Evaluating shifts in size and age at maturity of Golden tilefish from the Mid-Atlantic Bight

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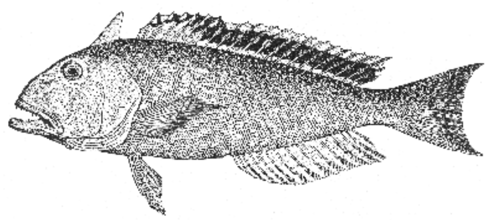

Summary
Macroscopic and histological analysis of golden tilefish sampled from the 2008 fishery indicates smaller size at maturity and younger age at maturity than similar analysis of samples from the 1982 fishery. Histology results from analysis of 2008 data indicate that size at 50% maturity was 46cm for females and 48cm for males. Size at age observations also suggest changes in growth rates since the 1980s.

Introduction

The objective of this research was to evaluate size and age at maturation for male and female tilefish, *Lopholatilus chamaeleonticeps*, from the Mid-Atlantic stock. This analysis used macroscopic maturity class data from at-sea sampling on commercial longline vessels combined with histological analysis. The size at maturation for the 2008 stock was then compared to the 1982 stock, to determine if the proportion mature, as a function of size, has shifted towards maturation at smaller sizes. A shift towards maturation at smaller sizes could be an indication that the population size has decreased (Grift et al. 2003; Ernande et al. 2004; Anderson et al. 2007). An ageing study was performed to evaluate changes in the growth curves since 1982 and to determine age at length and maturation and to assess whether or not size at maturity has shifted from 1982, the last time the reproductive biology was evaluated (Grimes et al. 1988). Understanding and evaluating changes in size and age at maturation are important in understanding the broader population dynamics of this stock.

Methods

Sampling Design

Tilefish were sampled from commercial longline catches using a systematic sampling design stratified by fish length and gender; sampling one fish per cm interval per sex. The systematic sampling design was to ensure that the entire size distribution of the fish encountered was sampled, and that the sizes more and less frequently encountered, were not over or under-sampled, respectively. Two commercial trips, for sample collection, were made during the spawning season; June and July. Additional samples, approximately 10 fish bimonthly, were collected portside from commercial trips to obtain samples throughout the year. These fish were selected randomly from market categories: kitten, medium, and large, from the last haul of the trip.

Macroscopic staging

Tilefish are gonochoristic (i.e., they have separate sexes) and are indeterminate serial spawners (i.e., they spawn in multiple batches). Tilefish gonads are paired organs located posteriorly in the body cavity below the swim bladder, with the ovaries suspended by thin mesovaria; testis by mesorchia (Idelberger 1985). Gonads were classified to six macroscopic classes: immature, developing, ripe, ripe and running, spent, and resting; the criteria to classify individuals to a given class were based on Idelberger's (1985) classification criteria. All classes, except immature (and fish of unknown sex and/or class) were considered to be mature. Fish developing to spawn for the first time were not differentiated from repeat spawners.

One ovarian lobe or testis was removed and preserved in 10% buffered formalin; alternatively a transverse section of the medial portion of one ovary or testis was preserved for histology. In the laboratory, the gonad tissue samples were dehydrated through a series of increasing ethanol concentrations, cleared with Clear Rite™, and embedded into paraffin. The paraffin blocks were allowed to harden, trimmed around the edges using a razor blade to remove excess paraffin, sectioned at a thickness of 4µm using a microtome, mounted on glass slides, stained with hematoxylin, counterstained with eosin and coverslipped. The hematoxylin and eosin (H&E) staining method used was based on H&E procedures detailed by Luna (1968).

Microscopic staging

Microscopic criteria for staging gonadal cells were based on maturity classifications described for the following species: tilefish (Grimes et al. 1988, Erickson et al. 1985), round scad (McBride et al. 2002), tilapia (Hyder 1969), and common snook (Grier et al. 1998). Females were considered immature if the perinucleolar stage was the most advanced stage of oocyte development observed. An individual was considered to be mature if cortical alveolar, vitellogenic, or hydrated oocytes were observed. The presence of postovulatory follicles was also an indication of prior spawning. For males, the presence of spermatozoa in the spermatogenic crypts and/or lobules was the criterion for maturity.

Ageing

The fish sampled for histology were also aged. The sagittal otoliths were extracted at sea, mounted on a wax pillow atop a paper tab with crosshairs for alignment with a low-speed diamond blade Isomet® saw, completely embedded in wax, and thin sectioned through the core. The right sagittae was used unless it was broken or unavailable. Annular rings were counted to determine fish age. Each annulus, or ring, represents one year of growth; with the annuli typically laid down by June of each year (Turner 1986). Confirmation of this aging method has been done through marginal increment analysis. Otoliths from Turner's (1986) aging study were used as a reference collection to maintain consistency in the aging method.

Statistical Analysis

Logistic regression was used predict the maturity ogives for males and females from the 2008 population using the GLM function with a logit link, in the R statistical software program.

$$P_i = \frac{e^{\beta_0+\beta_1 X_i}}{1+e^{\beta_0+\beta_1 X_i}} \qquad (1)$$

P_i: proportion mature at size or age i
B_0: intercept of logistic model
B_1: logistic regression coefficient for explanatory variable X1
X_i: the ith observation of the explanatory variable (size or age)

The 95% confidence bands were calculated as +/- 1.96 times the standard error of the estimate of proportion mature at a given size.

The maturity ogives, for males and females, based on macroscopic and histological data were compared, and precision estimates between the two methods were determined. The macroscopic results were compared to the Grimes et al. (1988) data. The raw data were not available from the Grimes et al. (1988) study, so the binned data were expanded out and treated as raw data. This is not an ideal method for comparison, but should provide a general idea as to whether or not there have been shifts in the ogives.

To quantitatively determine whether the proportion mature as a function of length was significantly different between the macroscopic and histological methods logistic regression models were used. Logistic regression was also used to test difference in length and age at maturation between 1982 and 2008. The p-values associate with the z-statistics from the model output, in addition to the Bayesian information Criterion (BIC)

$$BIC = z - statistic^2 - \ln(n) \qquad (2)$$

were used to test the significance of the regression parameters (Pampel 2000).

Growth curves were computed for the sampled 2008 population using a von Bertalanffy (1938) growth model,

$$L_t = L_\infty [1 - e^{-k(t-t_0)}] \qquad (3)$$

Lt: length at age *t*
$L\infty$: asymptotic length
k: Brody growth coefficient
t_0: age at length=0

and a von Bertalanffy growth model with equally weighted mean length at age values. Growth model parameters were estimated using the SAS nlin procedure using Turner's (1986) parameter estimates as the initial values for L_∞, k, and t_0. Age at length was calculated and used to asses shifts in age at maturation, ignoring growth variation and overlapping length distributions, but associating each length with an age using the estimated von Bertalanffy parameter estimates (Hilborn and Walters 1992).

$$\hat{t} = t_0 - \left(\frac{1}{k}\right)\log\left[1 - \left(\frac{L_t}{L_\infty}\right)\right] \qquad (4)$$

Growth curves were estimated for both sexes combined as well as males and females separately.

Results

Females – macroscopic

The logistic regression model predicted the proportion of fish mature at length with 95% confidence bands around the estimates. The macroscopic data analyzed were for fish sampled for histology as well; the results indicate that female tilefish begin maturing around 40 cm and are almost 100% mature by 50 cm (Figure 1). The regression cannot fully predict to the lower tails due to a lack of small fish. There is some size selectivity based on the hook size, which selects against the smallest fish in the population. As a result there is limited data for the small sizes, however the ogive fits the data fairly well. Fifty percent maturity (M_{50}) is achieved at approximately 45 cm (n=66; Table 1) and 5 years (Table 2).

Females – histological

Histological evaluation indicated that M_{50} is 46 cm (n=70; Table 3; Figure 2) and 5 years (Table 2). There was strong agreement between the two staging methods for females, with 92% precision. Eighty percent of the disagreement was due to immature fish between 42 and 50 cm being classified as developing macroscopically.

Males – macroscopic

The macroscopic maturity ogive for the 2008 males (Figure 3) shows that they begin maturing around 48 cm and are almost 100% mature at about 73 cm. The length range over which maturation occurs is much wider for the males than for the females. M_{50} is approximately 56 cm (n=149; Table 4; Figure 4) and 6 years (Table 2).

Males – histological

Agreement between the two staging methods for males was less than for the females with 85% precision. Ninety one percent of the disagreement was due to developing fish classified as immature in the field. Fifty percent maturity based on histological evaluation was predicted to be 48 cm (n=151; Table 5) and 5 years (Table 2).

All macroscopic staging

Additional macroscopic observations were made beyond those that were paired with histology. Figures 5 and 6 show all macroscopic staging data for females and males respectively from 2008. Length at 50% maturity (L_{50}) for females is predicted at 44 cm (n=321) and L_{50} for males predicted at 57 cm (n=479; Tables 6 and 7); ages 5 and 6 respectively.

Comparison to 1982 stock

The 1982 data were macroscopic observations expanded out based on the sample sizes noted on the logistic regression plots in the Grimes et al. (1988) study. The data represented proportion mature at each 5 cm length bin; the raw data were not available. Both the macroscopic and histological results were compared to the 1982 macroscopic data. Figures 7 and 8 are qualitative ways to visualize the shifts in maturity ogives from 1982 to the present. The blue line represents the 2008 data and the green line is the 1982 data from Grimes et al. (1988). Each of these plots indicates a shift toward maturation at smaller sizes in 2008 as compared to observations in 1982.

The full regression models, sexes combined, indicated that maturity schedules were significantly different between sexes; sexes were therefore analyzed separately. For all models, year was significant ($p<<0.05$; BIC>10; Tables 8-13), indicating a significant shift in size and age at maturation between 1982 and 2008. M_{50} in 1982 for females was approximately 52 cm (Table 14) and 6 years; 8 cm larger than the combined macroscopic results in 2008 and 6 cm larger than the histology results. M_{50} for males in 1982 was approximately 63 cm (Table 15) and 8 years; 6 cm larger than the combined macroscopic results in 2008 and 16 cm larger than the histology results.

Age at Length

The age-length keys developed from the two growth models: von Bertalanffy using raw data and the von Bertalanffy growth model using equally weighted mean length-at-age values are shown in Tables 16 and 2.

Growth models

Von Bertalanffy growth model results based on individual observations are displayed in Tables 17-19; Figures 9-11. Asymptotic length was substantially larger than previous estimates, due to few old fish in the sample and relatively high frequency of fish ages 5-10. To address this uneven sample distribution, alternative von Bertalanffy growth models were fit to mean length-at-age, which weights each age equally (Tables 20-22; Figures 12-14).

Discussion

These results show a significant decrease in size and age at maturation since the last evaluation of this stock in the early 1980's (Grimes et al. 1986). An environment in which survival rates are low for potentially reproducing individuals, often favors selection of individuals that are able to reproduce at smaller sizes and younger ages (Hutchings 1993; Reznick et al. 1990). In a hook fishery, it is assumed that the smallest fish in the population are less vulnerable to the gear depending on the hook size. In this fishery, hook size has been intentionally increased to avoid catch of the smallest fish in the population. The fact that such dramatic changes have manifested in this stock may suggest a density-dependent effect of decreased population size. It is uncertain at this point in time, whether these changes are consequences of phenotypic plasticity or selection towards genotypes with lower size and age at maturation.

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Table 1. Proportion mature at length for 2008 females (macroscopic)

Proportion	Length	SE
p = 0.025	36.35355	3.005000
p = 0.250	42.22186	1.487536
p = 0.500	44.73536	1.115889
p = 0.750	47.24885	1.203578
p = 0.975	53.11716	2.545929

Table 2. Age-length keys from von Bertalanffy growth model using mean length at age (sexes combined)

Age at Length		Length at Age	
Length (cm)	Age (years)	Length (cm)	Age (years)
10	1	7	1
11	1	20	2
12	1	31	3
13	1	40	4
14	2	49	5
15	2	56	6
16	2	63	7
17	2	68	8
18	2	73	9
19	2	78	10
20	2	81	11
21	2	85	12
22	2	88	13
23	2	90	14
24	2	92	15
25	2	94	16
26	3	96	17
27	3	98	18
28	3	99	19
29	3	100	20
30	3	101	21
31	3	102	22
32	3	103	23
33	3	103	24
34	3	104	25
35	3	104	26
36	4	105	27
37	4	105	28
38	4	106	29
39	4	106	30
40	4	106	31
41	4	106	32
42	4	107	33
43	4	107	34

44	4
45	5
46	5
47	5
48	5
49	5
50	5
51	5
52	5
53	6
54	6
55	6
56	6
57	6
58	6
59	6
60	7
61	7
62	7
63	7
64	7
65	7
66	8
67	8
68	8
69	8
70	8
71	9
72	9
73	9
74	9
75	9
76	10
77	10
78	10
79	10
80	11
81	11
82	11
83	11
84	12
85	12
86	12
87	13
88	13
89	14
90	14
91	14
92	15
93	15
94	16
107	35
107	36
107	37
107	38
107	39
107	40
107	41
107	42
108	43
108	44
108	45
108	46
108	47
108	48
108	49
108	50

95	16
96	17
97	18
98	18
99	19
100	20
101	21
102	22
103	24
104	25
105	28
106	31
107	36

Table 3. Proportion mature at length for 2008 females (histological)

Proportion	Length	SE
p = 0.025	36.62657	3.160495
p = 0.250	43.10680	1.433769
p = 0.500	45.88239	1.043394
p = 0.750	48.65799	1.256798
p = 0.975	55.13821	2.898430

Table 4. Proportion mature at length for 2008 males (macroscopic)

Proportion	Length	SE
p = 0.025	39.32151	3.381805
p = 0.250	51.07196	1.644096
p = 0.500	56.10488	1.289149
p = 0.750	61.13780	1.496608
p = 0.975	72.88825	3.145142

Table 5. Proportion mature at length for 2008 males (histological)

Proportion	Length	SE
p = 0.025	38.14695	2.954953
p = 0.250	45.13220	1.528347
p = 0.500	48.12411	1.142997
p = 0.750	51.11601	1.141340
p = 0.975	58.10127	2.299208

Table 6. Proportion mature at length for 2008 females (all macroscopic observations)

Proportion	Length	SE
p = 0.025	31.60688	2.2969273
p = 0.250	40.49261	1.1497262
p = 0.500	44.29852	0.8305603
p = 0.750	48.10443	0.8333328
p = 0.975	56.99016	1.7842602

Table 7. Proportion mature at length for 2008 males (all macroscopic observations)

Proportion	Length	SE
p = 0.025	38.11876	1.8763305
p = 0.250	51.60568	0.8664657
p = 0.500	57.38236	0.7582732
p = 0.750	63.15904	1.0026450
p = 0.975	76.64596	2.0903147

Table 8. Logistic regression model output for length at maturation (females - macro)

Coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-12.91363	0.74598	-17.311	< 2e-16 ***
length	0.24692	0.01372	17.994	< 2e-16 ***
year2008	2.05630	0.25472	8.073	6.87e-16 ***

Table 9. Logistic regression model output for length at maturation (males - macro)

Coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-8.787480	0.443466	-19.815	< 2e-16 ***
year2008	0.741363	0.159973	4.634	3.58e-06 ***
length	0.139662	0.007022	19.889	< 2e-16 ***

Table 10. Logistic regression model output for length at maturation (females – histo 2008; macro 1982)

Coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-12.8166	0.7826	-16.376	< 2e-16 ***
length	0.2451	0.0144	17.017	< 2e-16 ***
year2008	1.5979	0.3856	4.144	3.41e-05 ***

Table 11. Logistic regression model output for length at maturation (males – histo 2008; macro 1982)

Coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-8.310188	0.485691	-17.110	< 2e-16 ***
year2008	2.445288	0.298275	8.198	2.44e-16 ***
length	0.131946	0.007707	17.120	< 2e-16 ***

Table 12. Logistic regression model output for age at maturation (females)

Coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-8.88270	0.58353	-15.22	<2e-16 ***
age	1.49627	0.09428	15.87	<2e-16 ***
year2008	2.26650	0.24190	9.37	<2e-16 ***

Table 13. Logistic regression model output for age at maturation (males)

Coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-5.23012	0.27635	-18.926	< 2e-16 ***
age	0.62969	0.03419	18.415	< 2e-16 ***
year2008	1.20293	0.15711	7.657	1.91e-14 ***

Table 14. Proportion mature at length for 1982 females (Grimes et al. 1988)

Proportion	Length	SE
p = 0.025	37.05423	1.0855842
p = 0.250	47.69894	0.5337725
p = 0.500	52.25825	0.3908343
p = 0.750	56.81757	0.4133665
p = 0.975	67.46228	0.8934191

Table 15. Proportion mature at length for 1982 males (Grimes et al. 1988)

Proportion	Length	SE
p = 0.025	33.76355	1.8815446
p = 0.250	54.25703	0.8505181
p = 0.500	63.03475	0.7033085
p = 0.750	71.81246	0.9232099
p = 0.975	92.30595	1.9925294

Table 16. Age-length keys from von Bertalanffy growth model (sexes combined)

Age at Length		**Length at Age**	
Length (cm)	Age (years)	Length (cm)	Age (years)
10	1	12	1
11	1	23	2
12	1	32	3
13	1	40	4
14	1	48	5
15	1	55	6
16	1	61	7
17	1	67	8
18	2	72	9
19	2	77	10
20	2	81	11
21	2	85	12
22	2	89	13
23	2	92	14
24	2	95	15
25	2	98	16
26	2	100	17
27	2	102	18
28	3	104	19
29	3	106	20
30	3	108	21
31	3	109	22
32	3	111	23
33	3	112	24
34	3	113	25
35	3	114	26
36	3	115	27
37	4	116	28
38	4	116	29
39	4	117	30
40	4	118	31
41	4	118	32
42	4	119	33
43	4	119	34
44	4	120	35
45	5	120	36
46	5	120	37
47	5	121	38
48	5	121	39

49	5	121	40
50	5	121	41
51	5	122	42
52	6	122	43
53	6	122	44
54	6	122	45
55	6	122	46
56	6	123	47
57	6	123	48
58	6	123	49
59	7	123	50
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118	32
119	33
120	36
121	39
122	44
123	52

Table 17. von Bertalanffy growth model parameter estimates (sexes combined)

Parameter	Estimate	Std Error	Approximate 95% Confidence Limits	
li	123.8	7.7452	108.5	139.1
k	0.0969	0.0127	0.0719	0.1219
t0	-0.0778	0.2908	-0.6519	0.4962

Table 18. von Bertalanffy growth model parameter estimates (females)

Parameter	Estimate	Std Error	Approximate 95% Confidence Limits	
li	112.0	9.1182	93.8035	130.2
k	0.0964	0.0175	0.0614	0.1313
t0	-0.5450	0.4590	-1.4618	0.3717

Table 19. von Bertalanffy growth model parameter estimates (males)

Parameter	Estimate	Std Error	Approximate 95% Confidence Limits	
li	141.5	12.1959	117.3	165.7
k	0.0833	0.0136	0.0564	0.1102
t0	-0.0920	0.3331	-0.7527	0.5687

Table 20. von Bertalanffy growth model parameter estimates using mean length at age (sexes combined)

Parameter	Estimate	Std Error	Approximate 95% Confidence Limits	
li	107.9	5.7375	95.9875	119.8
k	0.1338	0.0226	0.0869	0.1807
t0	0.4944	0.5182	-0.5802	1.5690

Table 21. von Bertalanffy growth model parameter estimates using mean length at age (females)

Parameter	Estimate	Std Error	Approximate 95% Confidence Limits	
li	100.1	7.1457	84.1627	116.0
k	0.1393	0.0337	0.0643	0.2142
t0	0.4136	0.7551	-1.2688	2.0961

Table 22. von Bertalanffy growth model parameter estimates using mean length at age (males)

Parameter	Estimate	Std Error	Approximate 95% Confidence Limits	
li	122.2	7.6163	105.0	139.5
k	0.1134	0.0196	0.0691	0.1577
t0	0.4276	0.5271	-0.7649	1.6200

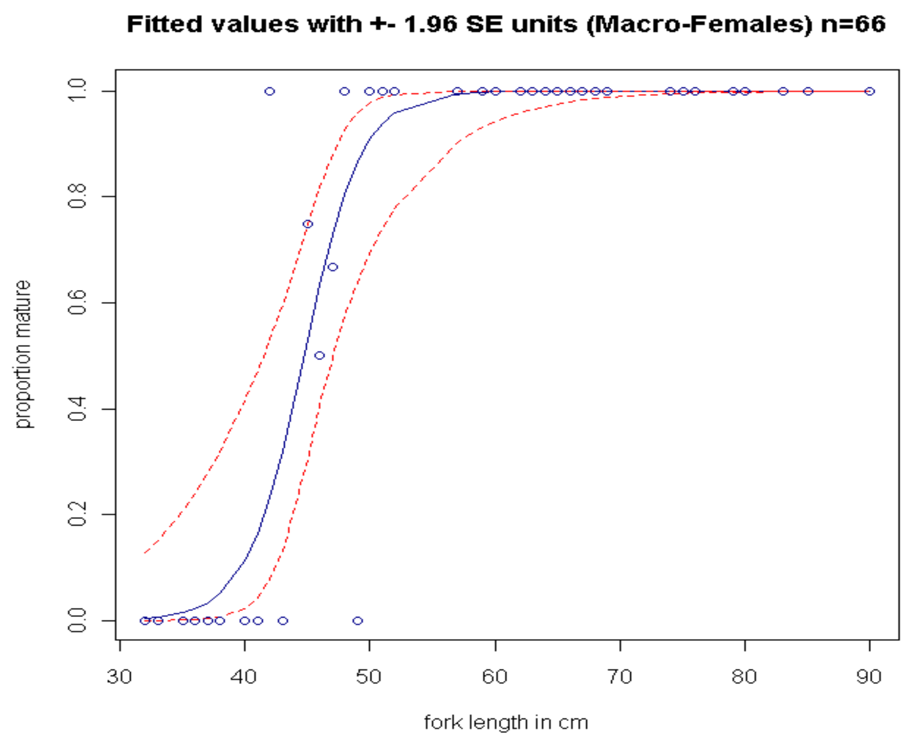

Figure 1. Maturity ogive for females based on macroscopic data (2008)

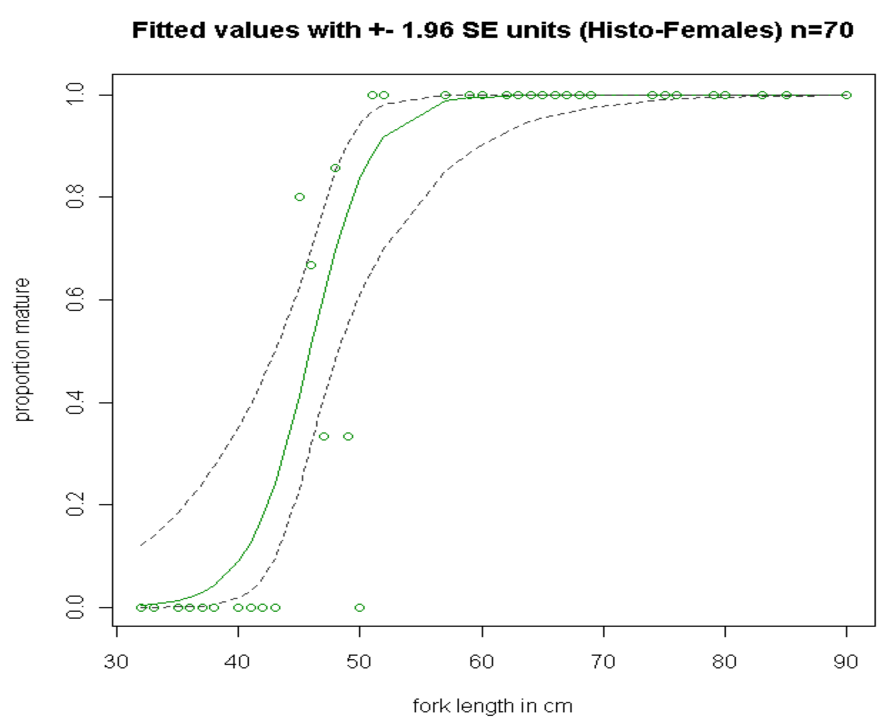

Figure 2. Maturity ogive for females based on histological data (2008)

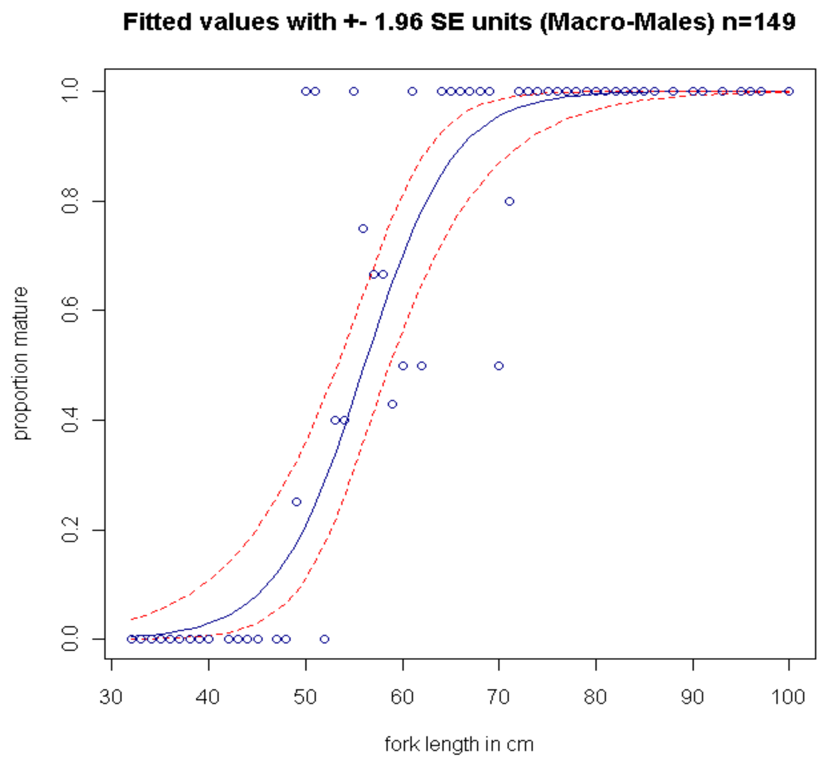

Figure 3. Maturity ogive for males based on macroscopic data (2008)

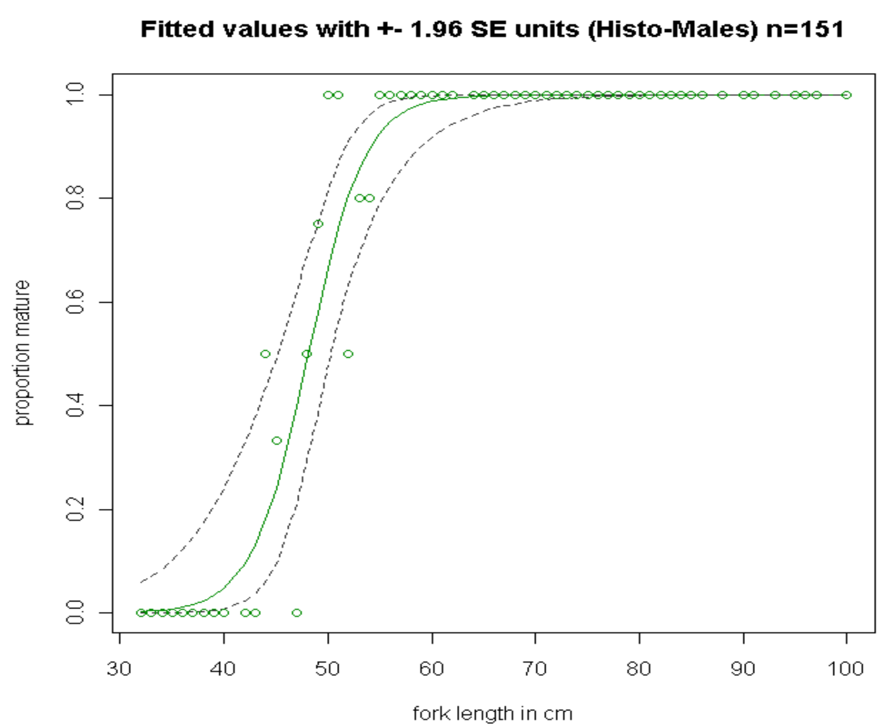

Figure 4. Maturity ogive for males based on histological data (2008)

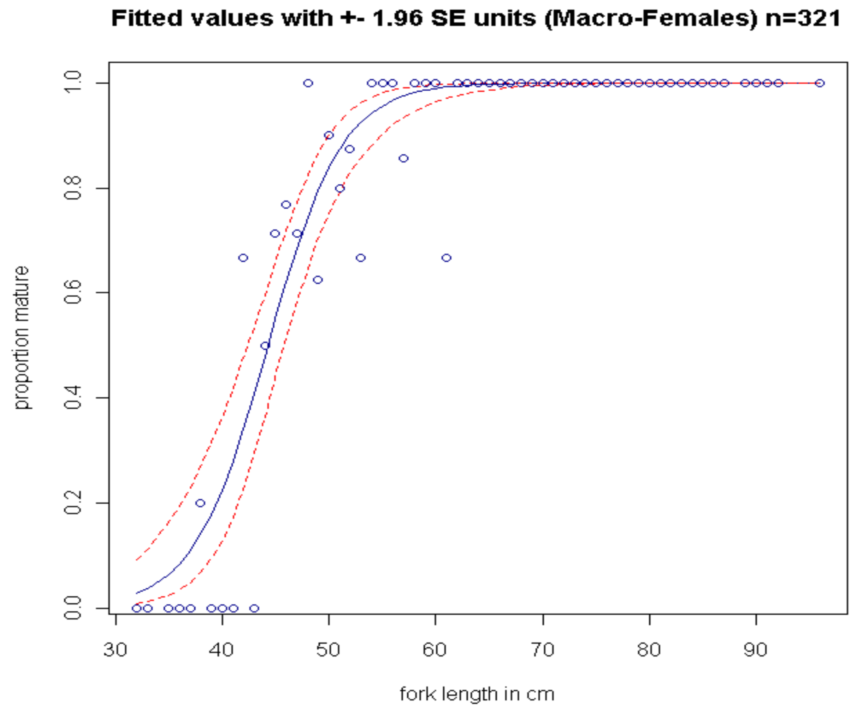

Figure 5. All macroscopic observations for females (2008)

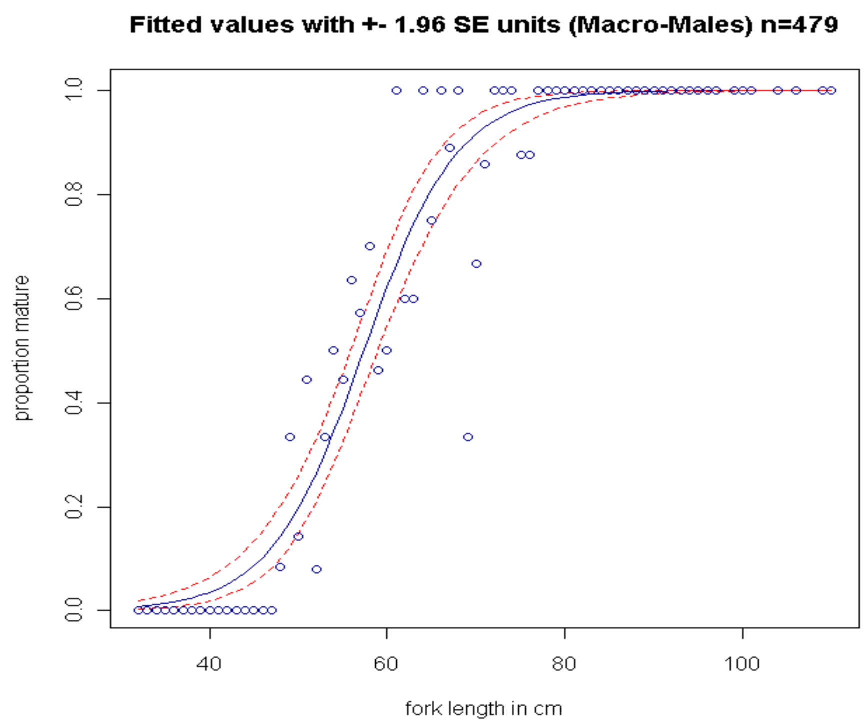

Figure 6. All macroscopic observations for males (2008)

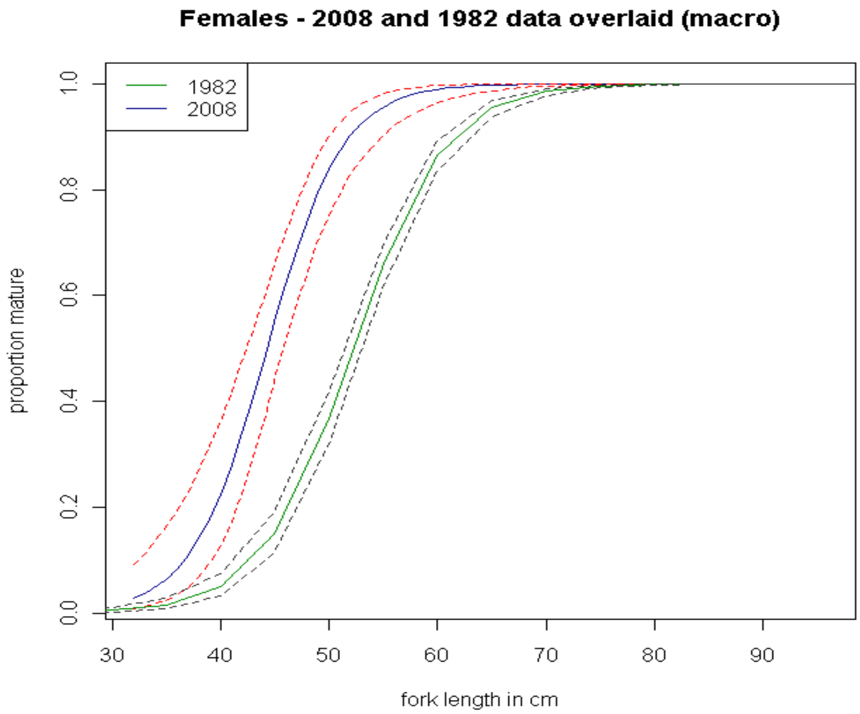

Figure 7. Maturity ogives, with 95% confidence limits, for the 1982 and 2008 females: green line=1982; blue line=2008. The 2008 data is based on all macroscopic observations..

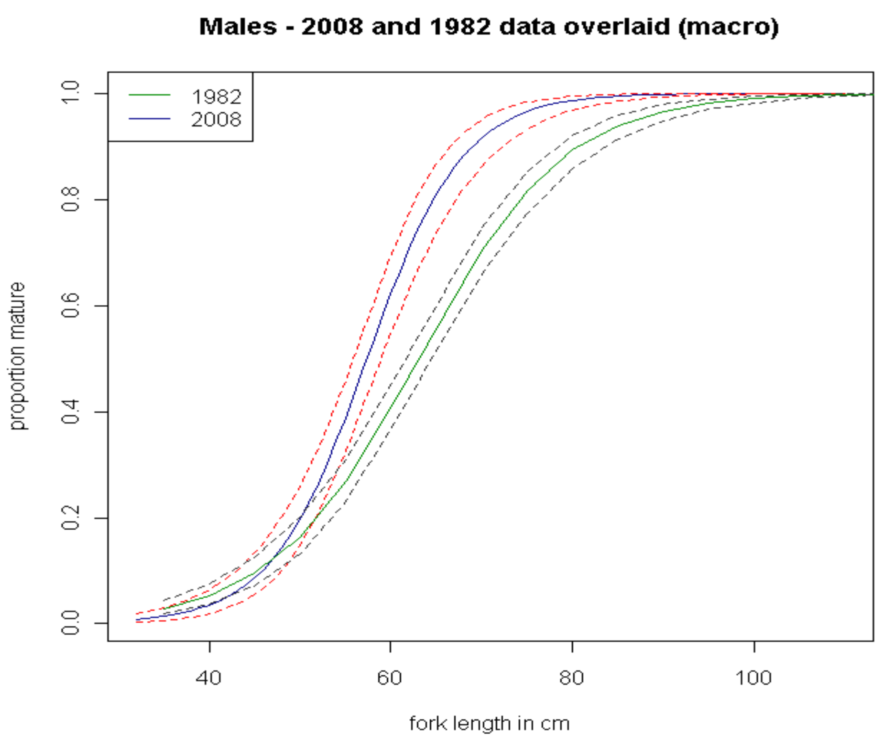

Figure 8. Maturity ogives, with 95% confidence limits, for the 1982 and 2008 males: green line=1982; blue line=2008. The 2008 data is based on all macroscopic observations

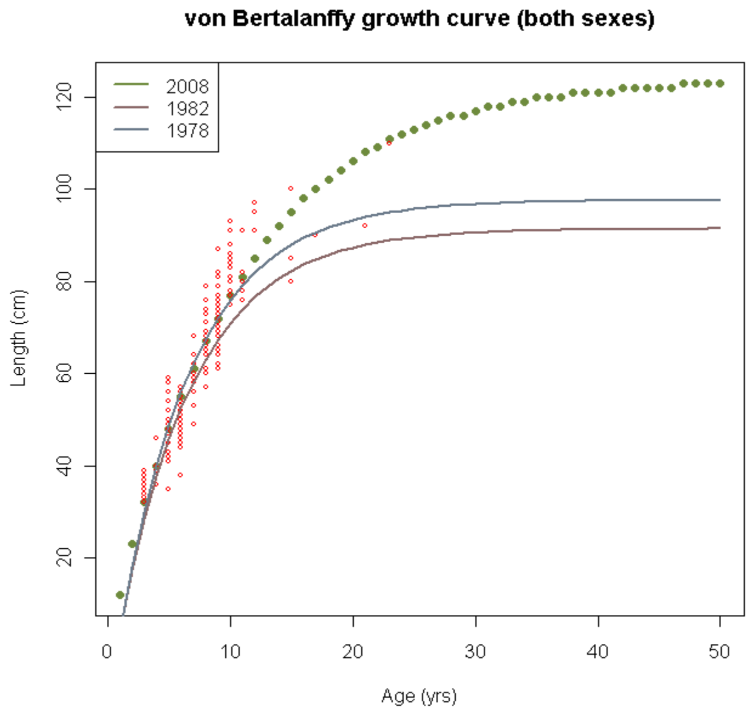

Figure 9. von Bertalanffy growth curve fit to observations of length at age (sexes combined)

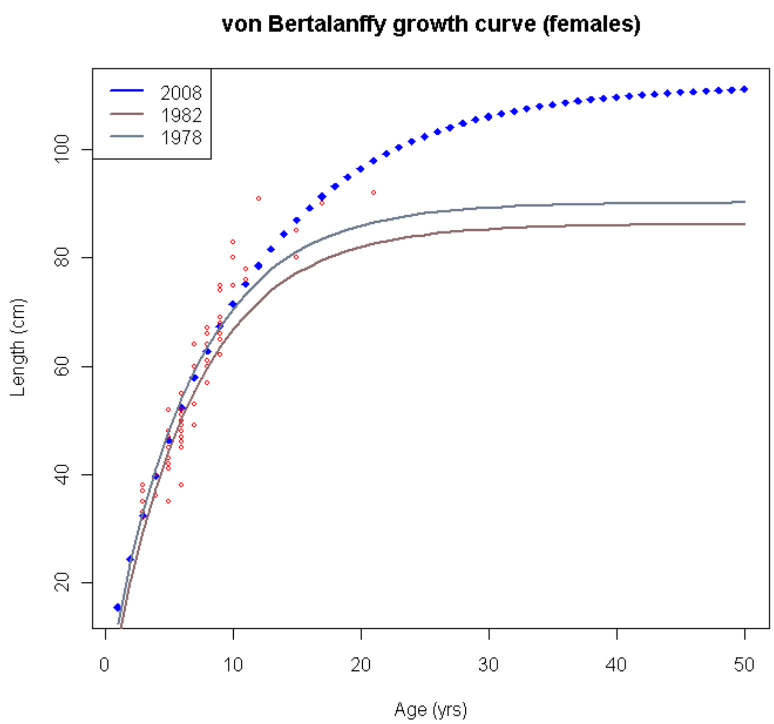

Figure 10. von Bertalanffy growth curve fit to observations of length at age (females)

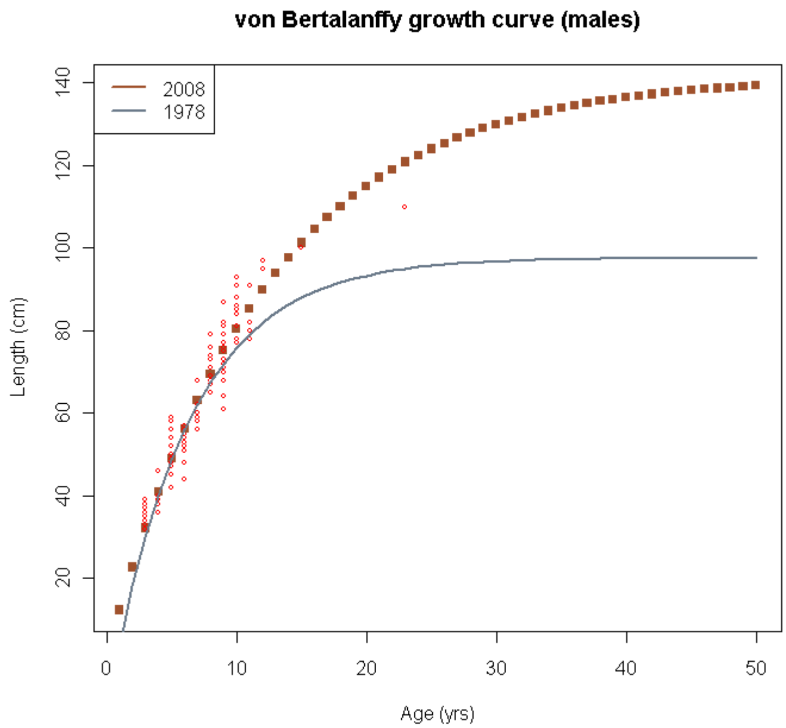

Figure 11. von Bertalanffy growth curve fit to observations of length at age (males)

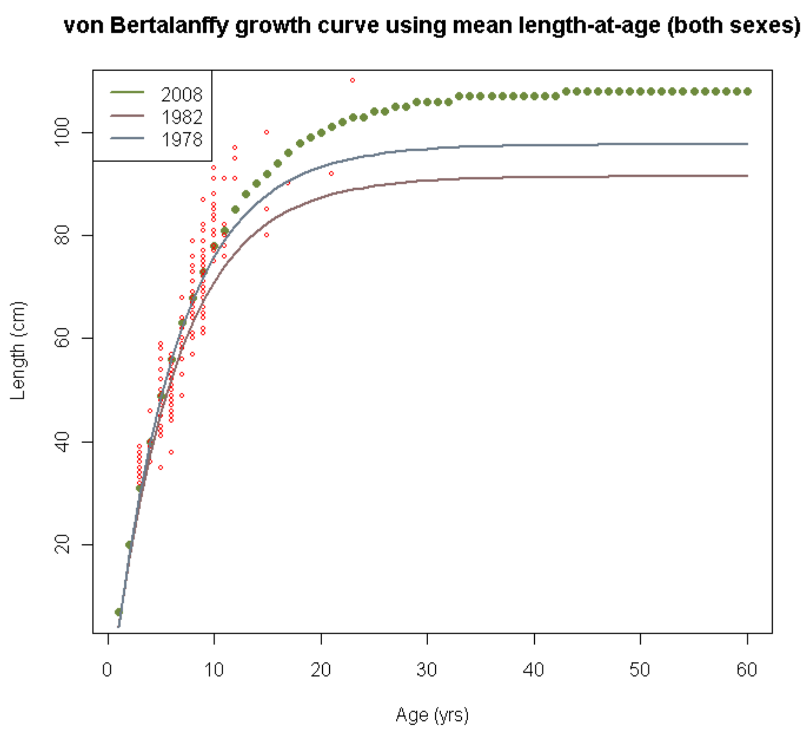

Figure 12. von Bertalanffy growth curve fit to mean length at age (sexes combined)

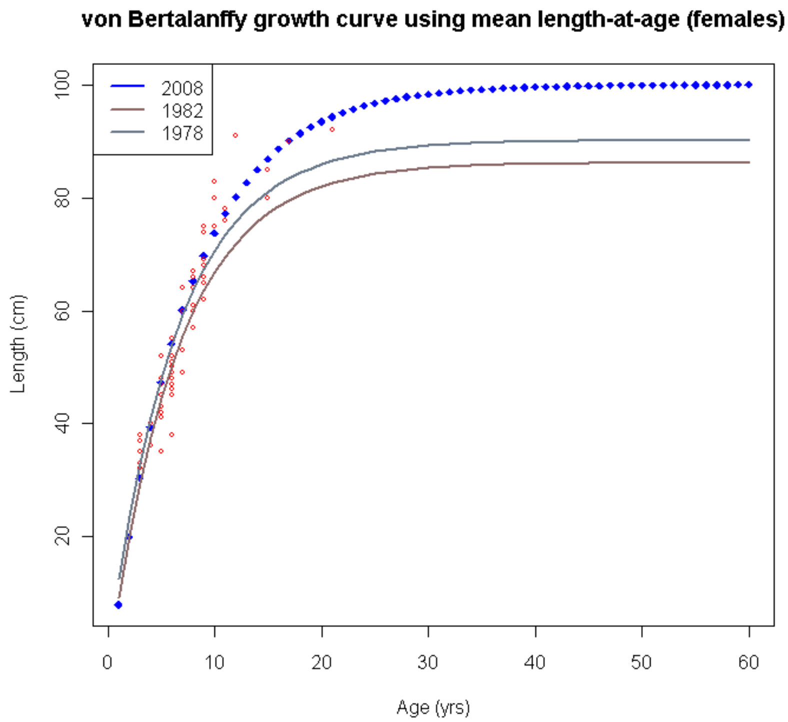

Figure 13. von Bertalanffy growth curve fit to mean length at age (females)

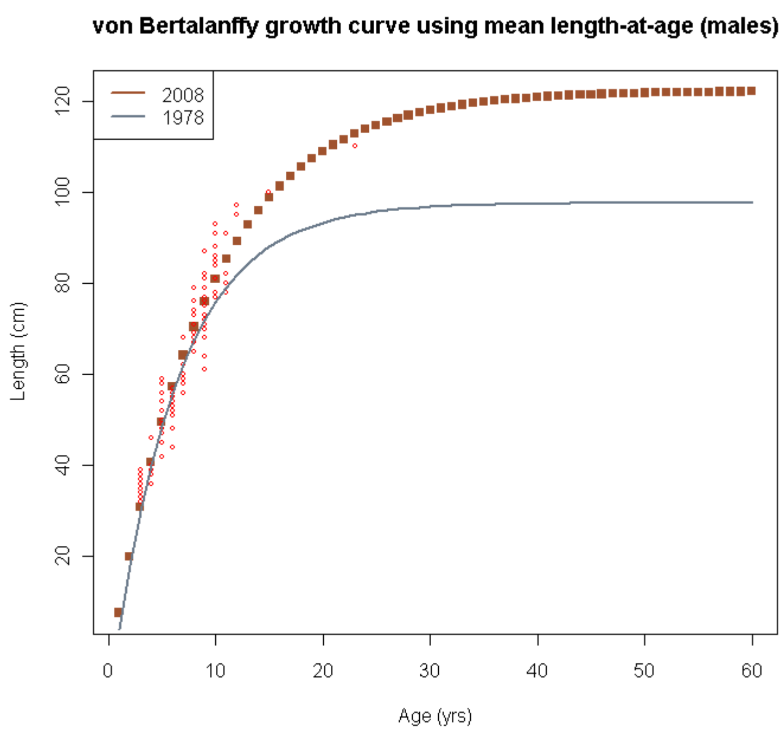

Figure 14. von Bertalanffy growth curve fit to mean length at age (males)