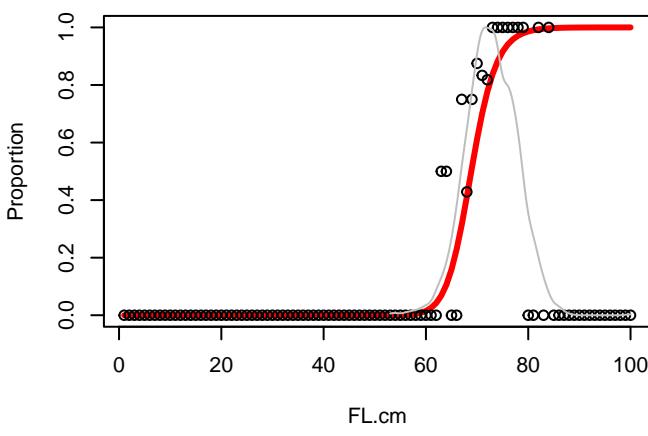


A0, 2010, spring**A1****A2****A3****A4****A5****A6**

All spring
2010 spring pred
○ 2010 spring obs

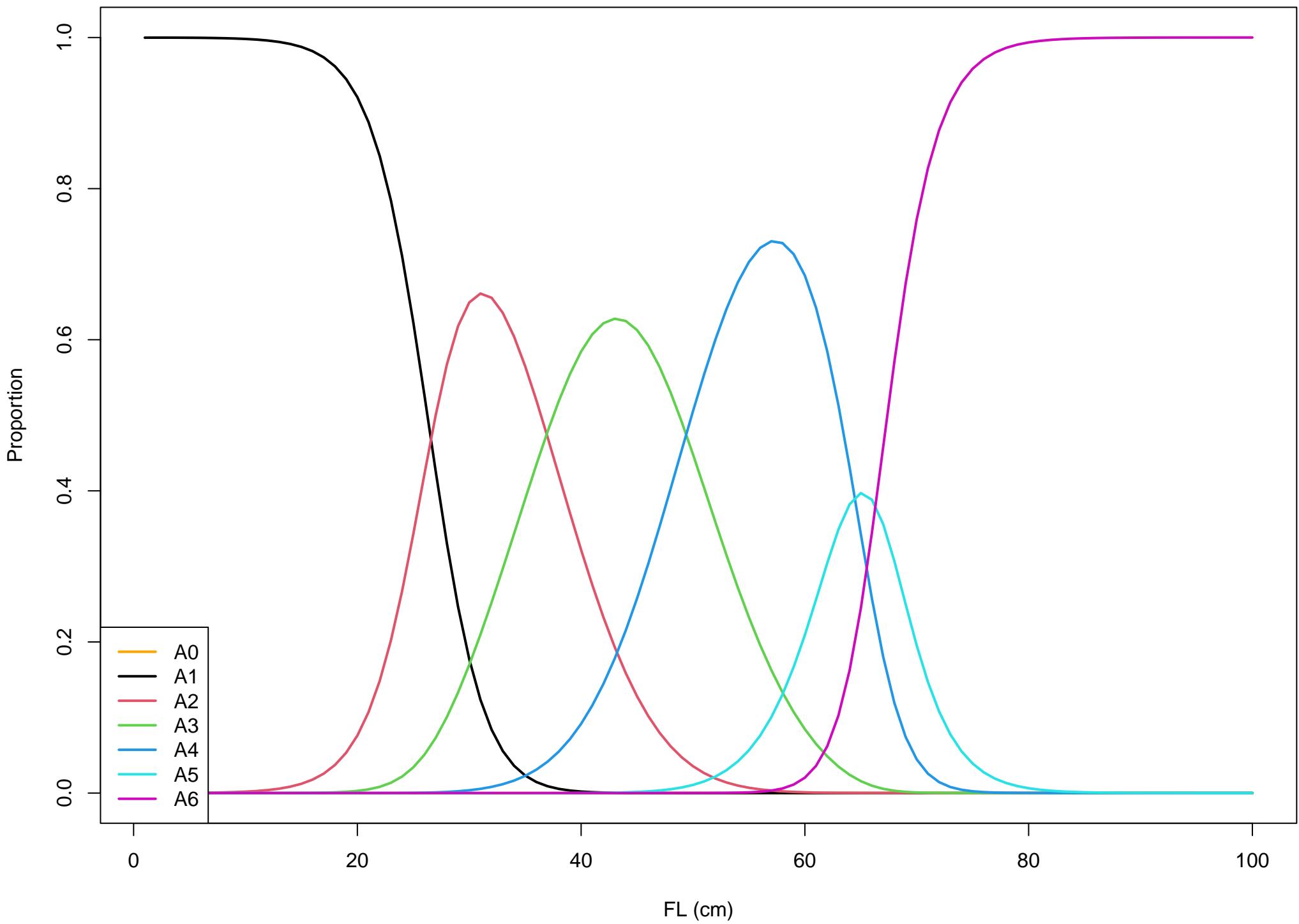
2011
spring

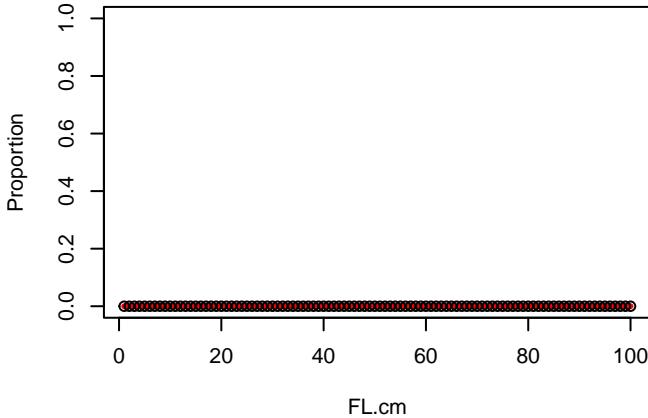
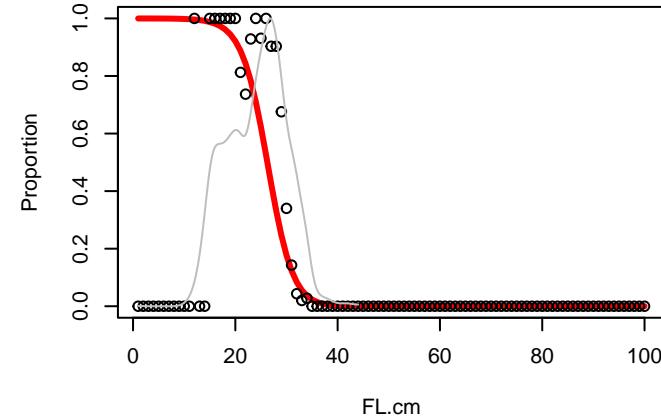
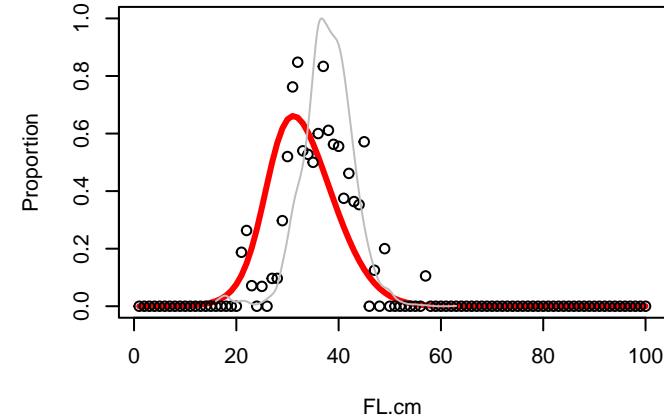
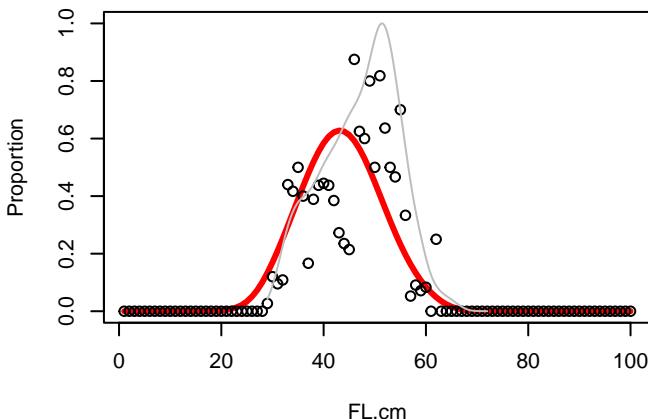
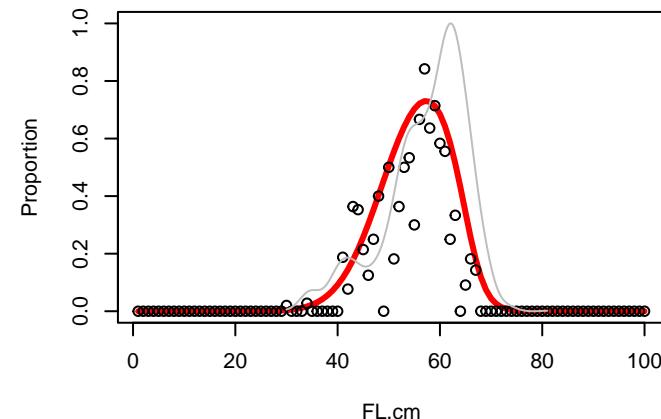
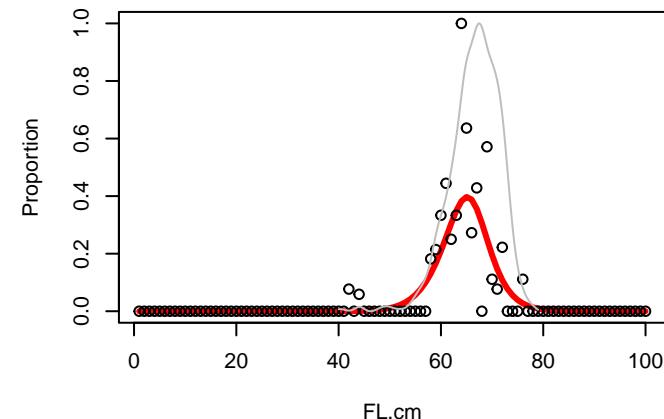
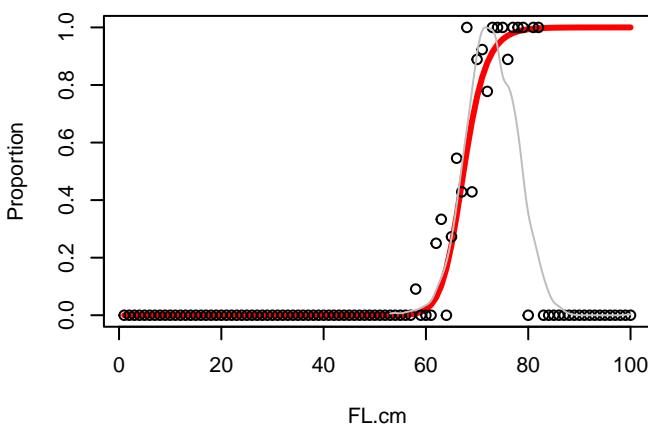


A0, 2011, spring**A1****A2****A3****A4****A5****A6**

All spring
2011 spring pred
○ 2011 spring obs

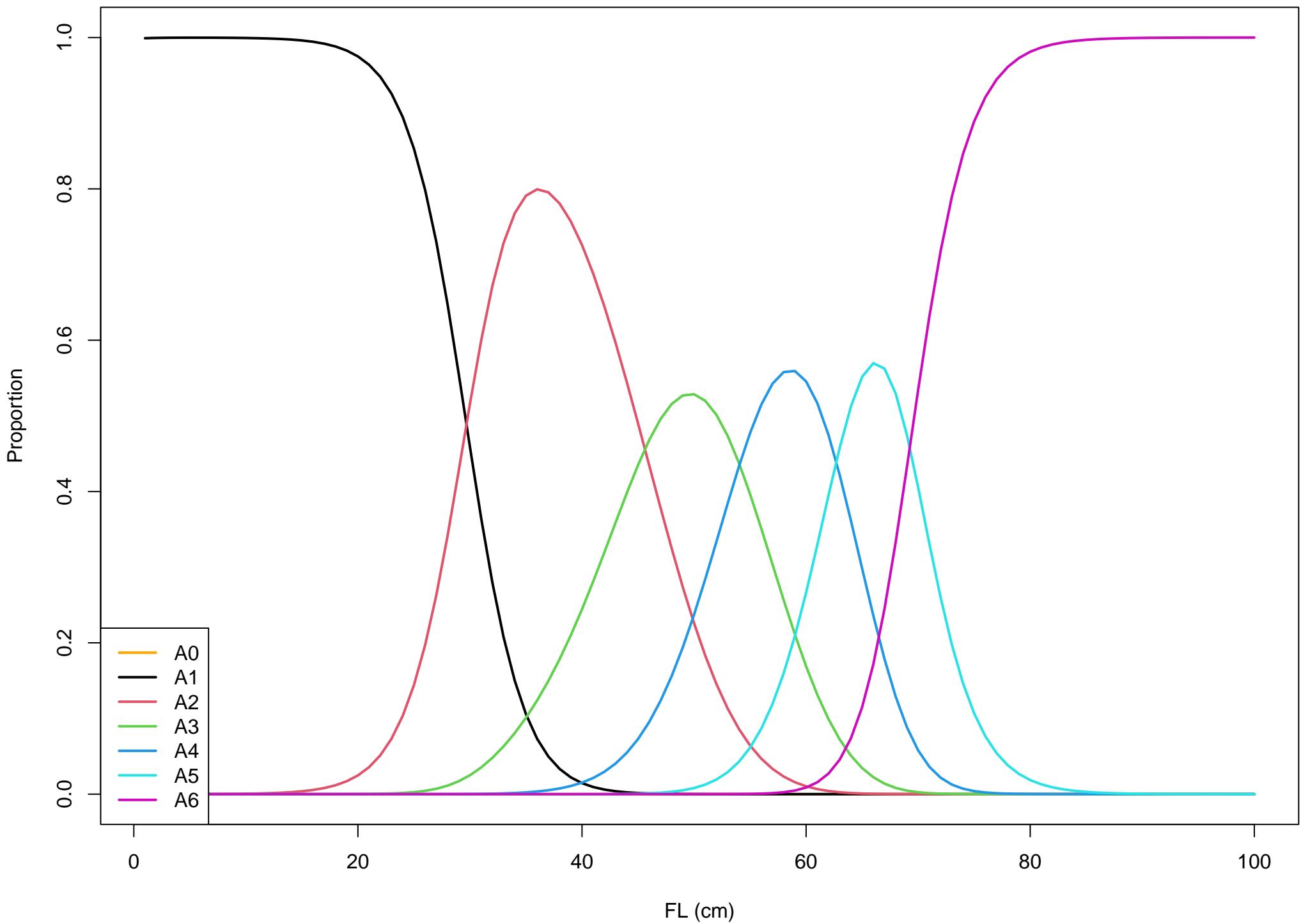
2012
spring



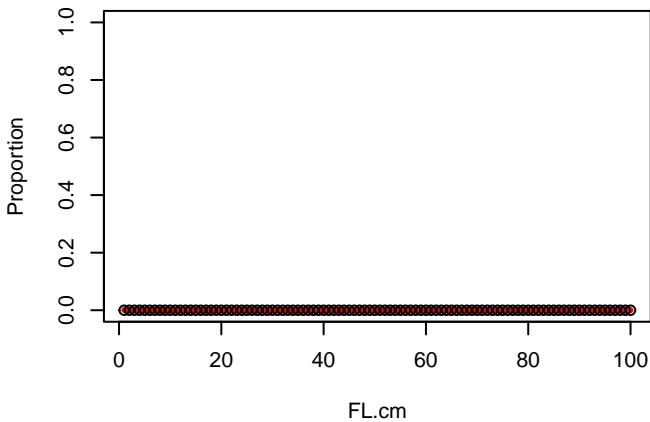
A0, 2012, spring**A1****A2****A3****A4****A5****A6**

All spring
2012 spring pred
○ 2012 spring obs

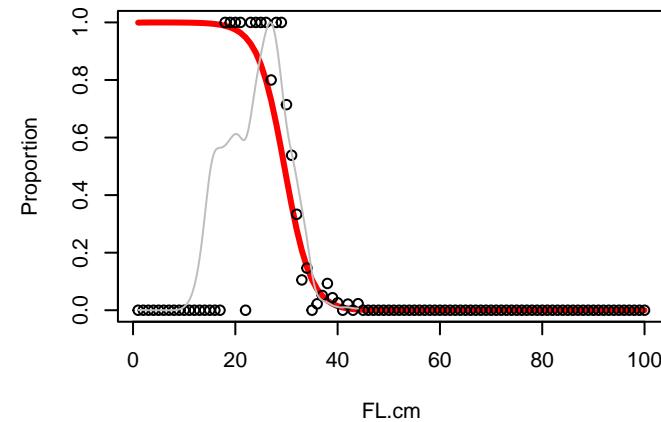
2013
spring



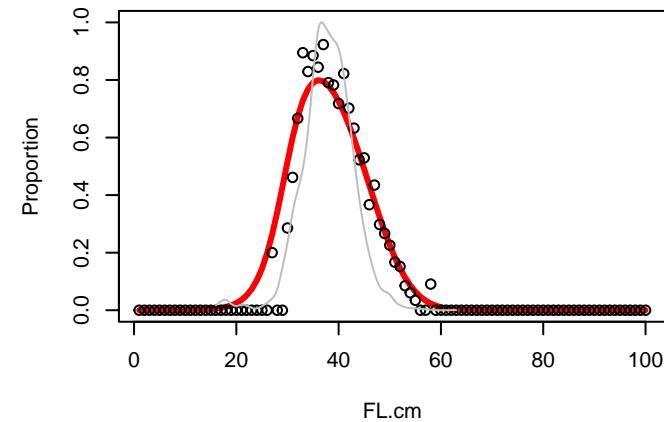
A0, 2013, spring



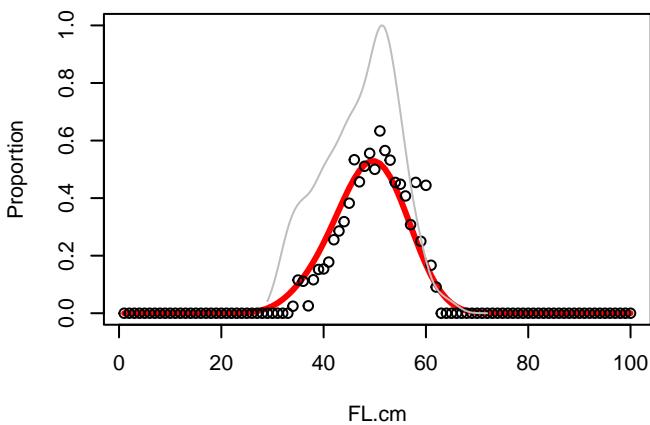
A1



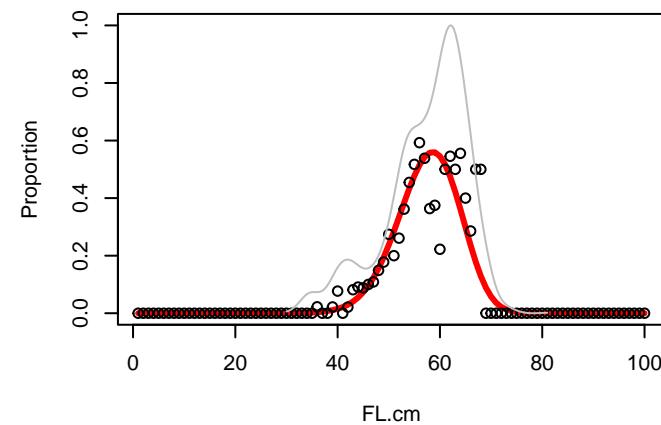
A2



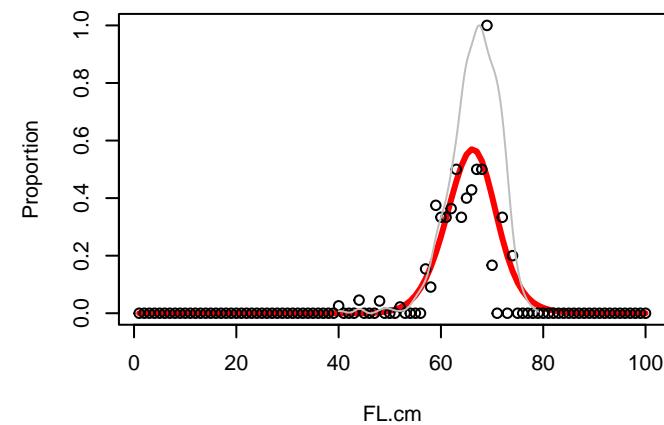
A3



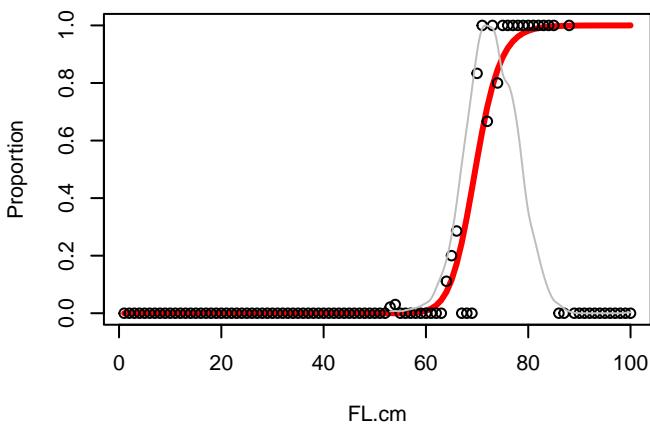
A4



A5

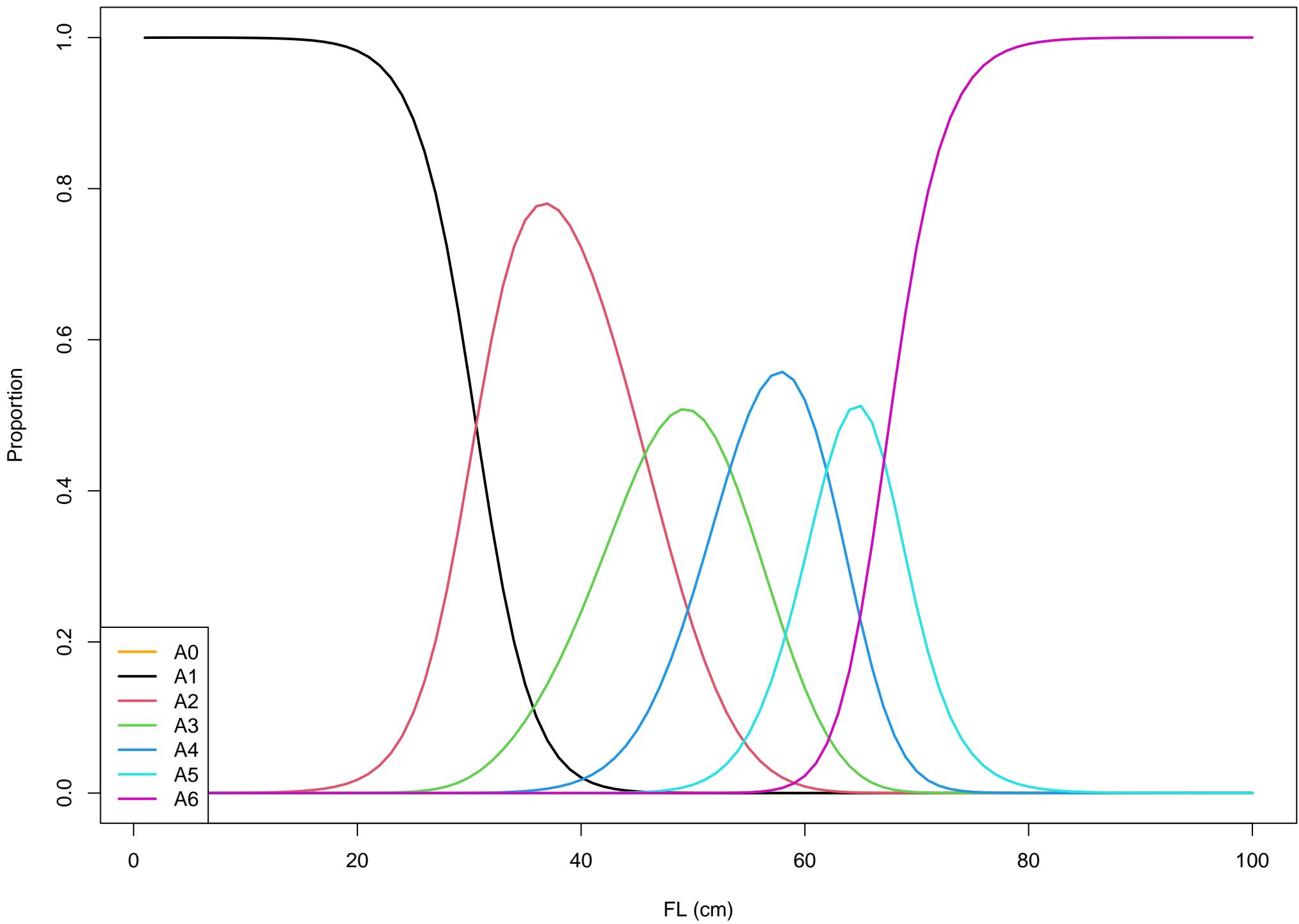


A6

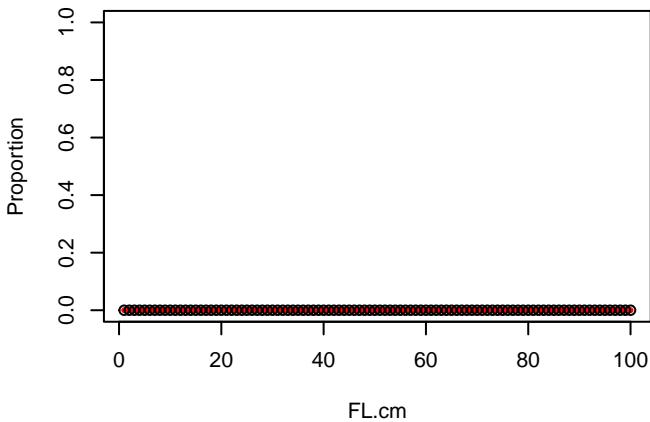


All spring
2013 spring pred
○ 2013 spring obs

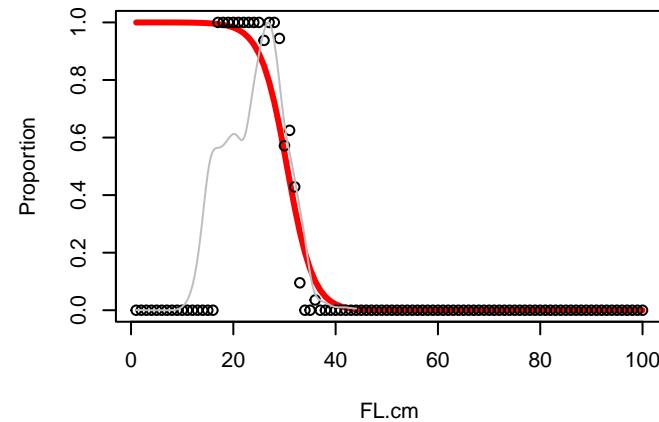
2014
spring



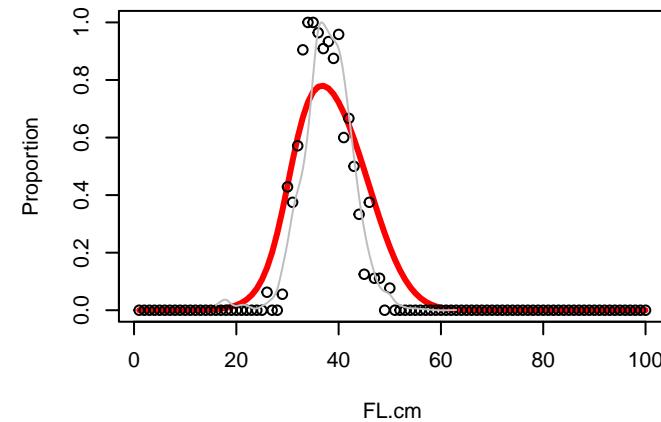
A0, 2014, spring



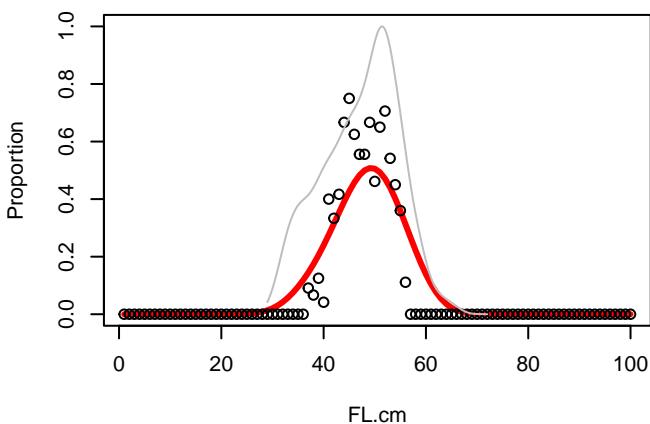
A1



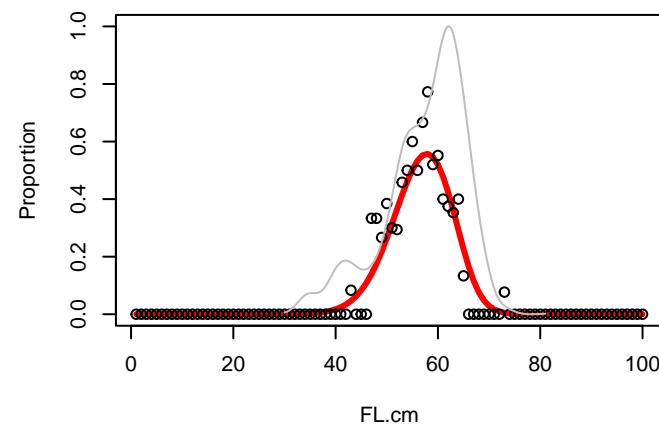
A2



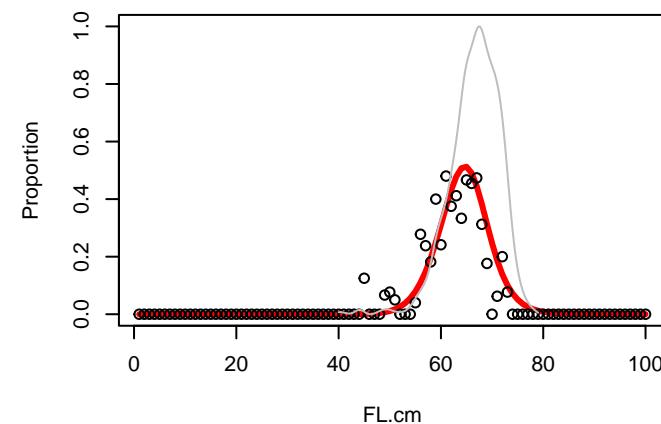
A3



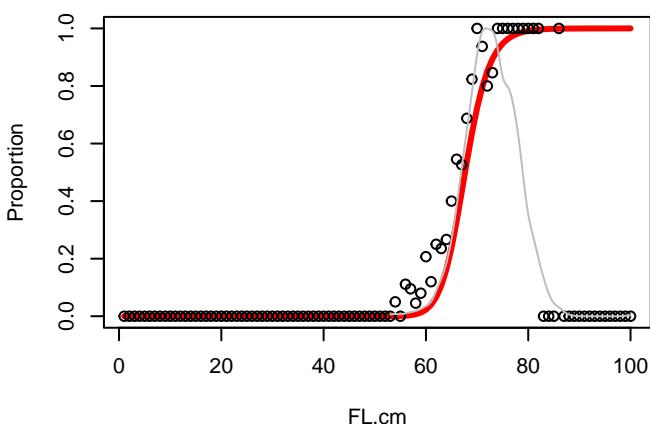
A4



A5

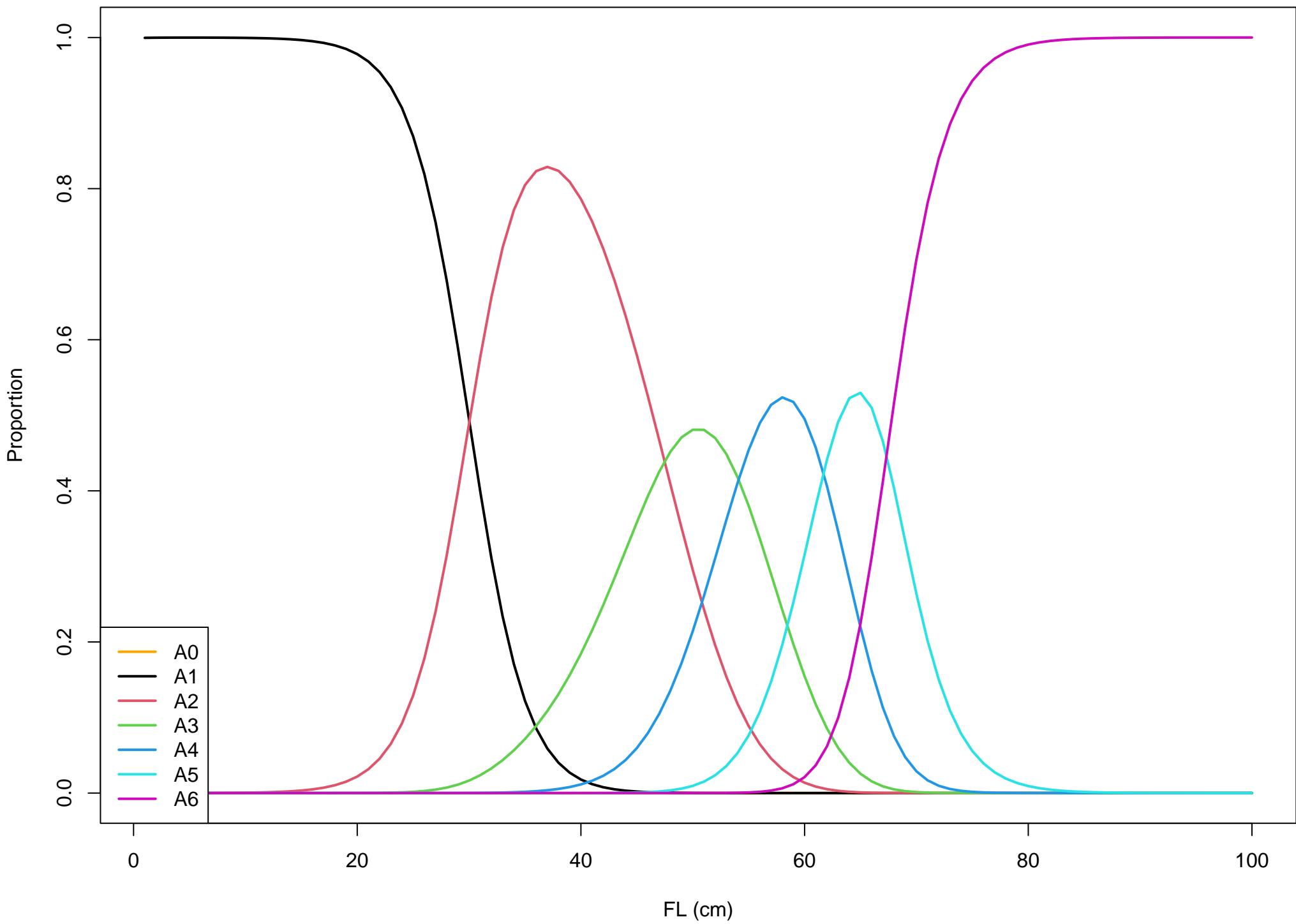


A6

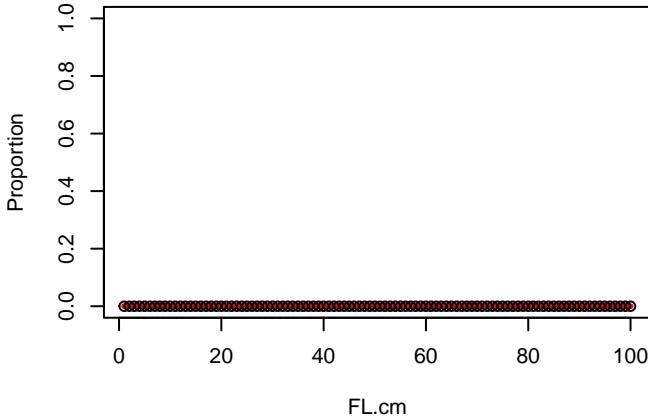


All spring
2014 spring pred
○ 2014 spring obs

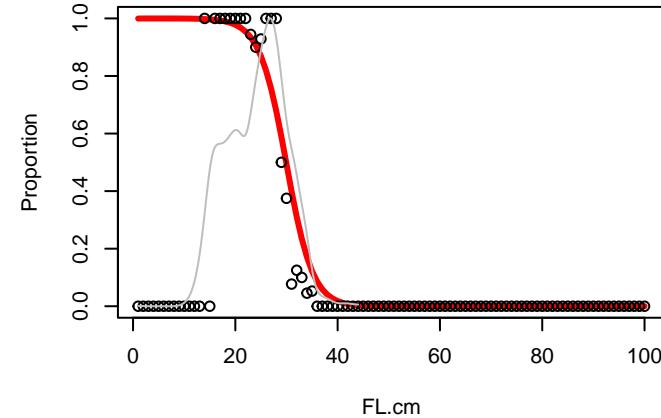
2015
spring



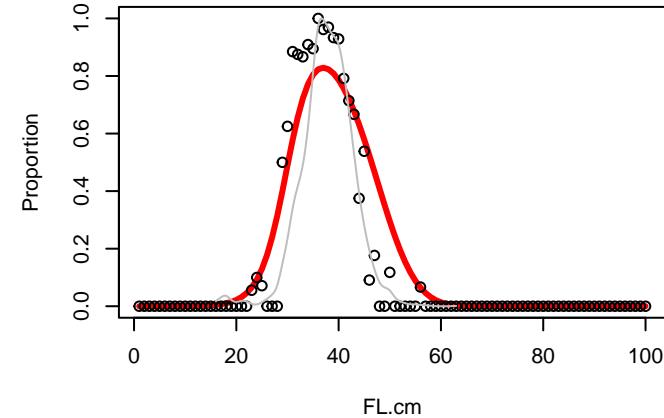
A0, 2015, spring



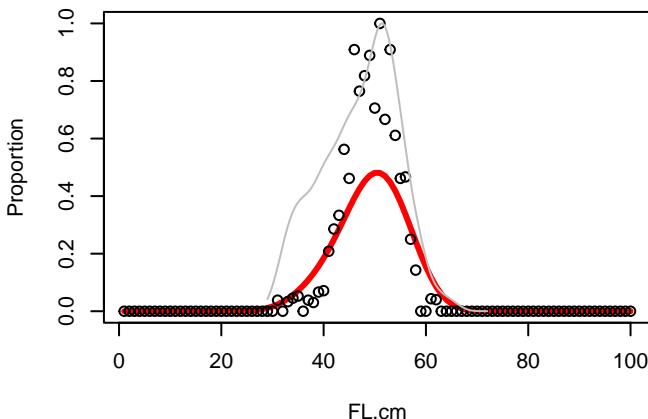
A1



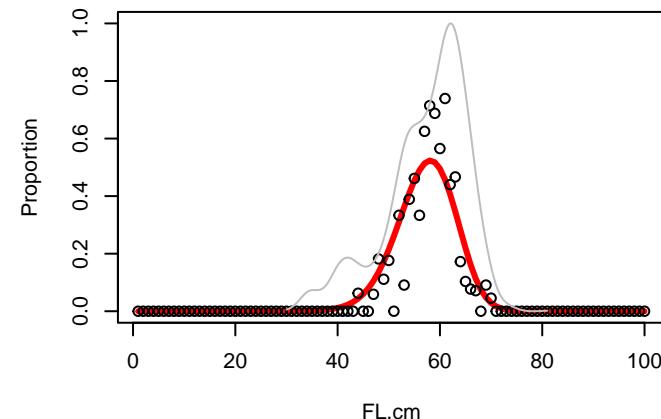
A2



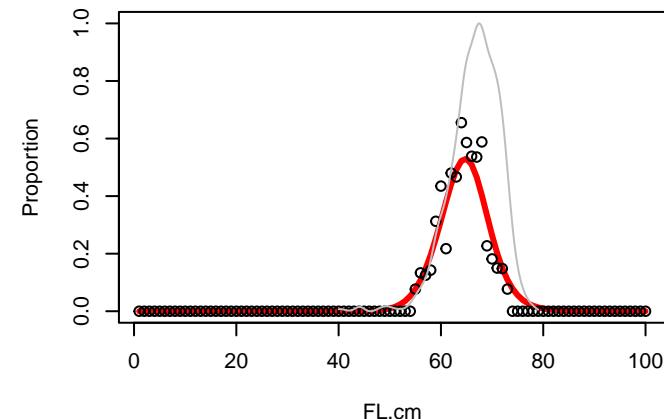
A3



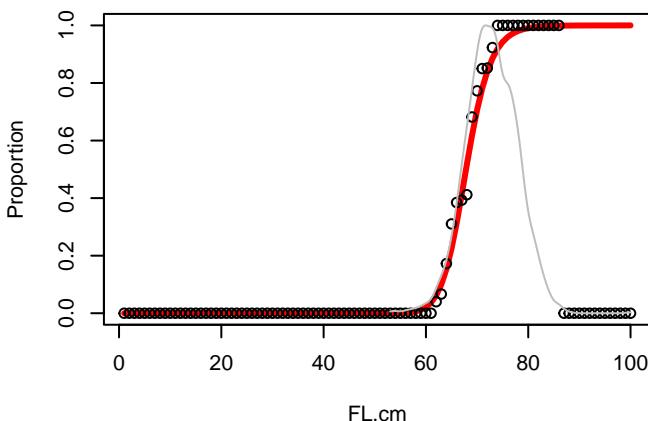
A4



A5

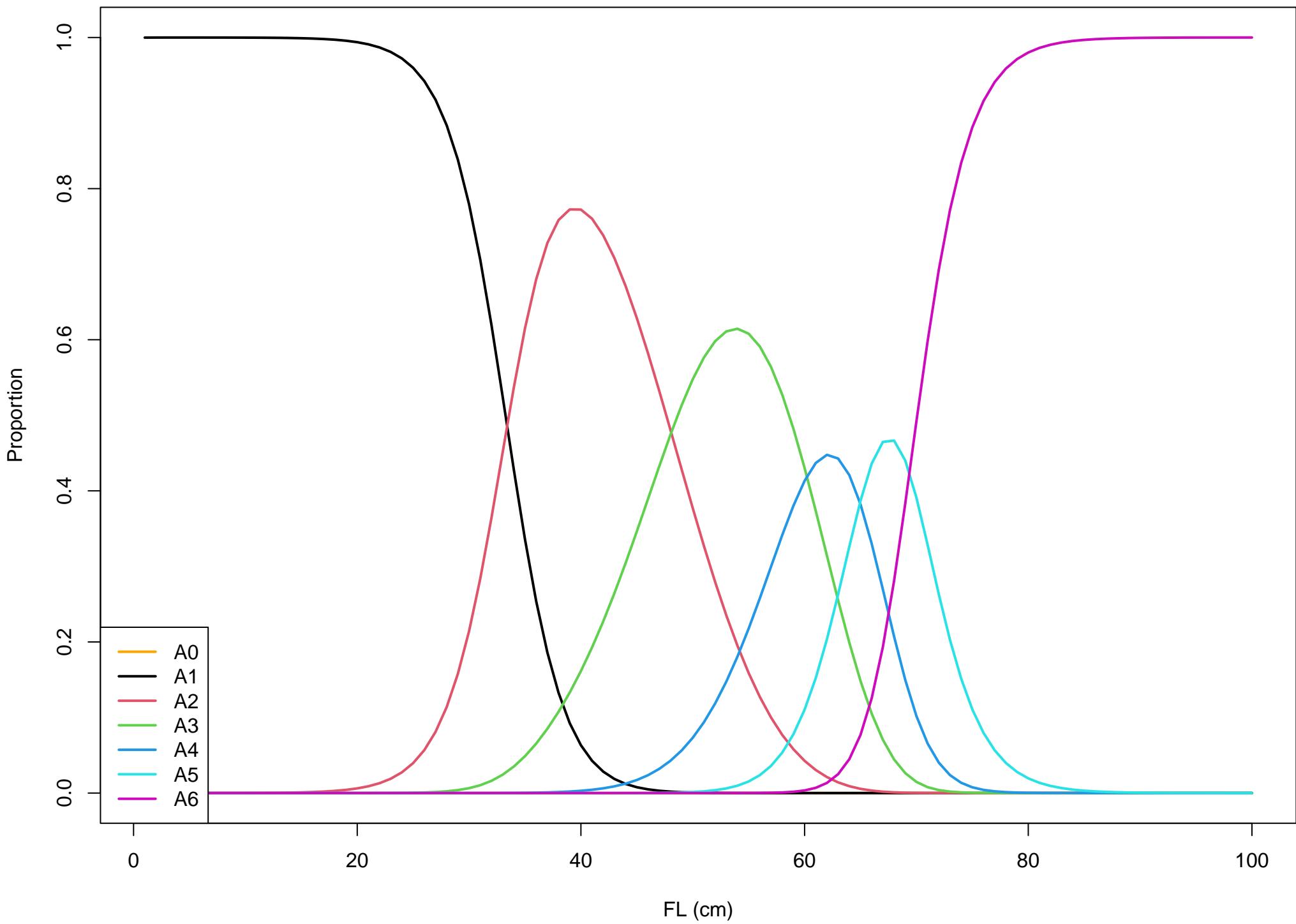


A6

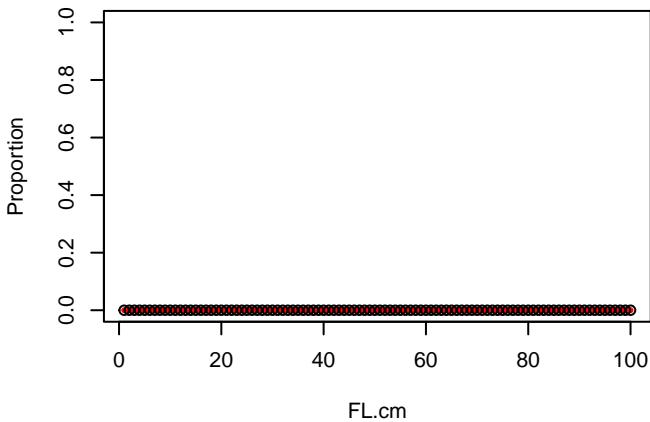


All spring
2015 spring pred
○ 2015 spring obs

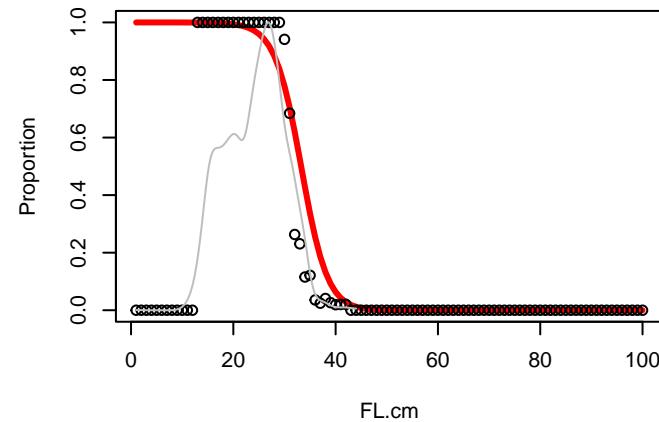
2016
spring



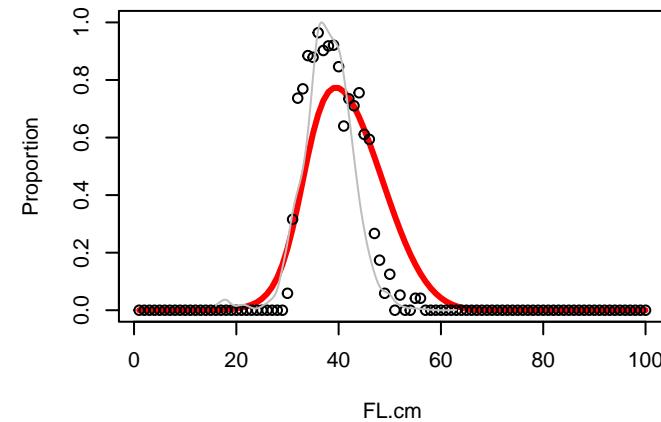
A0, 2016, spring



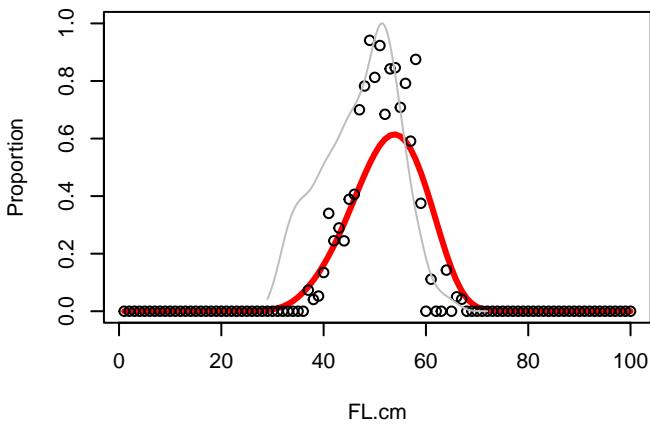
A1



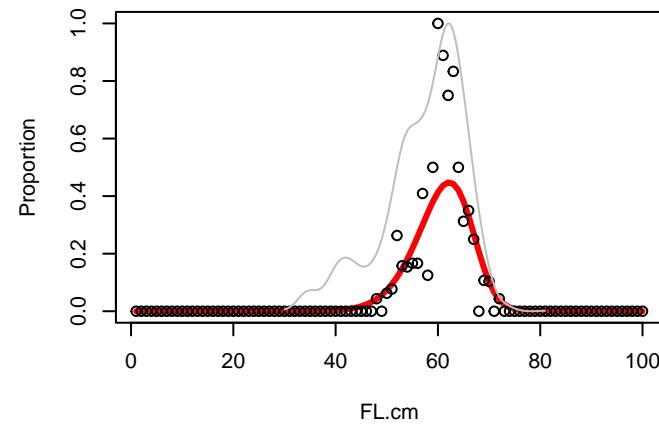
A2



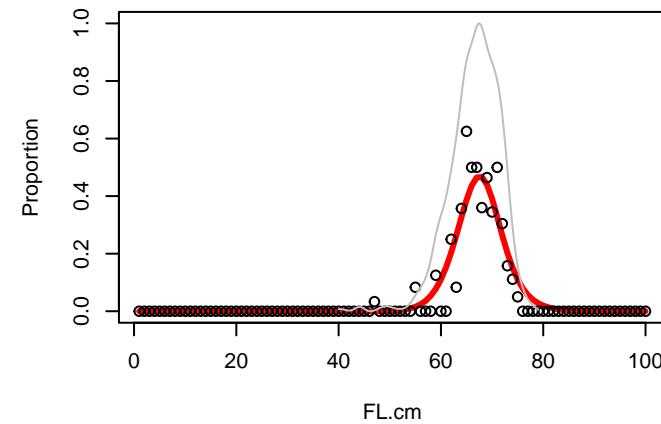
A3



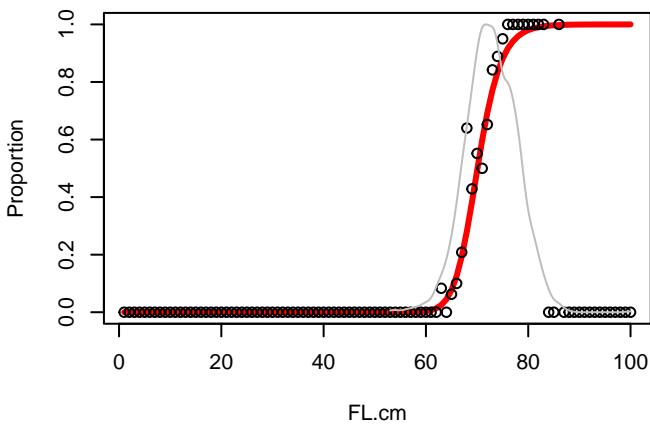
A4



A5

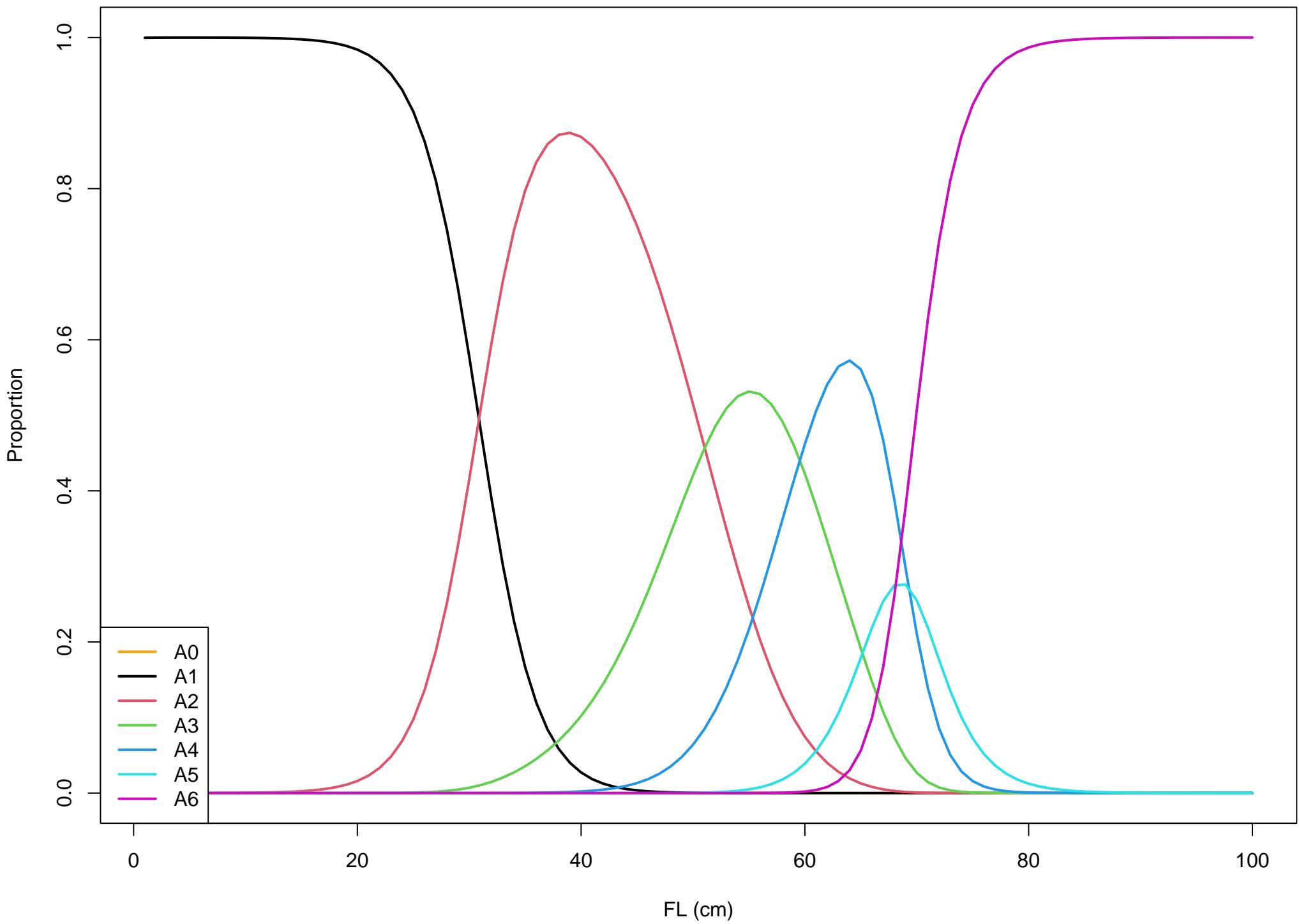


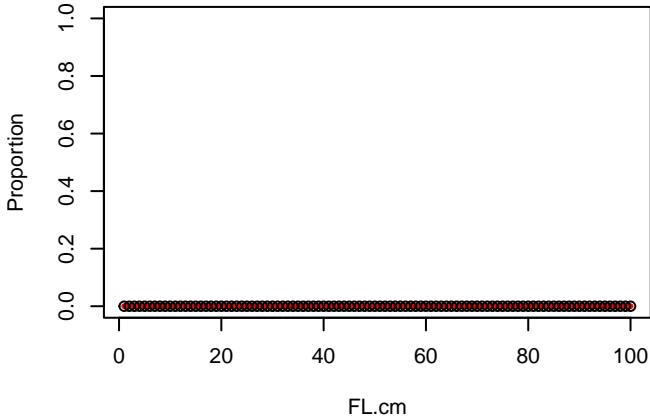
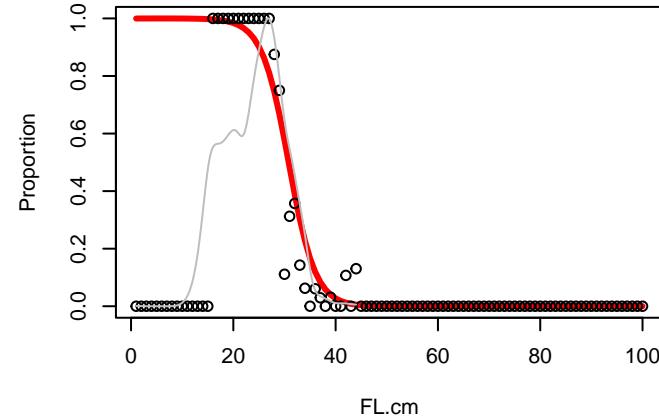
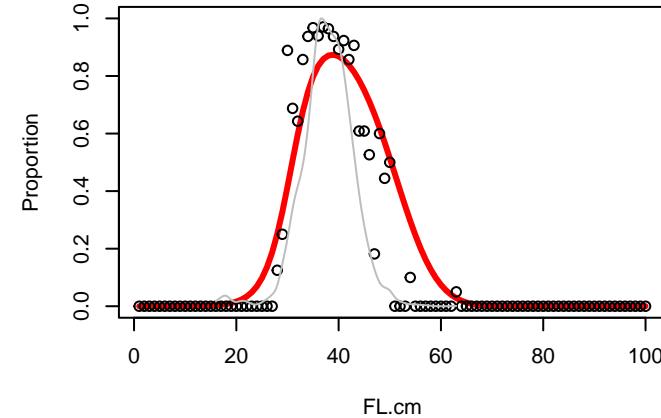
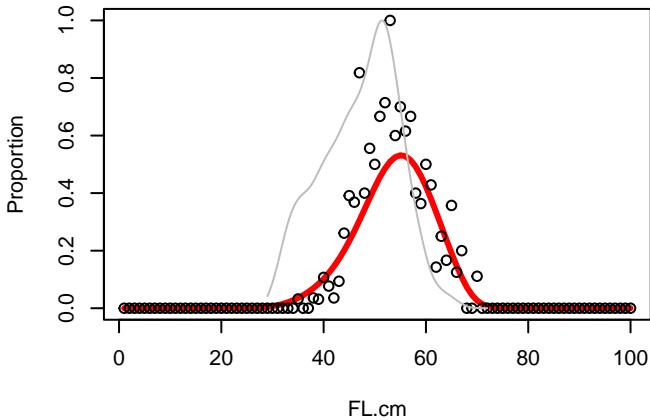
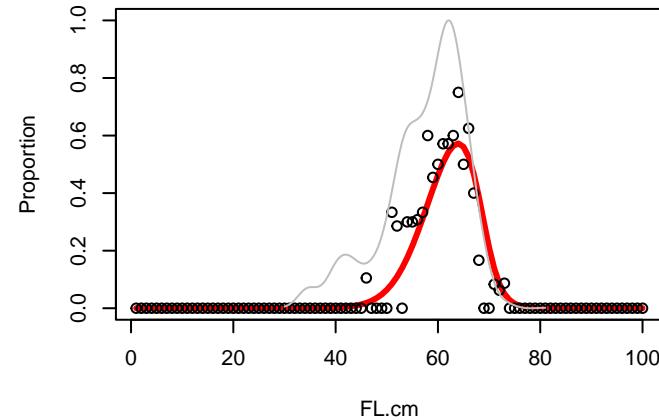
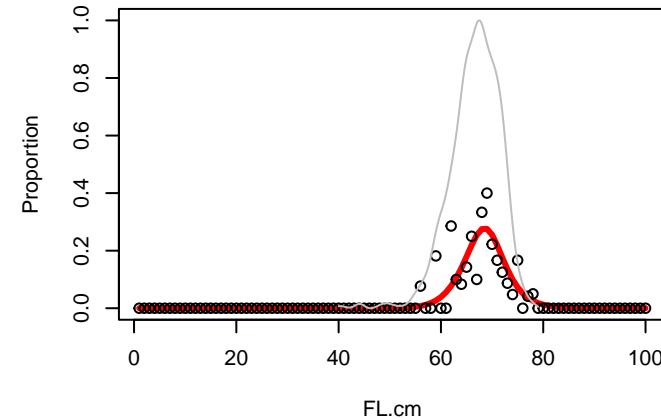
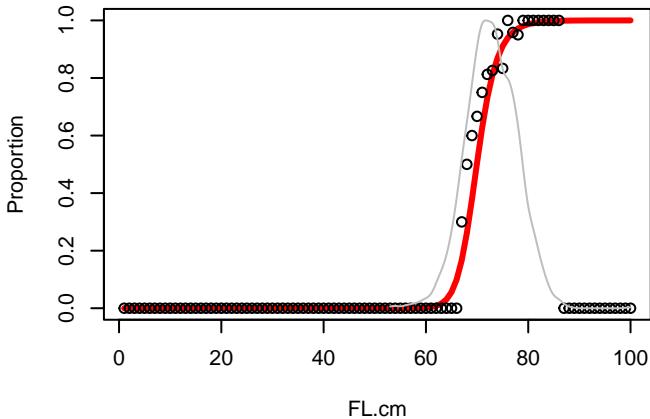
A6



All spring
2016 spring pred
○ 2016 spring obs

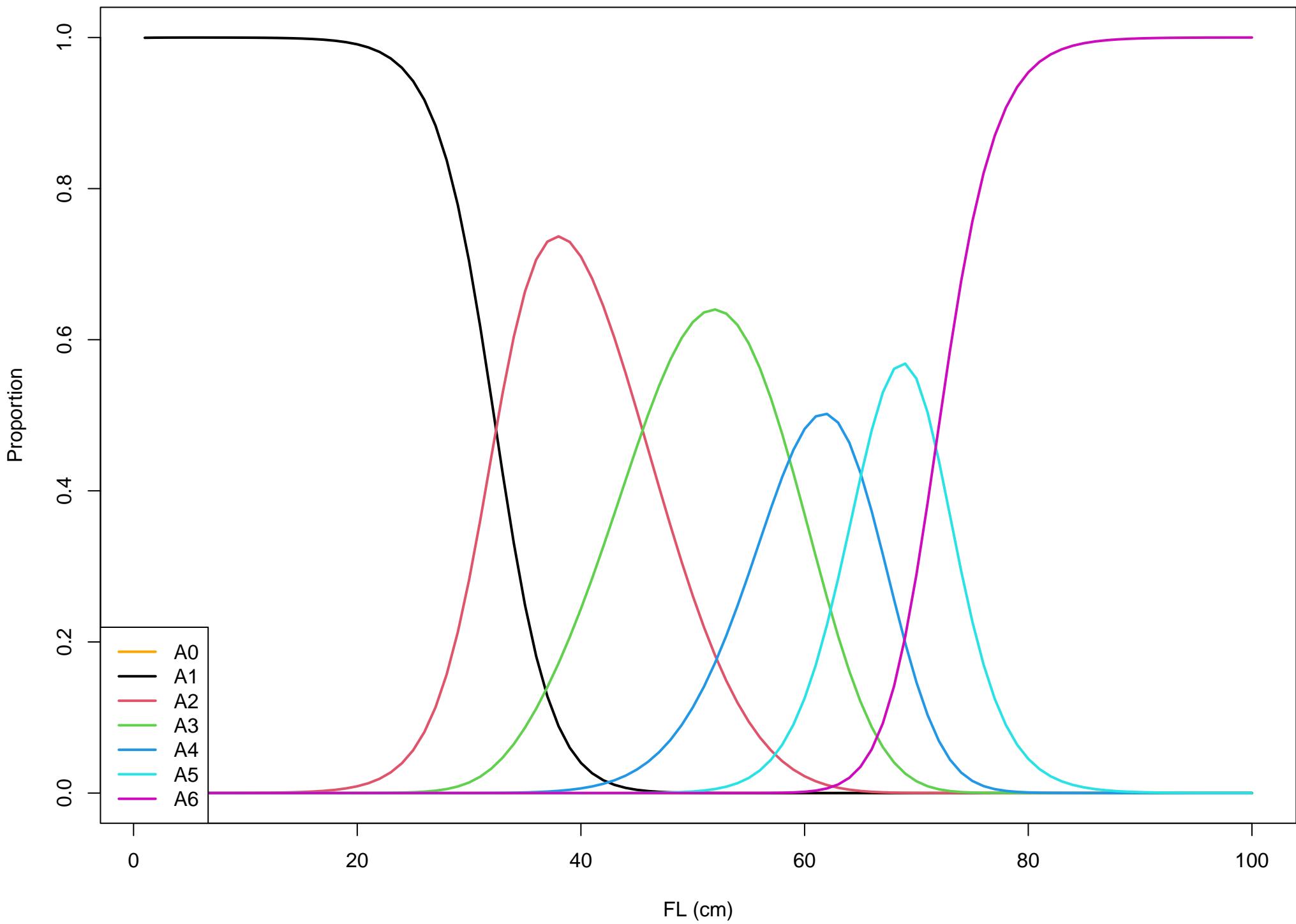
2017
spring



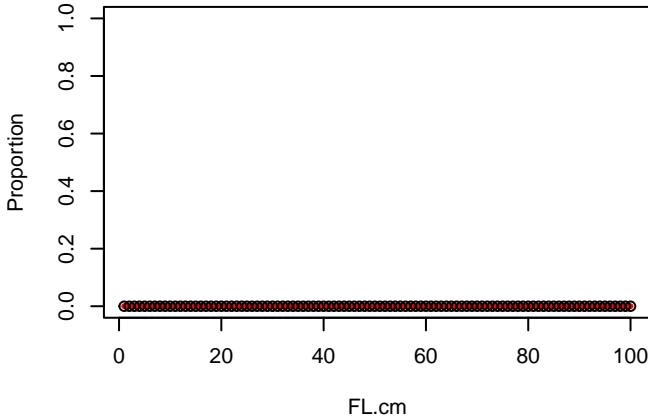
A0, 2017, spring**A1****A2****A3****A4****A5****A6**

All spring
2017 spring pred
○ 2017 spring obs

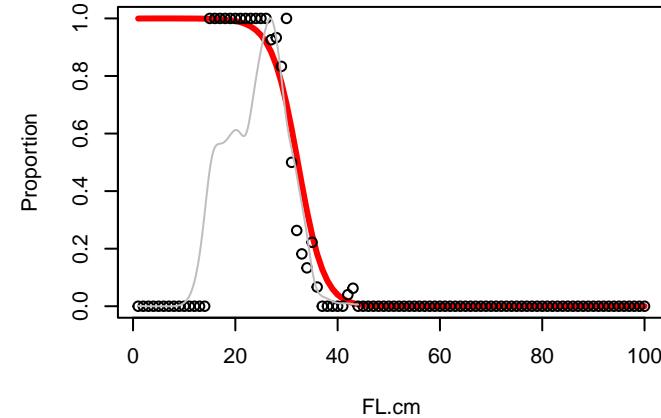
2018
spring



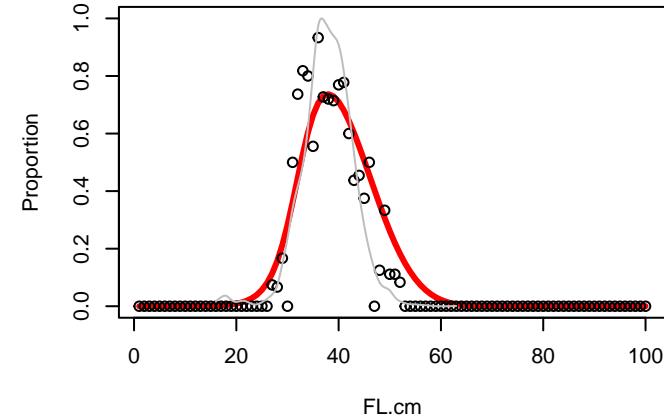
A0, 2018, spring



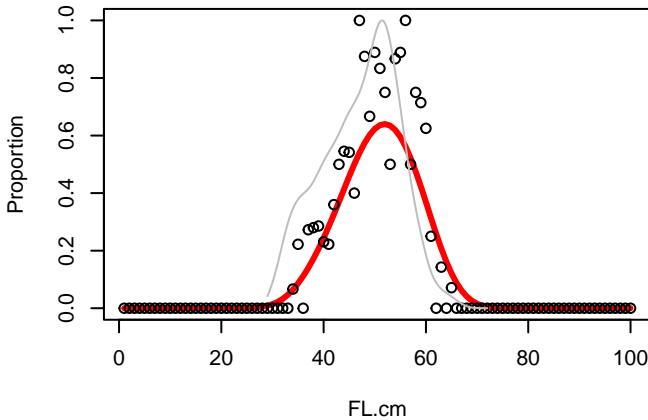
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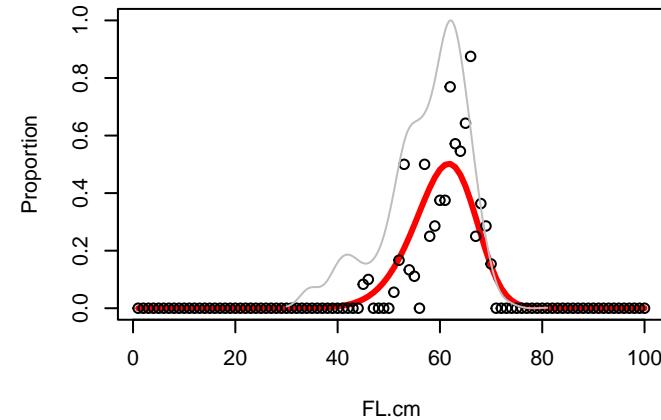
A2



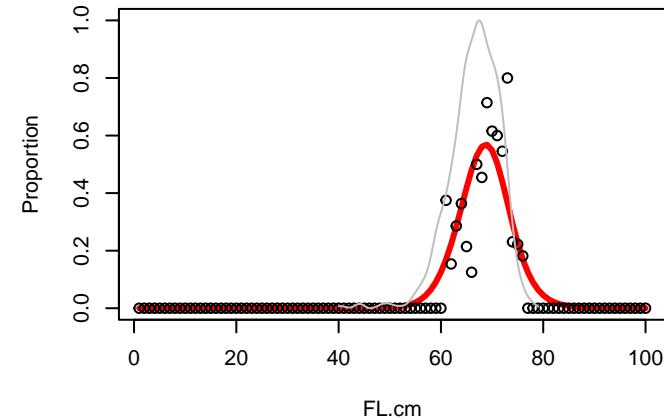
A3



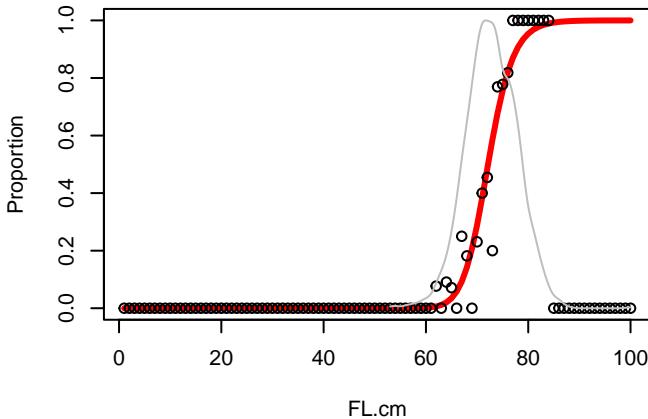
A4



A5

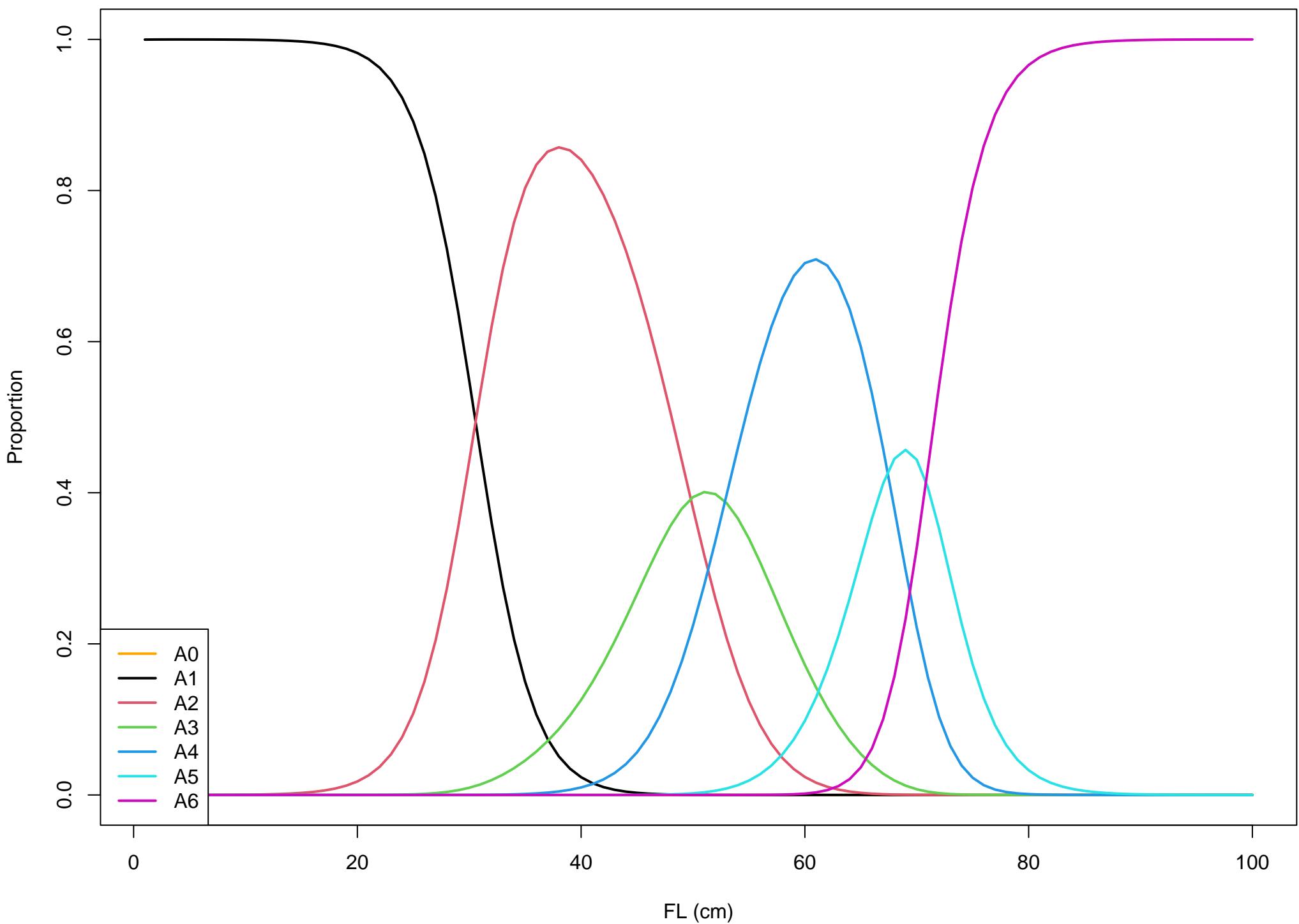


A6

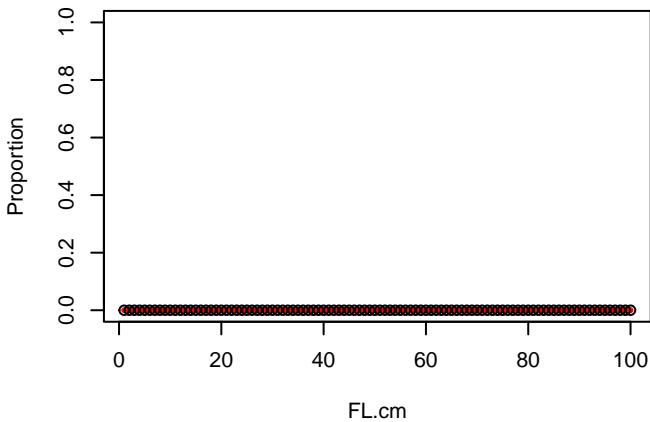


All spring
2018 spring pred
2018 spring obs

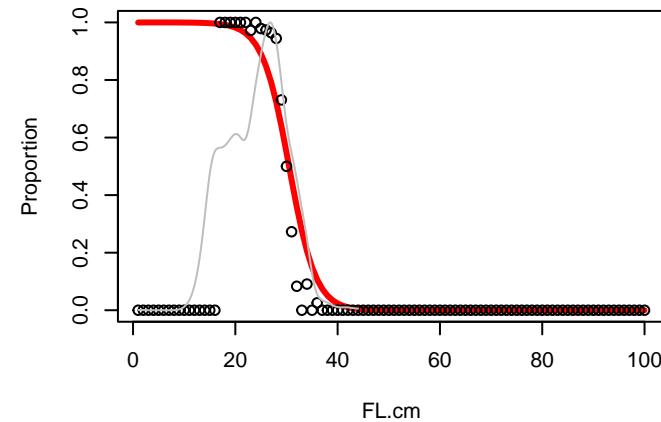
2019
spring



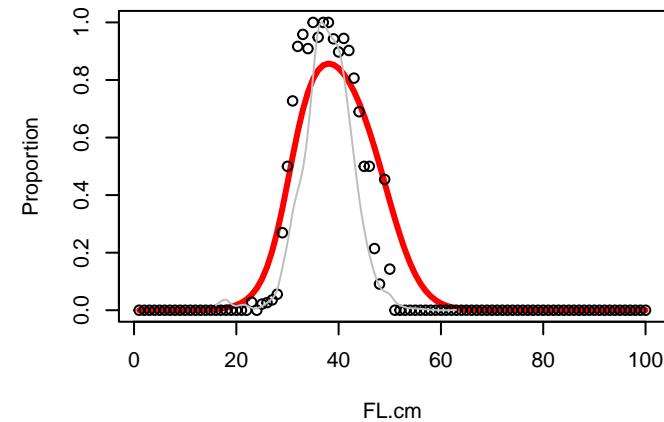
A0, 2019, spring



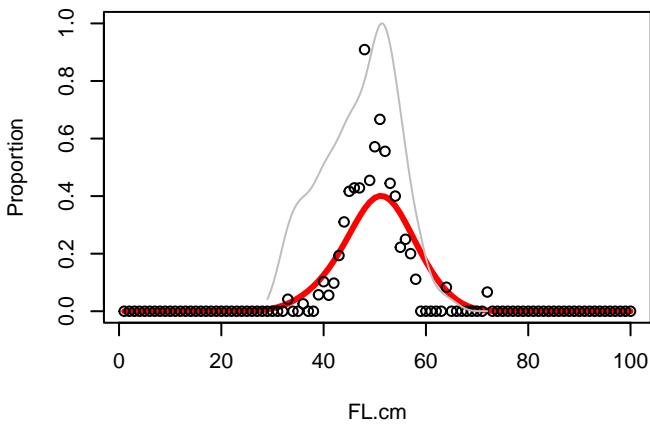
A1



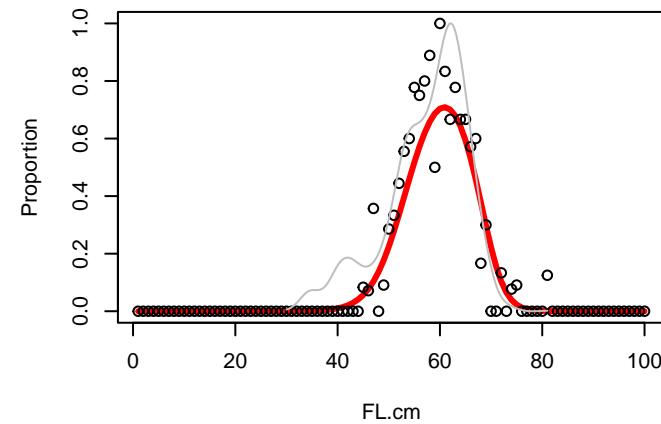
A2



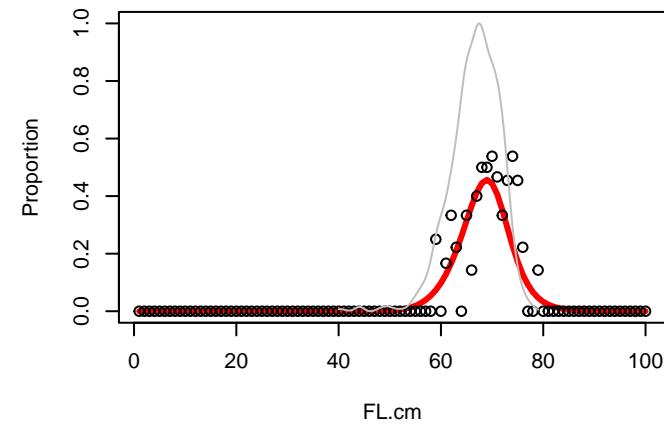
A3



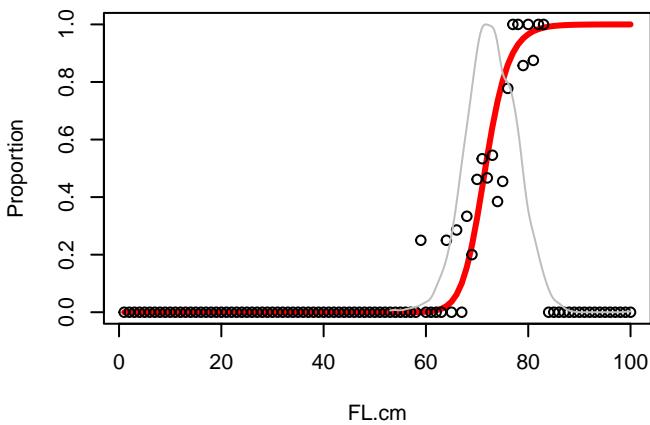
A4



A5

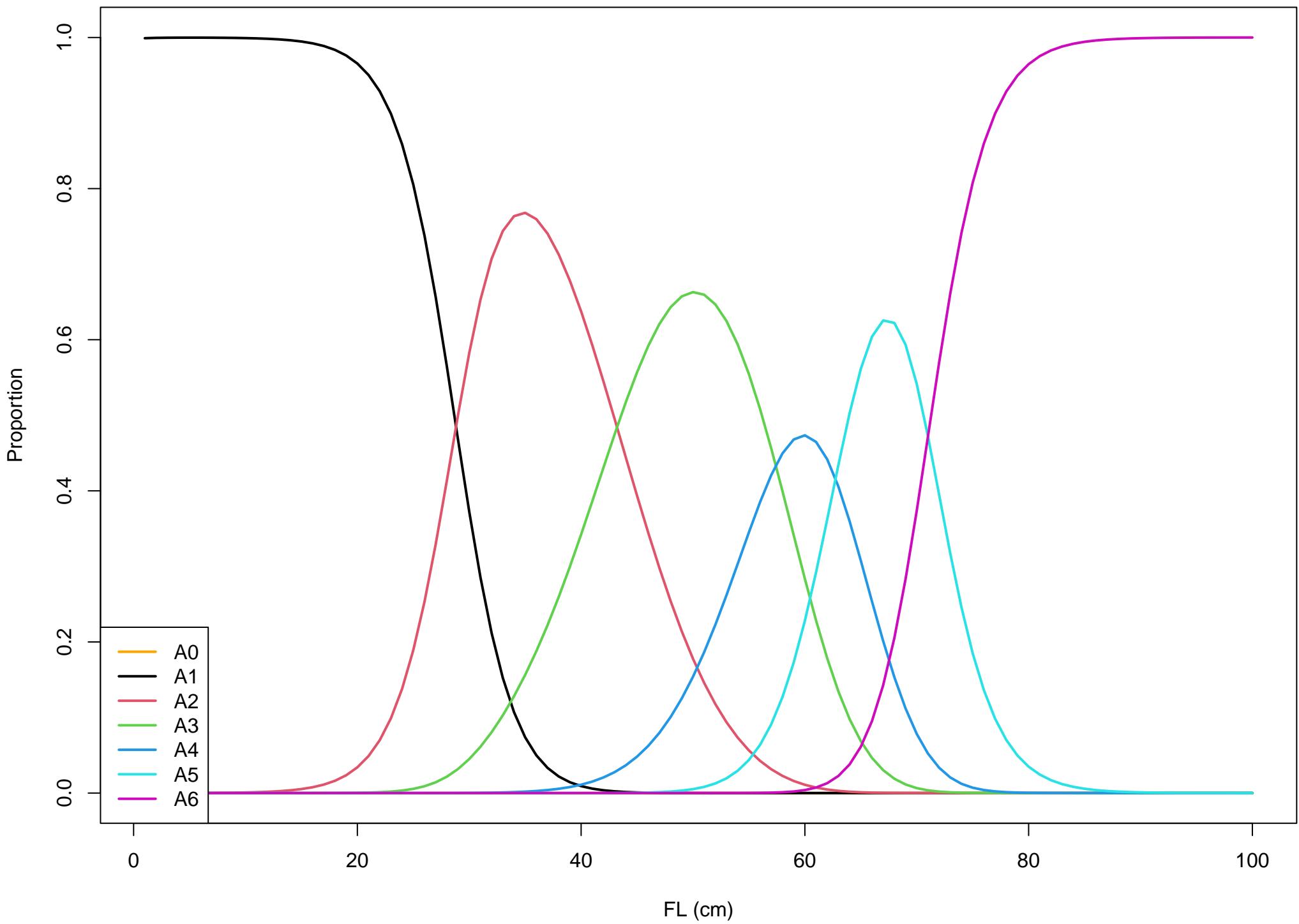


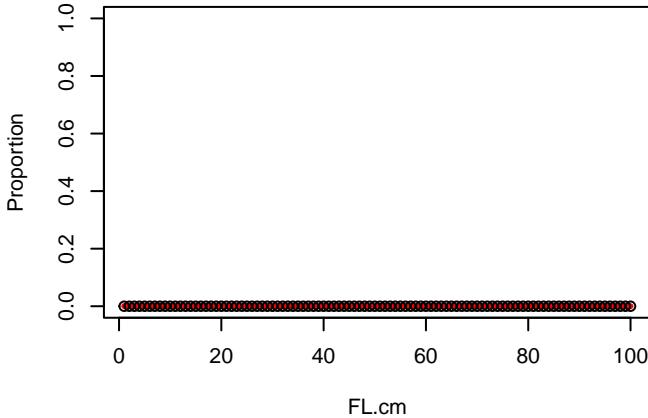
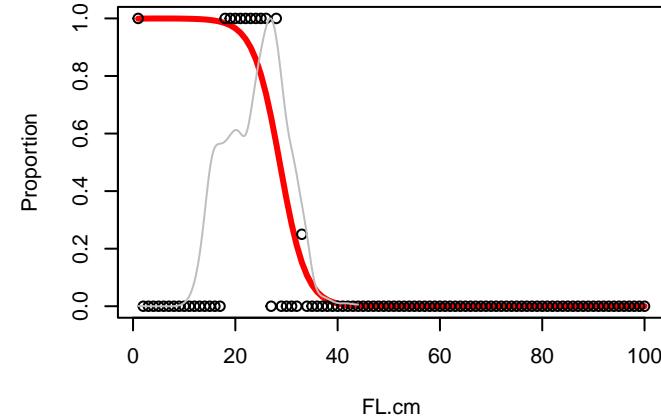
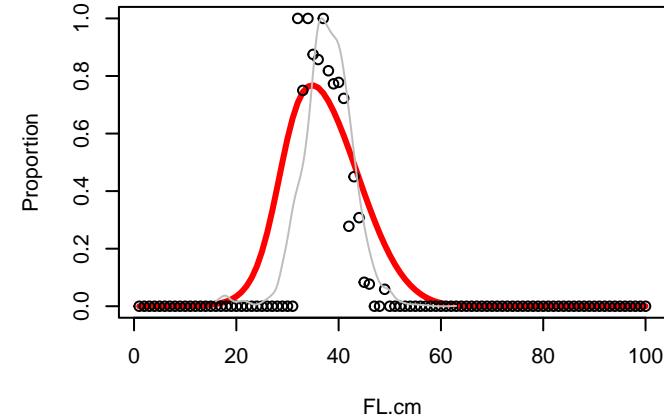
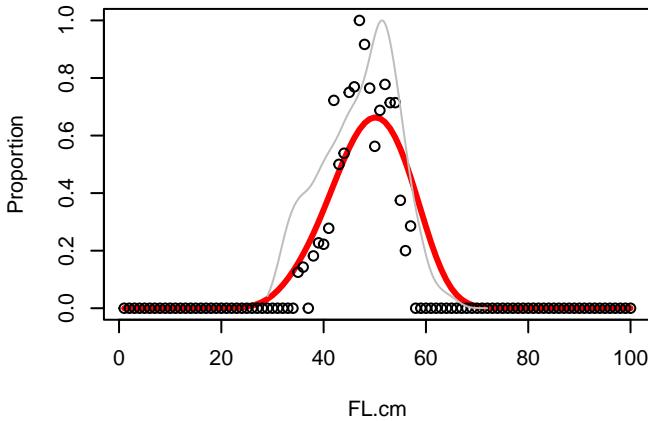
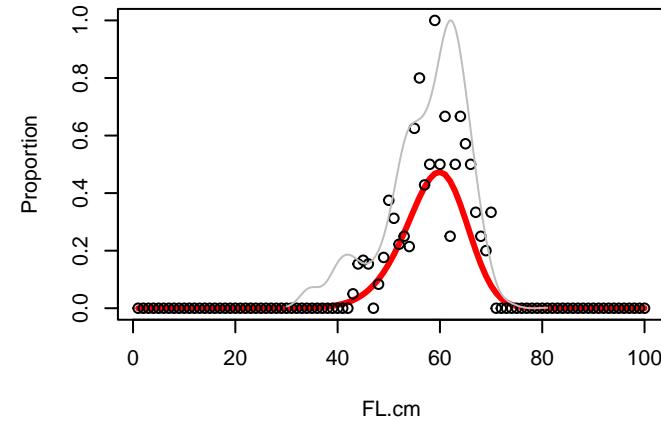
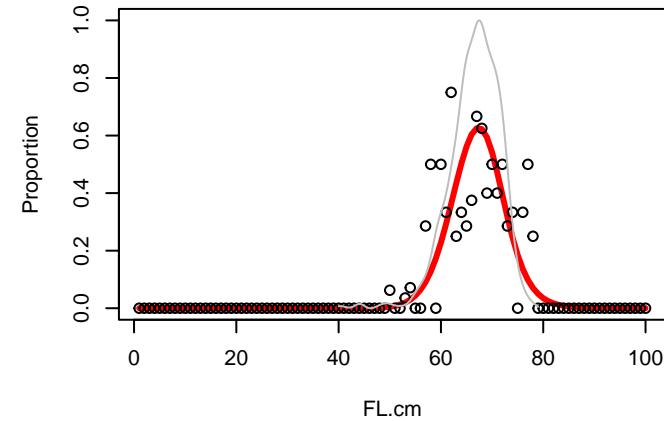
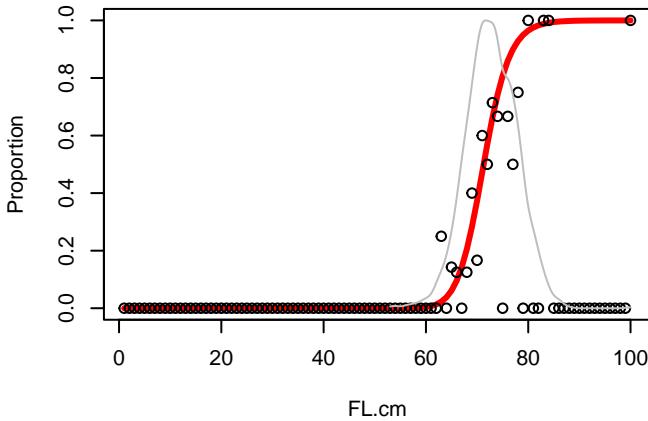
A6



All spring
2019 spring pred
○ 2019 spring obs

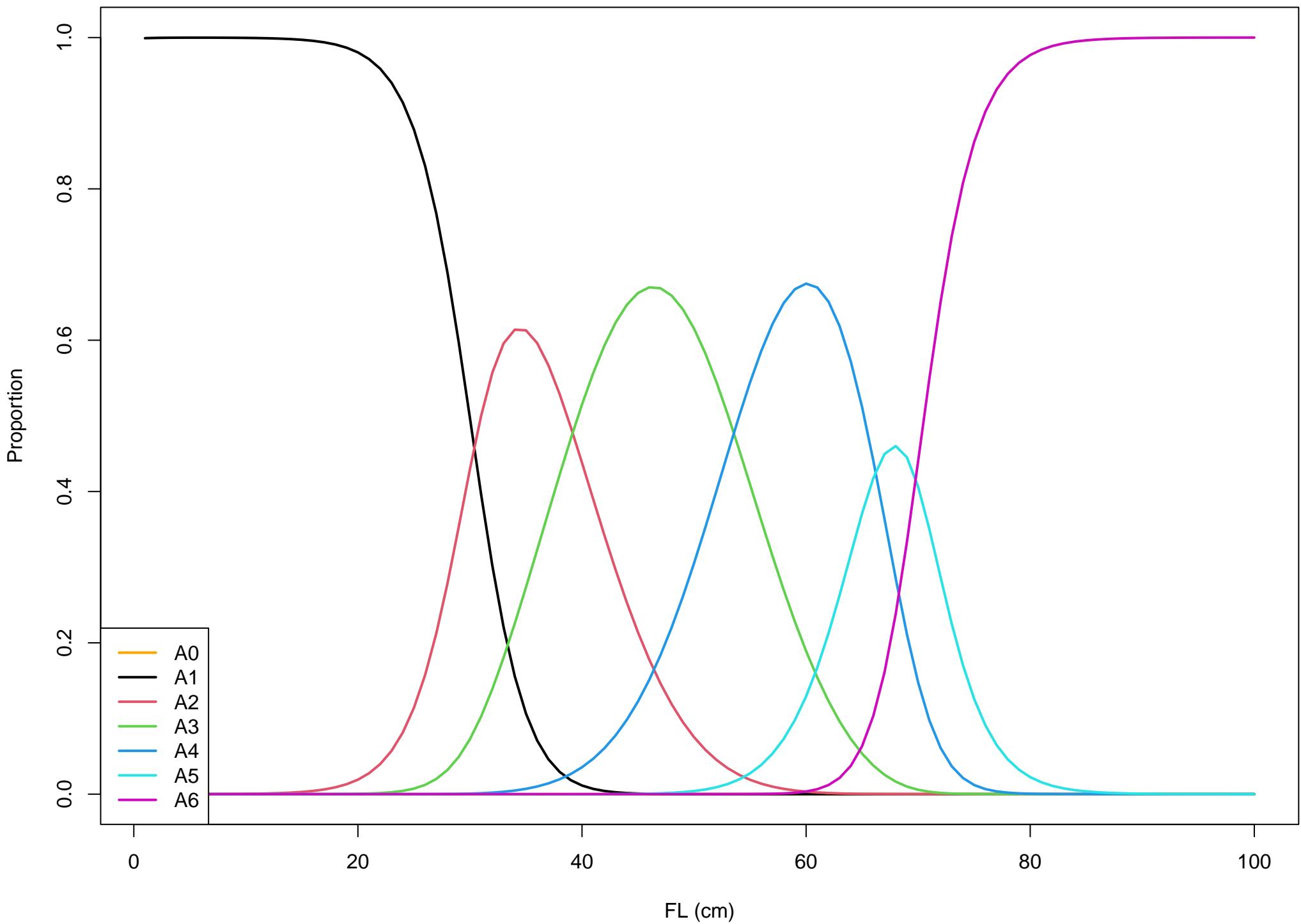
2020
spring



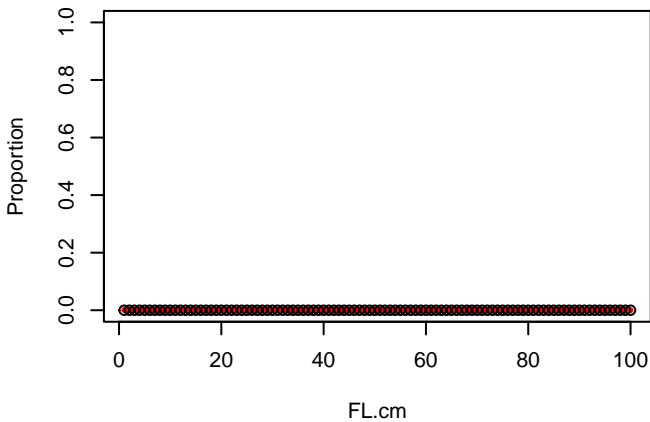
A0, 2020, spring**A1****A2****A3****A4****A5****A6**

All spring
2020 spring pred
○ 2020 spring obs

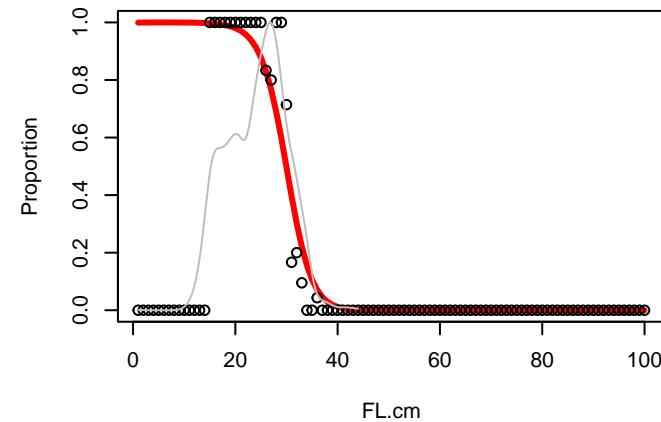
2021
spring



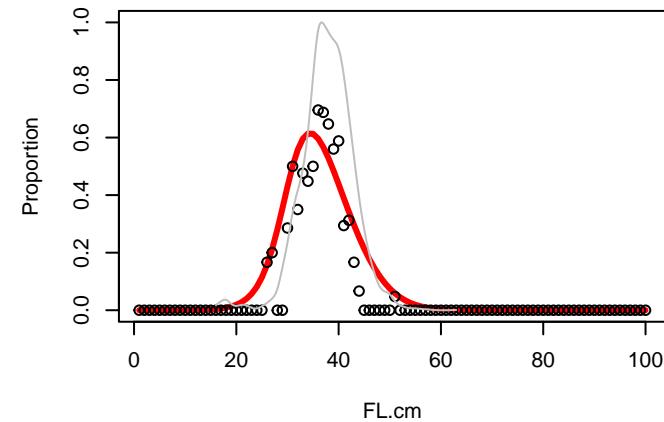
A0, 2021, spring



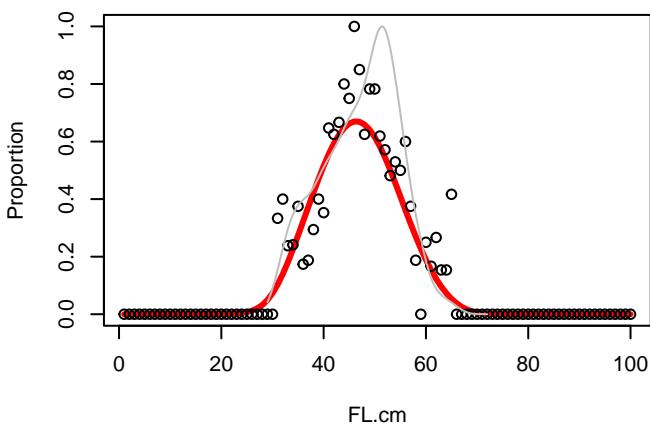
A1



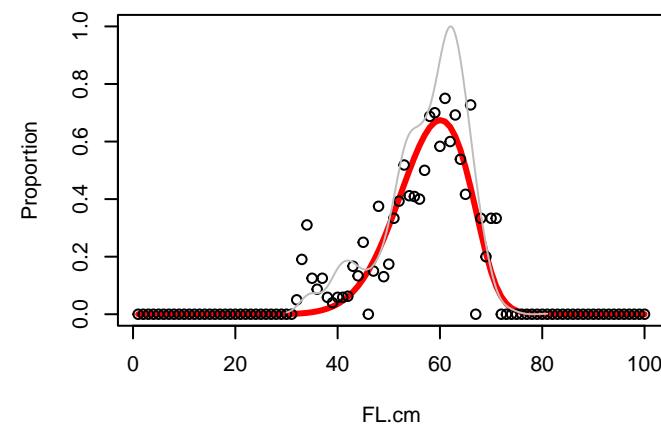
A2



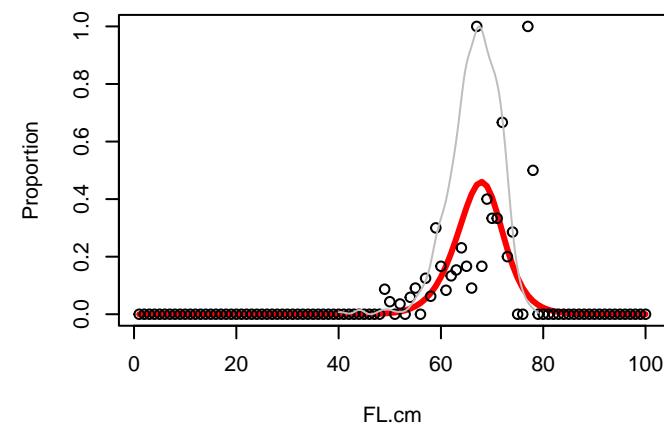
A3



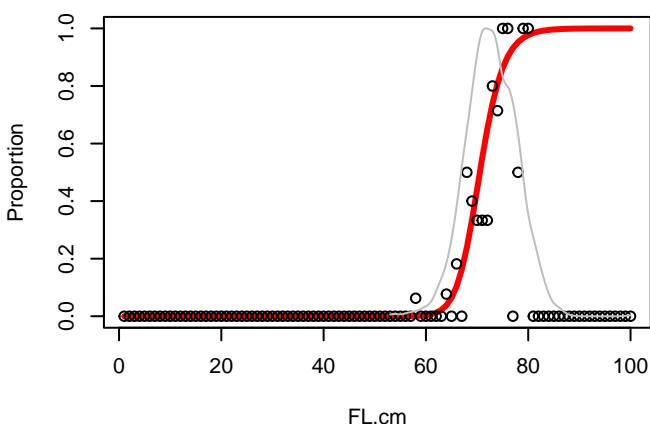
A4



A5

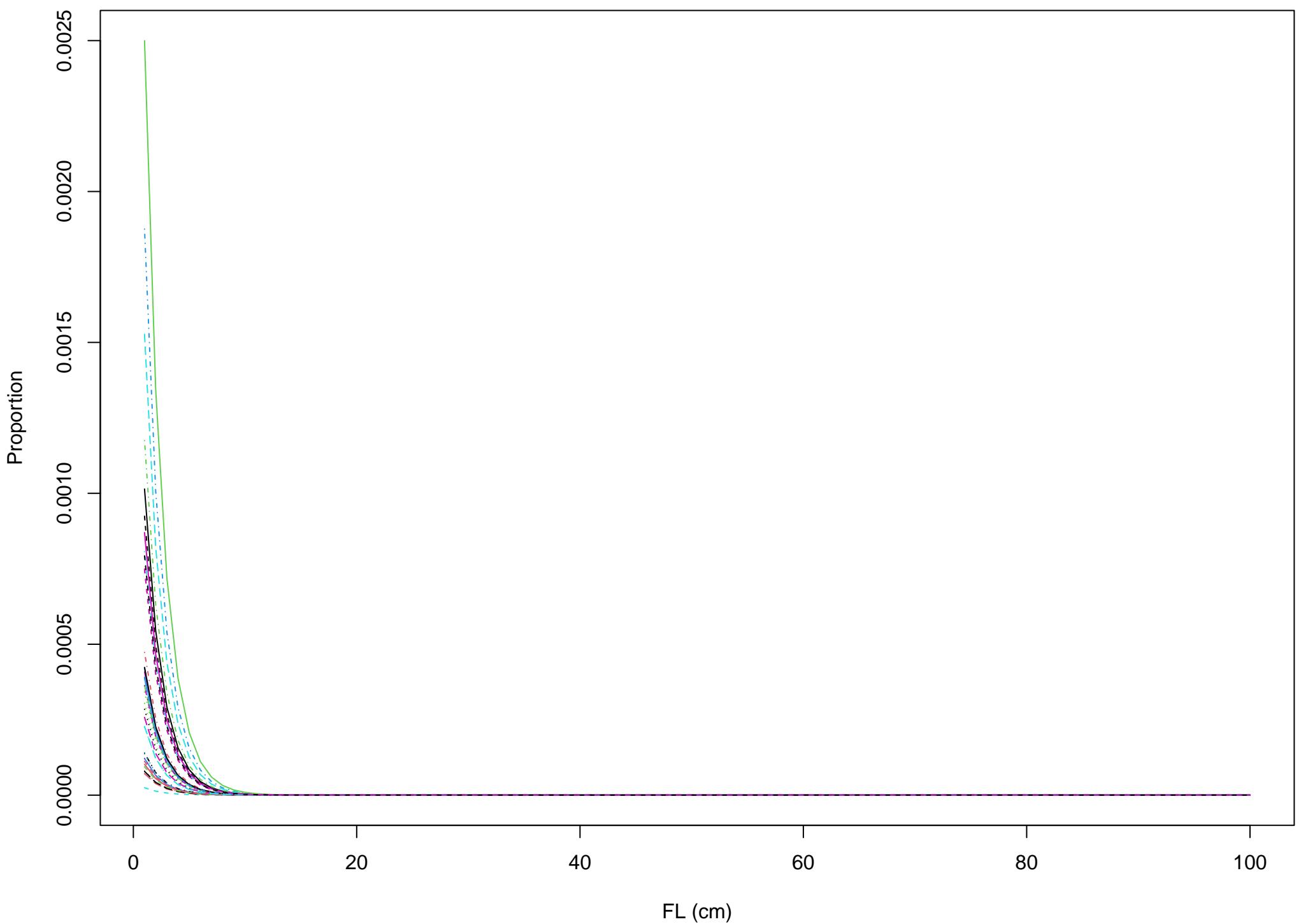


A6

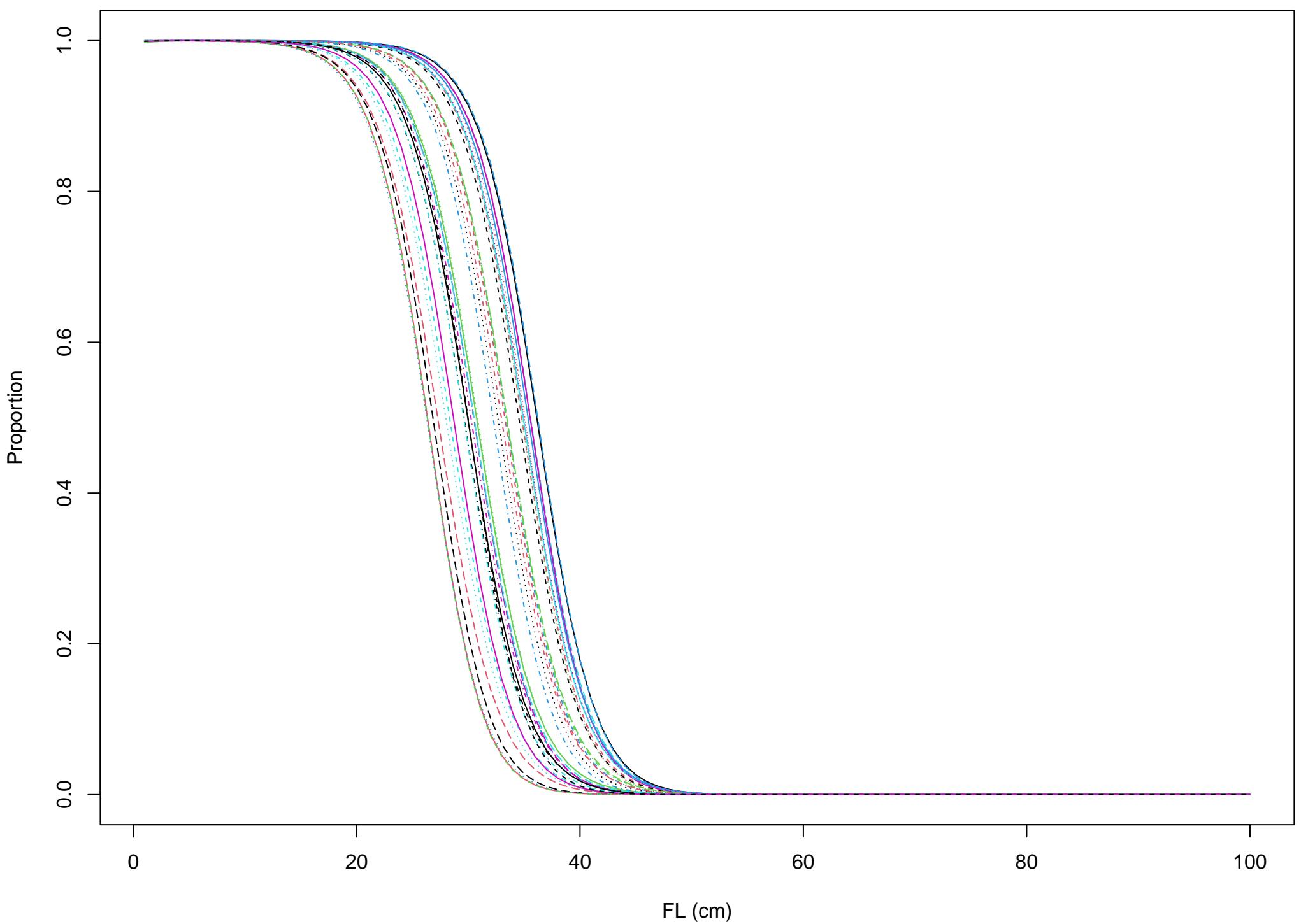


All spring
2021 spring pred
2021 spring obs

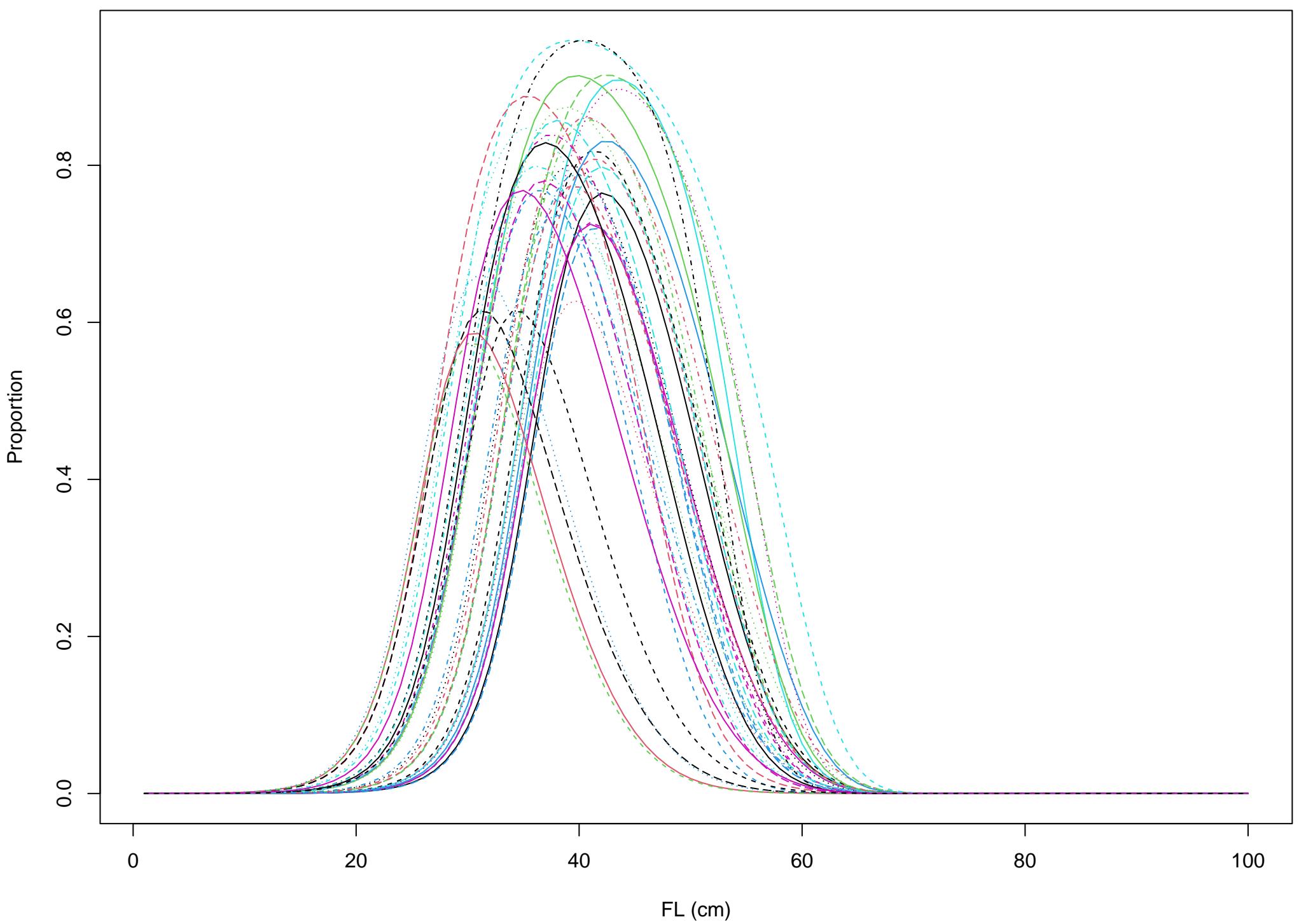
A 0



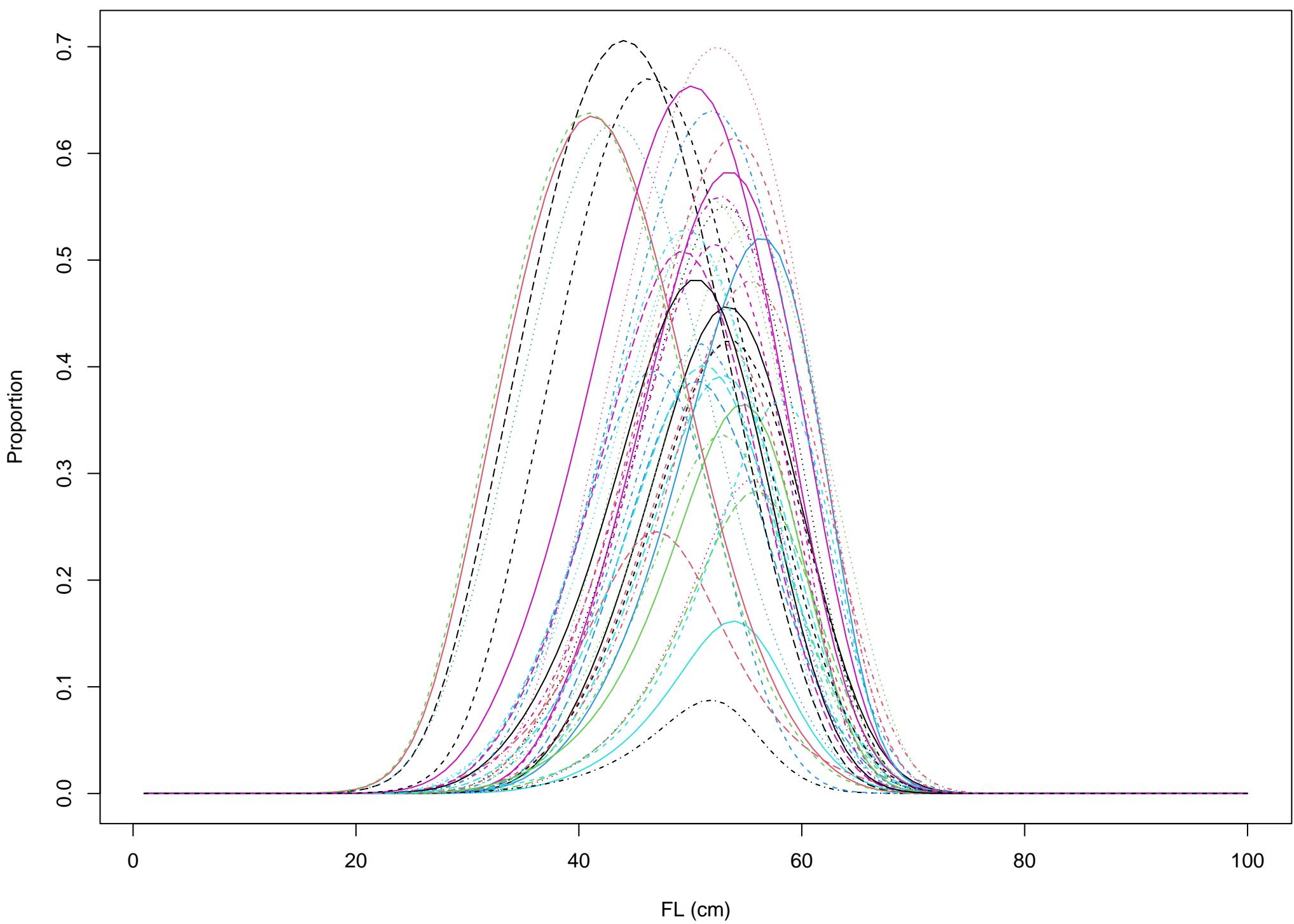
A 1

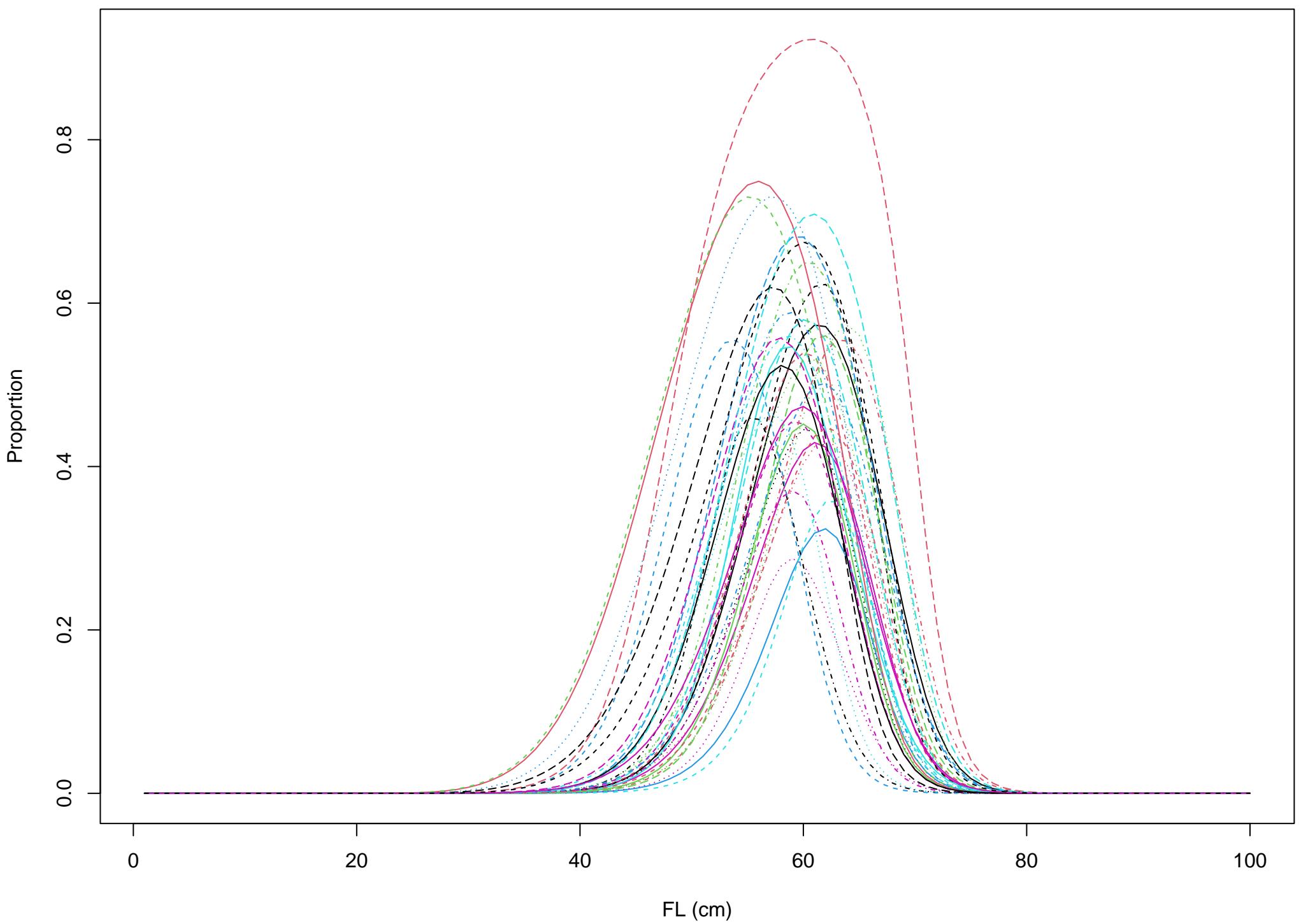


A 2

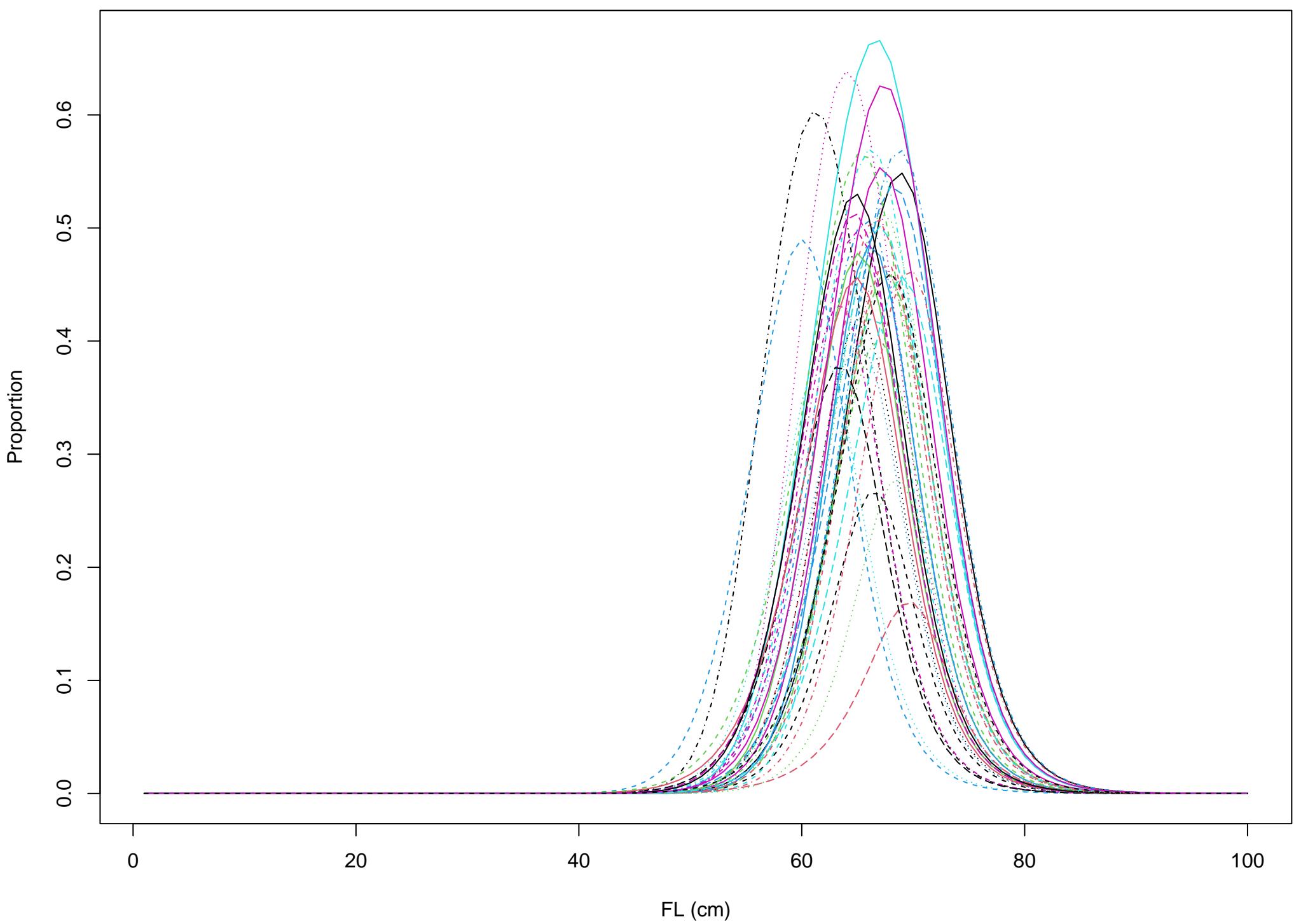


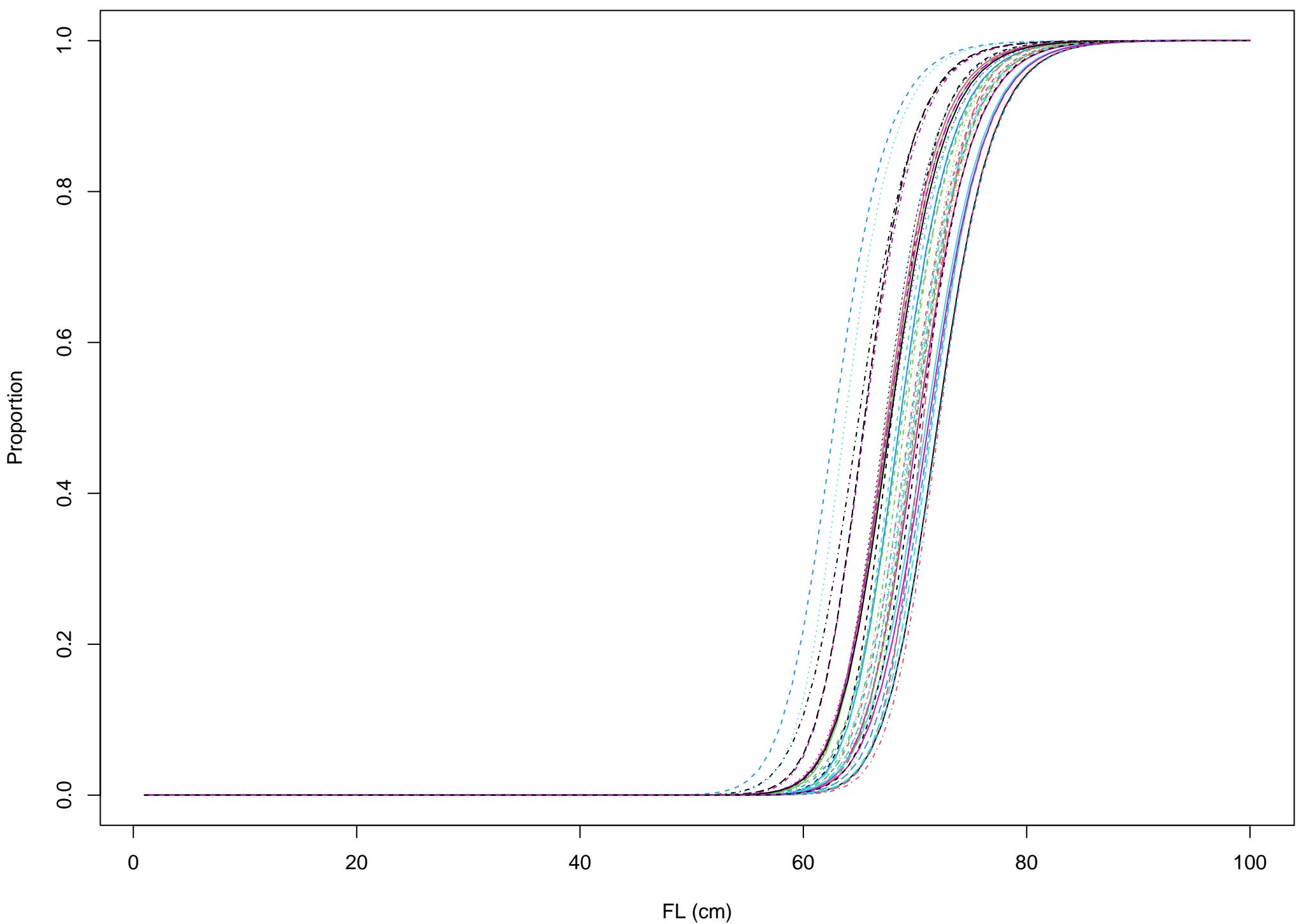
A 3



A 4

A 5



A 6

Appendix III

Exploration of age length keys on catch at age

During the bluefish modeling workshop (August 2022), a model bridge building table suggested that SSB decreased with the change from traditional age length keys (ALKs) to multinomial ALKs. The WG sought to understand why we observed this change. Using simulated length frequency data (Figure 1):

```
x <- rlnorm(n=10e3,meanlog=log(30),sdlog=0.5)
floor(x[x<101])
```

and representative sparse and data rich ALKs (fall 1991 and fall 2019, respectively), catch at ages were calculated from four ALKs:

1. Sparse, traditional ALK
2. Data rich, traditional ALK
3. Sparse, multinomial ALK
4. Data rich, multinomial ALK

Figures 2a-c show the total number of fish at age and weight at age as a function of ALK and sample size of ALK (i.e., sparse or rich); the figure suggests that the number of fish in the plus group is reduced using the multinomial ALK, relative to the that from the traditional ALK in both the example data rich and sparse years (2a); while the mean weight at age is higher using the multinomial ALK (2b), this higher average weight times fewer fish results in lower overall total weight (2c). Figure 3 shows the numbers of age 6 fish at length for both sparse and rich ALKs. For the largest sized age 6 fish, the two ALKs produce the same number of fish at length (i.e., in both ALKs, 100% of large fish are age 6s); however, at smaller sizes, the numbers at length start to diverge as the multinomial ALK assigns fish as small age 6 fish and as age 5 fish (Figure 4, and see Appendix I). Figure 5 shows the age proportions (from numbers and weight at age), and shows that the proportion of total numbers and weight that are assigned to the plus group decreases with the multinomial ALK, relative to the traditional ALK. These collective results appear to explain the shift we saw in the bridge build table. We saw a similar pattern when ageing the MRIP index (T Wood, pers. comm. October 2022).

Figure 1. Simulated length frequency from which catch at age was calculated.

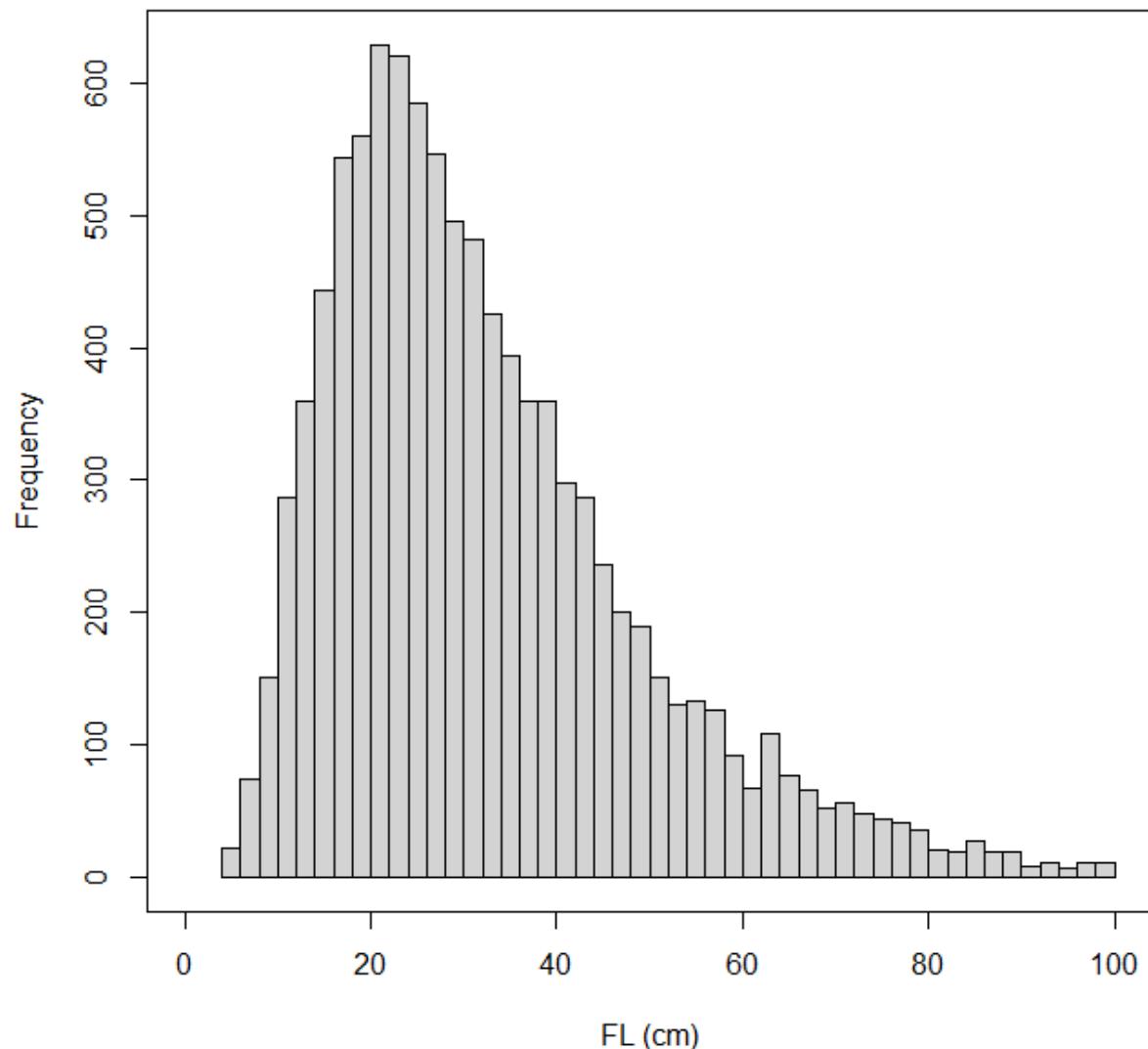
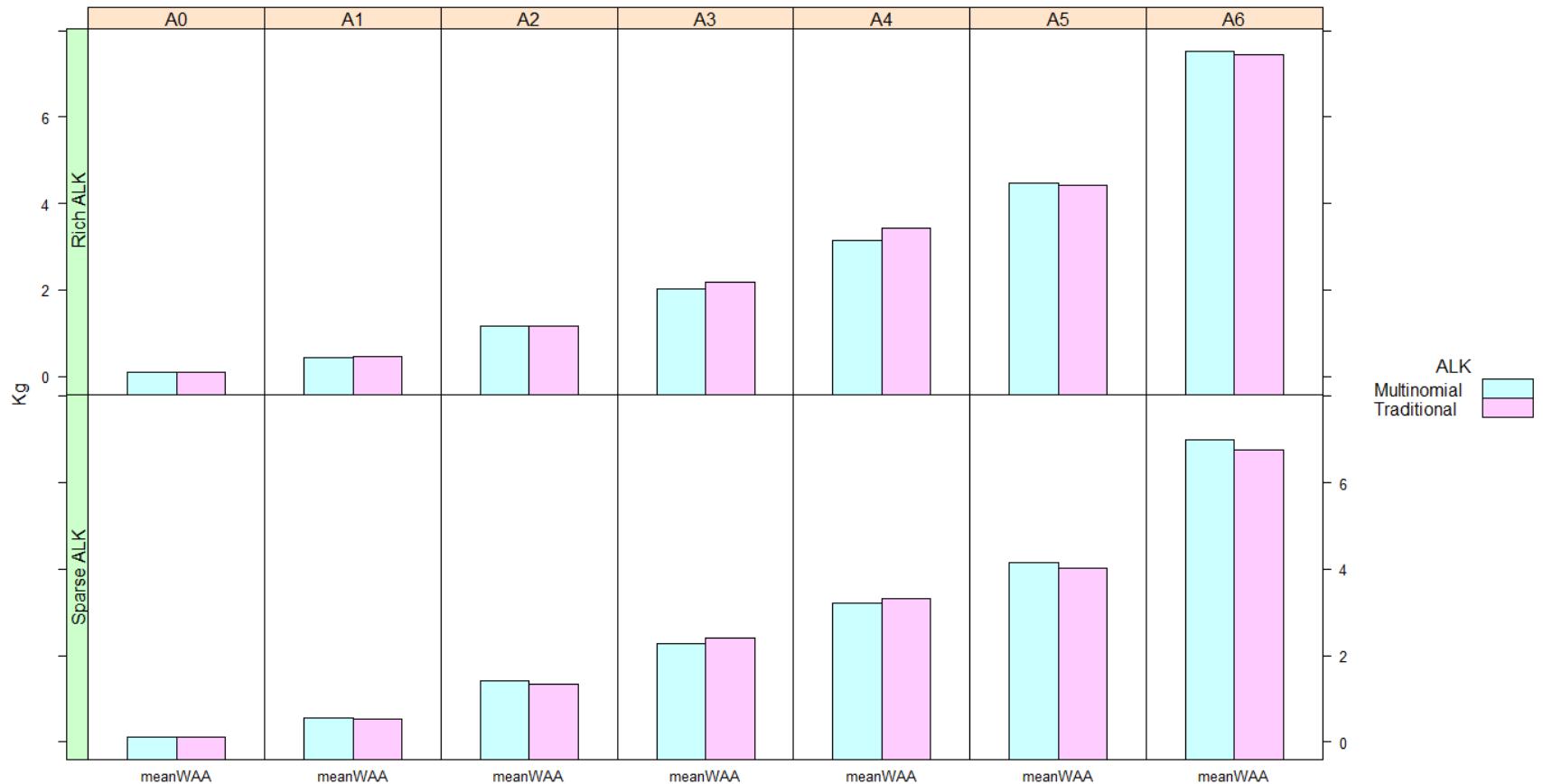


Figure 2a-c. Numbers at age (NAA), total weight at age (WAA), and average weight at age (meanWAA), estimated from a hypothetical length frequency (see Figure 1) using multinomial and traditional ALKs. We explored example data rich (fall 2019), and sparse (fall 1991) ALKs. A6 is a plus group (i.e., A6+).

a) NAA



b) meanWAA



c) total WAA

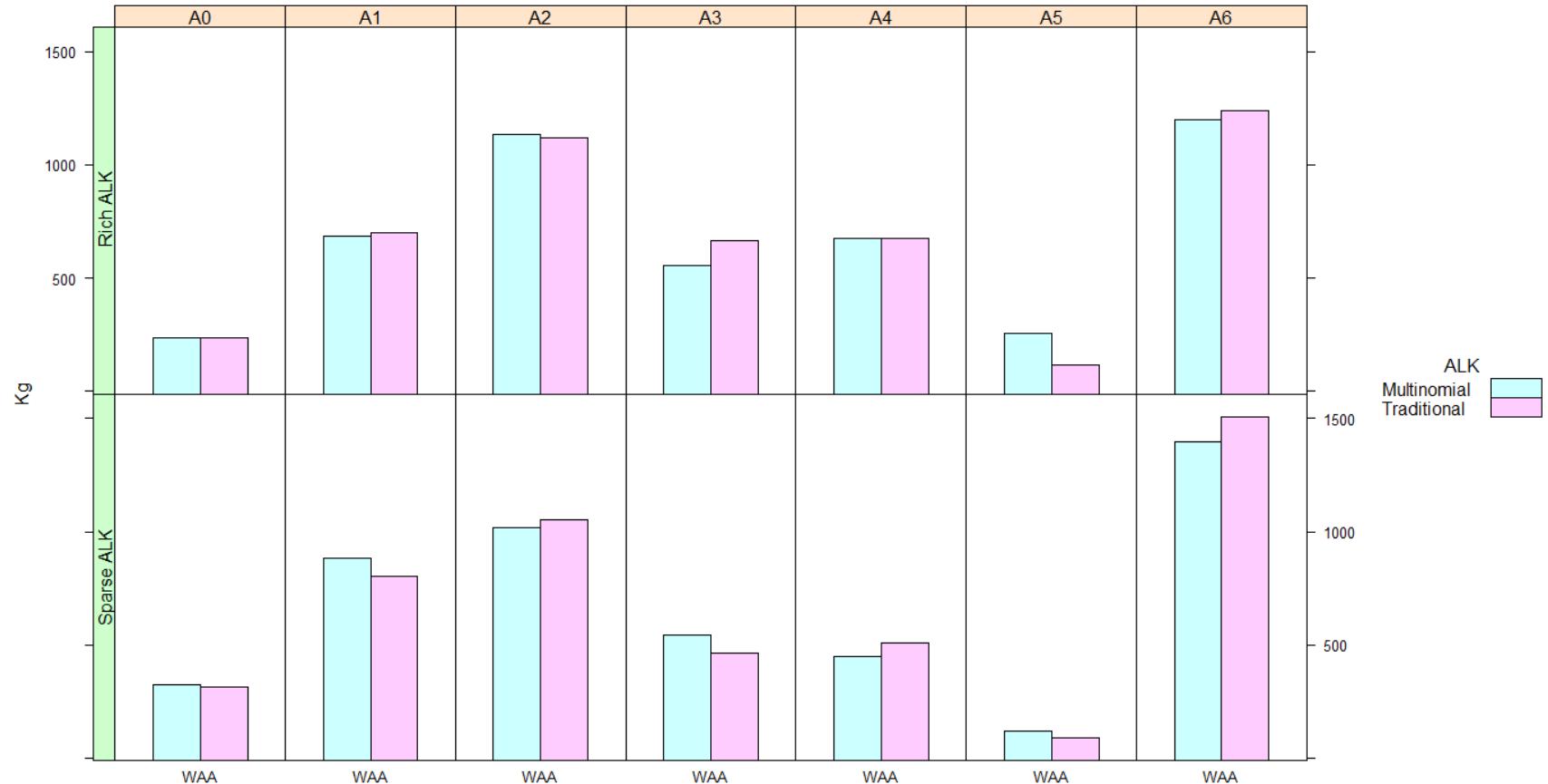


Figure 3. Number of age 6 fish at length for sparse and data rich ALKs.

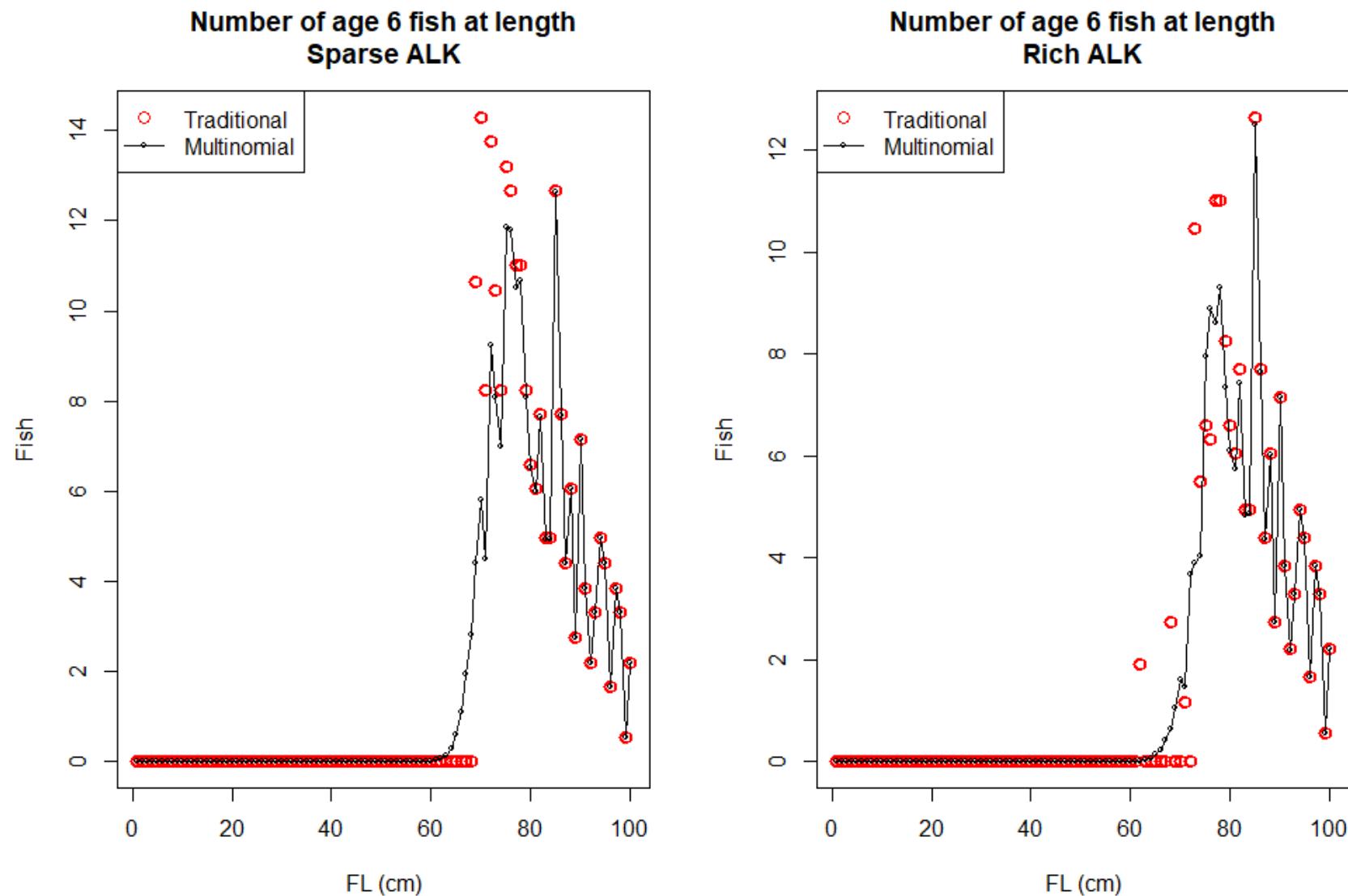


Figure 4. Visual depictions of traditional and multinomial ALKs from sparse (fall 1991) and data rich (fall 2019) years.

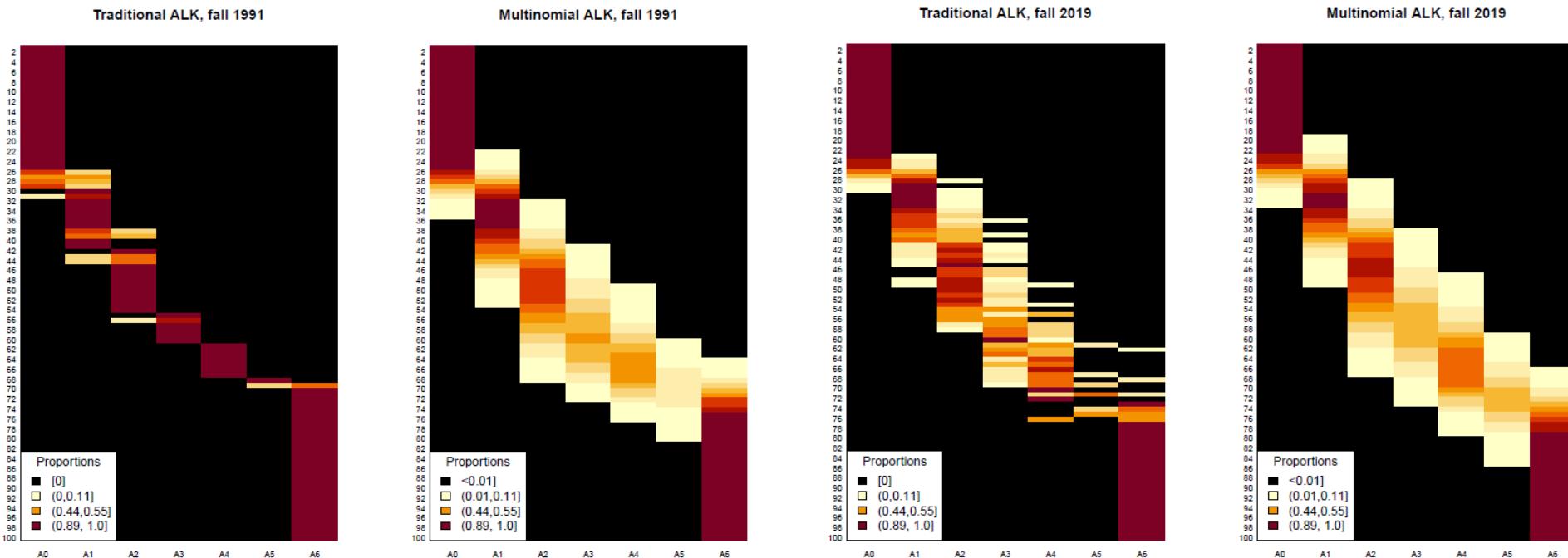


Figure 5. Age proportions derived from numbers at age and weight at age using sparse and rich traditional and multinomial ALKs.

| n | Metric | ALK type | Age proportions | | | | | | |
|------------|--------|-------------|-----------------|-------|-------|-------|-------|-------|-------|
| | | | A0 | A1 | A2 | A3 | A4 | A5 | A6+ |
| Rich ALK | NAA | Multinomial | 0.405 | 0.289 | 0.178 | 0.050 | 0.039 | 0.010 | 0.029 |
| Rich ALK | NAA | Traditional | 0.411 | 0.286 | 0.177 | 0.055 | 0.036 | 0.005 | 0.030 |
| Sparse ALK | NAA | Multinomial | 0.469 | 0.289 | 0.131 | 0.044 | 0.026 | 0.005 | 0.037 |
| Sparse ALK | NAA | Traditional | 0.466 | 0.281 | 0.145 | 0.035 | 0.028 | 0.004 | 0.041 |
| Rich ALK | WAA | Multinomial | 0.05 | 0.14 | 0.24 | 0.12 | 0.14 | 0.05 | 0.25 |
| Rich ALK | WAA | Traditional | 0.05 | 0.15 | 0.24 | 0.14 | 0.14 | 0.02 | 0.26 |
| Sparse ALK | WAA | Multinomial | 0.07 | 0.19 | 0.22 | 0.11 | 0.09 | 0.03 | 0.29 |
| Sparse ALK | WAA | Traditional | 0.07 | 0.17 | 0.22 | 0.10 | 0.11 | 0.02 | 0.32 |