

A method of estimating the sex composition of commercial landings from setline survey data

William G. Clark

Abstract

The sex ratio of fish of a given age and length in survey catches does not vary appreciably with depth or with location within a regulatory area in any given year, so it seems safe to assume that commercial landings of fish in the same category have the same sex ratio as survey catches. The relationship between length and sex ratio (proportion female) for fish of a given age does vary among regulatory areas and years, but in all cases it is well described by a simple logistic function. For recent years, the commercial age/length samples can therefore be keyed out to sex by estimating the two logistic parameters for each area/year/age category from the survey data. For earlier years when the actual lengths of fish in the commercial landings were not measured, the age-specific sex and size compositions of legal-sized fish in the survey catches appear to be reasonable estimates of the commercial values.

Introduction

Setline gear is selective for larger fish, and the commercial fishery has an 81 cm minimum size limit. Female halibut are larger at each age than males, so they presumably sustain a higher fishing mortality. The dramatic reduction in halibut growth rates over the last fifteen years, especially in Alaska, has likely increased the difference in fishing mortality between the sexes.

Because halibut are eviscerated at sea, we have no sample data on the sex composition of commercial landings, so the annual stock assessment has never distinguished the sexes. Instead a single catchability coefficient and selectivity schedule have been calculated for the combined sexes, and both exploitable and spawning biomass have been computed from estimates of combined abundance.

Concern about the actual fishing mortality rate of females and the actual level of female spawning biomass relative to earlier levels led to a decision to attempt an age- and sex-structured assessment in 2003; i.e. to use a model that does the usual population calculations for females and males separately. Sex-specific catchability and selectivity parameters can be estimated for the survey because we have a sexed sample, but the commercial data are a problem.

One approach is to continue estimating a single commercial catchability coefficient and age-specific selectivity schedule. Because those parameters are modeled as random walks, they could in principle track changes in the age-specific averages due to changes in age-specific sex composition. But that would mean applying the same fishing mortality rate to females and males at each age in the population accounting, which is almost certainly wrong.

Another possibility is to estimate a single commercial catchability coefficient and length-specific selectivity schedule (both random walks) and then use sex-specific mean length at age in the survey to predict fishing mortality and therefore catches at age by sex. This approach requires the strong assumption that the same length-specific values apply to both sexes, and even if that is true, it is doubtful that the parameters would be estimable in the absence of observations of catch

at age by sex. The resulting estimated commercial sex compositions could also turn out to be quite different from the observed survey sex compositions, which would be problematic.

The simplest solution is to somehow estimate commercial sex compositions from the survey sex compositions external to the assessment and then do straightforward, mostly parallel age-structured assessments of each sex. Sex-specific commercial parameters would then be readily estimable, and the working estimates of commercial sex composition would agree with the survey data. This paper reports a method of estimating the sex composition of the commercial catch at age using a survey-based estimate of the age-specific relationship between length and sex ratio.

Mean length at age in survey catches and commercial landings

Because females are larger than males at each age, the mean length at age in commercial landings is an indicator of sex composition. In particular, if the mean length at age in commercial landings closely matched the mean length at age of legal-sized fish in survey catches, that would be strong evidence that commercial and survey sex ratios at age (and sex-specific length distributions at age) are the same. This appears to be the case in Area 2B, and until the last few years in Areas 2C and 3A (Figs. 1a-c). But in Areas 3B and 4 the mean length at age has always been much larger in commercial landings than in survey catches (Figs. 1d-e), and the same pattern has appeared in Areas 2C and 3A recently.

There are a number of possible reasons why the commercial fishery could select larger fish at each age than the survey, including ground selection, gear differences, and highgrading. Whatever the reason, selecting larger fish must result in a higher proportion of females in commercial landings, at least in some areas and years.

Length frequencies at age in survey catches and commercial landings

For all survey years back to 1993, when surveys resumed after a 6-year hiatus, it is possible to compare age-specific commercial and survey length frequencies to see what causes the differences in mean age at length. In the survey data the female and male components of each length interval can also be distinguished so as to show what sort of differences between survey and commercial sex composition might result from the differences in length composition.

Direct comparisons of length frequencies cannot be made for earlier years because the fork lengths of fish in commercial samples were not measured between 1963 and 1990. Instead one or another measurement of the otoliths was made and fork lengths were calculated from a predictive relationship. At best this sort of prediction would provide the expected fork length of each fish, but the distribution of expected fork lengths would not be the same as the distribution of true fork lengths. To further complicate matters, the relationship between otolith size and fork length changed over time. The staff has reworked the predictions to improve the estimates of mean size at age in commercial landings (Clark 1992), but there is still some doubt even about the means, and there is no satisfactory way to recover the entire length frequency distributions.

The available data are further complicated by a change in age reading practices at IPHC. All of the age data in the database through 2001 are surface readings, which on average underestimate the ages of fish older than 12 or so (Clark 2004). Beginning with 2002 all of the data are break-and-burn readings, which are accurate. For that reason the analysis in this paper will generally treat the age data types separately, meaning that most comparisons show data from the more numerous years of surface age readings, ending in 2001. The methods eventually

developed apply equally well to 2002 and later data, as is shown, and are applied to those data separately to obtain working formulas.

In recent years where direct comparisons between survey and commercial data can be made (i.e., surface reading years when surveys were done and commercial lengths were measured), the data show that relative to the survey length frequencies, the commercial landings contain substantially fewer fish under 90 cm and slightly more fish across a wide range of greater lengths (Figs. 2a-h), where apart from that slight difference the distributions are usually similar. This is true even in those cases where survey and commercial mean lengths at age agree closely, namely in Area 2B (Fig. 2a) and until 2000 in Areas 2C and 3A (Figs. 2c and 2d). The pattern is simply more pronounced in the cases where the commercial mean lengths are consistently higher (Figs. 2f-h). Interestingly, limiting the survey length frequencies to data from stations deeper than 100 fm largely eliminates the pattern in Area 3A (Fig. 2e) and to a lesser extent in other areas (Fig. 2b), suggesting that it results at least in part simply from the difference in grounds fished by the survey and the commercial fishery.

At every age the 80-90 cm length group contains a substantially higher proportion of males than the age group as a whole. The commercial landings have relatively fewer fish of this size than the survey catches, so they presumably contain a higher proportion of females than the survey catches. The commercial sex ratio can be estimated by applying the survey sex ratio to the commercial frequencies in each length interval, but only if the sex ratio in an age/length category does not vary among grounds within a regulatory area.

It is shown below that this is the case, which is somewhat surprising given the difference in size between females and males, and the difference in length compositions between shallow and deep survey stations. But Figs. 2a-b and 2e-f do in fact show little difference in sex ratio at a given age and size between deep stations and all stations in Areas 2B and 3A, and plots of the depth distributions of females and males of the same age are quite similar at all ages in all areas with the exception of teenaged fish in Area 2B, where the males tend to be shallower (Figs. 3a-f). Younger fish do have a more inshore distribution in all areas, but it appears that both males and females move deeper with age. Another confirmatory piece of evidence is that the sex ratio at a given length is the same in trawl and setline survey catches in Area 3A (Clark 2001) despite large differences in overall length composition and mean length at age.

Direct estimates of the sex composition of commercial catches

This section of the paper reports estimates of the sex composition of commercial landings computed by applying the raw survey values of proportion female in each age/length category to the age/length frequencies of the commercial data, with enough years of data pooled to avoid small-sample problems. This is the natural way of computing the estimates, and it will show in a simple and direct way the size of the differences between survey and commercial sex composition in the various regulatory areas in recent years. The following sections of the paper will use fitted curves to represent the relationship between length and sex ratio within an age group so as to simplify comparisons and eventually working calculations.

Applying the survey sex ratio (proportion female) in each length interval to the commercial length frequencies for a given age group provides estimates of the commercial sex ratio at that age and the size distributions of females and males of that age in the landings, all quantities of interest for purposes of stock assessment and harvest policy evaluation. These estimates show that for Area 2B, and until recently Areas 2C and 3A, the overall sex compositions of commercial landings were very similar to the sex compositions of legal-sized

fish in survey catches (Figs.4a-c), despite the relative paucity of 80-90 cm fish in the landings. In these cases the estimated proportion female and mean size at age by sex are very slightly higher in the commercial estimates, but all of the differences are small compared with the year-to-year variability of survey values and, for years before 1991, the uncertainty concerning the true mean size at age in commercial landings. In view of this finding, and the generally good agreement between survey and commercial mean size at age going back to 1974, it appears to be practical to use the observed sex composition of legal-sized fish in the survey catch as estimates of the commercial values in Areas 2B, 2C, and 3A from the 1970s through the late 1990s.

The commercial estimates of proportion female at age in recent years are consistently and substantially higher than the survey values in Areas 3B and 4A, and for most ages in Area 4B (Figs. 4d-f). It will therefore be necessary to key out the commercial length frequencies to estimate the commercial sex composition, effectively limiting the stock assessment in those areas to the beginning of systematic surveys in 1996-97.

Form of the relationship between sex ratio and length at a given age

It remains to be shown that the sex ratio at a given age and length is the same throughout a regulatory area in any given year. Comparisons between subareas and depth zones can be simplified by fitting a curve for each case of interest and then comparing the fitted curves. The relationship between proportion female p and fork length L for fish of a given age in a given area in a given year (all fish, not just legal-sized ones) is very well described in all cases by a simple logistic function:

$$p = 1 / (1 + \exp(-k \cdot (L - L_{50})))$$

where k is a slope parameter and L_{50} is the length at which 50% of the fish are female (Fig. 5). The location and steepness of this curve must depend in a very complicated way on the growth and exploitation histories of the females and males in the age group, so there is no question that the parameter values will vary among areas and years. But the form is remarkably consistent.

Another consistent feature of the relationship is a very tight linear trend with age in the estimate of L_{50} for the fish in a given area and year (second to last panel in Fig. 5). The estimates of k are more variable from one age to the next and sometimes exhibit a modest curvature (last panel in Fig. 5). The variation of L_{50} with age can be represented very well by a fitted straight line:

$$L_{50} = b_0 + b_1 \cdot age$$

and the variation of k with age can be represented well enough (the fits are not very sensitive to the precise value of k) by a fitted quadratic:

$$k = c_0 + c_1 \cdot age + c_2 \cdot age^2$$

Logistic functions with parameters predicted in this way closely match the age-specific fitted logistics for all ages except the plus group (e.g., 20+ for surface ages), which consists of a mixture of older age groups and therefore tends to have a higher L_{50} and lower k than predicted by the trends among the younger age groups. To specify the proportion female as a function of

length for all ages in a given area and year therefore requires seven meta-parameters: the coefficients b_0, b_1, c_0, c_1, c_2 shown above and estimated from the trends in L_{50} and k among all ages except the plus group, and the values of L_{50} and k for the plus group.

The comparisons in the next sections show separate logistics fitted to the data for each age group. Meta-parameter values are computed later in the paper for use in working calculations.

Consistency of the relationship between depth zones and subareas

Because survey and commercial effort are distributed differently, a single survey-based schedule of sex ratio at length for a given area/year/age will be correct only if the schedule is the same throughout the area, i.e. in all depths and all subareas.

When the survey data are divided in two by depth, the separate logistics fitted to the shallow and deep components are very close in all cases. The largest differences occur in Area 2B, which as noted above appears to be the only area where there is any difference in the depth distribution of females and males of the same age. But even in Area 2B, the relationship between length and sex ratio at a given age is almost the same for shallow and deep stations, at least through age 16 (Fig. 6a). Beyond that there are not enough old fish at shallow stations to make the comparison using only 2B data, but using data from all of Area 2 shows reasonably close agreement among the older fish as well (Fig. 6b). This is true both for the years with surface age data (through 2001; Figs. 6a and 6b), and for 2002-2003 when all the age data are break-and-burn readings (Fig. 6c). In other regulatory areas the agreement between shallow and deep fits is as good as or better than in Area 2.

In similar comparisons, there is no difference in the fits between the southern and northern halves of 2B or 2C, or between the eastern and western halves of 3A, 3B, 4A, or 4B (Figs. 7a and 7b). This is not to say that there are no differences at all within regulatory areas, but only that they are small enough to be disregarded.

There are some large differences between regulatory areas. In recent years there has been little difference between Areas 2B and 2C (Fig. 8a), or between Areas 2A and 2B, but some noticeable and consistent differences between Areas 2C and 3A (Fig. 8b); also between Areas 3A and 3B. Areas 3B and 4A are almost identical, but there are again large differences between Areas 4A and 4B. So while a single fit is sufficient for an entire regulatory area, it is desirable to treat regulatory areas separately, and there is no reason not to.

Changes in the relationship over time

Because of the large changes in growth schedules that have occurred in the last twenty years, the schedule of sex ratio at length has shifted toward smaller sizes, modestly in Area 2B where the growth changes were less (Fig. 9a) and dramatically in Area 3A (Fig. 9b). In the mid-1980s, the length at which the proportion female reached 50% among the modal age groups (ages 10-14) in Area 3A was 120-140 cm; now it is 80-90 cm. The bulk of this shift occurred between the mid-1980s and the mid-1990s; during the latter 1990s there was some small further movement, particularly in the 20+ age group, but not a great deal.

Working formulas

In 1996 setline surveys were begun in Area 3B, extended eastward in Area 3A to cover nearly the whole area, and resumed in Area 2C. It is therefore a convenient starting year for

estimating the sex composition of the commercial landings using the procedure developed above. Surveys in Areas 4A and 4B did not begin until 1997, but because the sex ratio at length (within age) does not appear to have been changing rapidly in the latter 1990s, it should be possible to key out the 1996 commercial data in those areas reasonably well using the 1997-1998 survey data. Commercial landings in Area 2A can be keyed out with Area 2B survey data at need.

For each area and each year beginning with 1996, the seven meta-parameters of age-specific logistic functions described above have been computed (Table 1). This was done using a moving three-year data window to calculate the estimates for the central year, except at the beginning and end where only two years of data were used. Where fewer than 100 observations were available at a given age, data were added from neighboring ages (to a maximum of ± 2 years) to reach a minimum sample size of 100 for each age-specific estimate. Extreme outliers from a fitted logistic were removed and the curve refitted to improve the parameter estimates. The data series were broken between 2001 and 2002 at the time of the change from surface to break-and-burn readings because that did affect the shape of the fitted logistics. The plus age is 20 for the surface years and 25 for the break-and-burn years. Only in Area 4 did fish over age 25 represent more than 1% of the landings—2% in Area 4A, 7% in 4B, and 5% in 4D.

For years before 1996, smoothed survey values (for legal-sized fish) were used to estimate the age- and sex-specific commercial values in Areas 2B, 2C, and 3A. This involved a long interpolation between 1986 and 1993 when surveys were suspended, but in fact this was a period of more or less steady decline in estimated commercial mean length at age, so the linear interpolation should be reasonably accurate.

Results

Application of the estimation procedure described above to commercial length frequencies produces estimates of sex and size frequencies that are very consistent with the observed characteristics of legal-sized fish in the survey in the mid-1990s. Mean size at age by sex (Figs. 10a and 10b) and sex ratio at age (Fig. 10c) show good continuity from the period where raw smoothed survey observations are used (1974-1995) to the period where the sex and size compositions are estimated from the commercial length frequencies at age (1996-2003). This is not surprising, since the logistic predictors were estimated from the survey data. What the good agreement shows is that the use of meta-parameters to summarize the logistics does not degrade the estimates.

There is a good deal of year-to-year variation in the sex ratio at a given age, in both the survey observations and the commercial estimates. It is doubtful that the sex ratio at age in the commercial landings really varies much from year to year, so it seems sensible to smooth the commercial sex ratio estimates at each age over years to compute the catch at age by sex in each year. Doing so makes very little practical difference because the year-to-year variability of estimated catch at age by sex is due almost entirely to the year-to-year variability of estimated catch at age rather than estimated sex ratio (Fig. 11).

Discussion

The procedure developed above seems to be quite reliable because the sex ratio at length within age has a very simple form that appears to be nearly uniform throughout a regulatory area in any given year. But that is only known to be true for the summer survey period. If there is a seasonal variation outside that period, the commercial landings could have a different sex composition. And even if the commercial fishery encounters the same sex ratio as the survey at a

given age and length, the sex composition of the catch could be different if the ratio of female to male catchability is not the same as in the survey, e.g. because of a strong effect of bait type on sex-specific catchability. Differences of this sort are somewhat far-fetched but not impossible. While it seems reasonable and worthwhile for the time being to estimate commercial sex compositions as proposed, it remains desirable to devise a method of determining the sex of fish in the commercial samples.

References

Clark, W.G. 1992. Estimation of halibut body size from otolith size. Int. Pac. Halibut Comm. Sci. Rep. No. 75.

Clark, W.G. 2001. Age and size composition and recent trawl and setline catches in Area 3A. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2000:345-352.

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Table 1. Estimates of meta-parameters of logistic functions for predicting sex ratio at length for fish in a given, area, year, and age group. See text for formulas. $L50+$ and $k+$ are the parameter values for the plus age group. Note that the plus age is 20 in 1996-2001 and 25 in 2002-2003.

Area	Year	+age	$b0$	$b1$	$c0$	$c1$	$c2$	$L50+$	$k+$
2A	1996	20	42.31	4.02	4.057E-02	1.724E-02	-6.300E-04	121.82	0.112
2A	1997	20	41.17	4.16	1.931E-01	-5.801E-03	3.095E-04	121.41	0.114
2A	1998	20	40.04	4.20	-2.454E-01	6.588E-02	-2.393E-03	121.46	0.096
2A	1999	20	42.97	3.96	-1.999E-01	5.788E-02	-1.990E-03	117.49	0.142
2A	2000	20	43.13	3.87	-5.131E-02	3.233E-02	-1.068E-03	119.58	0.175
2A	2001	20	47.74	3.43	5.874E-03	2.093E-02	-5.932E-04	119.76	0.204
2A	2002	25	55.47	2.58	1.889E-02	2.293E-02	-5.952E-04	123.45	0.275
2A	2003	25	55.47	2.58	1.889E-02	2.293E-02	-5.952E-04	123.45	0.275
2B	1996	20	42.31	4.02	4.057E-02	1.724E-02	-6.300E-04	121.82	0.112
2B	1997	20	41.17	4.16	1.931E-01	-5.801E-03	3.095E-04	121.41	0.114
2B	1998	20	41.22	4.09	-1.830E-01	5.390E-02	-1.843E-03	120.69	0.094
2B	1999	20	45.79	3.67	-1.822E-01	5.494E-02	-1.911E-03	116.74	0.139
2B	2000	20	44.57	3.70	-7.604E-02	3.590E-02	-1.207E-03	119.20	0.166
2B	2001	20	45.95	3.60	-1.308E-02	2.238E-02	-6.040E-04	119.03	0.227
2B	2002	25	56.62	2.48	1.801E-02	2.204E-02	-5.902E-04	116.58	0.275
2B	2003	25	56.62	2.48	1.801E-02	2.204E-02	-5.902E-04	116.58	0.275
2C	1996	20	32.31	5.06	2.354E-01	-2.080E-02	1.111E-03	128.45	0.244
2C	1997	20	30.99	5.10	1.895E-01	-1.401E-02	8.422E-04	134.69	0.142
2C	1998	20	33.22	4.86	1.640E-01	-9.493E-03	5.960E-04	132.90	0.124
2C	1999	20	36.37	4.44	-8.386E-02	2.622E-02	-6.344E-04	128.63	0.136
2C	2000	20	34.51	4.59	-1.377E-01	3.476E-02	-1.014E-03	127.54	0.132
2C	2001	20	40.22	4.16	-7.709E-02	2.914E-02	-9.706E-04	126.05	0.156
2C	2002	25	45.47	3.41	1.561E-01	-5.870E-03	3.676E-04	132.33	0.262
2C	2003	25	45.47	3.41	1.561E-01	-5.870E-03	3.676E-04	132.33	0.262
3A	1996	20	33.43	4.59	-2.824E-02	2.569E-02	-8.363E-04	126.43	0.120
3A	1997	20	30.52	4.67	5.614E-02	2.811E-02	-1.292E-03	123.27	0.147
3A	1998	20	32.01	4.52	2.322E-01	4.372E-03	-5.310E-04	121.69	0.128
3A	1999	20	30.22	4.57	9.574E-03	3.220E-02	-1.298E-03	115.44	0.129
3A	2000	20	37.59	3.91	-1.800E-01	5.722E-02	-2.016E-03	111.91	0.186
3A	2001	20	38.17	3.82	-4.080E-01	9.688E-02	-3.555E-03	110.99	0.246
3A	2002	25	48.67	2.86	2.779E-01	-2.034E-03	-1.198E-05	119.31	0.275
3A	2003	25	48.67	2.86	2.779E-01	-2.034E-03	-1.198E-05	119.31	0.275

Table 1 continued.

Area	Year	+age	<i>b0</i>	<i>b1</i>	<i>c0</i>	<i>c1</i>	<i>c2</i>	<i>L50+</i>	<i>k+</i>
3B	1996	20	29.68	4.99	2.098E-01	-2.047E-02	1.113E-03	119.59	0.216
3B	1997	20	29.88	4.94	7.296E-02	1.521E-04	3.632E-04	121.31	0.166
3B	1998	20	31.25	4.77	1.711E-01	-1.549E-02	9.648E-04	128.19	0.200
3B	1999	20	29.66	4.80	1.483E-01	-1.251E-02	8.658E-04	121.74	0.169
3B	2000	20	26.54	4.98	1.401E-01	-6.237E-03	3.919E-04	115.00	0.275
3B	2001	20	26.54	4.92	-1.002E-01	2.837E-02	-7.863E-04	118.14	0.209
3B	2002	25	49.99	2.77	1.549E-01	-1.445E-03	1.555E-04	127.48	0.275
3B	2003	25	49.99	2.77	1.549E-01	-1.445E-03	1.555E-04	127.48	0.275
4A	1996	20	32.91	4.74	-1.678E-01	4.133E-02	-1.187E-03	138.70	0.114
4A	1997	20	32.91	4.74	-1.678E-01	4.133E-02	-1.187E-03	138.70	0.114
4A	1998	20	30.20	4.90	-2.230E-01	4.747E-02	-1.327E-03	141.12	0.083
4A	1999	20	29.82	4.89	8.436E-02	-7.746E-03	8.965E-04	130.66	0.097
4A	2000	20	34.05	4.61	-3.368E-02	1.401E-02	-6.380E-05	125.96	0.120
4A	2001	20	37.91	4.25	3.449E-02	4.495E-03	1.937E-04	123.18	0.124
4A	2002	25	48.98	3.08	-7.287E-02	2.598E-02	-5.672E-04	132.05	0.106
4A	2003	25	48.98	3.08	-7.287E-02	2.598E-02	-5.672E-04	132.05	0.106
4B	1996	20	52.99	3.78	-4.509E-01	9.347E-02	-3.239E-03	134.49	0.146
4B	1997	20	52.99	3.78	-4.509E-01	9.347E-02	-3.239E-03	134.49	0.146
4B	1998	20	48.08	4.11	-4.615E-01	9.209E-02	-3.081E-03	132.72	0.119
4B	1999	20	44.53	4.35	-3.638E-01	7.786E-02	-2.563E-03	131.51	0.115
4B	2000	20	41.73	4.60	-3.764E-01	7.880E-02	-2.742E-03	132.32	0.128
4B	2001	20	42.14	4.56	-1.996E-01	4.968E-02	-1.519E-03	134.23	0.135
4B	2002	25	59.68	2.97	-1.210E-01	4.361E-02	-1.318E-03	134.96	0.275
4B	2003	25	59.68	2.97	-1.210E-01	4.361E-02	-1.318E-03	134.96	0.275
4CDE	1996	20	32.85	4.46	-2.391E-01	5.194E-02	-1.465E-03	120.34	0.100
4CDE	1997	20	32.85	4.46	-2.391E-01	5.194E-02	-1.465E-03	120.34	0.100
4CDE	1998	20	32.85	4.46	-2.391E-01	5.194E-02	-1.465E-03	120.34	0.100
4CDE	1999	20	31.59	4.35	-3.093E-01	6.580E-02	-2.036E-03	115.02	0.202
4CDE	2000	20	31.85	4.34	-4.865E-01	9.480E-02	-3.294E-03	117.45	0.141
4CDE	2001	20	31.85	4.34	-4.865E-01	9.480E-02	-3.294E-03	117.45	0.141
4CDE	2002	25	40.91	3.27	-1.054E-01	3.371E-02	-9.002E-04	125.42	0.125
4CDE	2003	25	40.91	3.27	-1.054E-01	3.371E-02	-9.002E-04	125.42	0.125

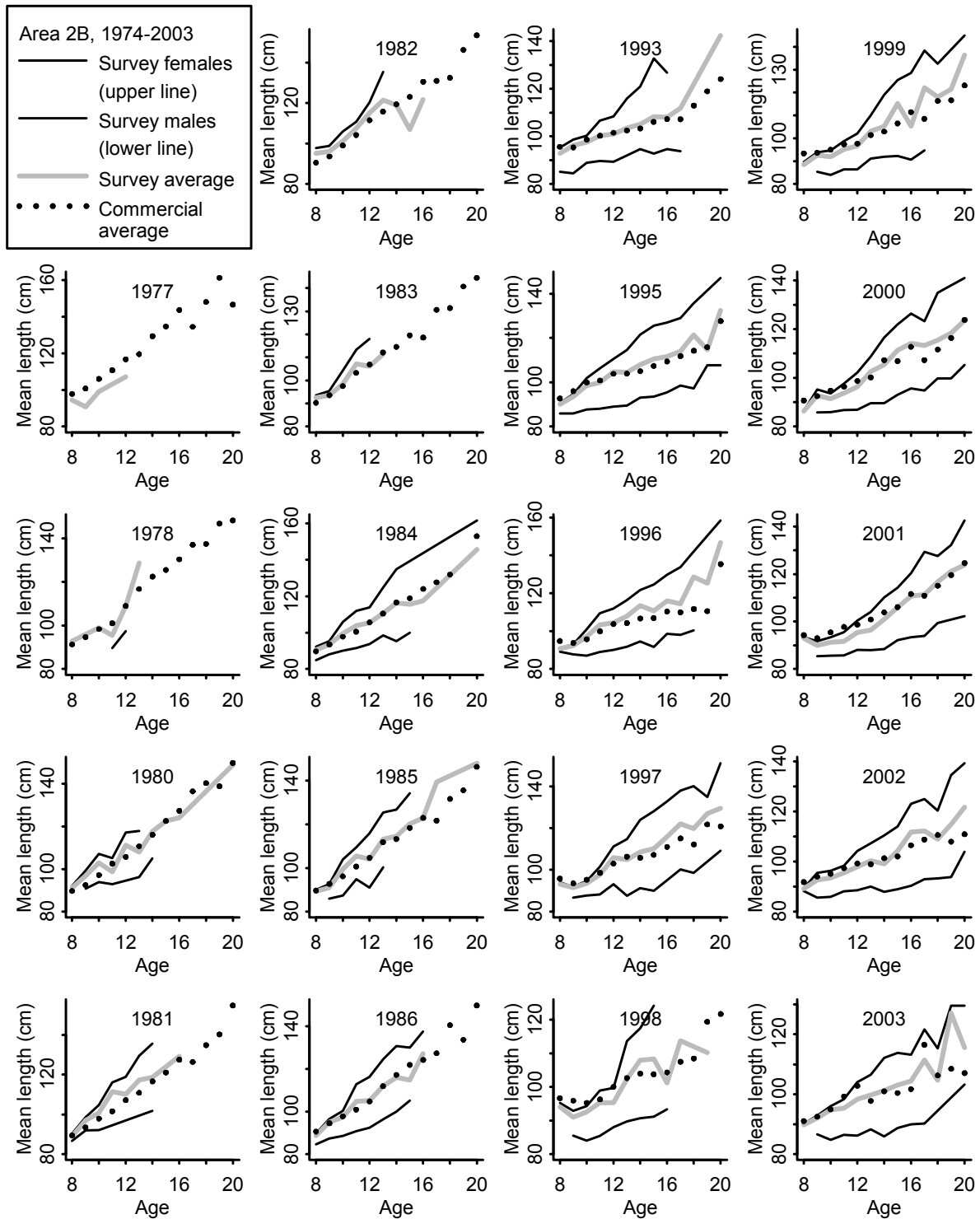


Figure 1a. Mean length at age of legal-sized fish in commercial landings and survey catches in Area 2B.

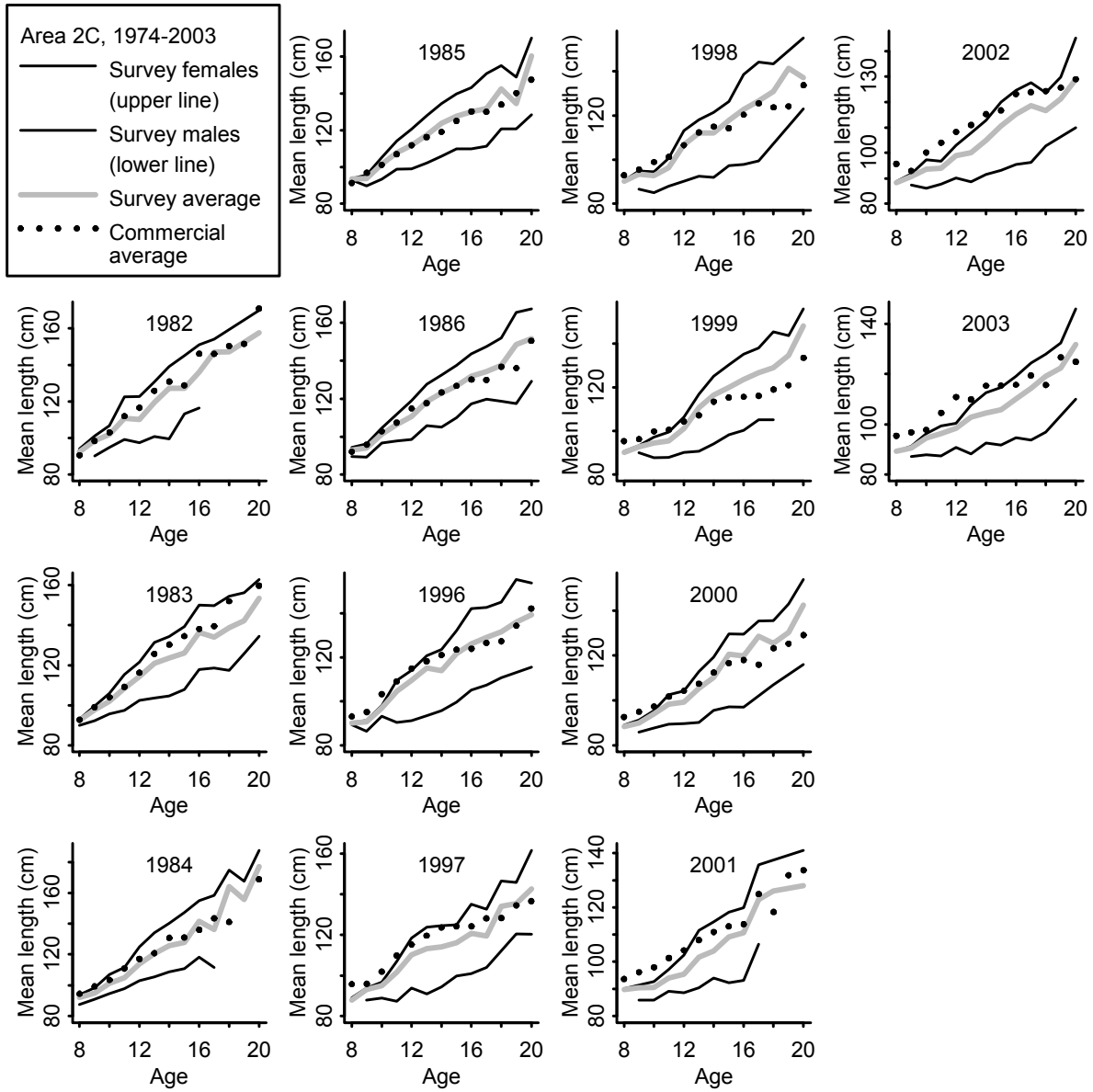


Figure 1b. Mean length at age of legal-sized fish in commercial landings and survey catches in Area 2C.

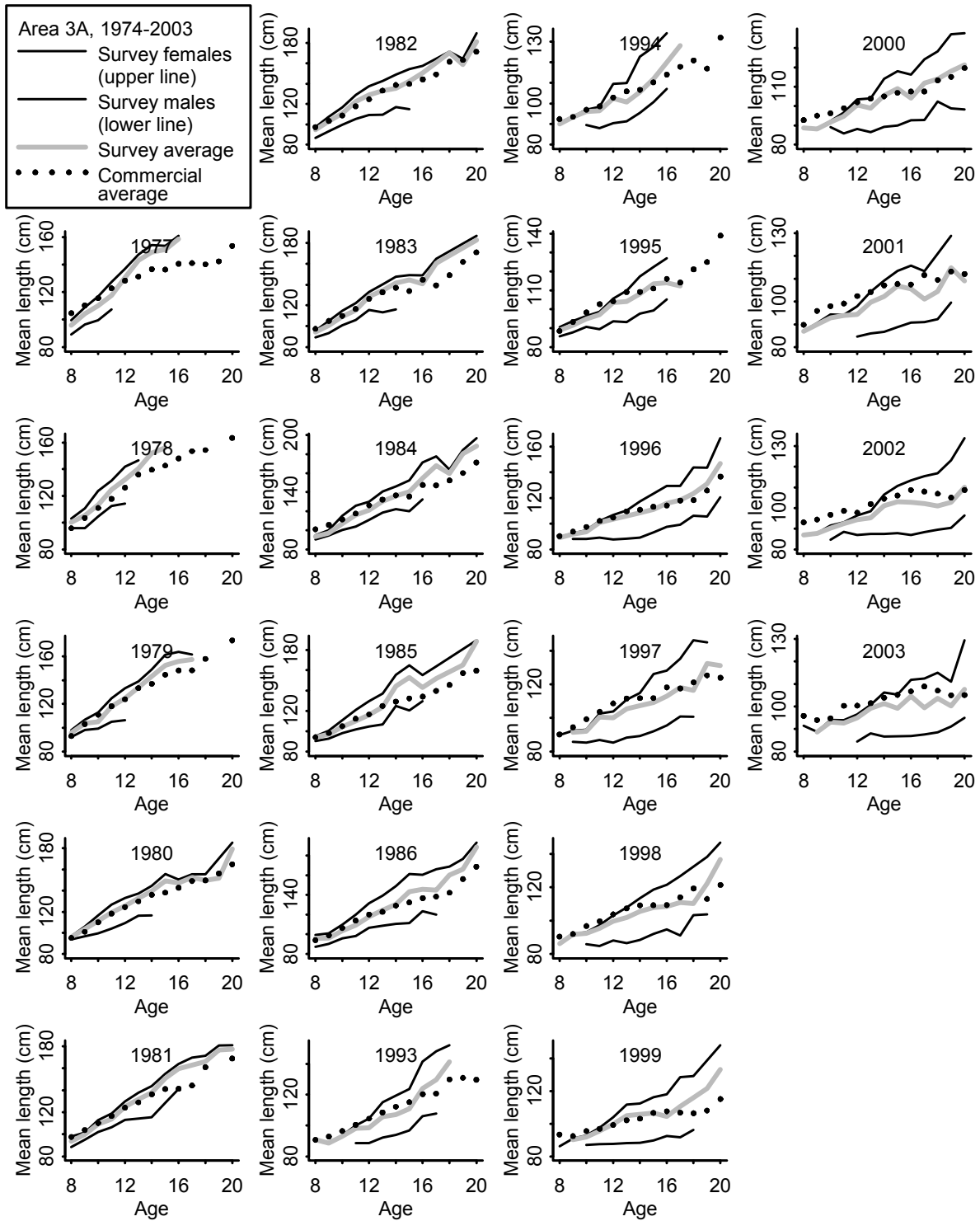


Figure 1c. Mean length at age of legal-sized fish in commercial landings and survey catches in Area 3A.

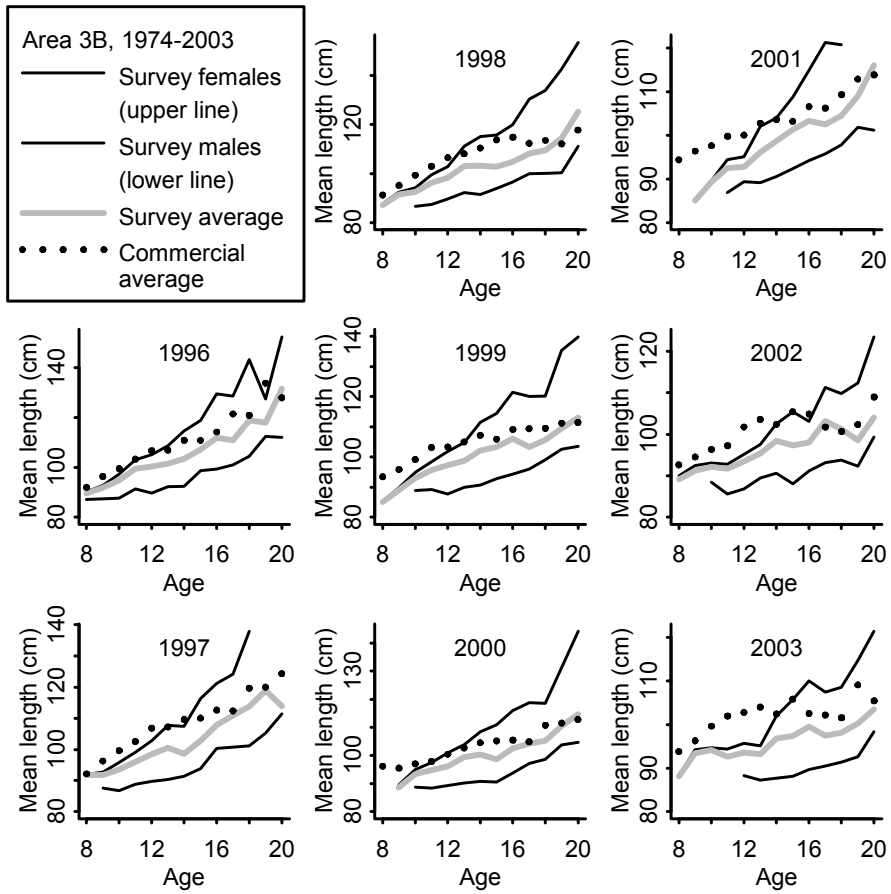


Figure 1d. Mean length at age of legal-sized fish in commercial landings and survey catches in Area 3B.

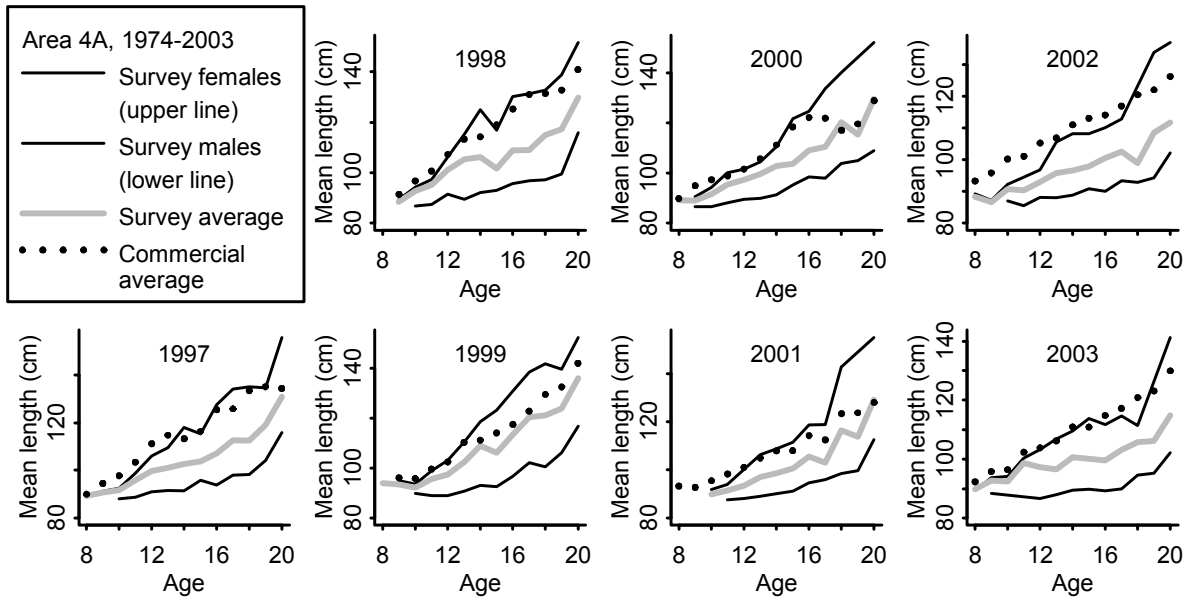


Figure 1e. Mean length at age of legal-sized fish in commercial landings and survey catches in Area 4A.

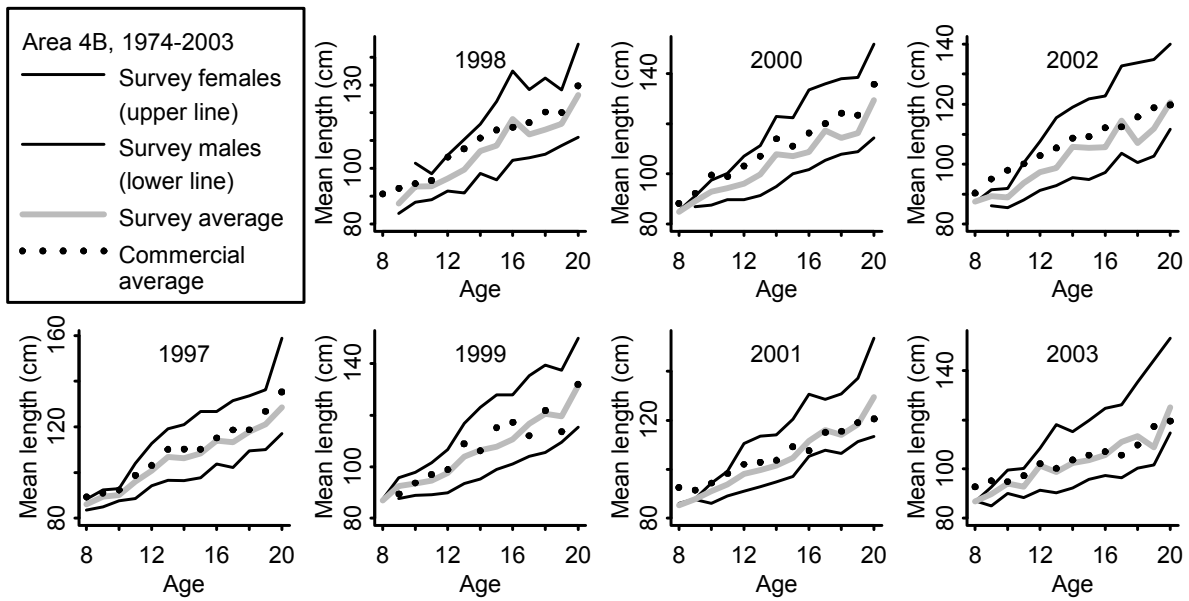


Figure 1f. Mean length at age of legal-sized fish in commercial landings and survey catches in Area 4B.

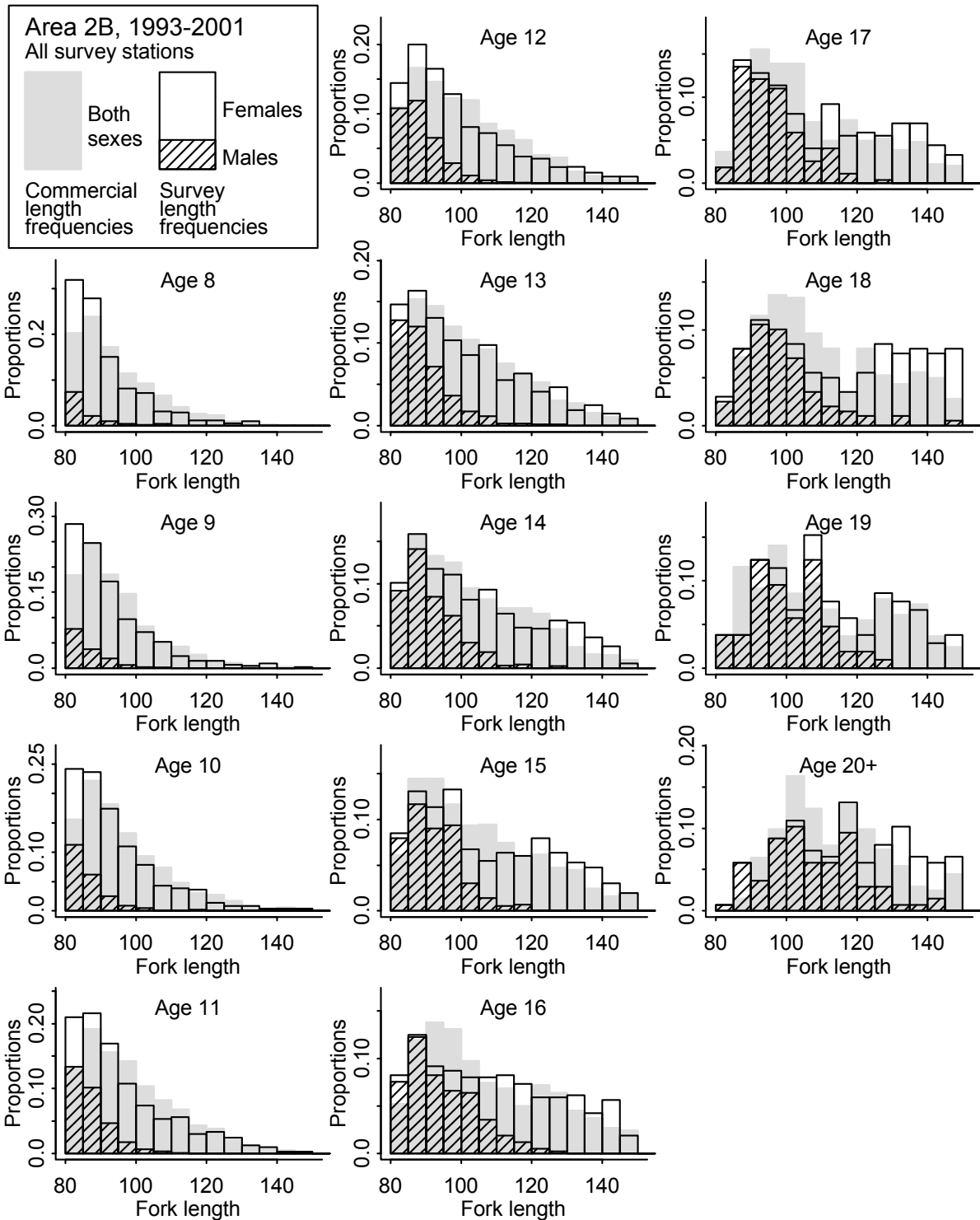


Figure 2a. Survey and commercial length frequencies at age in Area 2B, 1993-2001 data pooled. Survey and commercial mean length at age agreed well in all these years.

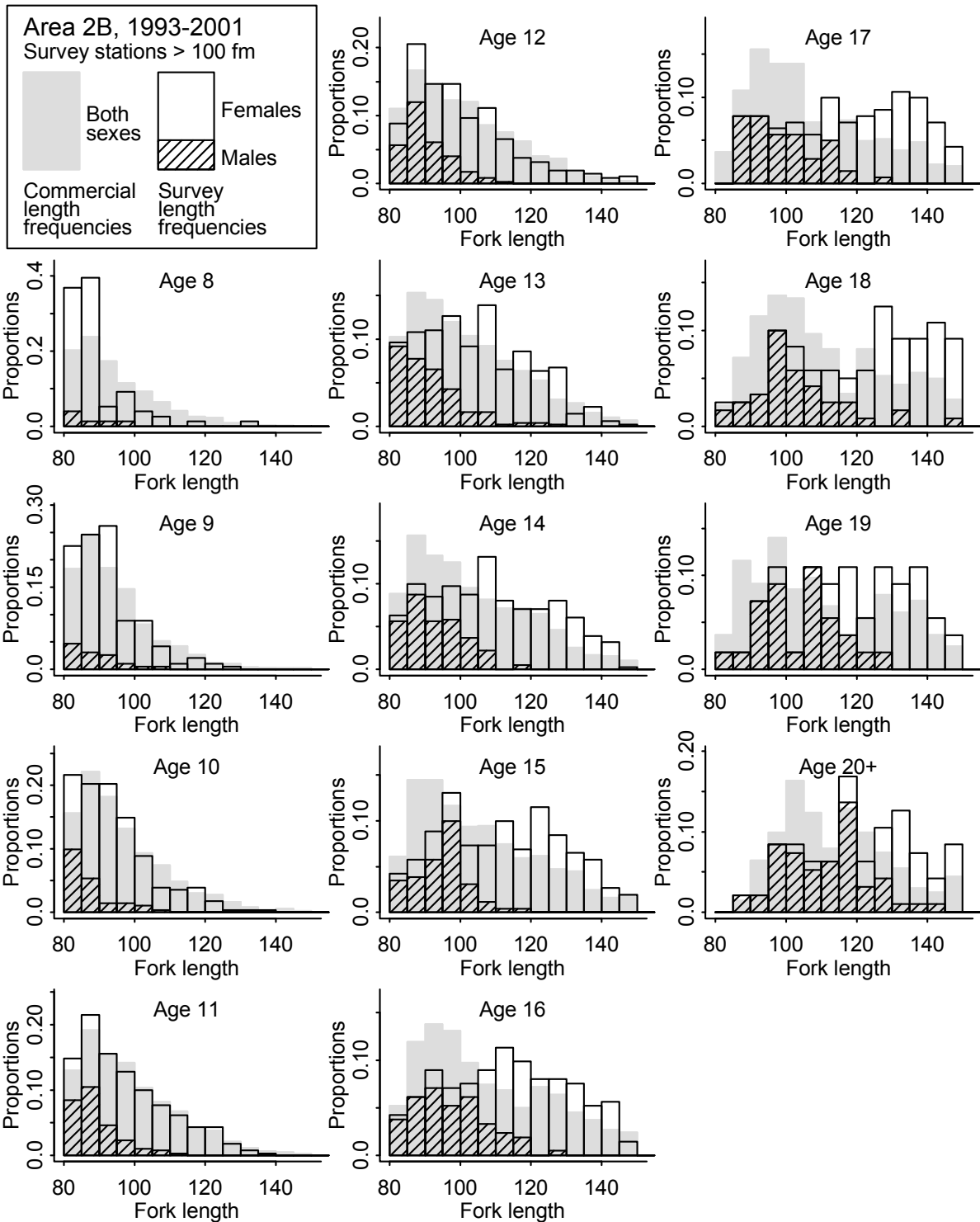


Figure 2b. Survey and commercial length frequencies at age in Area 2B, 1993-2001 data pooled but only from survey stations deeper than 100 fm. Commercial frequencies reflect all commercial data.

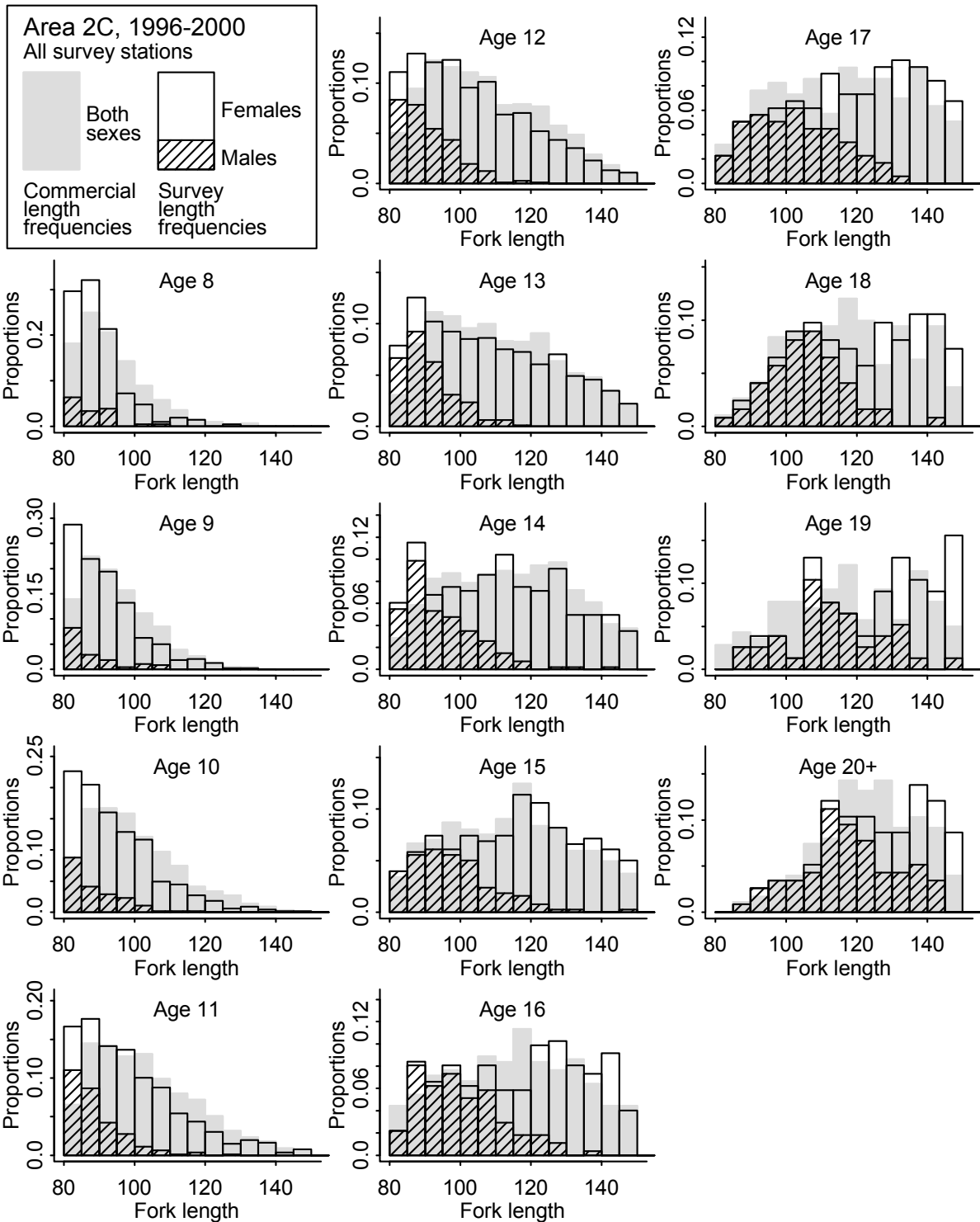


Figure 2c. Survey and commercial length frequencies at age in Area 2C, 1996-2000 data pooled. Survey and commercial mean length at age agreed well during these years.

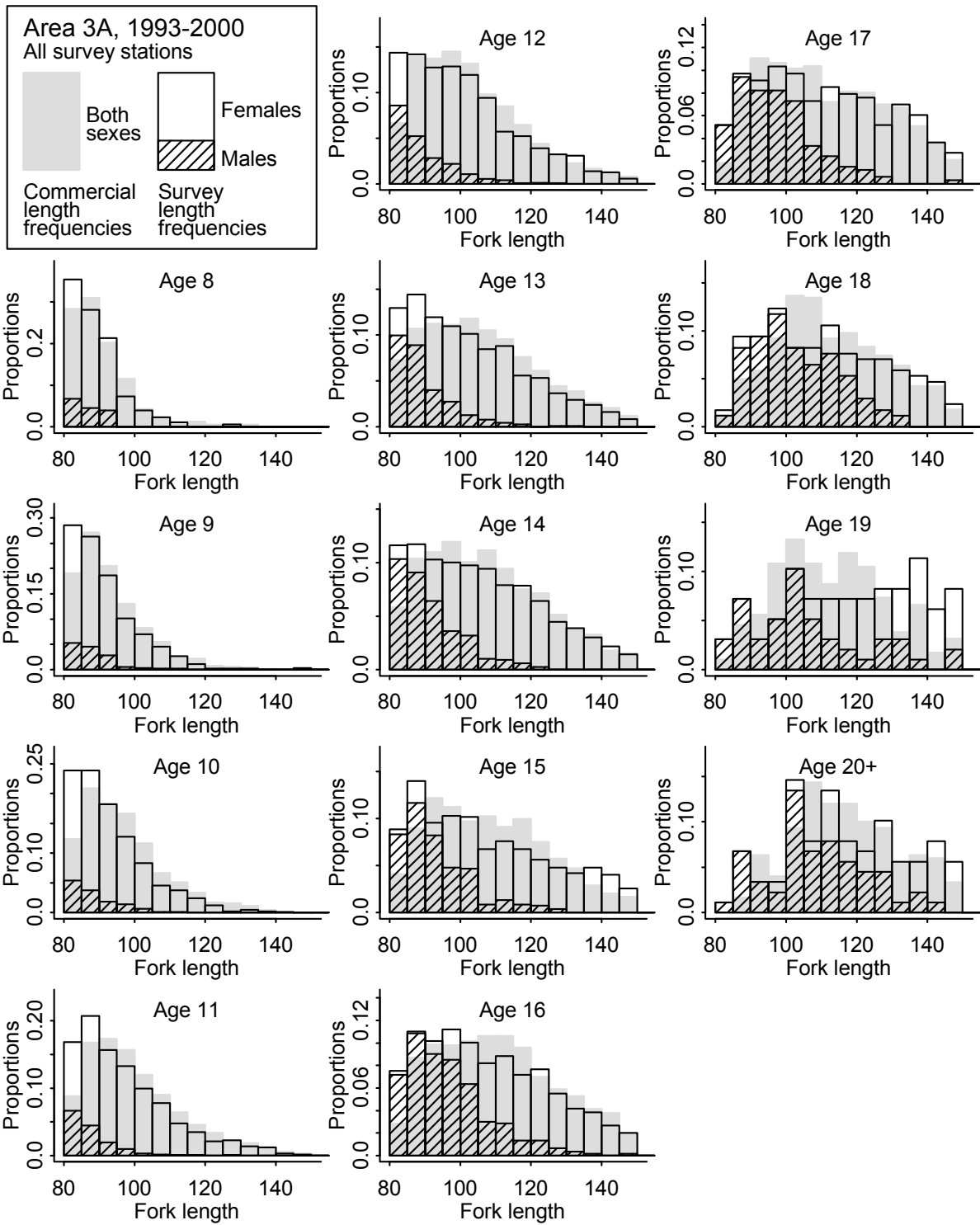


Figure 2d. Survey and commercial length frequencies at age in Area 3A, 1993-2000 data pooled. Survey and commercial mean length at age agreed well during these years.

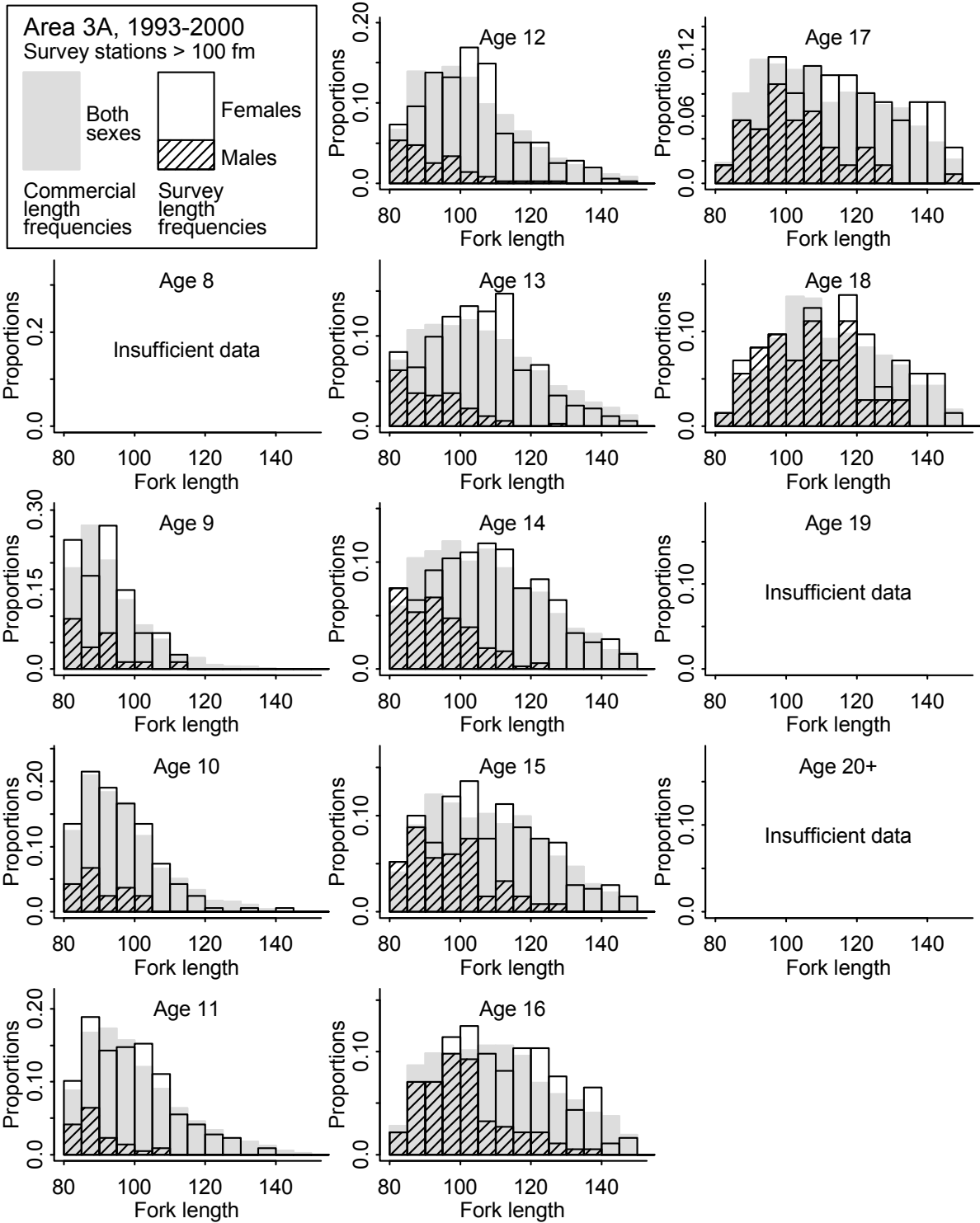


Figure 2e. Survey and commercial length frequencies at age in Area 3A, 1993-2000 data pooled but only from survey stations deeper than 100 fm. Commercial frequencies reflect all commercial data.

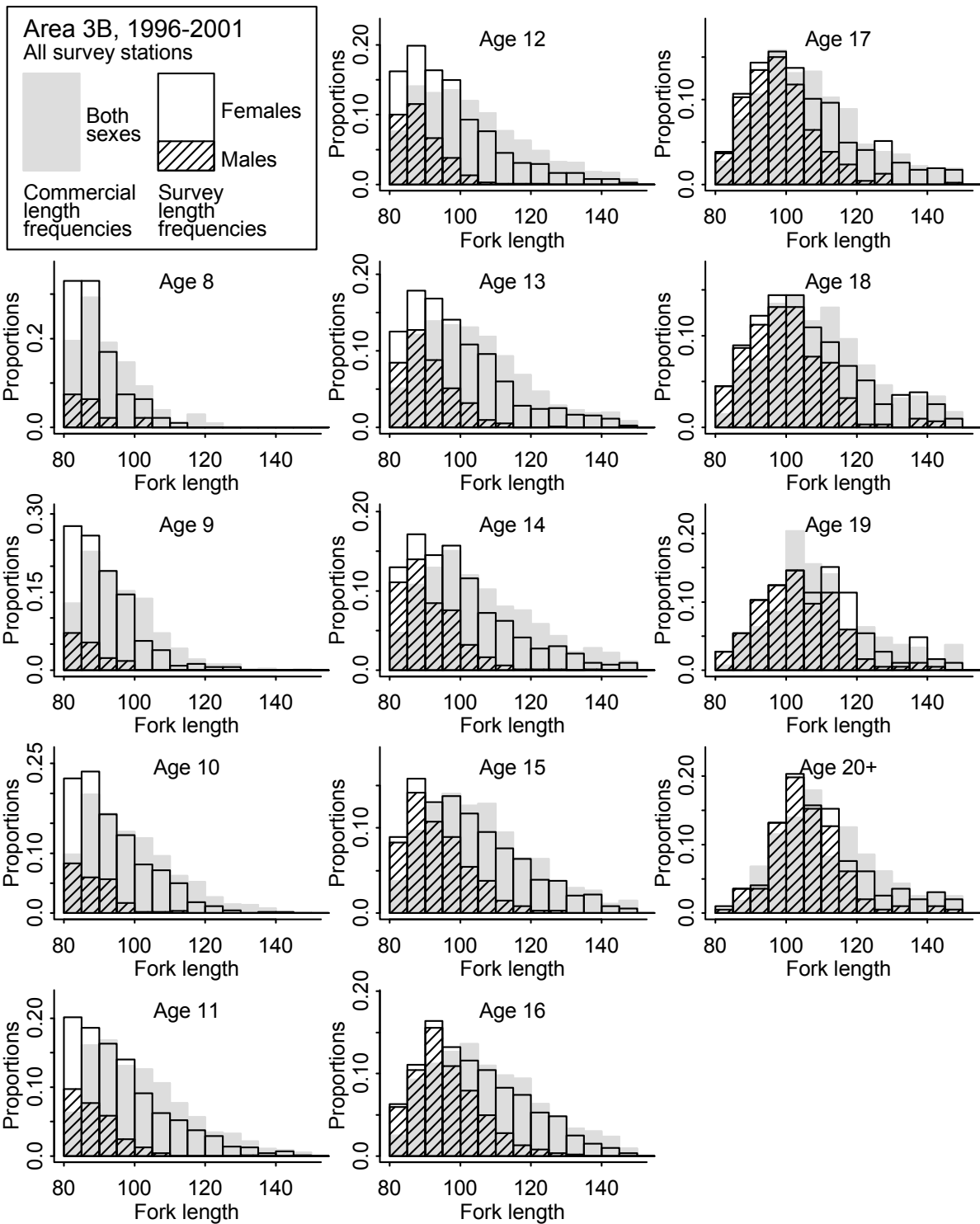


Figure 2f. Survey and commercial length frequencies at age in Area 3B, 1996-2001 data pooled. Commercial mean lengths at age exceeded survey means in these years.

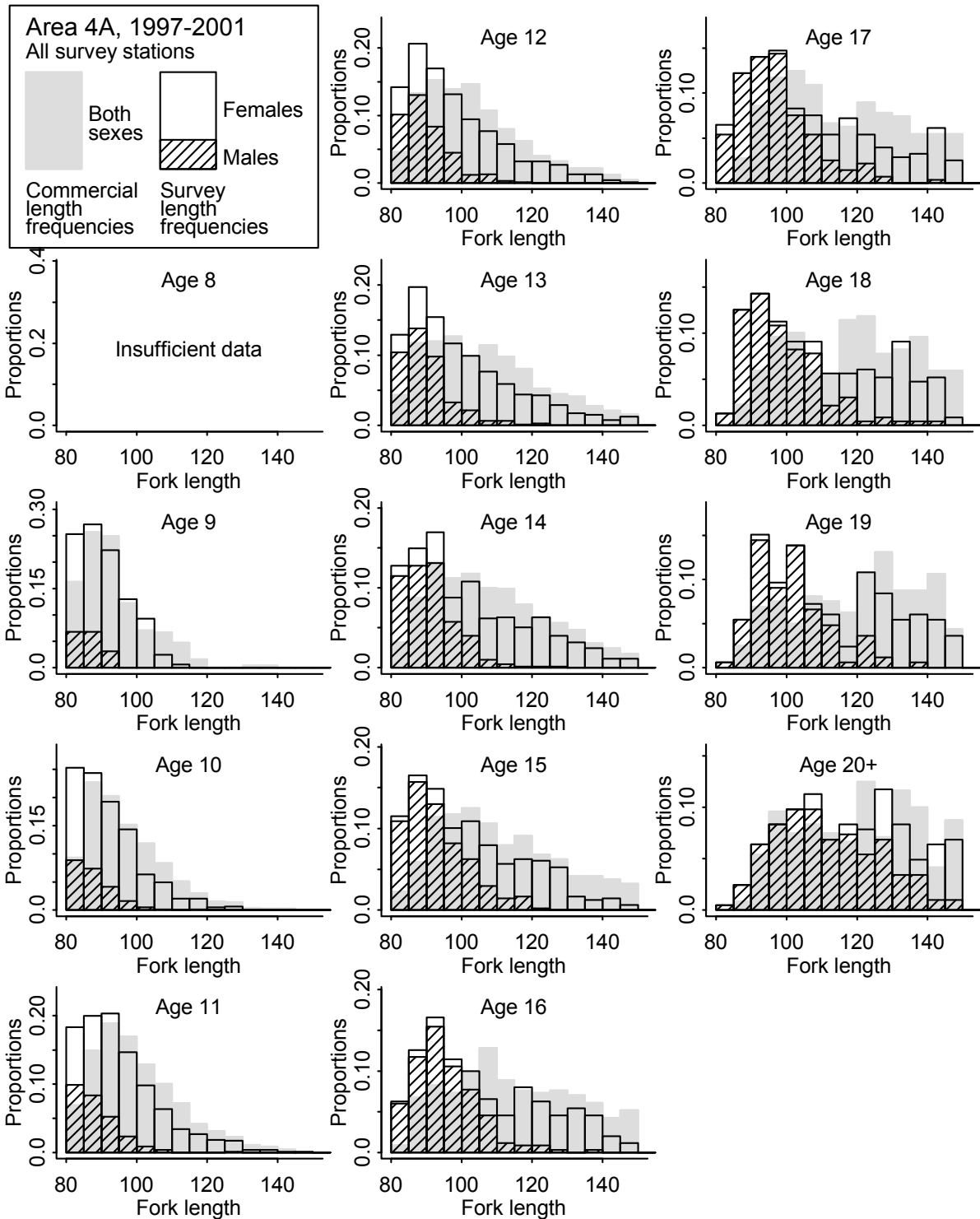


Figure 2g. Survey and commercial length frequencies at age in Area 4A, 1997-2001 data pooled. Commercial mean lengths at age exceeded survey means in these years.

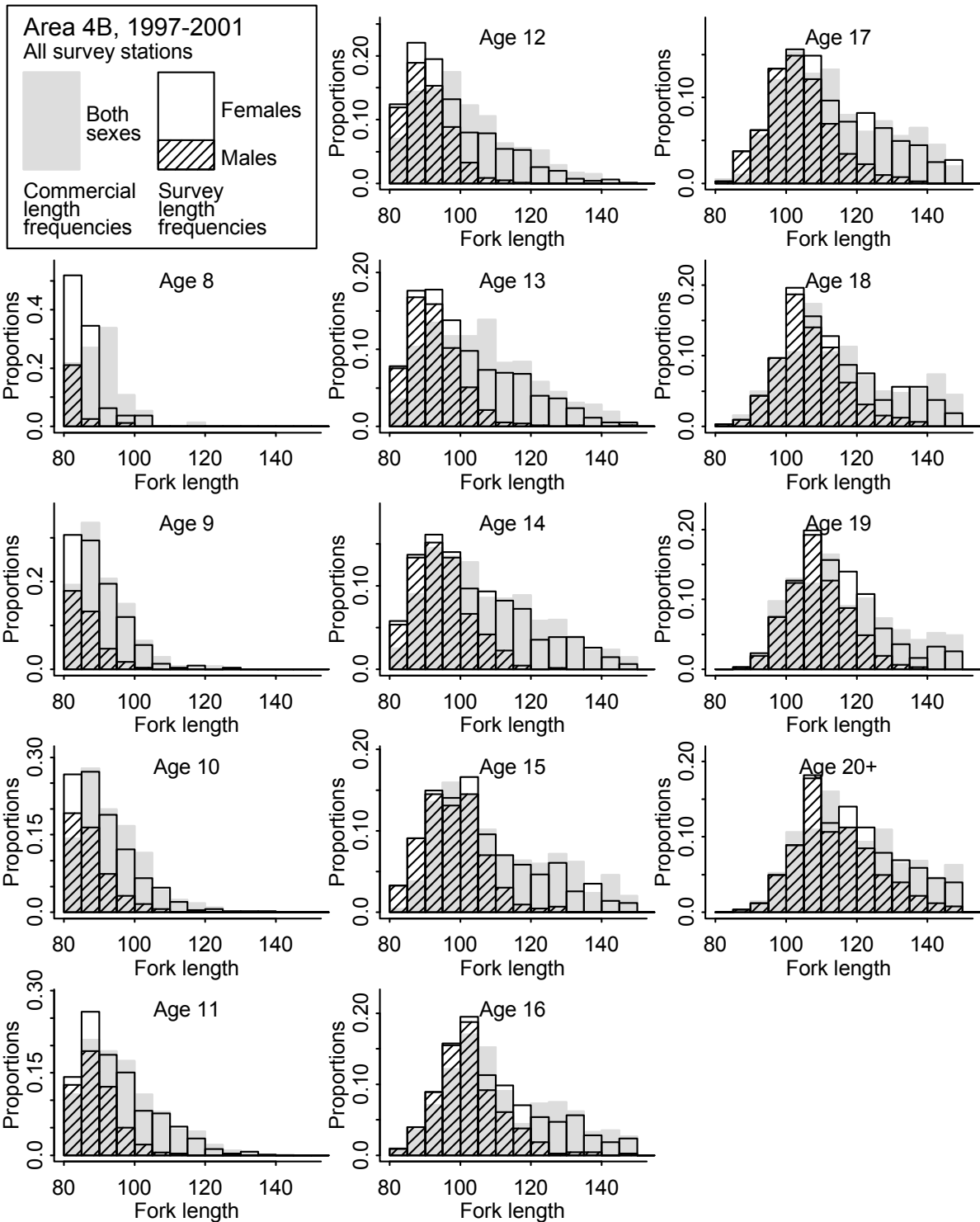


Figure 2h. Survey and commercial length frequencies at age in Area 4B, 1997-2001 data pooled. Commercial mean lengths at age exceeded survey means in these years but not greatly.

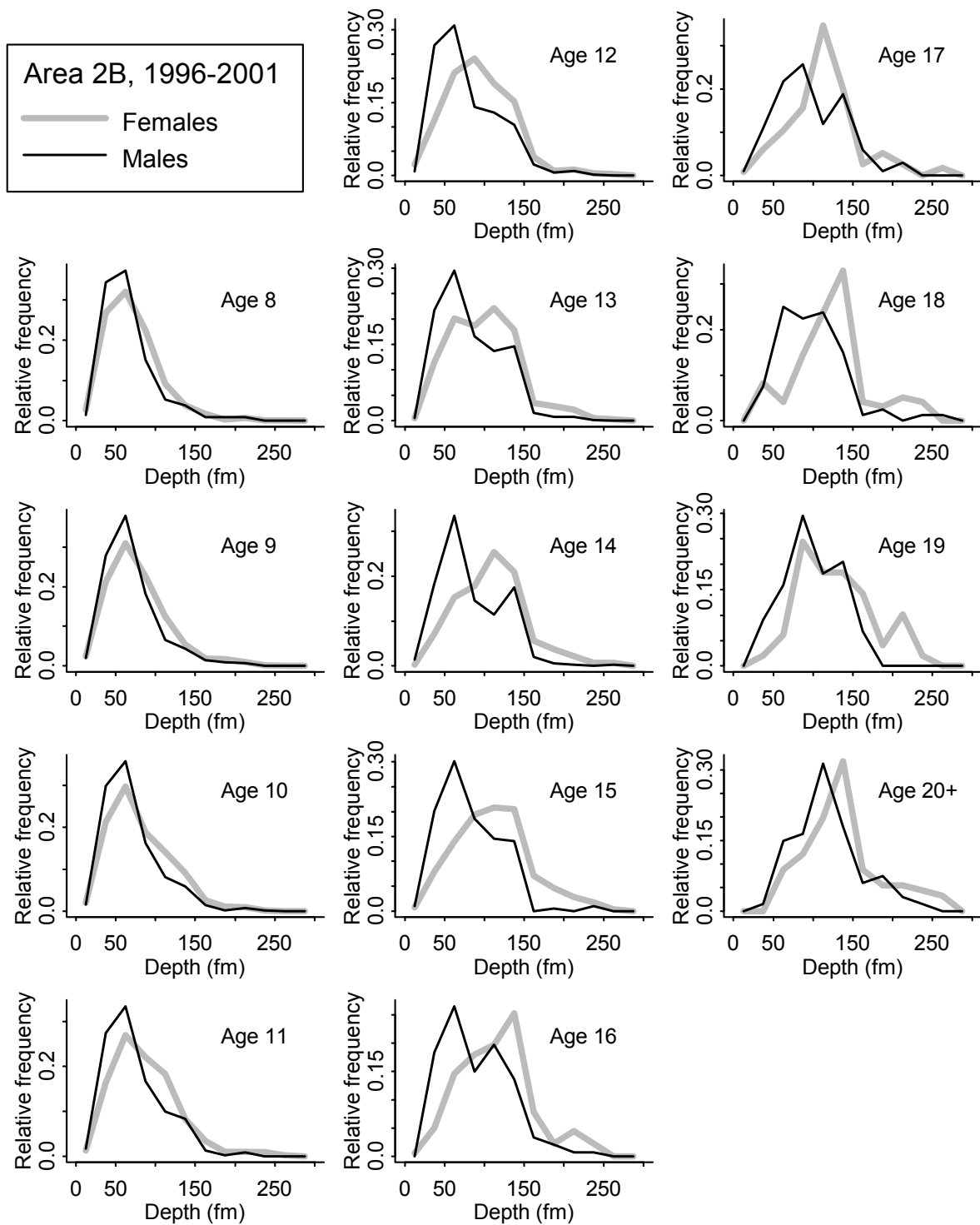


Figure 3a. Depth distributions of survey catches of females and males of the same age in Area 2B.

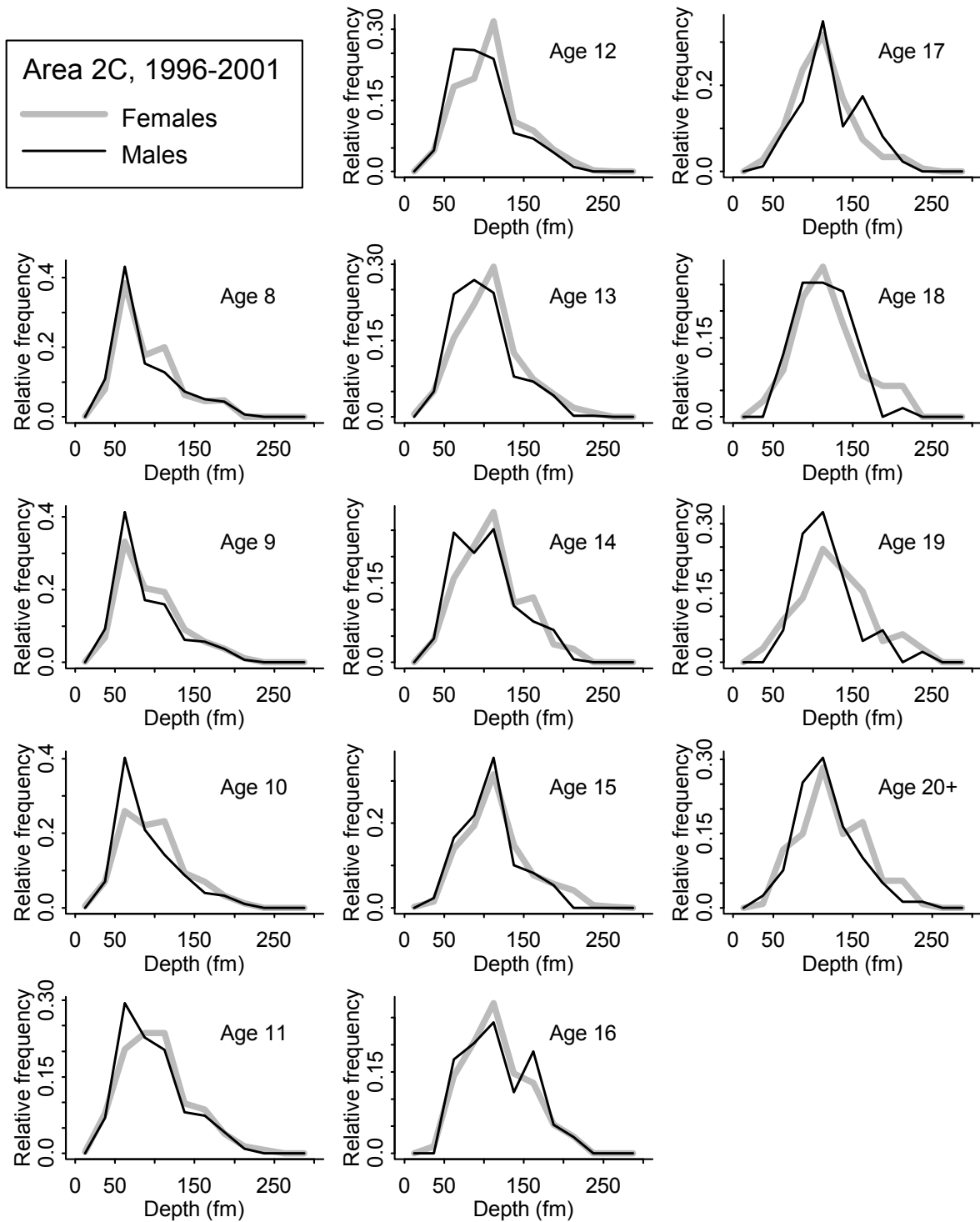


Figure 3b. Depth distributions of survey catches of females and males of the same age in Area 2C.

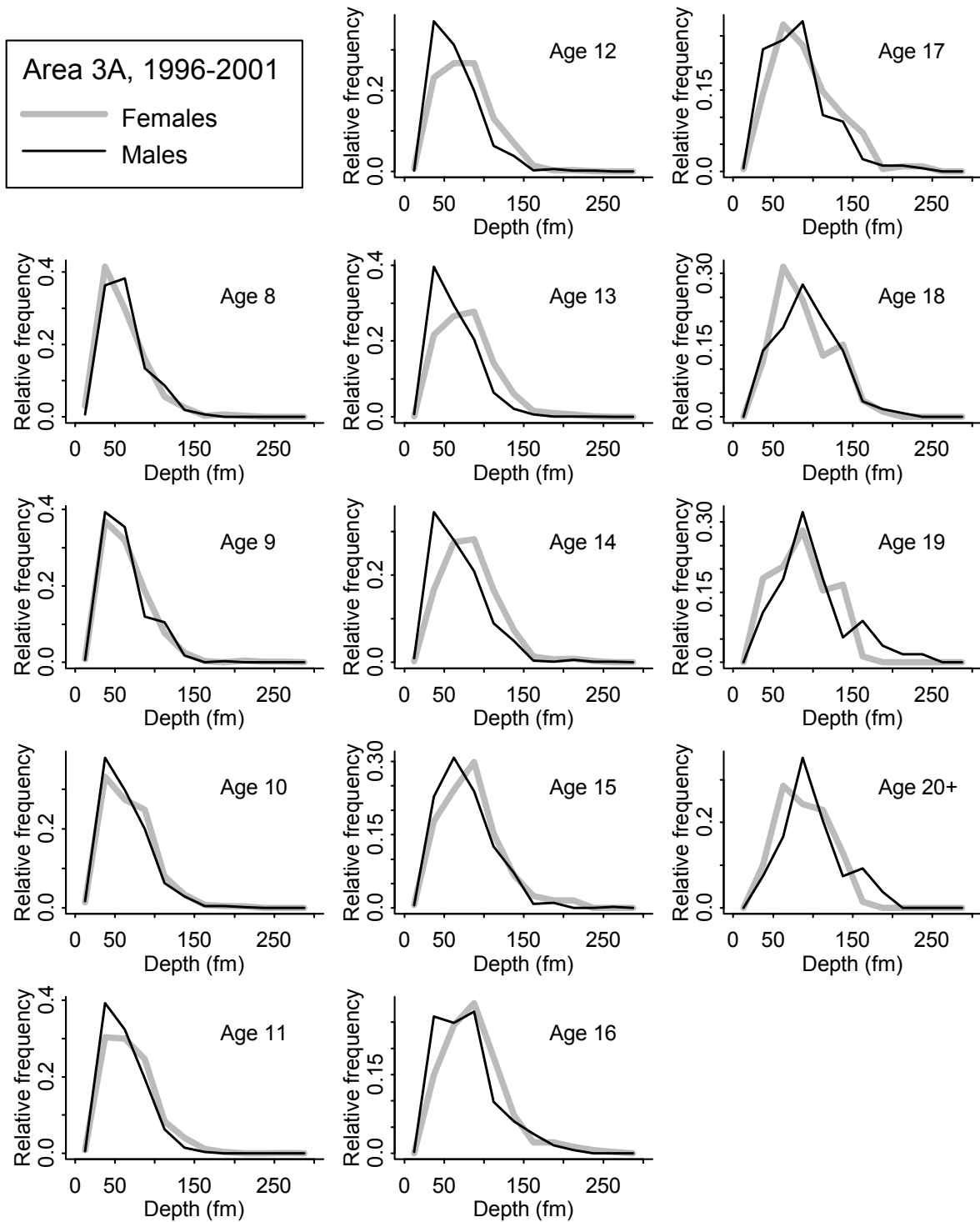


Figure 3c. Depth distributions of survey catches of females and males of the same age in Area 3A.

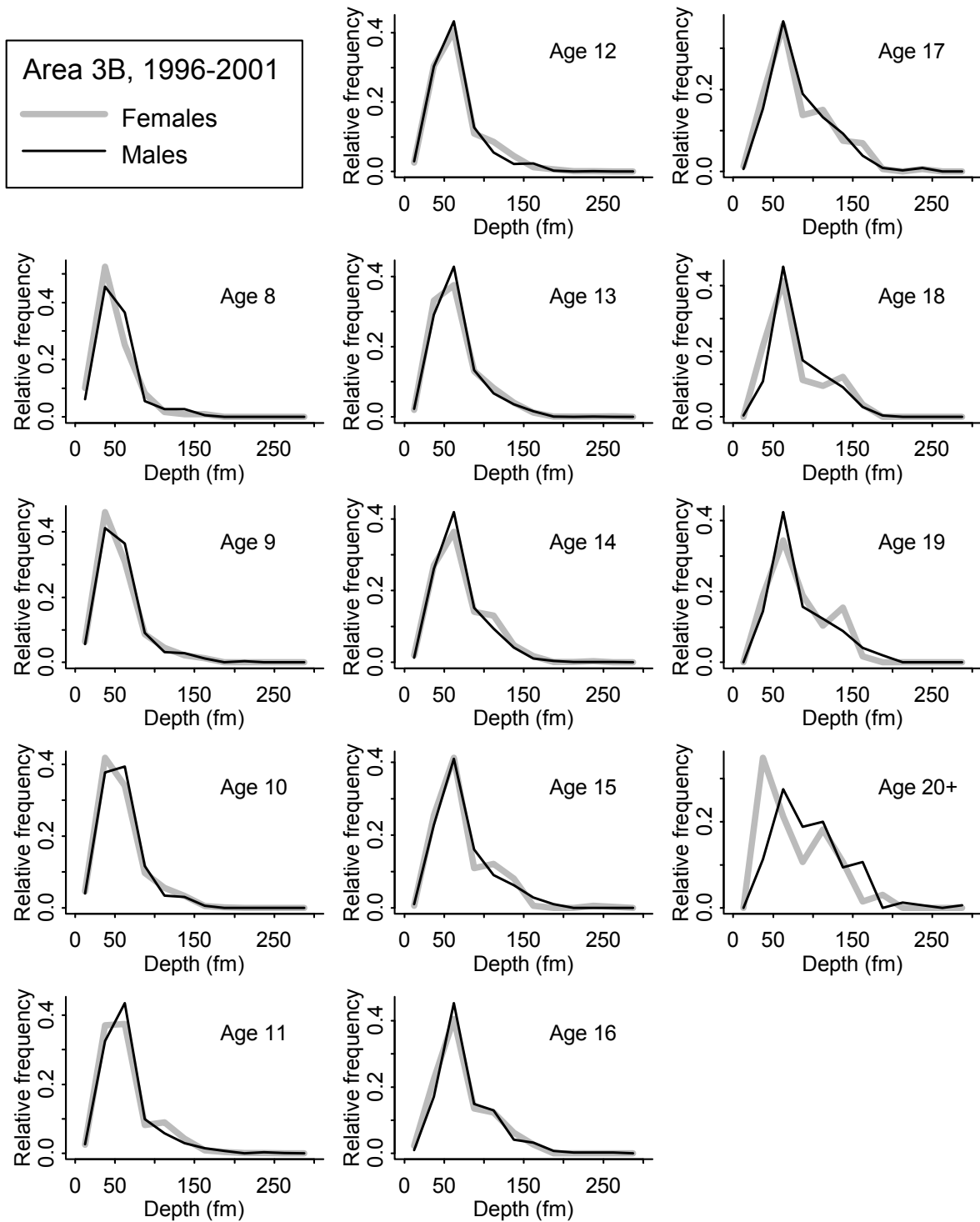


Figure 3d. Depth distributions of survey catches of females and males of the same age in Area 3B.

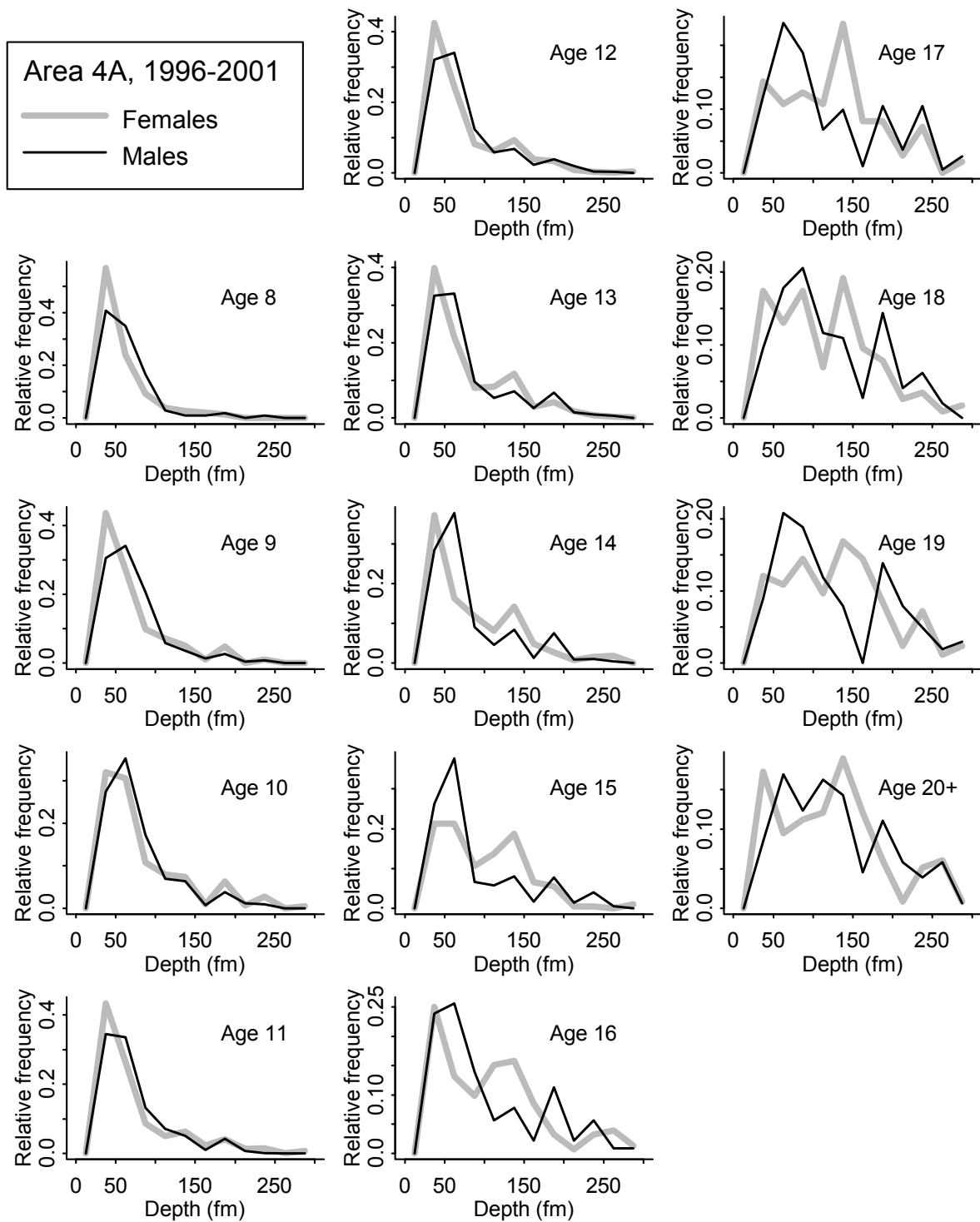


Figure 3e. Depth distributions of survey catches of females and males of the same age in Area 4A.

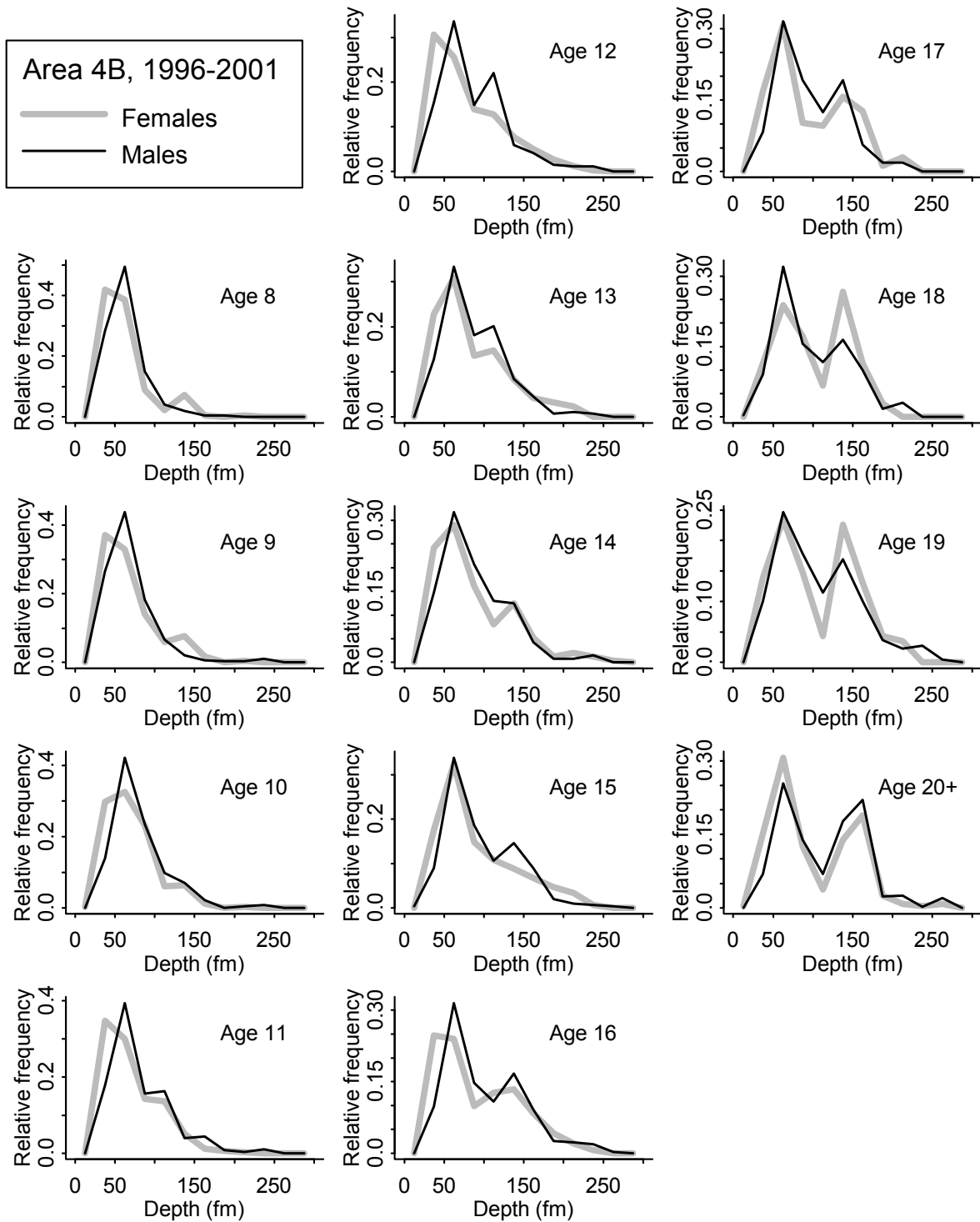


Figure 3f. Depth distributions of survey catches of females and males of the same age in Area 4B.

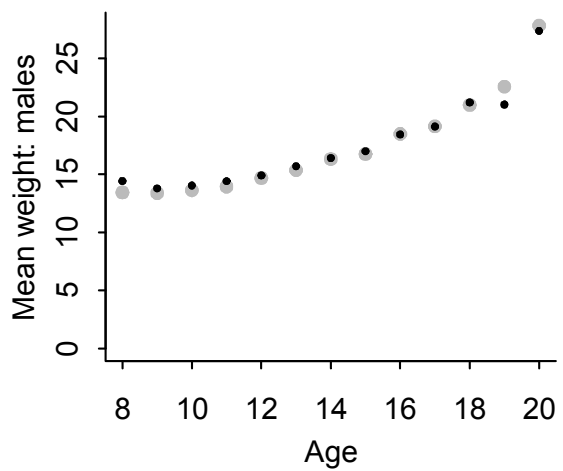
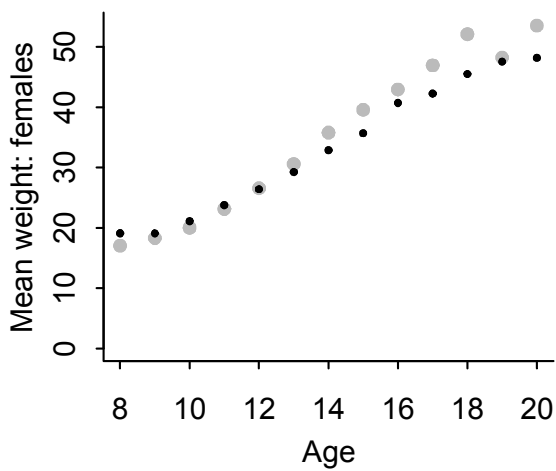
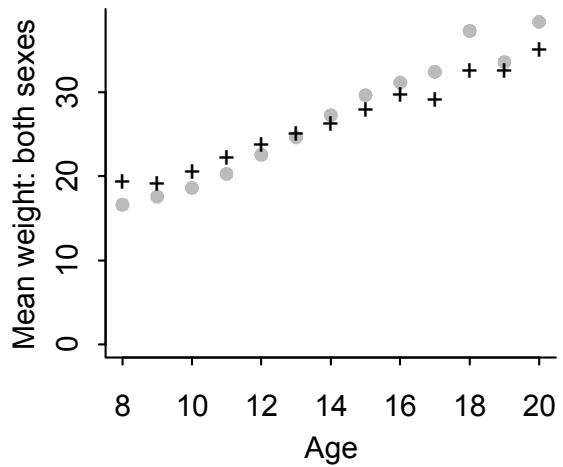
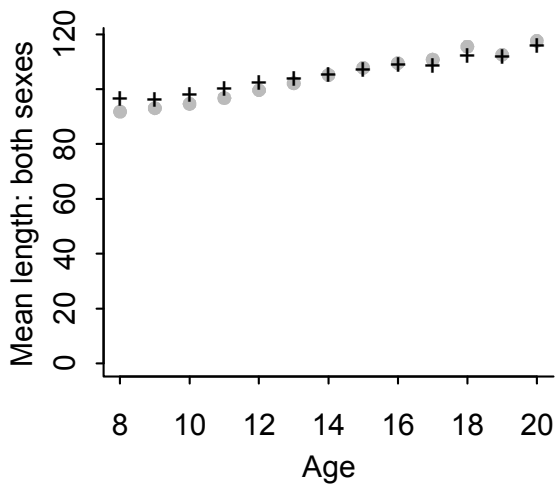
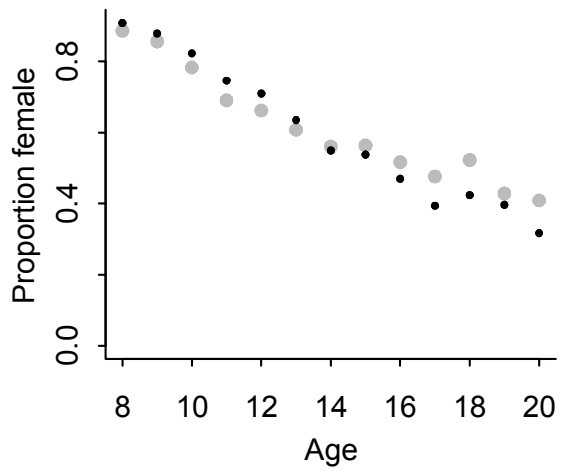
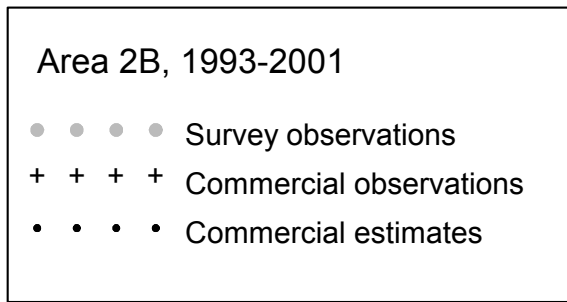


Figure 4a. Estimates of proportion female and mean size by sex in commercial landings in Area 2B, 1993-2001 combined, computed for each age by applying the sex ratio at length in survey catches to the length frequencies of commercial landings.

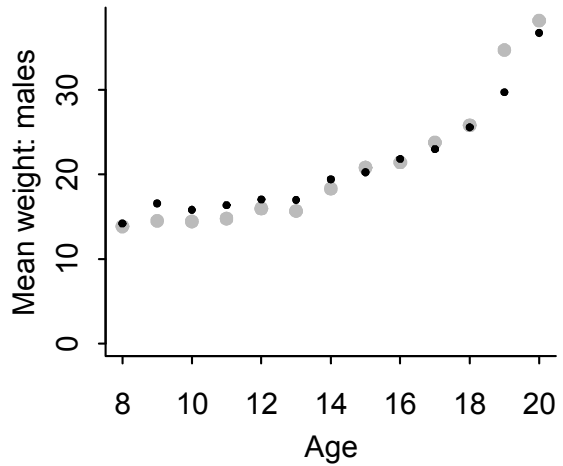
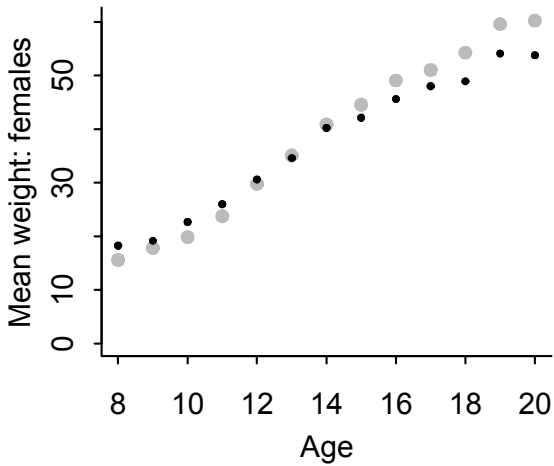
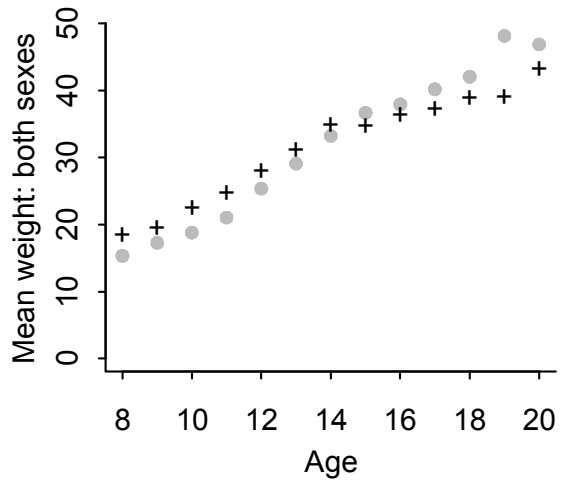
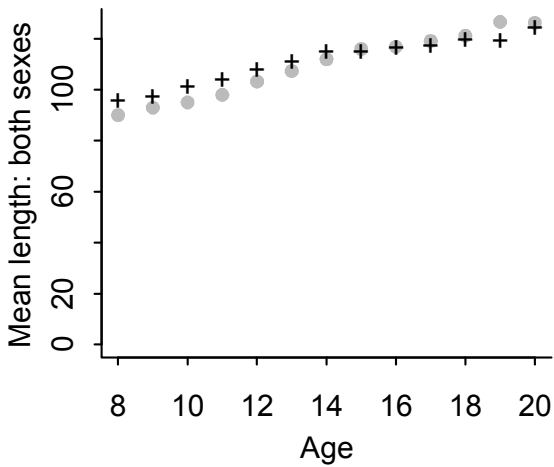
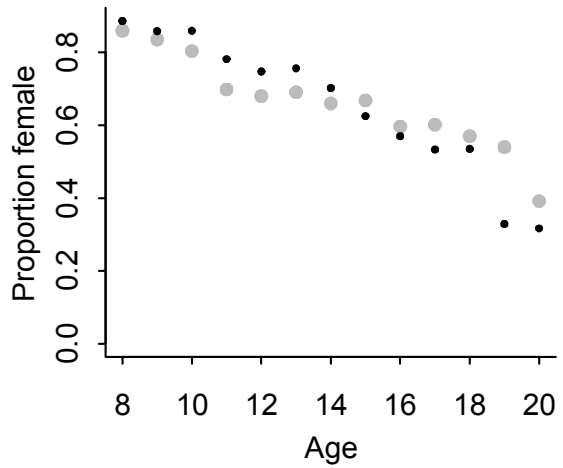
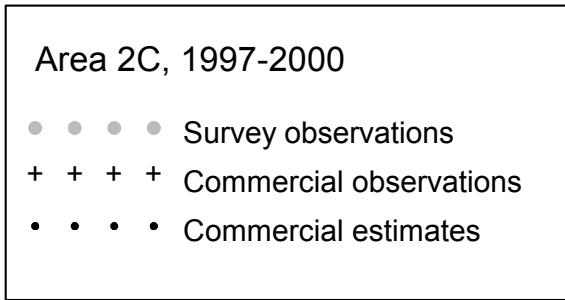


Figure 4b. Estimates of proportion female and mean size by sex in commercial landings in Area 2C, 1996-2000 combined, computed for each age by applying the sex ratio at length in survey catches to the length frequencies of commercial landings.

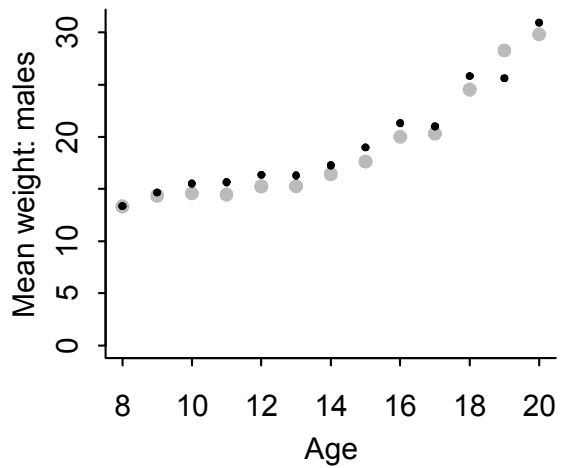
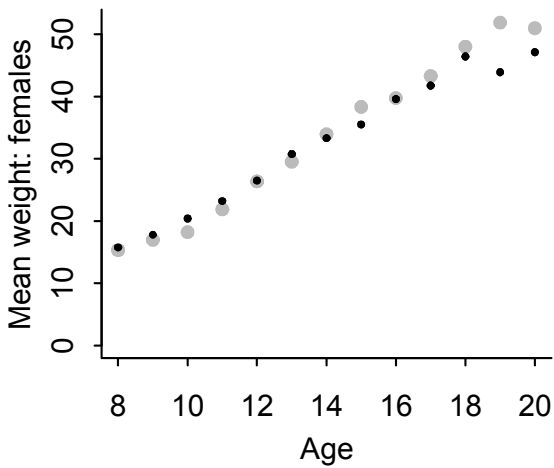
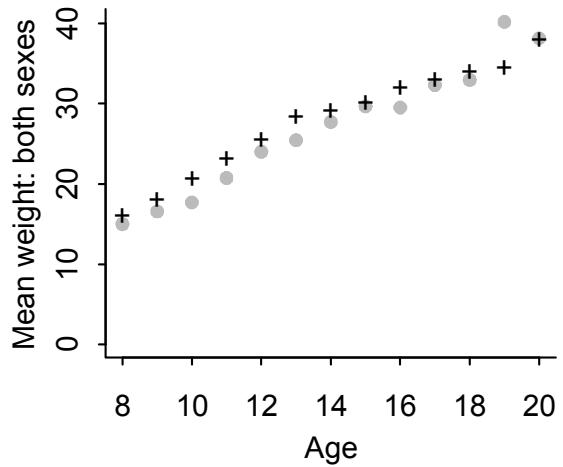
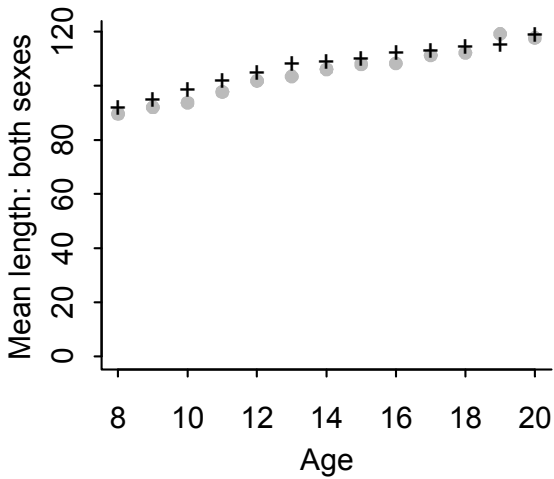
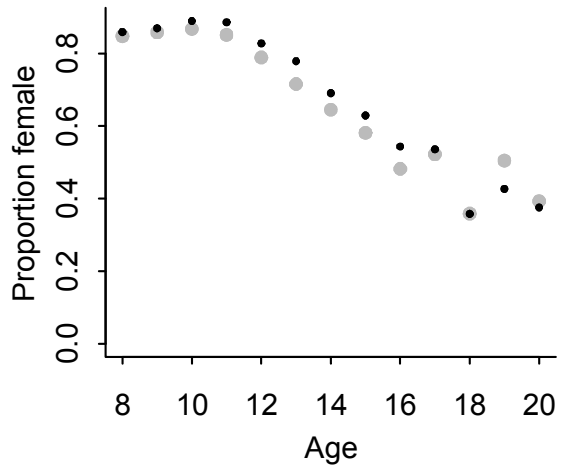
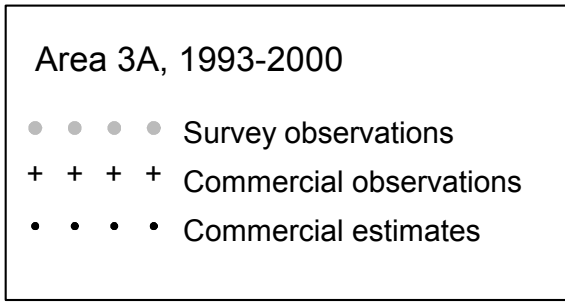


Figure 4c. Estimates of proportion female and mean size by sex in commercial landings in Area 3A, 1993-2000 combined, computed for each age by applying the sex ratio at length in survey catches to the length frequencies of commercial landings.

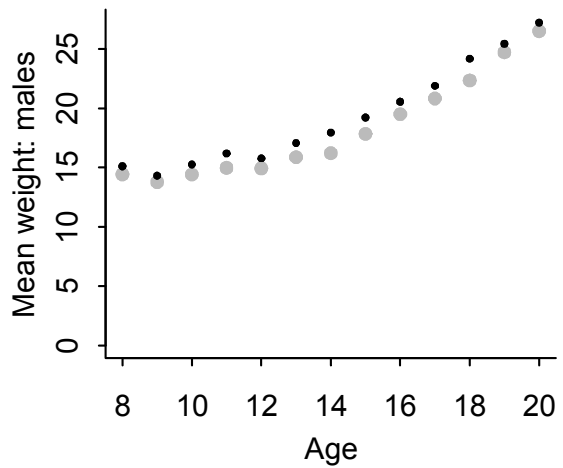
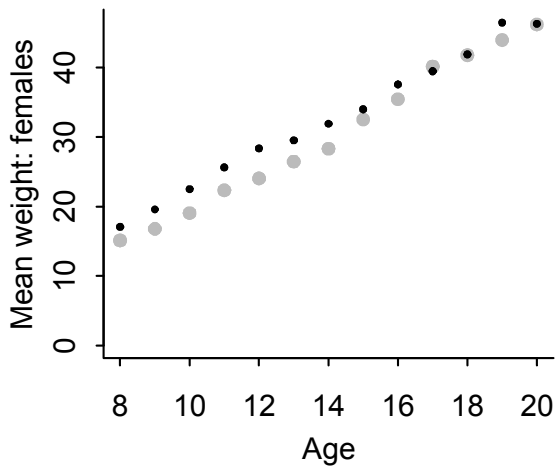
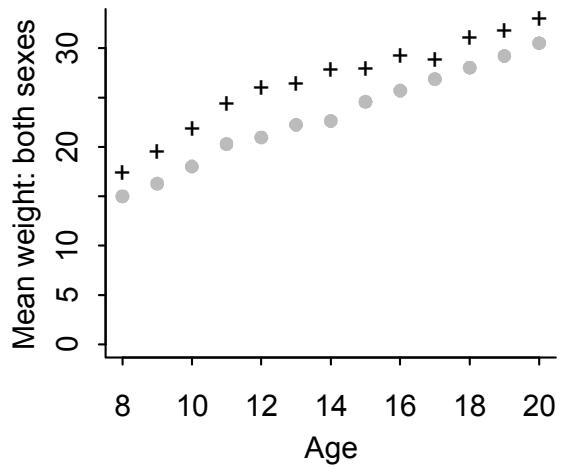
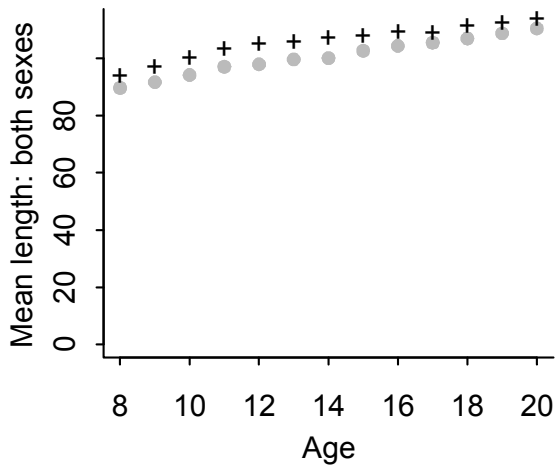
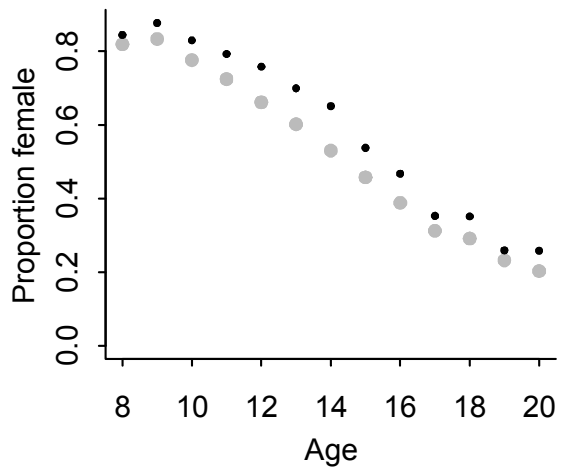
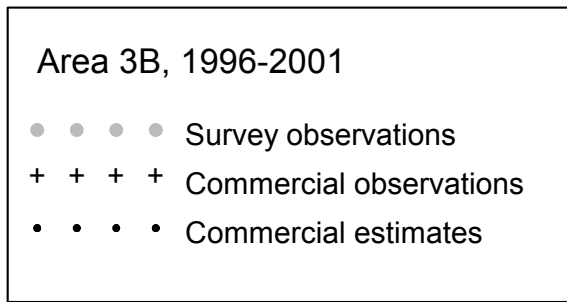


Figure 4d. Estimates of proportion female and mean size by sex in commercial landings in Area 3B, 1996-2001 combined, computed for each age by applying the sex ratio at length in survey catches to the length frequencies of commercial landings.

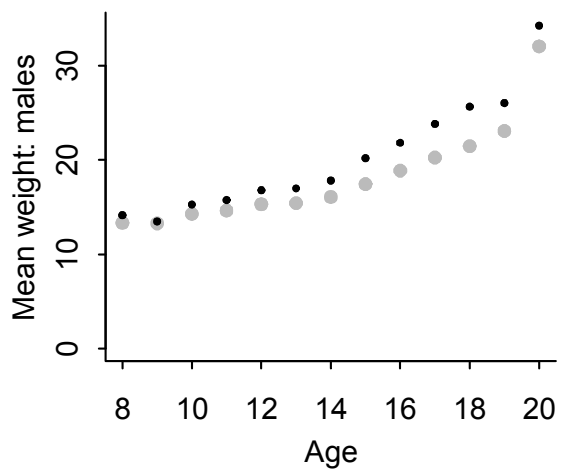
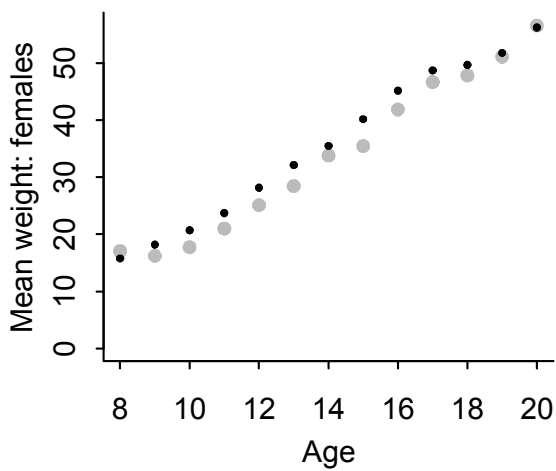
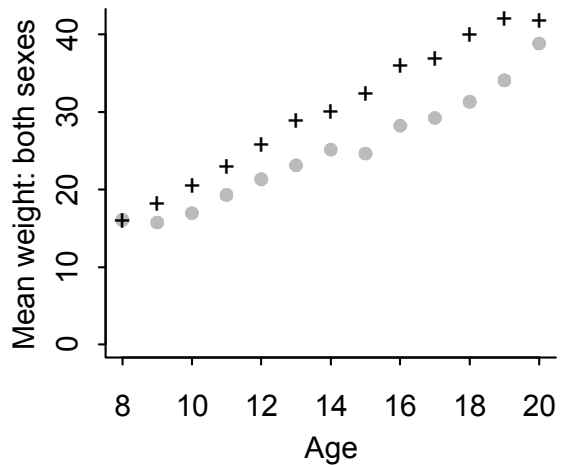
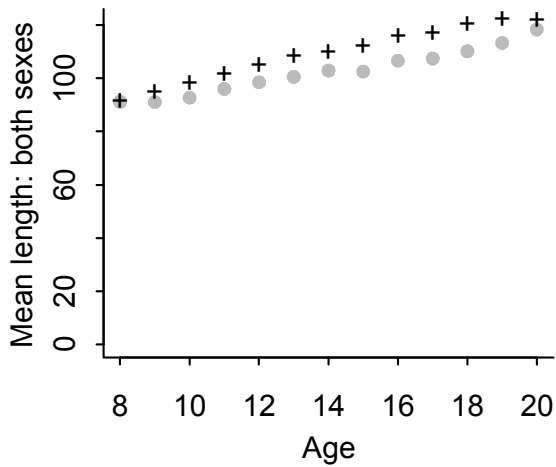
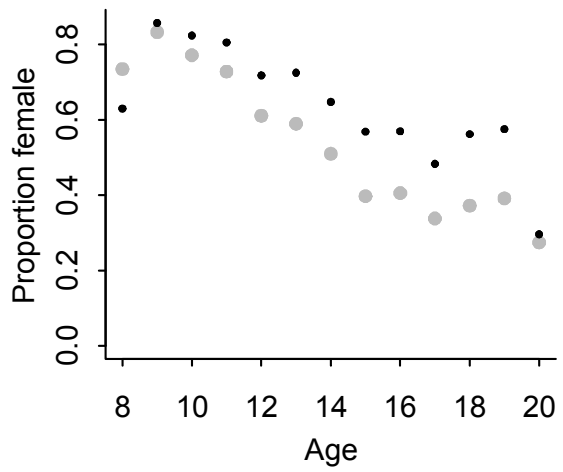
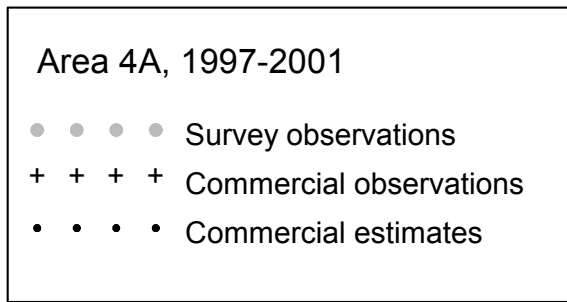


Figure 4e. Estimates of proportion female and mean size by sex in commercial landings in Area 4A, 1997-2001 combined, computed for each age by applying the sex ratio at length in survey catches to the length frequencies of commercial landings.

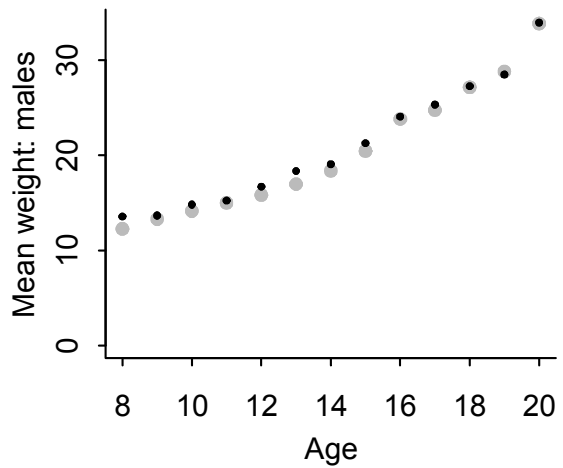
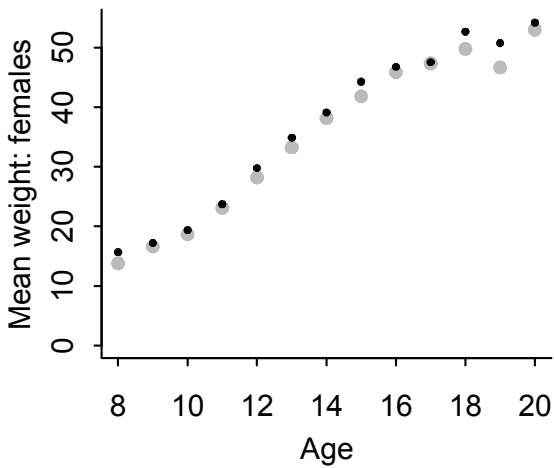
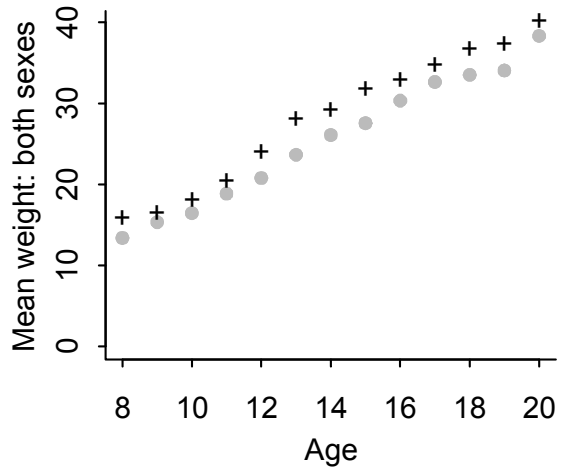
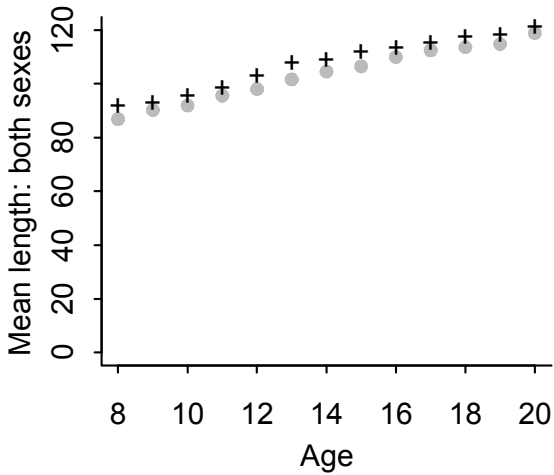
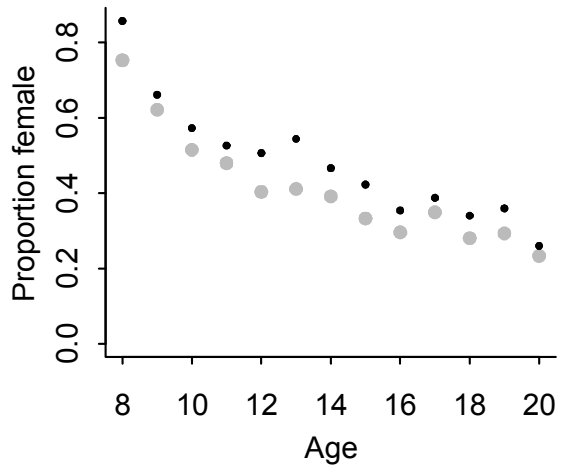
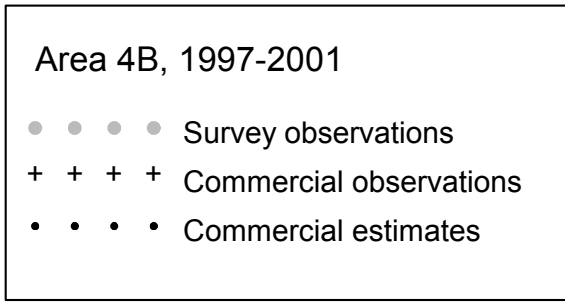


Figure 4f. Estimates of proportion female and mean size by sex in commercial landings in Area 4B, 1997-2001 combined, computed for each age by applying the sex ratio at length in survey catches to the length frequencies of commercial landings.

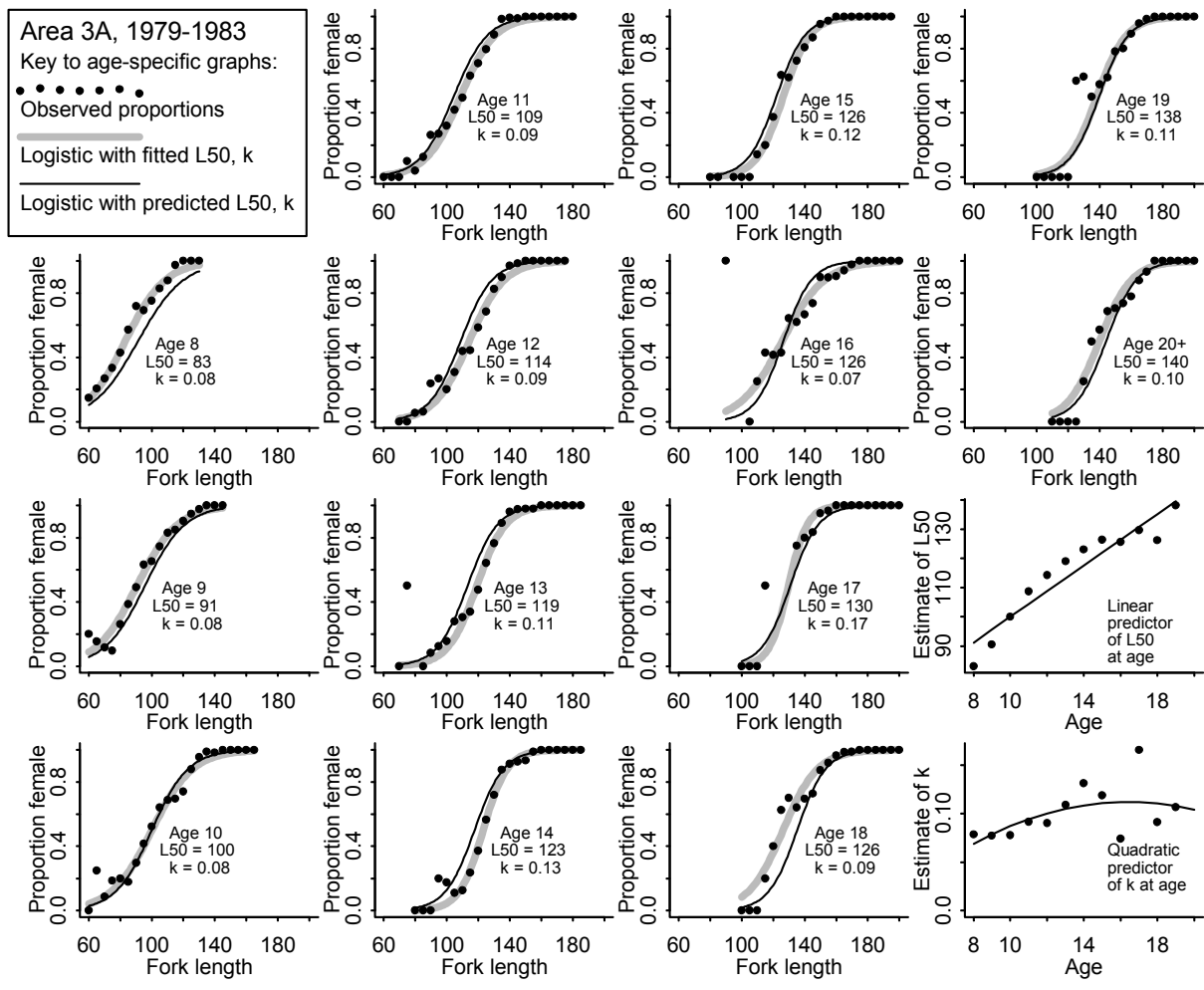


Figure 5a. Logistic fits to the proportion female at length, by age, in J-hook survey catches in Area 3A, 1979-83. These fits include sublegal fish. The thick gray line in each graph is the logistic fitted to the plotted data for that age group; the thin black line is a logistic with parameters predicted from the linear trend with age in $L50$ and the quadratic trend in k (last two panels).

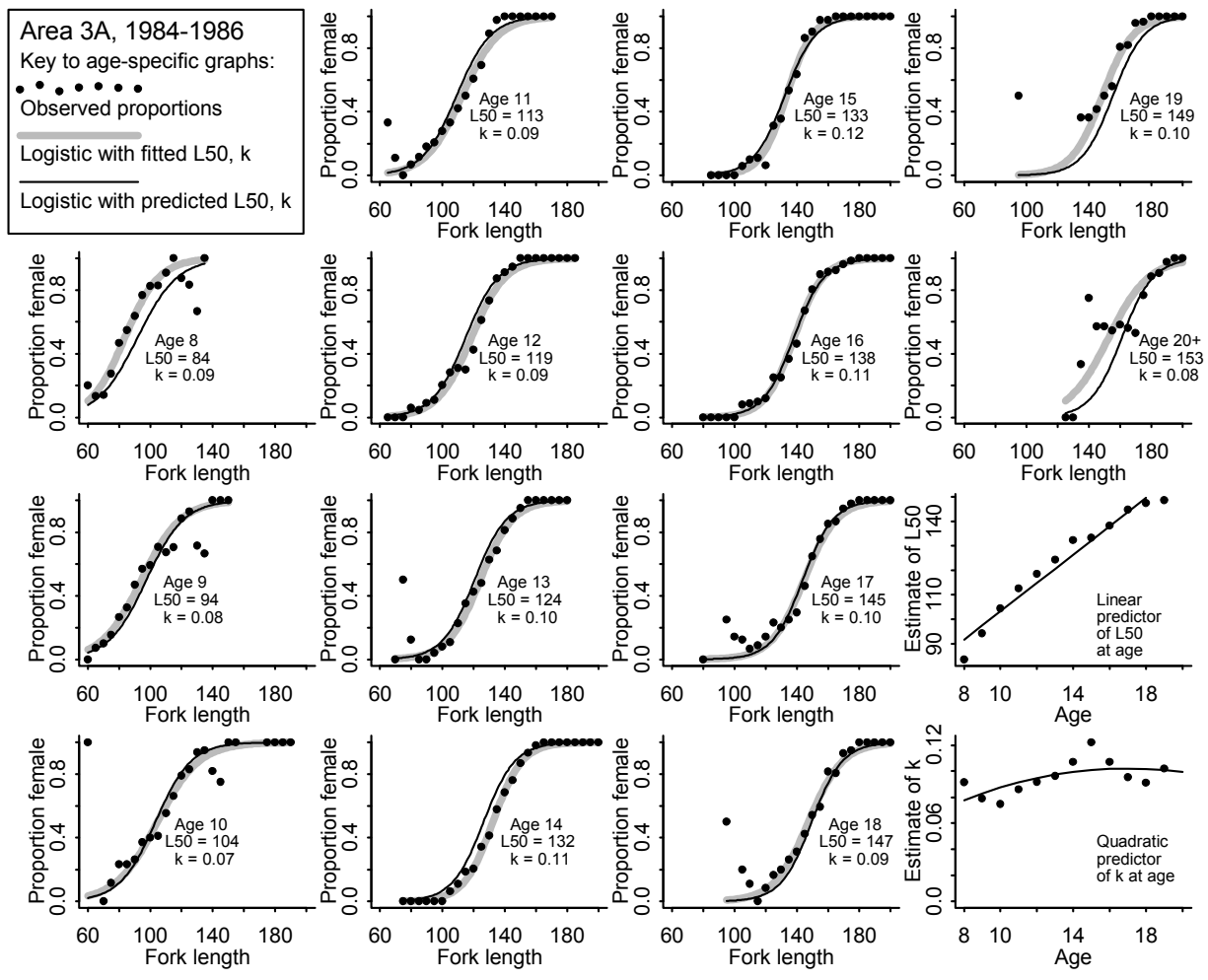


Figure 5b. Logistic fits to the proportion female at length, by age, in C-hook survey catches in Area 3A, 1984-86.

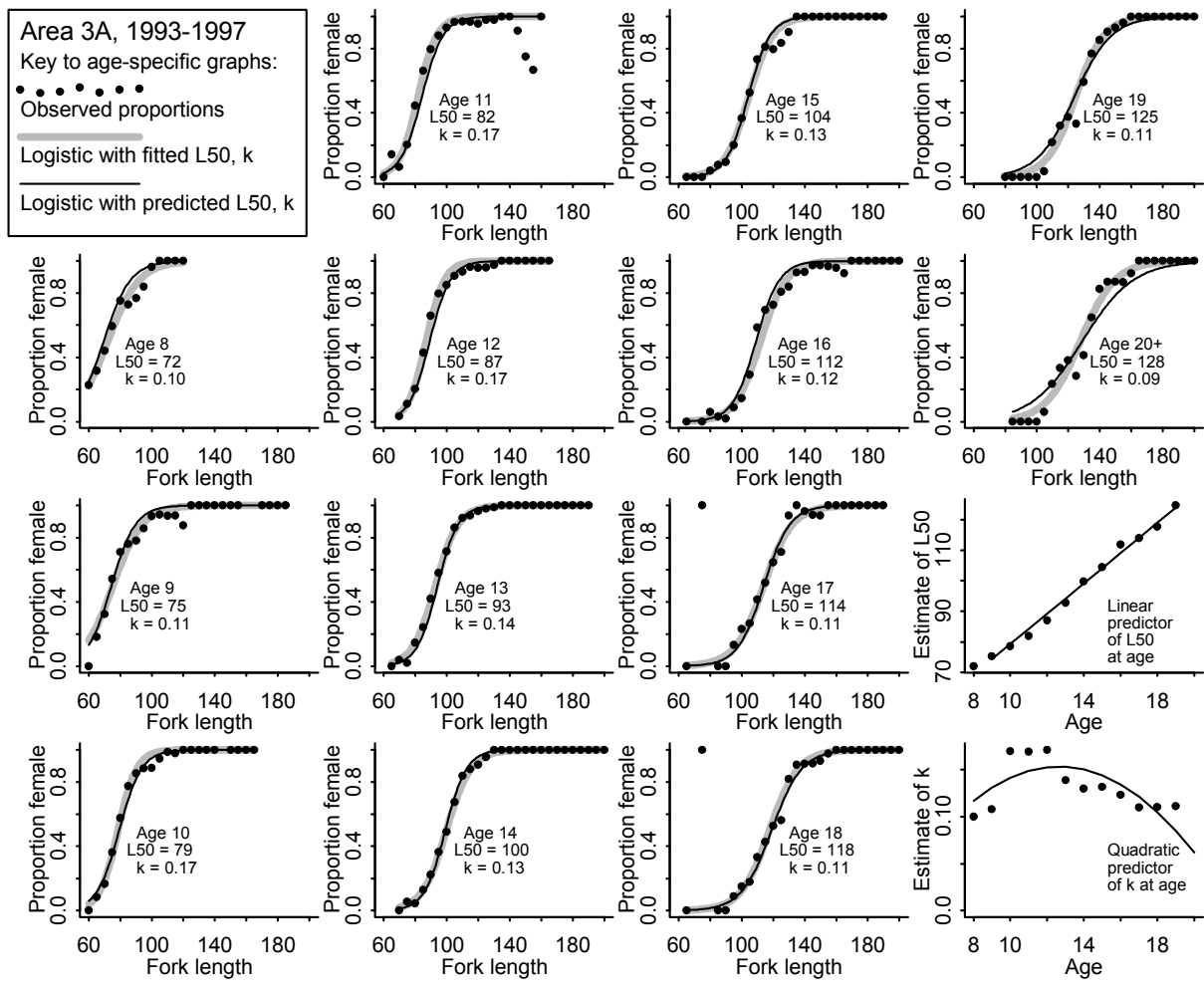


Figure 5c. Logistic fits to the proportion female at length, by age, in C-hook survey catches in Area 3A, 1993-97. The fits in other areas are similarly good in recent years.

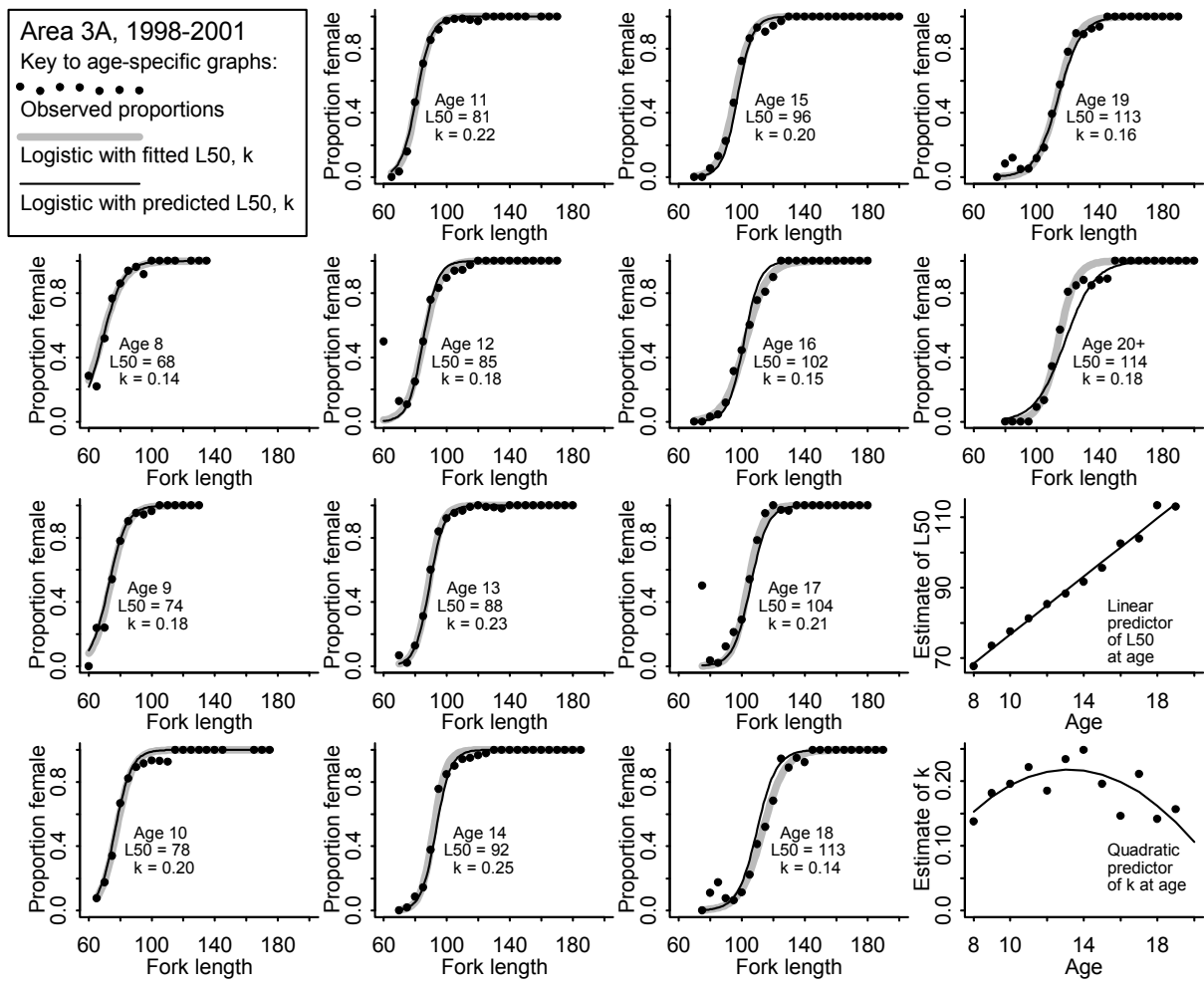


Figure 5d. Logistic fits to the proportion female at length, by age, in C-hook survey catches in Area 3A, 1998-2001.

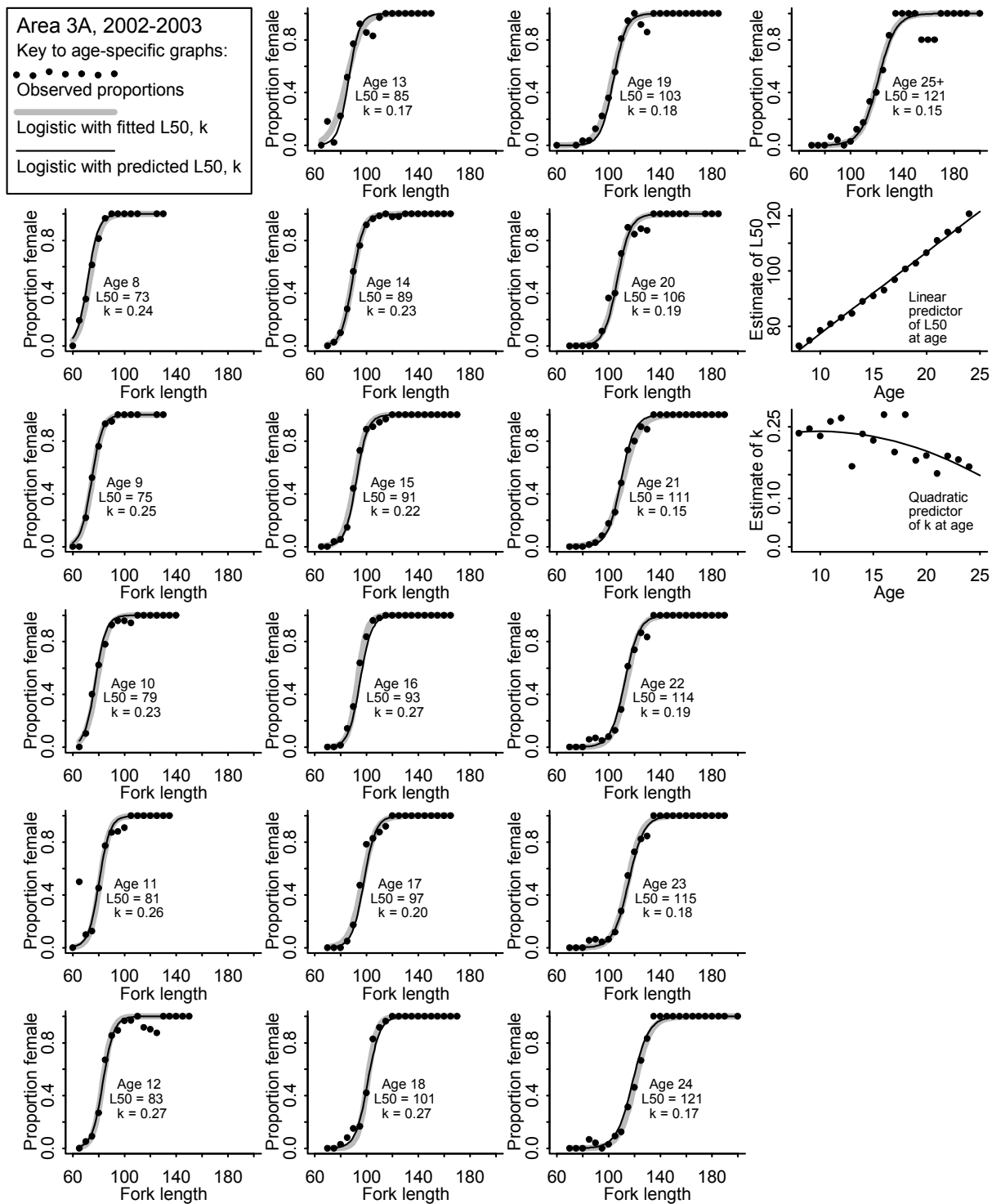


Figure 5e. Logistic fits to the proportion female at length, by age, in C-hook survey catches in Area 3A in 2002-2003, when the age data are break-and-burn readings.

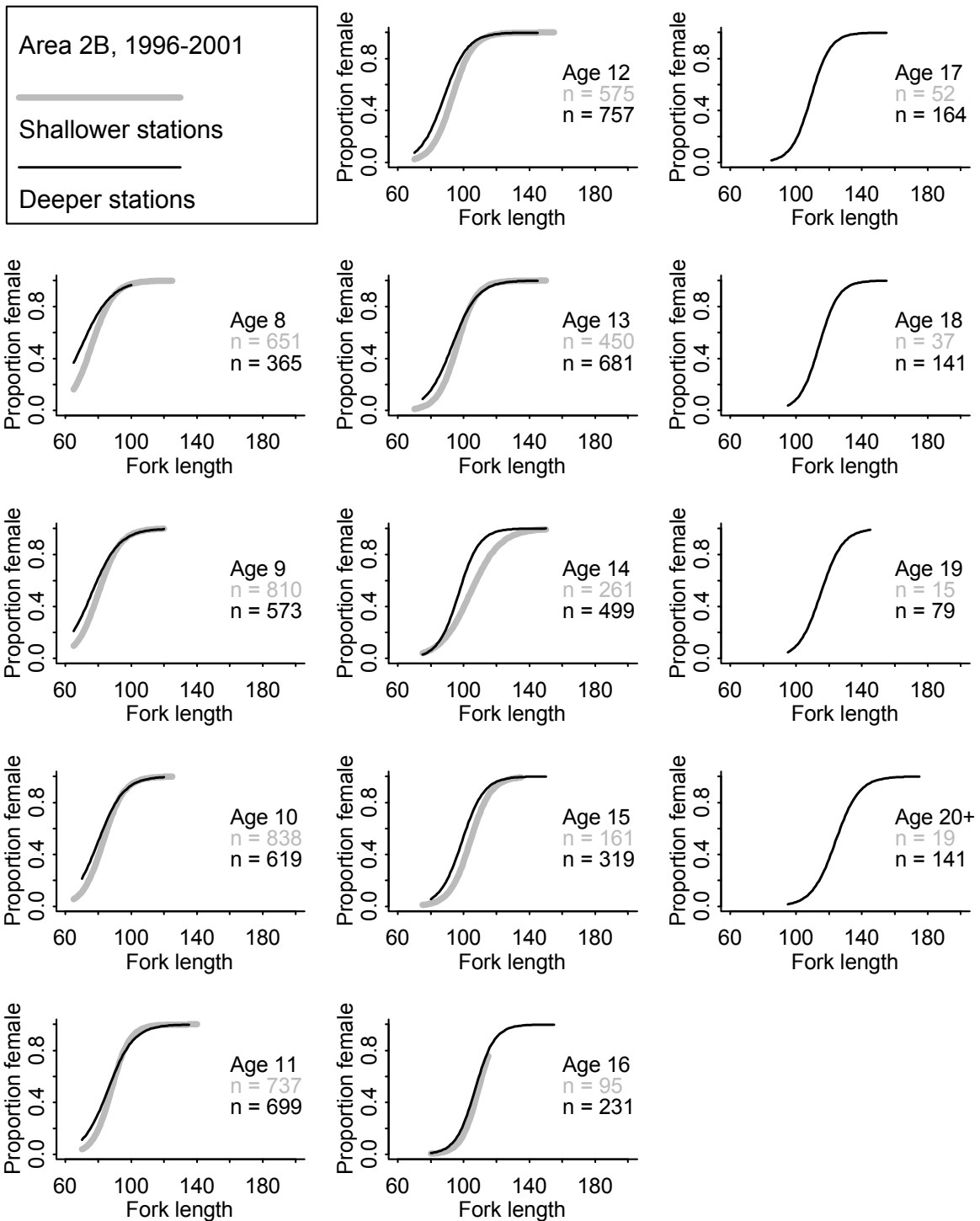


Figure 6a. Logistic fits to proportion female at length, by age and depth zone, for Area 2B survey catches in 1996-2001.

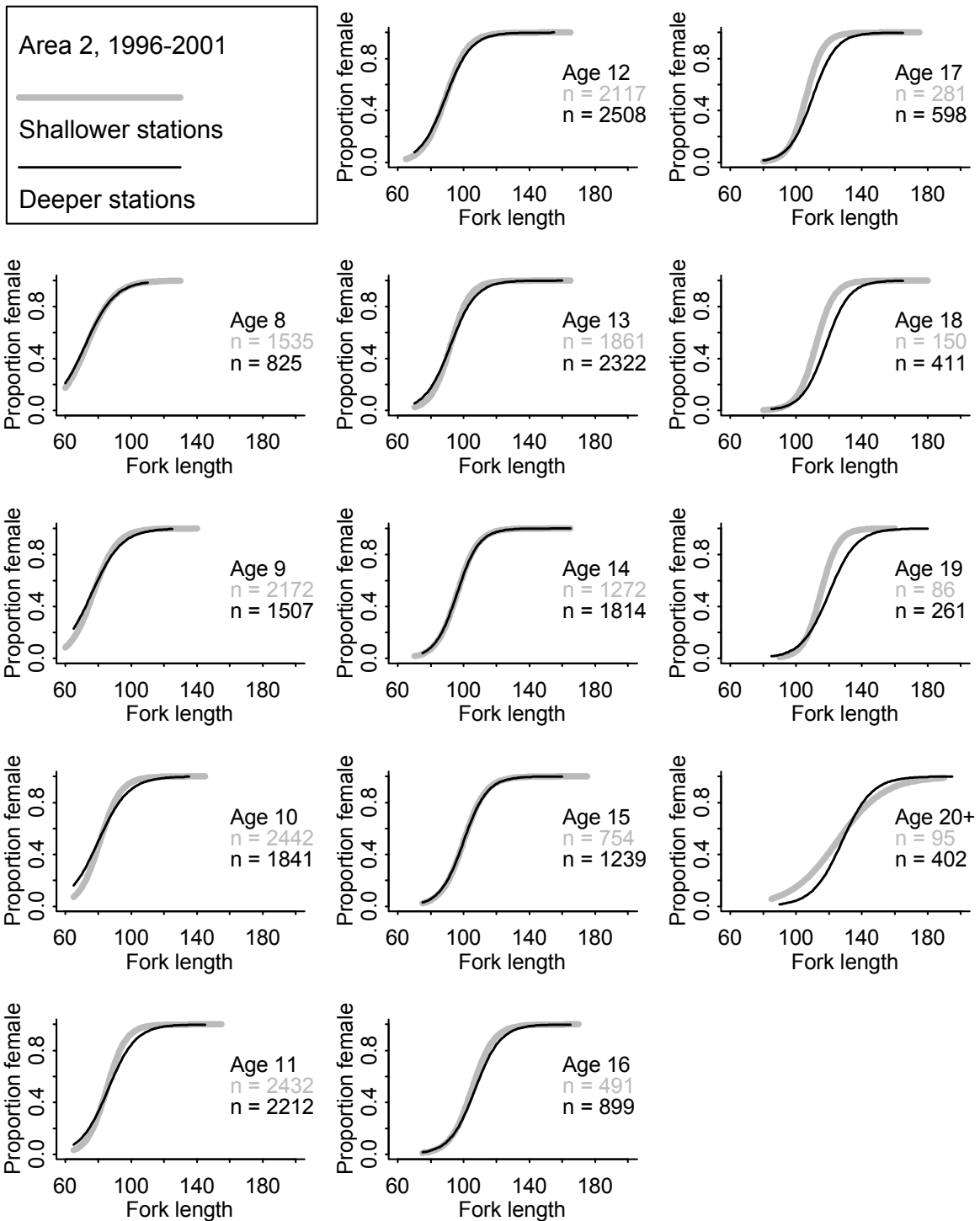


Figure 6b. Logistic fits to proportion female at length, by age and depth zone, for all Area 2 survey catches in 1996-2001.

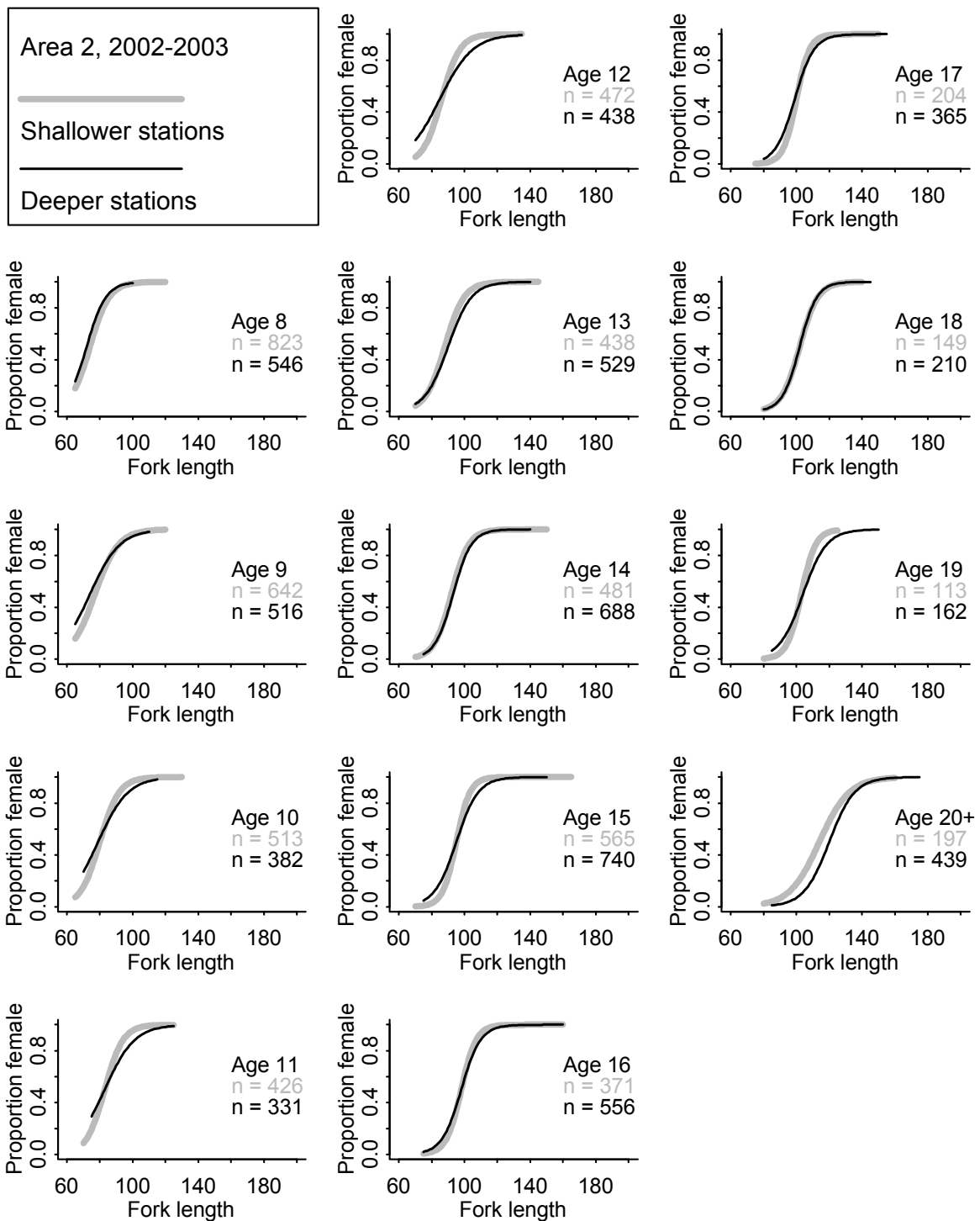


Figure 6c. Logistic fits to proportion female at length, by age and depth zone, for all Area 2 survey catches in 2002-2003, after the switch to break-and-burn readings.

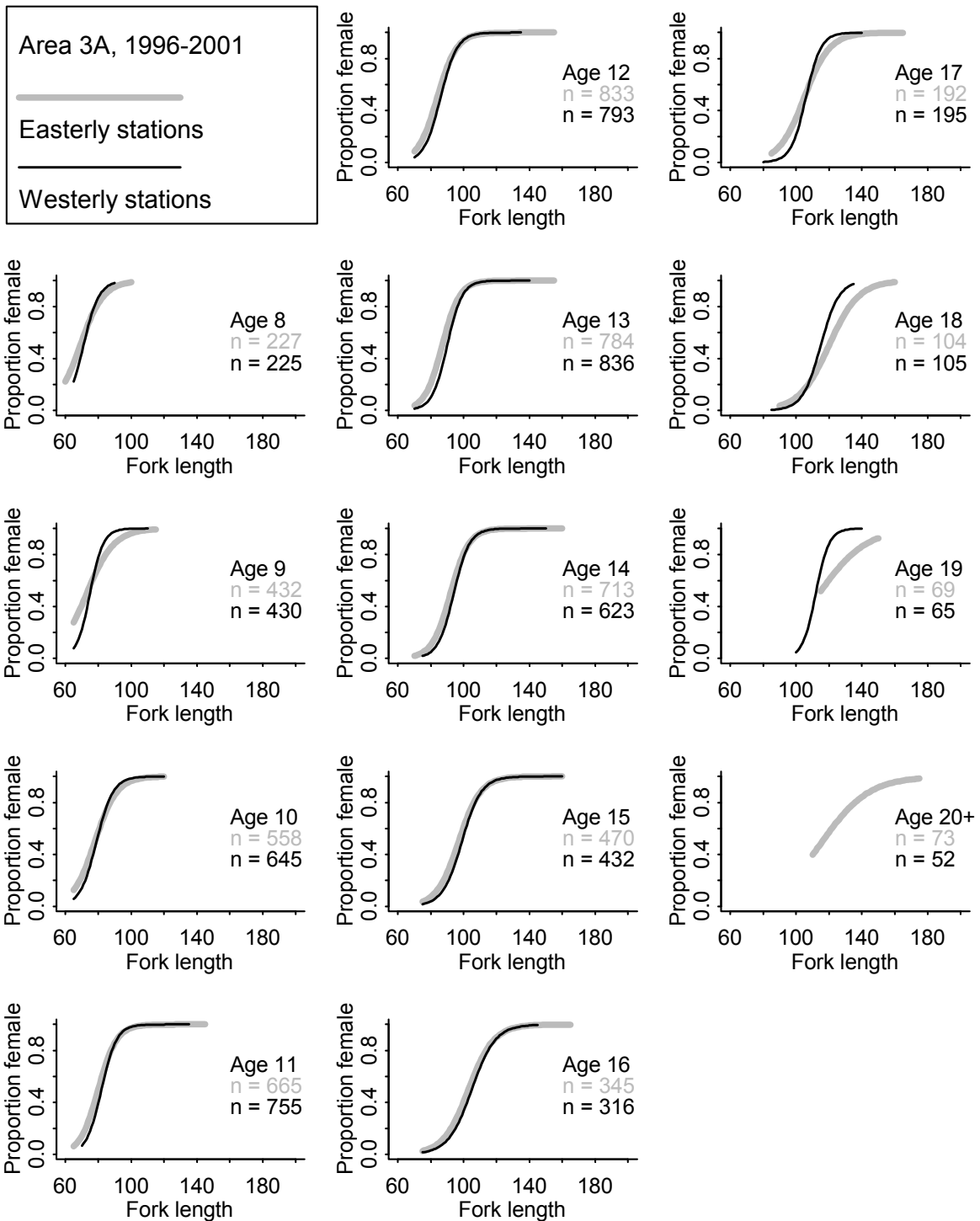


Figure 7a. Logistic fits to proportion female at length, by age, in survey catches on the eastern and western sides of Area 3A, 1996-2001.

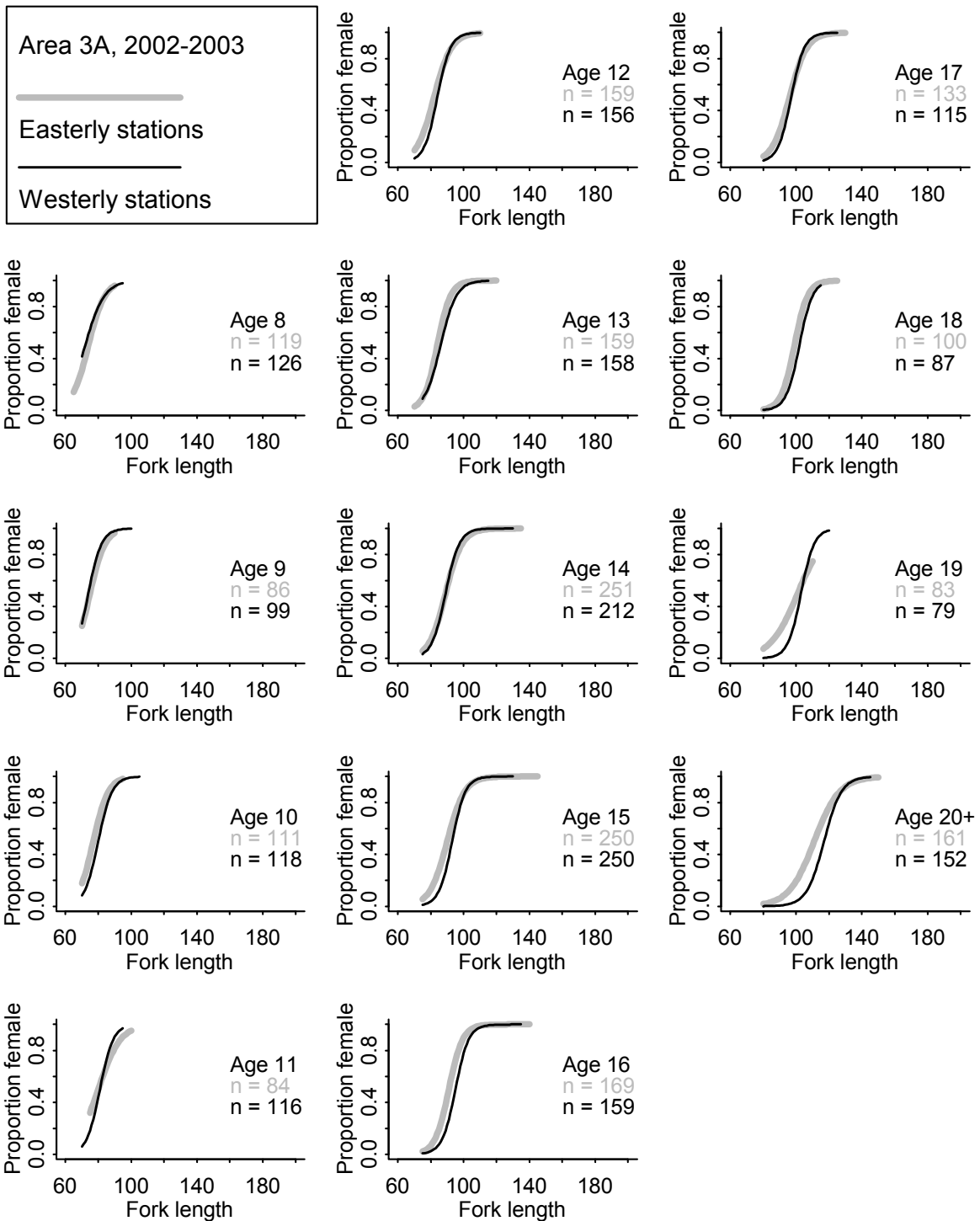


Figure 7b. Logistic fits to proportion female at length, by age, in survey catches on the eastern and western sides of Area 3A, 2002-2003, after the switch to break-and-burn readings.

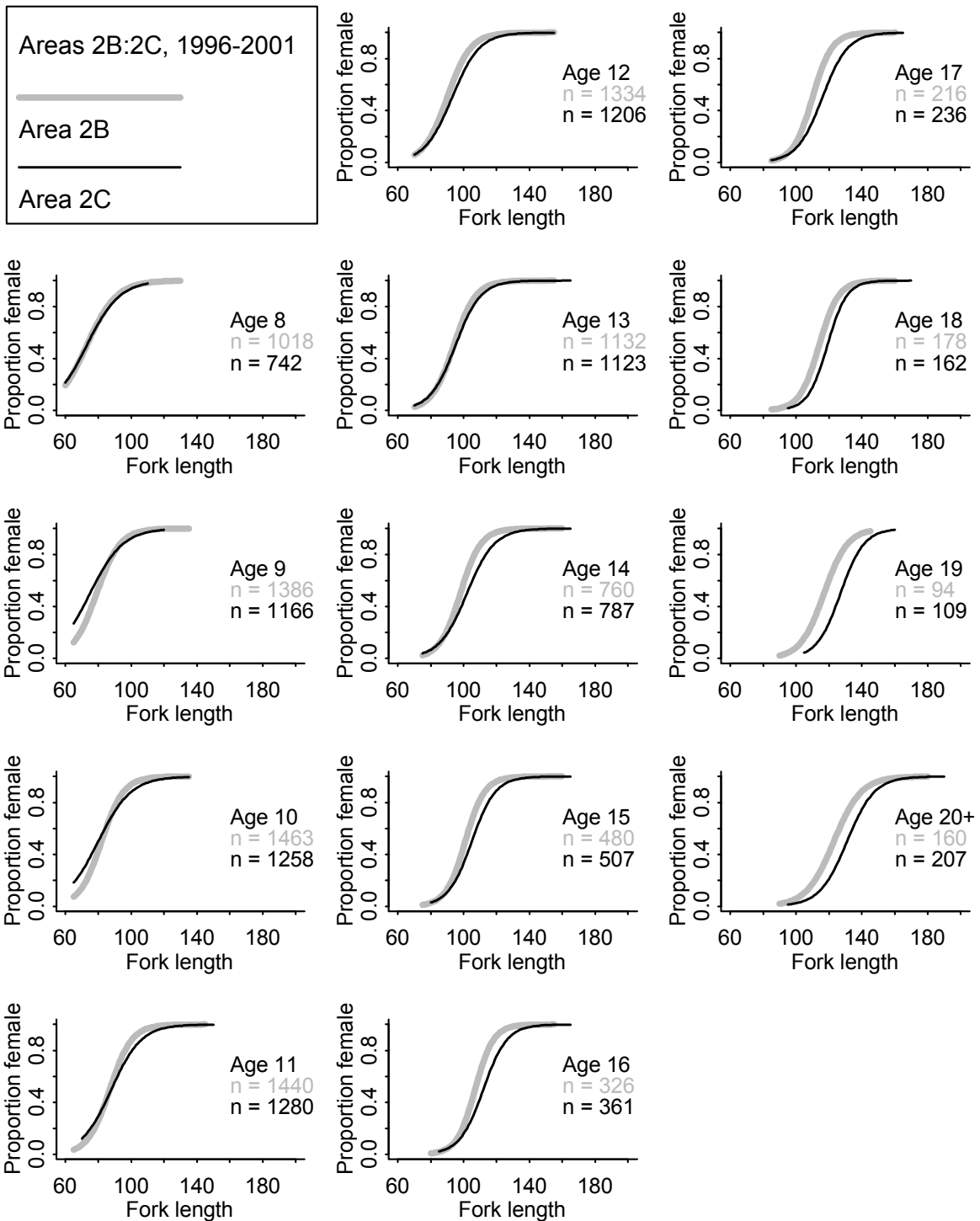


Figure 8a. Logistics fitted to proportion female at length in Areas 2B and 2C, 1996-2001.

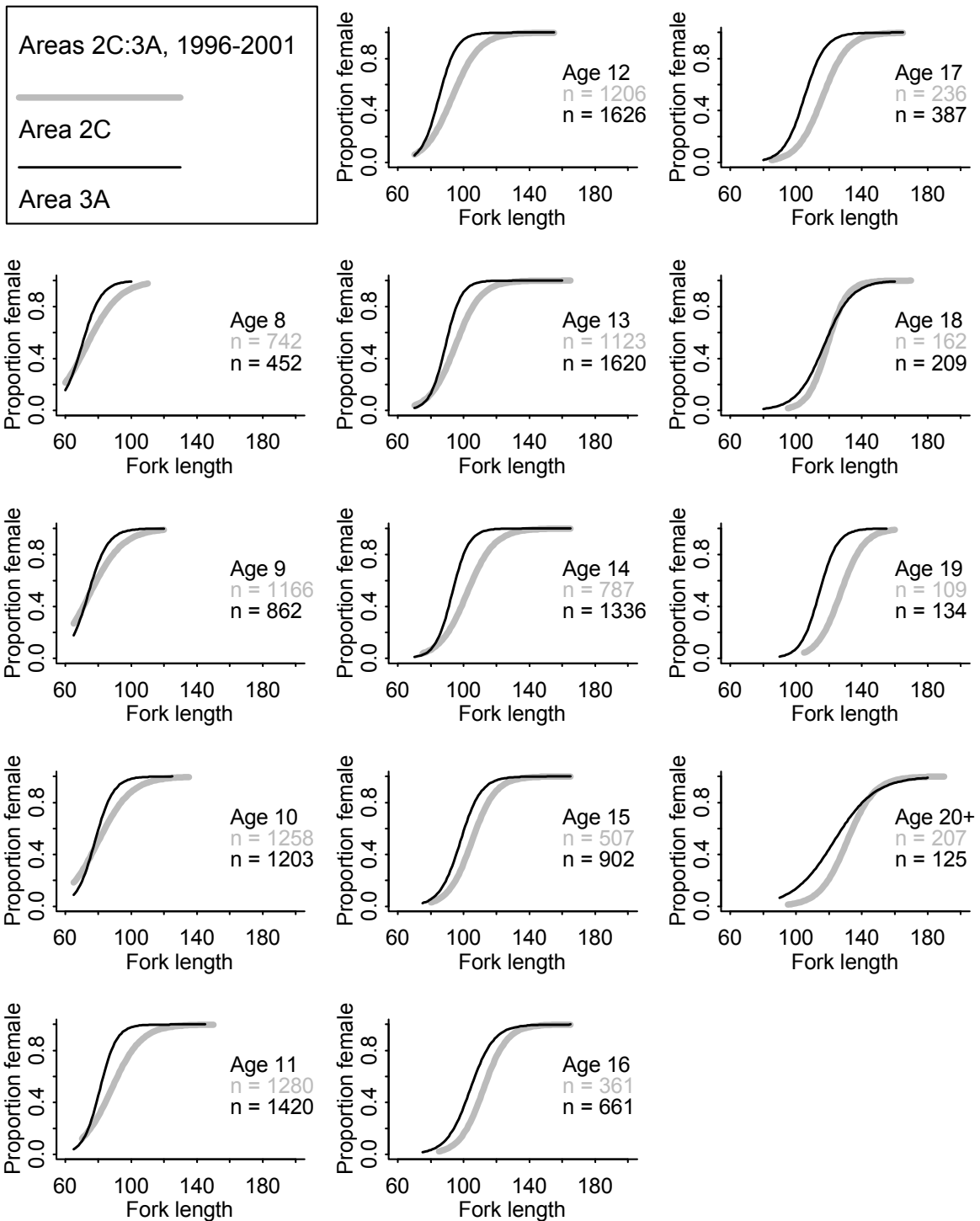


Figure 8b. Logistics fitted to proportion female at length in Areas 2C and 3A, 1996-2001.

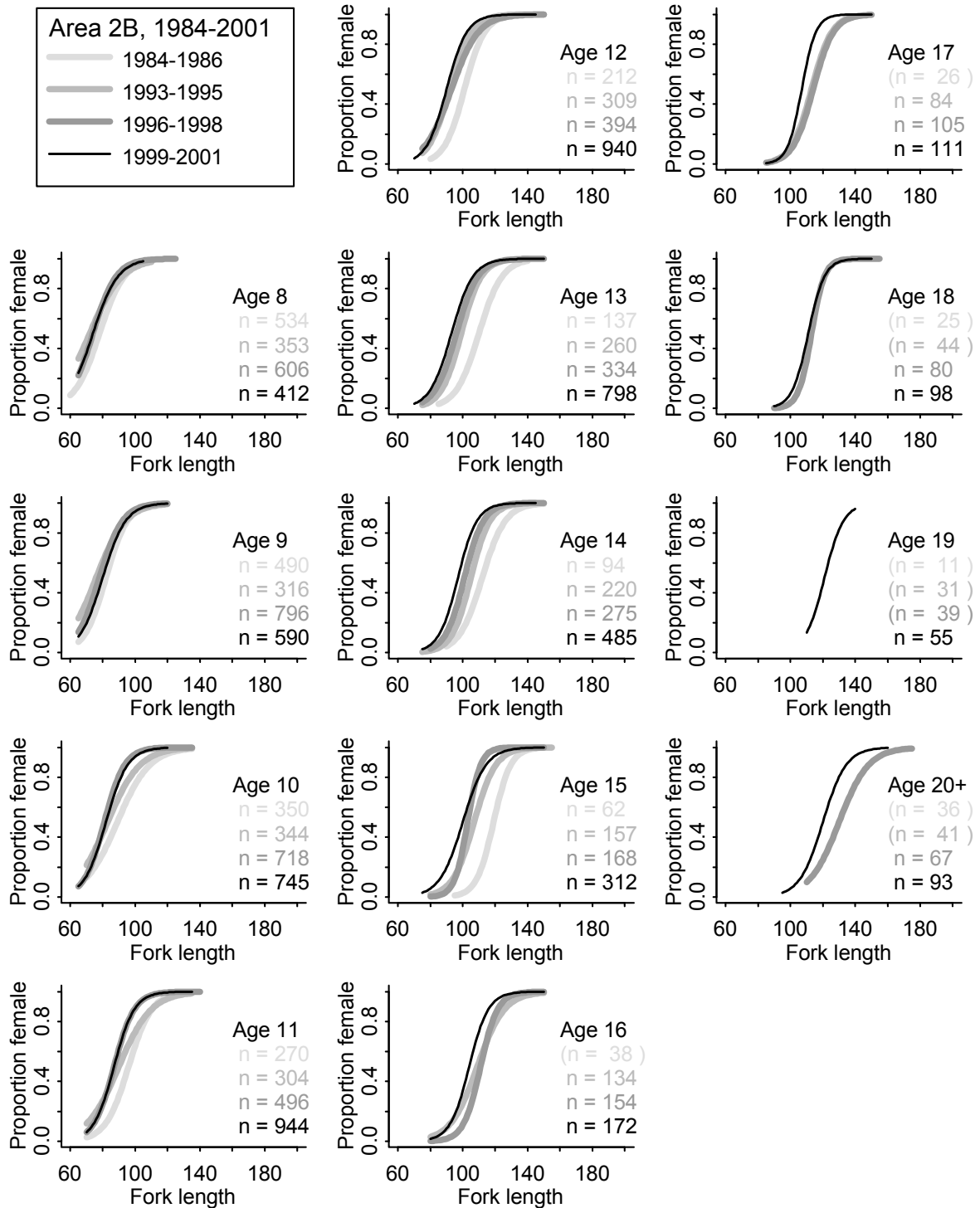


Figure 9a. Logistics fitted to proportion female at length in Area 2B by three-year periods.

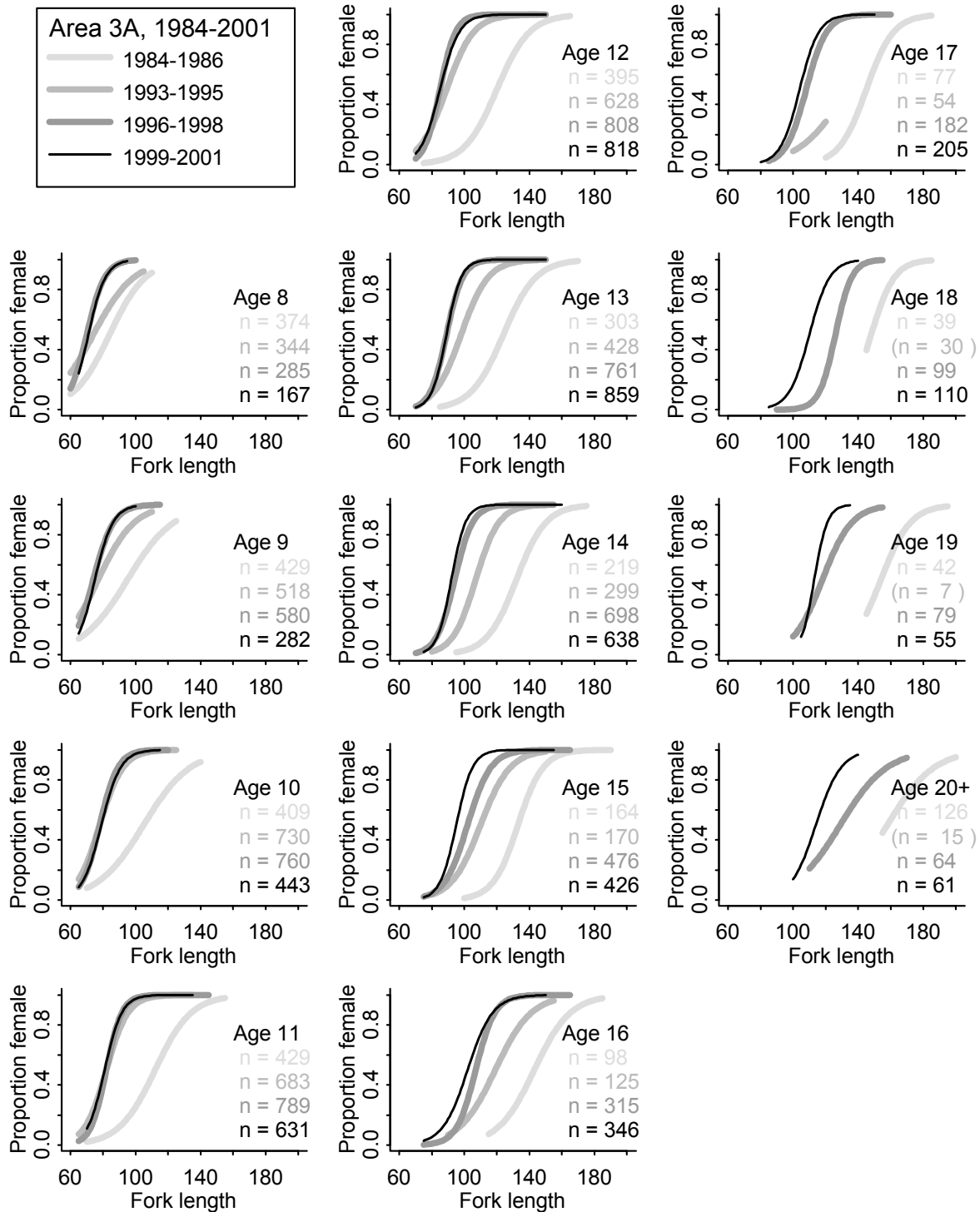


Figure 9b. Logistics fitted to proportion female at length in Area 3A by three-year periods.

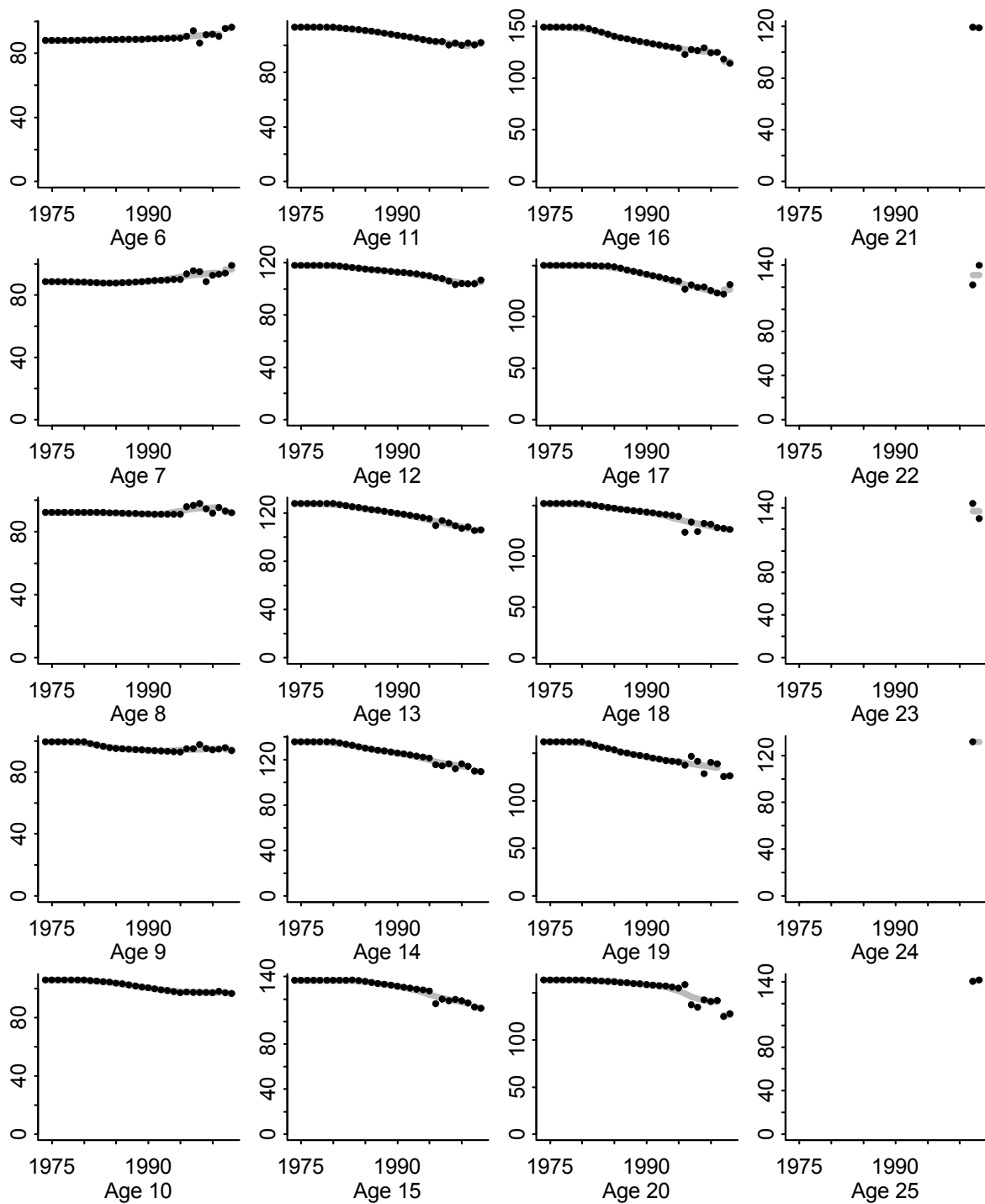


Figure 10a. Estimated mean length at age of females in Area 2B landings. Values through 1995 are smoothed survey observations (mean length at age by sex of legal-sized fish). Values after 1995 are estimated by applying the logistic predictor to the commercial length frequencies at age, where the sexes are not known. The gray line is a data smoother.

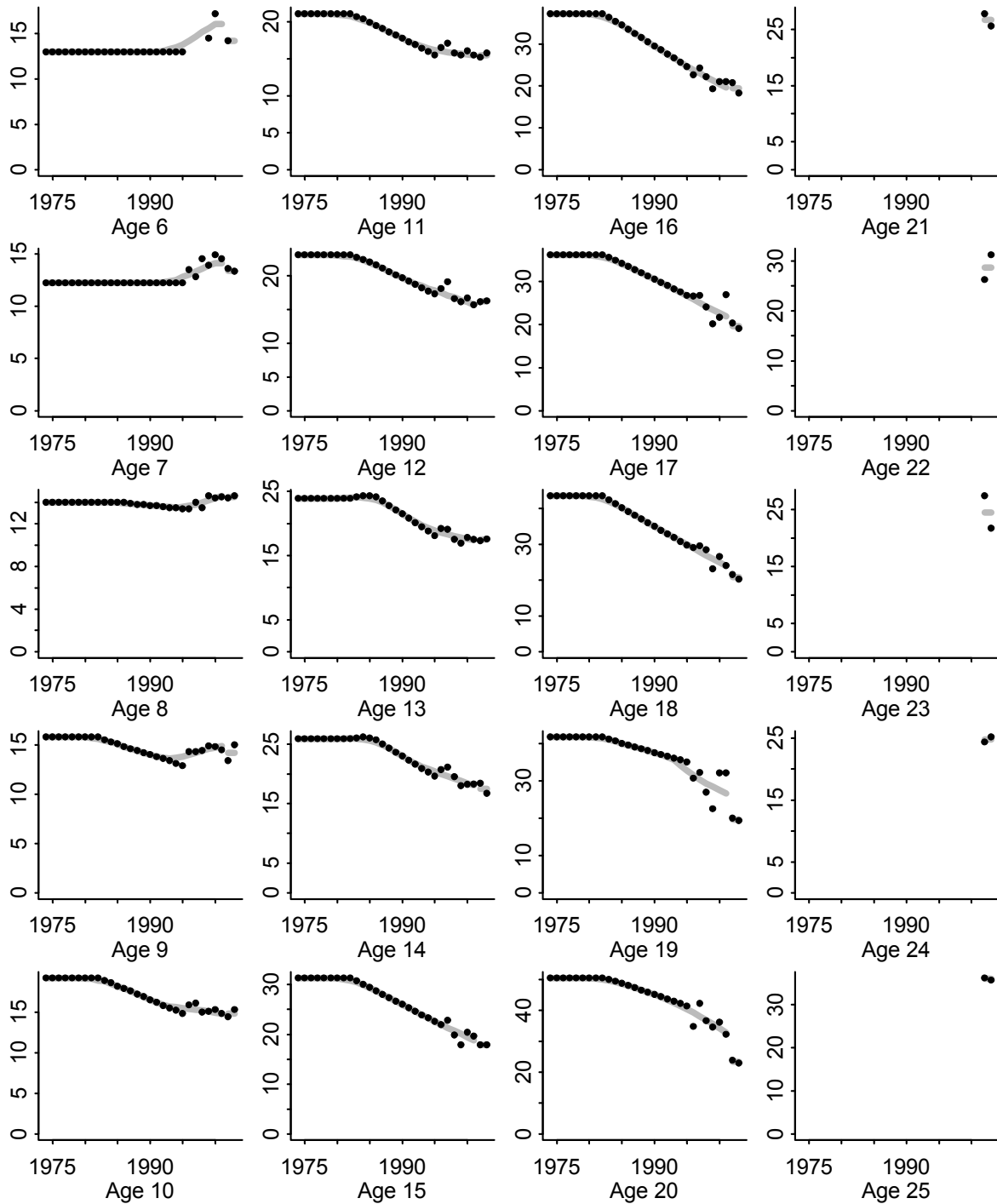


Figure 10b. Estimated mean weight at age of males in Area 2C landings. Values through 1995 are smoothed survey observations (mean length at age by sex of legal-sized fish). Values after 1995 are estimated by applying the logistic predictor to the commercial length frequencies at age, where the sexes are not known. The gray line is a data smoother.

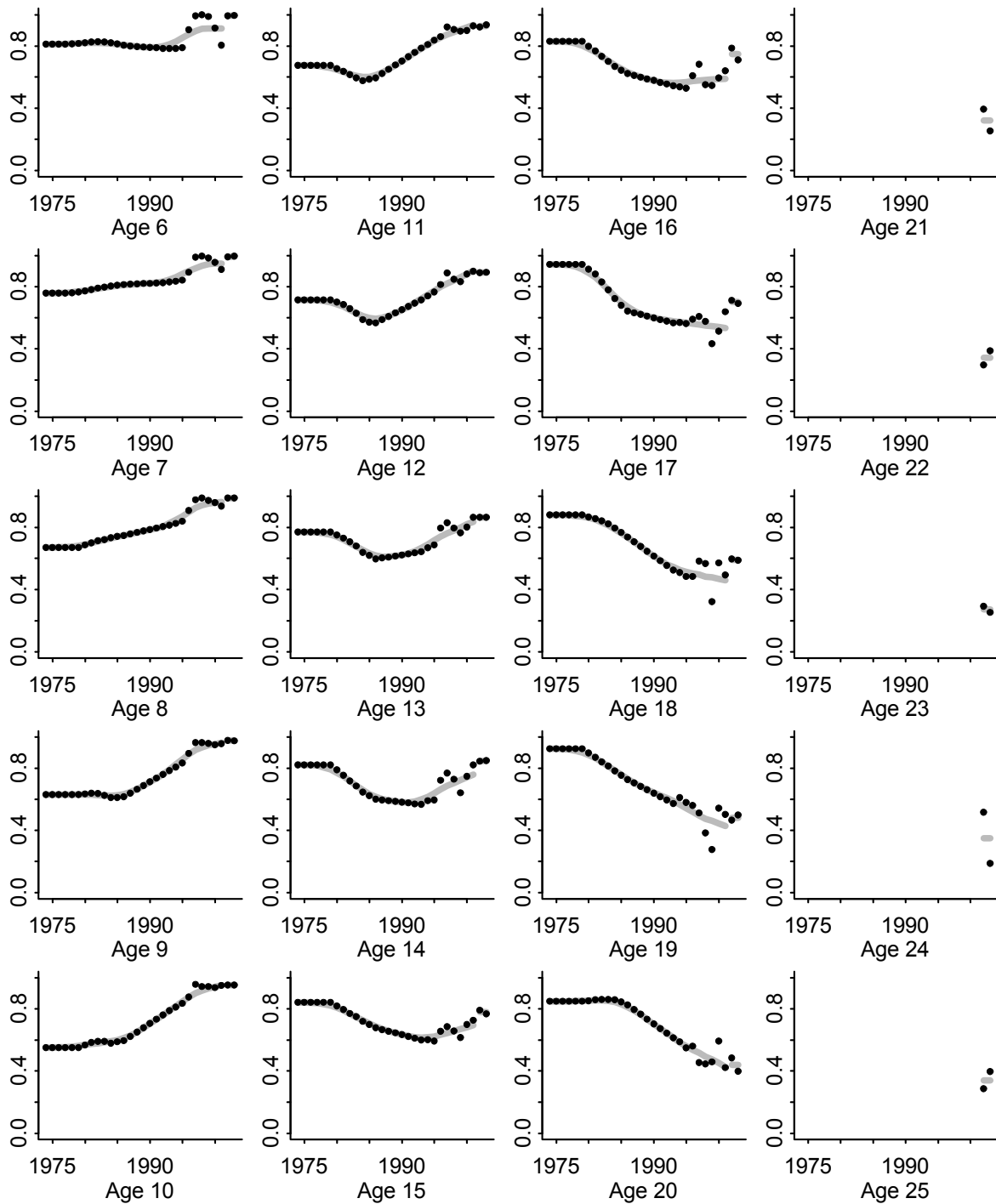


Figure 10c. Estimated sex ratio (proportion female) in Area 3A landings. Values through 1995 are smoothed survey observations (mean length at age by sex of legal-sized fish). Values after 1995 are estimated by applying the logistic predictor to the commercial length frequencies at age, where the sexes are not known. The gray line is a data smoother.

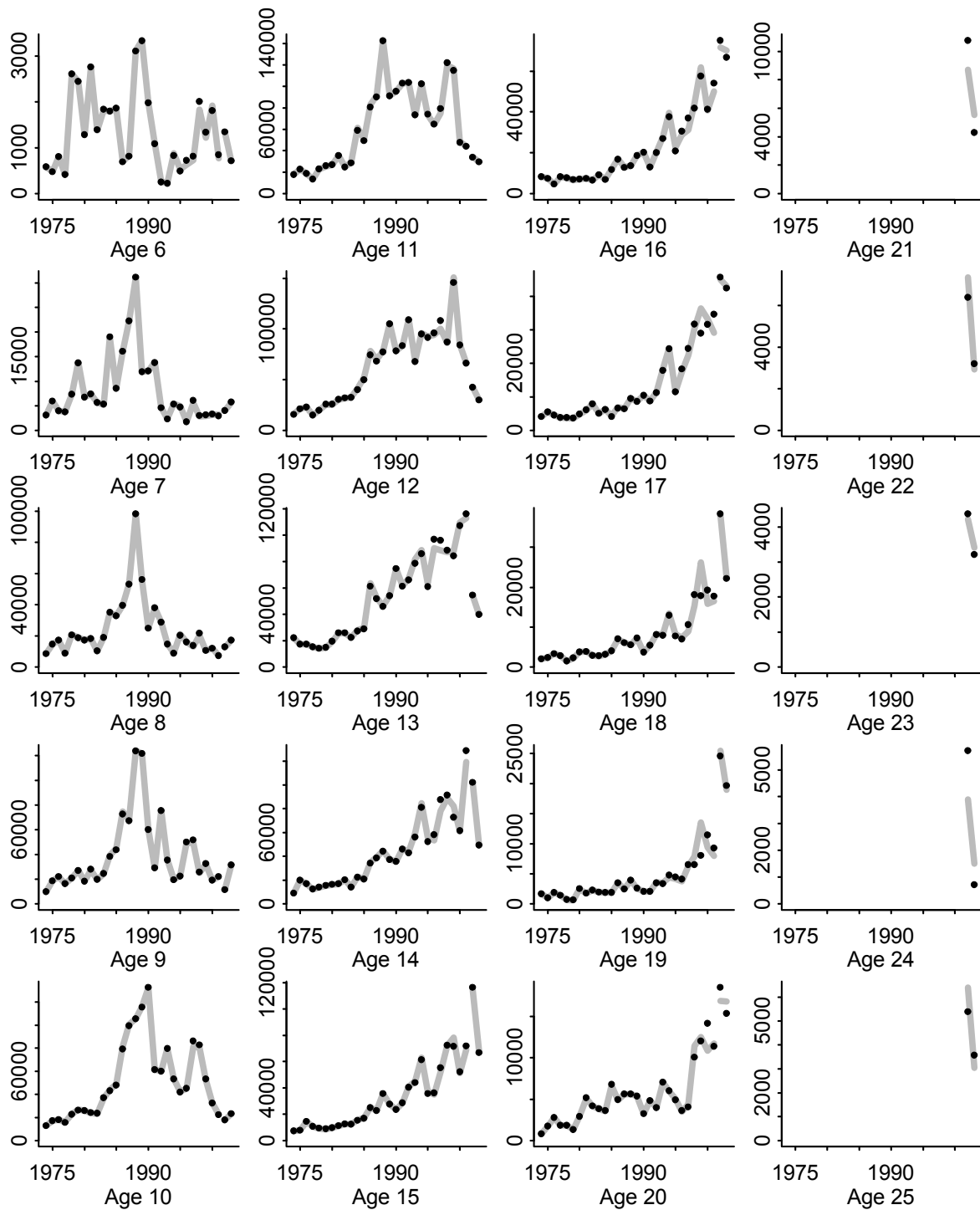


Figure 11. Estimated catch at age (numbers of fish) of females in Area 3A. The points are the values computed with sex ratios estimated individually from the commercial length frequencies for a given area/year/age (beginning in 1996). The gray lines are the values computed with the sex ratio estimates for a given age in a given area smoothed over years.