RED DRUM MATURITY ANALYSES

Steve Arnott (SCDNR), March 2015

SUMMARY

This report presents analyses of red drum maturity for the 2015 stock assessment by ASMFC. The report is divided into two parts, as follows:

In Part 1, preliminary analyses of maturity data is presented for South Carolina male and female red drum. The results from these analyses were discussed at the assessment data workshop in October 2014, and during subsequent conference calls.

In Part 2, follow-up analyses were performed to address issues arising from the preliminarily analyses. In addition, raw data were provided from a NC red drum maturity study by Ross et al (1995). This allowed data from the northern and southern red drum management units to be directly compared with one another and analyzed using common methodology. (Note that, in the 2009 SEDAR 18 red drum stock assessment, maturity relationships from the northern region were assigned to the southern region; none were developed independently using southern data).

The analyses in Part 2 found significant differences between the maturity relationships of NC and SC red drum. **Table 2.5** summarizes the final regression model parameters and the 50% maturity length and age for males and females from each region.

In SC (which had more data available), significant differences in size and age of maturity relationships were detected between time periods from the 1980s to 2013. However, these differences may have been driven by poor data availability in certain time periods or certain sizes, ages or maturity studies. Furthermore, the majority of maturity assessments (in both regions) were made by macroscopic inspection of gonads and, in SC, by multiple workers, so it is difficult to validate and standardize the assessments *post hoc*. It is recommended that maturity should be assessed annually, with at least a portion of gonad samples processed and archived histologically, so specimens can be kept for future temporal and regional comparisons.

PART 1: INITIAL ANALYSES OF SOUTH CAROLINA RED DRUM MATURITY FOR THE ASSESSMNENT DATA WORKSHOP (OCT 2015)

Description of South Carolina red drum maturity data

Length and age at maturity were examined using an initial dataset of 7,177 red drum collected from the waters of South Carolina between 1984 and 2013 (data file: Minitab file *RedDrumMaturity.MPJ*, which has maturity data taken from the Excel file *SC LifeHistoryDataAll-RAW_14-10-07.xlsx*). From this dataset, specimens identified as females or males were partitioned (some fish were too young to have sex assigned). Further details of data available for South Carolina females and males are given in **Table 1.1** and **Table 1.2**, respectively.

Comparison of sexes
A significant difference was detected between male and female length at maturity (logistic regression, TL*sex interaction, $p < 0.001$). Similarly, a significant difference between sexes was found in age at maturity (logistic regression, sex effect, $p < 0.001$). Maturity in males generally occurred at a smaller size and younger age than in females. Therefore, maturity was examined separately for each sex.

South Carolina female red drum length at maturity
Maturity data were available from a total of 2,614 female red drum collected by a variety of gear types (**Table 1.1**). To test the effects of gear type, data were compared from the years 2007-2013, and from specimens collected by trammel net, 1/3rd mile longline and hook & line (i.e. gear types with the most data). This revealed no significant effect of gear type on the relationship between TL and maturity (logistic regression, TL*gear interaction, $p = 0.258$; gear effect, $p = 0.239$). Therefore data from all gear types were pooled.

To test for temporal changes in female length at maturity, data from different years were pooled into the following categories: 1980s, 1990-94, 1995-99, 2000-04, 2005-09 and 2010-2013. A significant difference in length at maturity was detected among these time periods (logistic regression, TL*period interaction, $p = 0.017$, **Fig. 1.1**). This was apparently driven by smaller sizes at maturity during the 1980s and 2005-09. The 2005-09 effect may be an artifact caused by low numbers of large fish specimens during that time period (**Fig. 1.2**). The size at fifty percent maturity (TL_{50}) varied between approximately 730-850 mm, depending on period. Since maturity assessments rely upon some subjectivity, and were made by multiple assessors, it is difficult to determine whether the temporal differences were real of due to assessment errors.

For data pooled across all gears and periods, size at fifty percent maturity occurred at TL = 793 mm. A separate analysis of Jul-Dec data (i.e. around the spawning months) produced a similar result of 784.6 mm.

South Carolina female red drum age at maturity
For female age at maturity, age class data were used (assuming a Jan 1st age transition date; i.e. age class = year of capture – year of birth). Using data from the years 2007-2013 collected by trammel net, 1/3rd mile longline and hook & line, a significant gear effect was detected on age at maturity (logistic regression, $p = 0.002$). This was likely driven by habitat shifts as fish mature. For example, a comparison of trammel net red drum (inshore, sub-adult habitat) against 1/3rd mile longline red drum (offshore, adult habitat) indicated that trammel fish of a given age were smaller than equivalent aged longline red drum (i.e. maturity and movement into adult habitat appears to be associated more tightly with size than age).

An analysis of all the female data also indicated that age at maturity differed significantly across time periods (logistic regression, period*age interaction, $p < 0.001$; period, $p < 0.001$; **Fig. 1.3**).

Using all pooled female data, 50% maturing occurred at 4.7 years. The value was 4.4 years when data from just Jul-Dec were used. (See Part 2 for additional analyses using decimal ages).

South Carolina male red drum length at maturity
Maturity data were available for a total of 2,930 male red drum (**Table 1.2**). To test the effects of gear type on length at maturity, data from the years 2007-2013 collected by trammel net, 1/3rd mile longline and hook & line were compared. This revealed no significant effect of gear type on the relationship between TL and maturity (logistic regression, TL*gear interaction, p = 0.41; gear effect, p = 0.29). Therefore data from all gear types were pooled.

To test for temporal changes in male length at maturity, data from different years were pooled into the following categories: 1980s, 1990-94, 1995-99, 2000-04, 2005-09 and 2010-2013. A significant difference in length at maturity was detected among these time periods (logistic regression, TL*period interaction, p = 0.02). The size at fifty percent maturity varied between approximately 700-750 mm, depending on period (**Fig. 1.4**, **Fig. 1.5**).

For data pooled across all gears and periods, size at fifty percent maturity occurred at TL = 714 mm. A separate analysis of Jul-Dec data (i.e. during and just after spawning) produced a slightly smaller result of 694 mm.

South Carolina male red drum age at maturity
For male age at maturity, age class data were used (assuming a Jan 1st transition date; i.e. age = year of capture – year of birth). Using data from the years 2007-2013 collected by trammel net, 1/3rd mile longline and hook & line, a significant gear effect was detected on age at maturity (age*gear interaction, p < 0.001, gear effect, p < 0.001). As with females, this was probably associated with habitat (i.e. gear) shifts as fish grow and mature.

An analysis of all the male data also indicated that age at maturity differed significantly across time periods (period*age interaction, p < 0.017; period, p < 0.004; **Fig. 1.6**). Using all male data pooled, 50% maturing occurred at 3.8 years. The value was 3.3 years when data from just Jul-Dec were used. (See Part 2 for additional analyses using decimal ages).

PART 2: FOLLOW-UP ANALYSES OF SOUTH CAROLINA & NORTH CAROLINA RED DRUM MATURITY (FEB 2015)

Issues arising from the data workshop and conference calls
At the red drum stock assessment data workshop, and during subsequent conference calls, three questions arose from the analyses presented in Part 1 (above):

1) *Temporal variation in maturity of South Carolina red drum*: If time periods were blocked differently (cf 5 year blocks, as above), would temporal differences in maturity schedules still be detected?

2) *Macroscopic assessment compared with histological assessment of maturity*: Do analyses of histologically assessed maturity produce similar results to those from macroscopic (gross) assessments? (n.b. all the assessments presented in Part 1 are from macroscopic assessments).

3) *Differences between Northern and Southern Atlantic stocks*: Are SC maturity data significantly different from NC maturity data. (n.b. In SEDAR 18, maturity schedules from NC were used for the southern management unit).

The maturity analyses presented below focus primarily on relationship between female length and maturity because the model selected for the 2015 red drum stock assessment uses length at maturity. Note that age at maturity was used in the 2009 SEDAR 18 assessment, but the reviewers suggested that length would be a better parameter to use in future assessments. Furthermore, analyses presented in Part 1 (above) suggested that length is a better predictor of maturity than age, and that it is not sensitive to gear effects. Age at maturity and male maturity relationships were also examined for completeness, and also because age at maturity is used by some of the empirical methods for estimating natural mortality.

1) Temporal variation in maturity of South Carolina red drum

To address issue 1 (temporal variation in SC maturity relationships), logistic regressions were used to test male and female size at maturity data based on macroscopic gonad assessments. Data were filtered to only include specimens collected during July through December (i.e. months around the spawning season). Instead of 5 year time periods (as in Part 1), year was entered as a categorical factor in the models (interactions were not tested due to further data limitations). Some years had to be removed from the analyses due to data limitations that prevented the model from converging. The size at 50% maturity (TL_{50}) for each year was then calculated from the model parameters. These showed significant variations from year to year ($p < 0.001$), likely driven, to a degree, by data related issues (small samples sizes, or no data, within certain size categories from year to year). There were, however, no obvious long-term trends (**Fig. 2.1**).

Despite apparent temporal fluctuations in length at maturity, it was decided in a further conference call that the stock assessment model would assume a constant relationship over time. This was partly for model simplicity, and partly because there were no apparent long-term trends. Furthermore, it is uncertain whether the detected temporal variations are real, or due to data-related issues (e.g. macroscopic assessments by multiple workers over time, which cannot be validated *post-hoc*, or small sample sizes in certain data categories, as discussed above).

2) Macroscopic assessment compared with histological assessment of maturity, SC red drum.

Sex and maturity data from histological assessments were available from a total of 287 South Carolina red drum, including 118 males and 169 females (see **Table 2.1**). Two hundred and eighty-five of these also had macroscopic assessments made for sex and maturity. Disagreement of sex allocation between macroscopic and histological assessments was 0.4% (1/285). Among agreed males, disagreement in maturity was 7.8% (9/115) and among agreed females, disagreement in maturity was 4.1% (7/169) (**Table 2.2**).

The method of maturity assessment (macroscopic vs histology) had no significant effect on the relationship between the probability of being mature and TL (data from Jul-Dec specimens only; for females: method, p = 0.32; TL*method interaction, p = 0.48; n = 164; for males: method, p = 0.94; TL*method interaction, p = 0.71, n = 112).

Among females collected between the months July-December, there were 11, 68 and 85 specimens caught in 1998, 2010 and 2013, respectively. Year of capture had no apparent effect on the relationship between size at maturity (year, p = 0.95; TL*year, p = 0.32), although these results were not robust because the model did not fully converge (probably due to small numbers of immature fish in the dataset).

Among males collected between the months July-December, there were 10, 49 and 53 specimens caught in 1998, 2010 and 2013, respectively. Year of capture had no apparent effect on the relationship between size at maturity (year, p = 0.28; TL*year, p = 0.99), although, as with females, the model did not fully converge.

3) Differences between northern and southern Atlantic red drum stock

Description of datasets

Ross et al (1995) described the size at maturity of red drum caught in North Carolina between 1987 and 1990 (also summarized in NCDEHNR report F-29 by Ross & Stevens, 1992, project F-29). The study used a combination of macroscopic and histological (~29% of samples) assessments for assigning sex and maturity. Lee Paramore (NCDMF) accessed the original data from their study the purpose of reanalysis here. **Table 2.3** summarizes the data available from both NC and SC, by sex and month.

In the NC dataset provided by NC DMF, fish were measured in fork length. Those data were converted to total length using the northern Atlantic stock conversion factors from the current stock assessment (TL = 1.088085*FL – 23.9413). Reproductive condition in the NC dataset and the Ross & Stevens report (1992) was coded using numerical categories 1-8 (verified by Lee Paramore, NC DMF). This differed from the categories 1-7 reported in the Ross et al 1995 manuscript. **Table 2.4** summarizes the categories used for NC red drum, as well as categories used by SCDNR for SC red drum. Note that Ross & Stevens (1992) and Ross et al (1995) considered 'developing' fish to be immature, which is different from the more widely accepted practice outlined by Brown-Peterson et al (2011). Therefore, to standardize maturity analyses across SC and NC datasets, all data were categorized as mature if they had Brown-Peterson stages 'developing', 'spawning capable', 'regressing' or 'regenerating' (see **Table 2.4**; *n.b.* an additional two 'senescing' fish in the NC dataset were classified here as mature; they had ages of 36 and 49 years).

Female length at maturity

Initial exploration of the data indicated that, among the SC female fish, time of year (quarter) had a significant effect on length at maturity (logisitic regression with covariate TL and categorical factor quarter-of-year, $p < 0.001$ and $p = 0.015$, respectively). Time of year was not significant with the NC dataset ($p = 0.168$). Nevertheless, further analyses were restricted to data from just the second half of the year (Jul-Dec) for both SC and NC datasets to standardize comparisons around the period of spawning (fall months).

Using the July – December data, length at maturity was found to be significantly different between NC and SC regions (logistic regression with TL covariate, $p < 0.001$; region categorical factor, $p < 0.001$).

Using just data from July-December, TL_{50} was 784.6 mm for SC and 872.6 mm for NC red drum (**Fig 2.2**). Parameters of the fitted logistic models are given in **Table 2.5**.

Female age at maturity

Age at length, models were fit using calendar age (Jan 1 birth date) in decimal years (e.g. a fish born during 2010 and caught on 1 July 2011 would have and age of 1.5 years). Data from all months of the year were used for the analyses. A significant difference was detected between NC and SC age at maturity (logistic regression with covariate TL and categorical factor region, $p < 0.001$ for TL, region and the TL*region interaction). Therefore, maturity was fit separately for each region.

Analysis of just the SC data produced 50% maturity at 5.1 years (**Fig. 2.3**), whereas for NC females 50% maturity occurred at 4.1 years (**Fig. 2.4**). Parameters of the fitted logistic models are given in **Table 2.5**.

Male length at maturity

Using the data from just July – December, length at maturity was found to be marginally different between NC and SC regions (logistic regression: TL covariate, $p < 0.0001$; region factor, $p = 0.05$).

Using just data from July-December, TL_{50} was 693.7 mm for SC and 672.6 mm for NC red drum (**Fig 2.5**). Parameters of the fitted logistic models are given in **Table 2.5**.

Male age at maturity

Age at length, models were fit using calendar age (Jan 1 birth date) in decimal years (e.g. a fish born during 2010 and caught on 1 July 2011 would have and age of 1.5 years). Data from all months of the year were used for the analyses. A significant difference was detected between NC and SC age at maturity (logistic regression with covariate TL and categorical factor region, $p < 0.001$ for both TL and region). Therefore, maturity was fit separately for each region.

Analysis of just the SC data produced 50% maturity at 4.2 years (**Fig. 2.6**), whereas for NC females 50% maturity occurred at 2.9 years (**Fig. 2.7**). Parameters of the fitted logistic models are given in **Table 2.5**.

REFERENCES

Brown-Peterson NJ, Wyanski DM, Saborido-Rey F, Macewicz BJ, Lowerre-Barbieri SK (2011) A Standardized Terminology for Describing Reproductive Development in Fishes. Mar Coast Fish Dynam Manag Ecosys Sci, 3: 52-70

Ross JL & Stevens TM (1992) Life history and population dynamics of red drum (*Sciaenops ocellatus*) in North Carolina waters. Completion Report for Project F-29, North Carolina Department of Environment, Health, and Natural Resources. Morehead City, NC.

Ross JL, Stevens TM & Vaughan DS (1995) Age, growth, mortality, and reproductive biology of red drums in North Carolina waters. Trans Am Fish Soc, 124: 37–54.

TABLES, PART 1

Table 1.1 Samples available for maturity analyses of South Carolina female red drum

GEAR	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	All
75' FALCON TRAWL W/OUT TED	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	**5**
75' FALCON TRAWL WITH TED	0	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**22**
BOTTOM LONG LINE - 1 MILE	0	0	0	0	0	0	0	0	0	0	0	0	22	10	8	14	0	3	0	0	1	3	0	3	0	0	0	0	0	0	**64**
BOTTOM LONG LINE - 1/2 J HOOKS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	**1**
BOTTOM LONG LINE - 1/3 MILE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	32	38	66	34	59	0	**244**
DIP NET	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	**2**
ELECTROFISHING	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	22	0	1	2	0	0	0	0	0	0	4	0	**31**
GIG	0	0	4	13	1	0	0	0	0	0	0	0	1	0	4	0	33	0	10	17	7	8	8	10	5	2	3	1	1	0	**128**
GILL NET - MESH F - 2 1/2" STRE	0	2	1	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**15**
HAND PICKING	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	2	0	0	0	**6**
HOOK & LINE	1	12	63	86	63	20	39	30	22	12	13	36	62	44	51	41	49	50	69	55	34	18	22	50	26	29	30	33	34	11	**1105**
MARFIN TRAMMEL NET - 150 YD - 1	0	0	0	0	0	0	0	0	0	0	0	12	17	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**31**
ROTENONE	0	0	0	0	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**4**
SEMI - BALLOON OTTER TRAWL - 16	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
STOP NET - 366m x 3m x 51 mm st	0	0	34	45	11	13	5	4	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**120**
TRAMMEL NET - 200 YD X 8 FT - 1	0	0	0	0	0	0	0	8	21	50	32	33	39	32	15	16	20	56	63	90	70	37	25	12	35	86	35	34	17	8	**834**
All	**1**	**14**	**125**	**145**	**78**	**34**	**44**	**43**	**45**	**64**	**48**	**83**	**141**	**88**	**90**	**71**	**103**	**111**	**164**	**166**	**113**	**69**	**55**	**92**	**98**	**155**	**136**	**102**	**117**	**19**	**2614**

Table 1.2 Samples available for maturity analyses of South Carolina male red drum

Gear	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	**All**
75' FALCON TRAWL W/OUT TED	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	**4**
75' FALCON TRAWL WITH TED	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**5**
BOTTOM LONG LINE - 1 MILE	0	0	0	0	0	0	0	0	0	0	0	0	11	7	6	10	1	1	0	0	1	2	2	4	0	0	0	0	0	0	**45**
BOTTOM LONG LINE - 1/3 MILE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	24	32	37	21	36	0	**166**
CAST NET	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**4**
DIP NET	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	**2**
ELECTROFISHING	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	24	0	1	1	1	0	0	3	0	0	2	0	**35**
GIG	0	0	1	12	0	0	0	0	0	0	0	1	3	0	7	0	33	0	9	9	3	8	4	10	7	1	1	2	6	0	**117**
GILL NET - MESH F - 2 1/2" STRE	0	4	3	0	0	0	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**32**
GILL NET - MESH G - 3" STRETCH	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**
GILL NET - MESH H - 3 1/2" STRE	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
HAND PICKING	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	**1**
HOOK & LINE	1	13	64	77	45	21	23	32	36	17	18	70	59	63	44	44	47	59	81	74	46	26	46	41	40	43	53	37	49	40	**1309**
MARFIN TRAMMEL NET - 150 YD - 1	0	0	0	0	0	0	0	0	0	0	0	32	22	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**55**
ROTENONE	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
STOP NET - 366m x 3m x 51 mm st	0	1	27	63	10	7	4	1	1	3	7	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**126**
TRAMMEL NET - 200 YD X 8 FT - 1	0	0	0	0	0	0	0	9	34	82	37	37	41	54	33	31	26	47	92	94	89	43	18	21	24	93	39	33	20	27	**1024**
All	**1**	**22**	**103**	**152**	**57**	**28**	**28**	**42**	**71**	**102**	**62**	**142**	**136**	**125**	**115**	**85**	**107**	**110**	**206**	**181**	**140**	**80**	**71**	**92**	**95**	**172**	**131**	**93**	**114**	**67**	**2930**

TABLES, PART 2

Table 2.1 Number of South Carolina red drum samples with histological assessment of sex and maturity.

Collection Year	Male Qtr 1	Qtr 2	Qtr 3	Qtr 4	MALES	Female Qtr 1	Qtr 2	Qtr 3	Qtr 4	FEMALES	TOTAL
1998	2	2	4	6	14	1		2	9	12	26
2010		2	19	30	51		3	6	62	71	122
2013			8	45	53		1	17	68	86	139
TOTAL	2	4	31	81	118	1	4	25	139	169	287

Table 2.2 Comparison of macroscopic assessment and histological assessments of sex and maturity of South Carolina red drum.

MACROSCOPIC ASSESSMENT		**HISTOLOGICAL ASSESSMENT** MALE Imm	Mat	FEMALE Imm	Mat	Total
MALE	Imm	6	**5**			11
	Mat	**4**	100			104
FEMALE	Imm			17	**4**	21
	Mat		**1**	**3**	145	149
	Total	10	106	20	149	285

Table 2.3 Number of red drum maturity samples available for analysis, by state, sex and month.

	North Carolina			South Carolina			
Month	Female	Male	NC Total	Female	Male	SC Total	TOTAL
1	0	0	0	166	220	386	386
2	0	1	1	35	38	73	74
3	3	4	7	35	44	79	86
4	18	8	26	126	141	267	293
5	37	33	70	156	168	324	394
6	6	9	15	289	361	650	665
7	35	24	59	295	371	666	725
8	59	50	109	276	313	589	698
9	121	134	255	337	408	745	1,000
10	52	50	102	450	412	862	964
11	31	22	53	308	330	638	691
12	7	5	12	140	121	261	273
TOTAL	369	340	709	2,613	2,927	5,540	6,249

Table 2.4 Summary of reproductive terminology used by North Carolina and South Carolina red drum maturity datasets (numbers represent codes used in respective datasets). Gray shading shows stages considered as mature in the original analyses of NC and SC datasets, and in the Brown-Peterson et al (2011) manuscript on method standardization. For analyses presented in this report, mature fish were re-categorized based on Brown-Peterson et al (2011).

NORTH CAROLINA raw dataset (from Lee Paramore, NC DMF)	NORTH CAROLINA Ross et al (1995)	SOUTH CAROLINA SCDNR dataset	**Brown-Peterson et al (2011) terminology**
1: Immature	1: Immature	1: Immature	**Immature**
3: Maturing	2: Maturing	2: Developing	**Developing**
4: Well developed	3: Well developed		**Spawning capable**
5: Ripe	4: Ripe (gravid)	3: Ripe	**Spawning capable**
6: Partially spent	5: Partially spent		**Spawning capable**
		7: Repeat spawner	**Spawning capable**
7: Spent	6: Spent	4: Spent	**Regressing**
2: Recovering/Resting	7: Resting	5: Resting	**Regenerating**
8: Senescent*			**Regressing?***

* There were two ‘senescent’ female red drum in the NC dataset with biological ages of 36 and 49 years. They were categorized, here, as mature.

Table 2.5 Relationships between length at maturity and age at maturity in red drum from North Carolina and South Carolina. Parameters a and b (± SE) are for the logistic function $Proportion\ Mature = \frac{e^Z}{1+e^Z}$ where $Z = a + b * Predictor$.

Region	Sex	n	Predictor (independent variable)	*a* (const)	±se	*b* (slope)	±se	50% maturity	Data used
NC	Female	305	Length (TL, mm)	-38.8400	7.37006	0.0445117	0.0085605	872.6	Jul-Dec
NC	Female	334	Age (decimal years, Jan 1 birth date)	-29.8740	6.05016	7.2755200	1.5720700	4.1	Feb-Dec
NC	Male	340	Length (TL, mm)	-19.8010	3.76561	0.0294404	0.0054736	672.6	Jul-Dec
NC	Male	318	Age (decimal years, Jan 1 birth date)	-10.8147	1.88893	3.6662400	0.6152680	2.9	Feb-Dec
SC	Female	1,805	Length (TL, mm)	-17.8929	1.13022	0.0228056	0.0014545	784.6	Jul-Dec
SC	Female	2,613	Age (decimal years, Jan 1 birth date)	-9.0749	0.45404	1.7918600	0.1073900	5.1	Jan-Dec
SC	Male	2,927	Length (TL, mm)	-18.3791	1.14192	0.0264934	0.0016986	693.7	Jul-Dec
SC	Male	2,930	Age (decimal years, Jan 1 birth date)	-10.1218	0.45237	2.4274500	0.1250110	4.2	Jan-Dec

FIGURES, PART 1

Fig. 1.1 Female South Carolina red drum maturity vs TL during different time periods

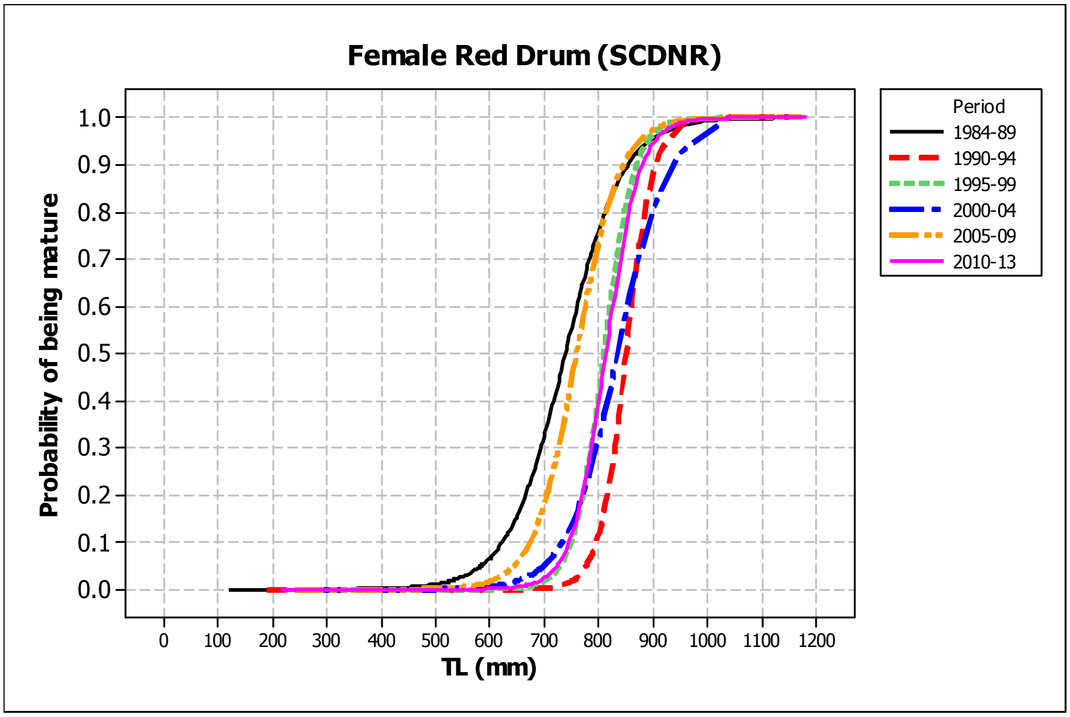


Fig. 1.2 Plot of raw immature (0) and mature (1) data for South Carolina female red drum from different time periods.

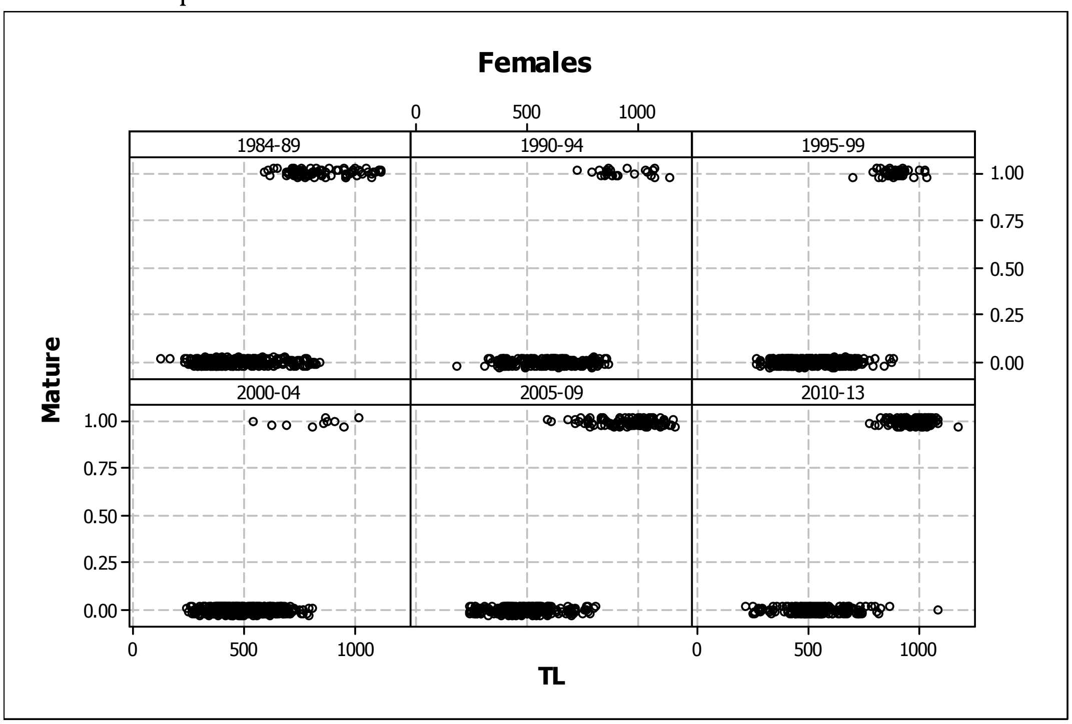


Fig. 1.3 South Carolina female red drum age at maturity for different time periods (fitted logistic regression curves).

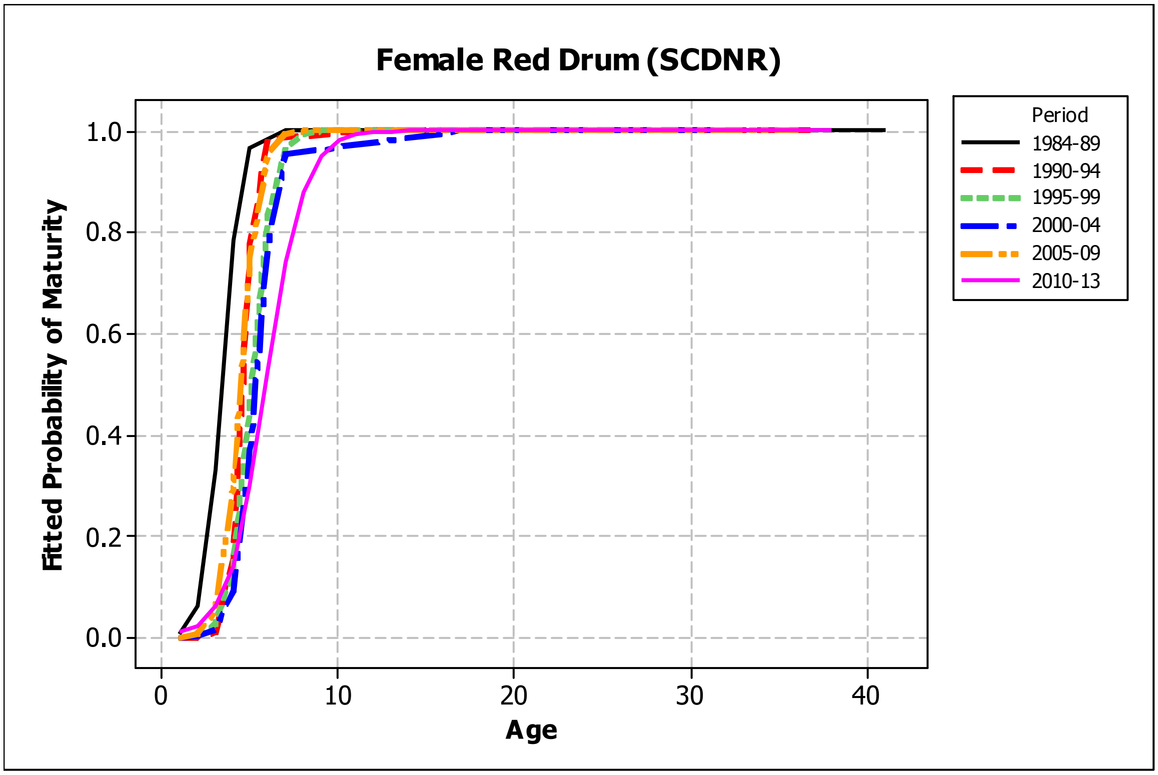


Fig. 1.4 Male SC red drum maturity vs TL during different time periods

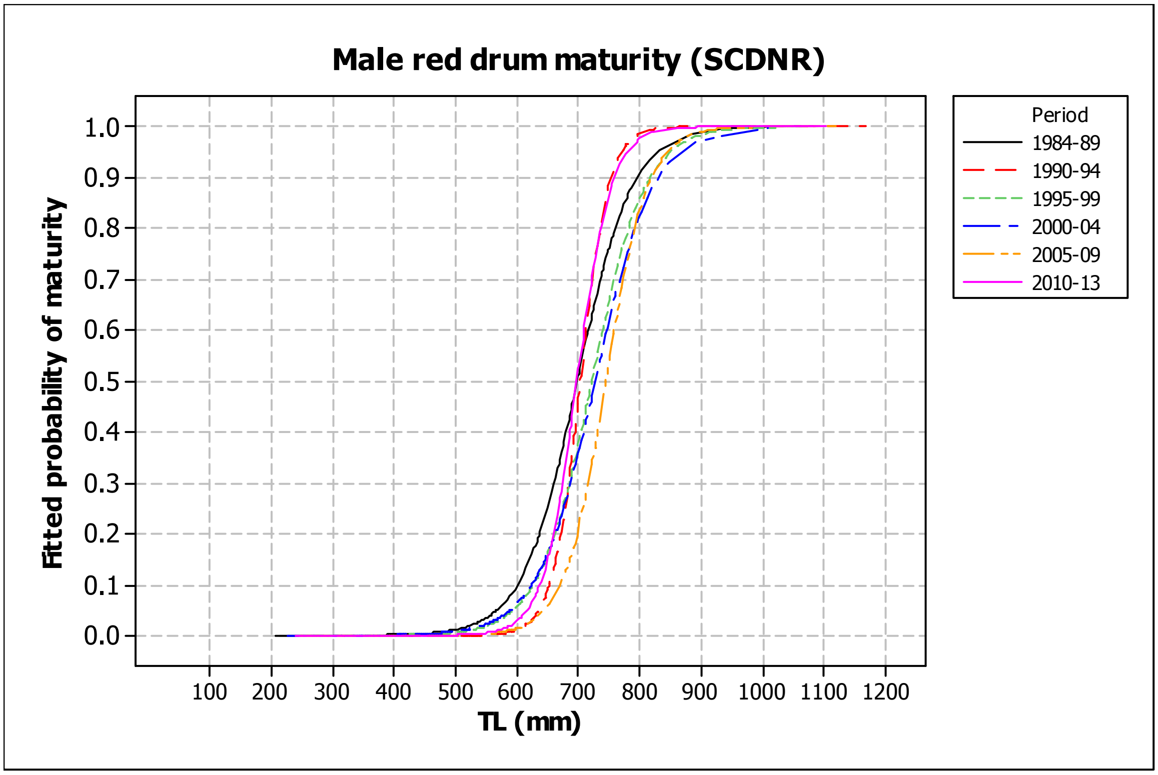


Fig. 1.5 Plot of raw immature (0) and mature (1) data for SC male red drum from different time periods.

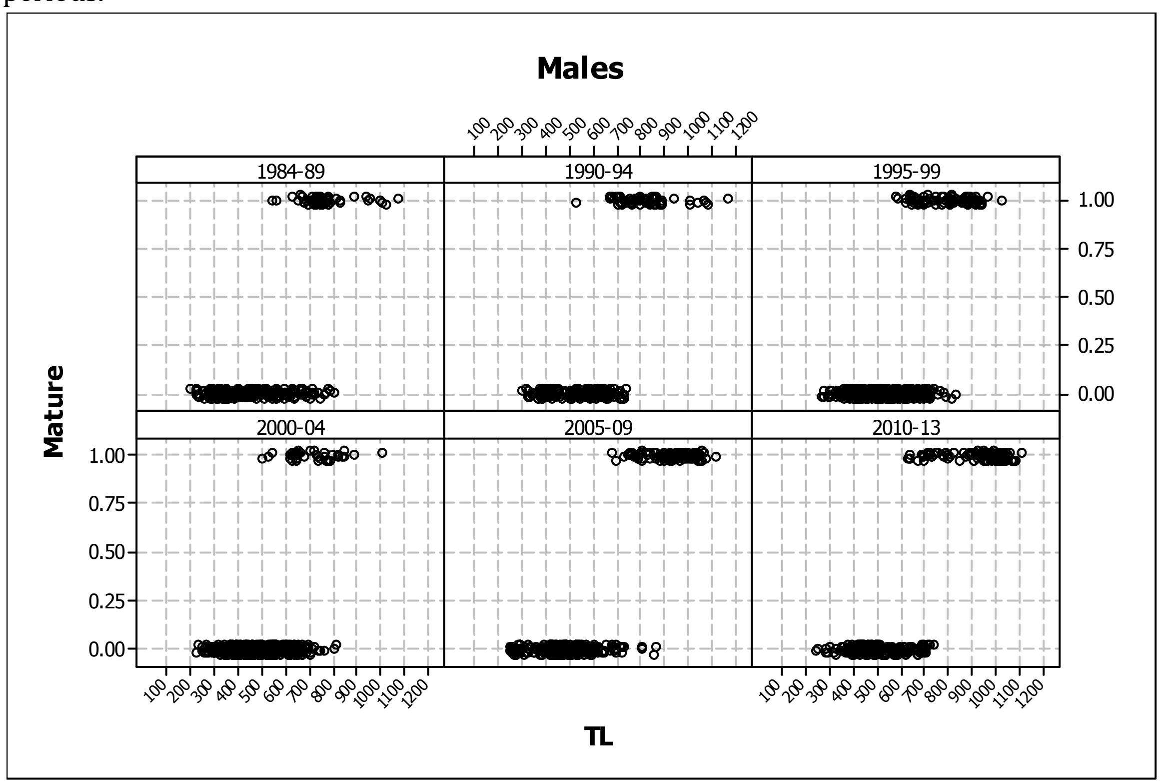
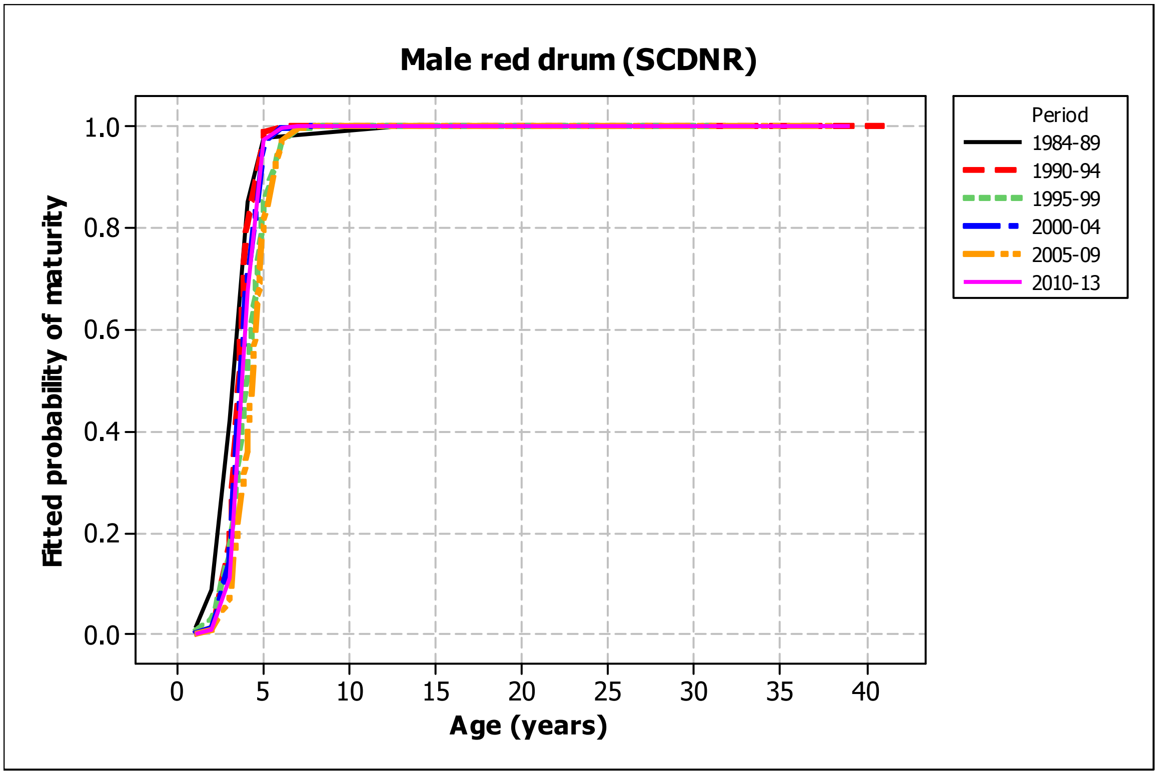
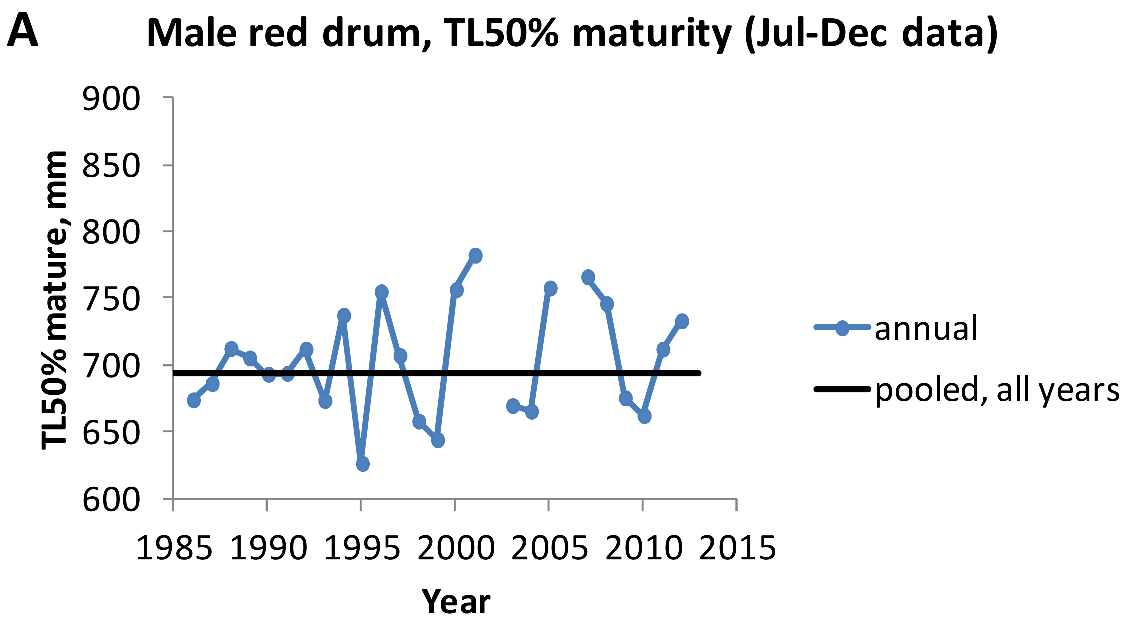


Fig. 1.6 Male red drum age at maturity for different time periods.



FIGURES, PART 2

Fig. 2.1 Length (TL, mm) at 50% maturity, by year, for (A) male and (B) female red drum from South Carolina. Values were estimated using parameters from logistic regressions.



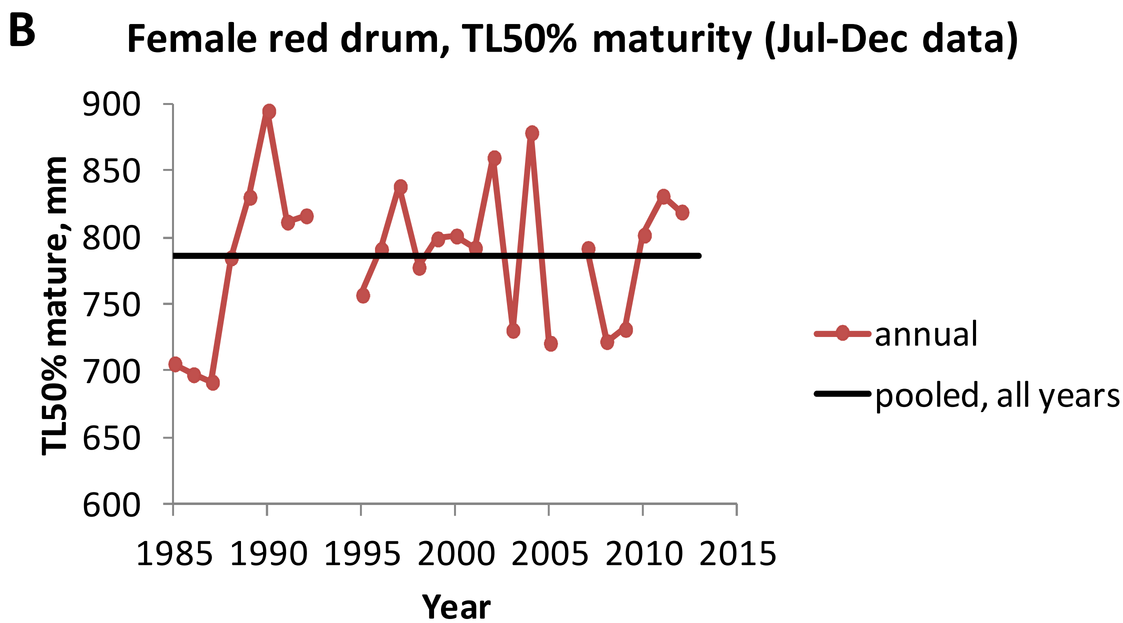


Fig 2.2 Female length at maturity for (A) South Carolina red drum, and (B) North Carolina red drum. Data points represent individual fish (binary immature/mature data, jittered around 0 = immature and 1 = mature to reduce overlap). Fitted lines (± 95% CI) are from logistic regressions fitted to data from fish captured during July-December.

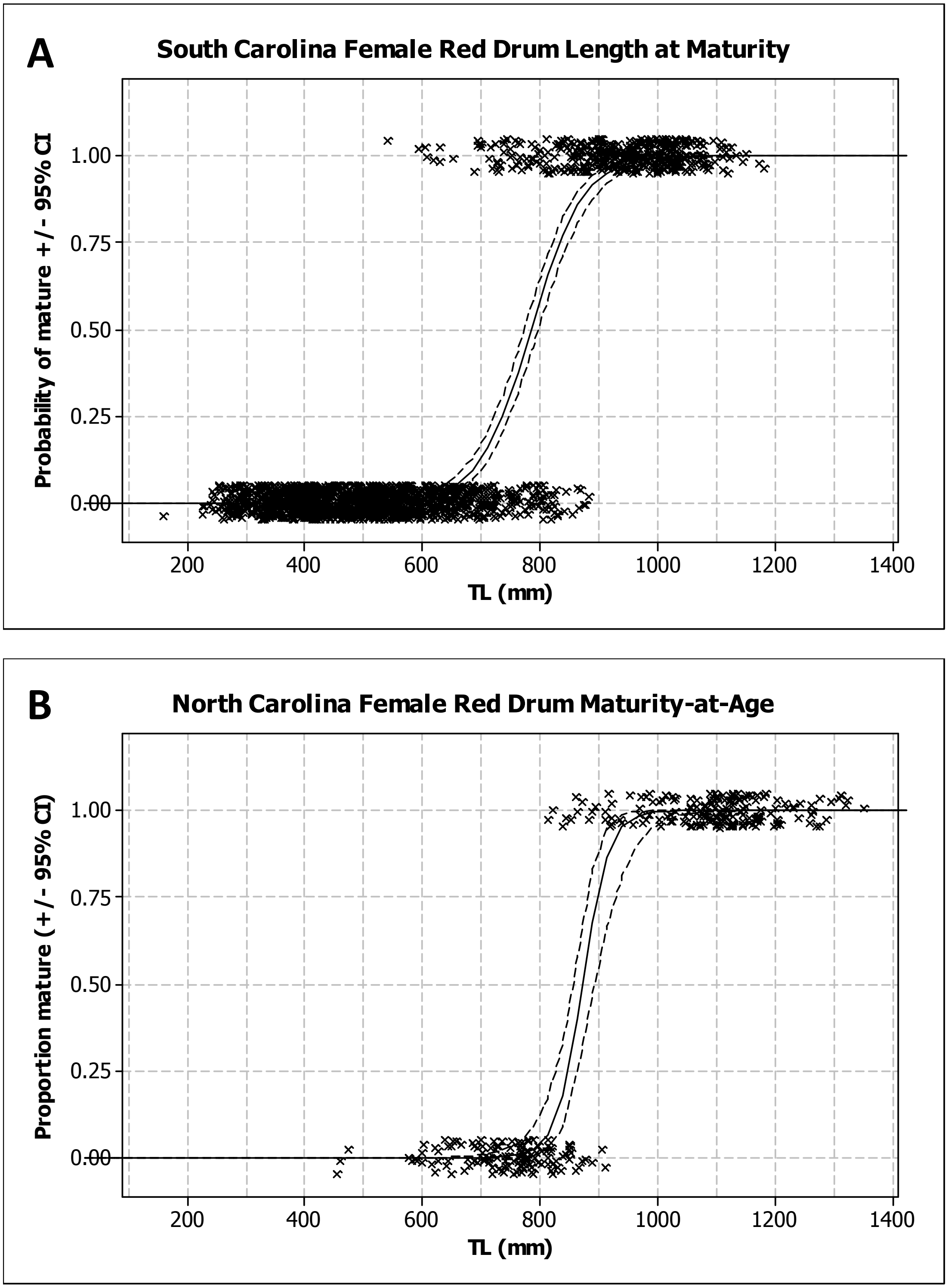
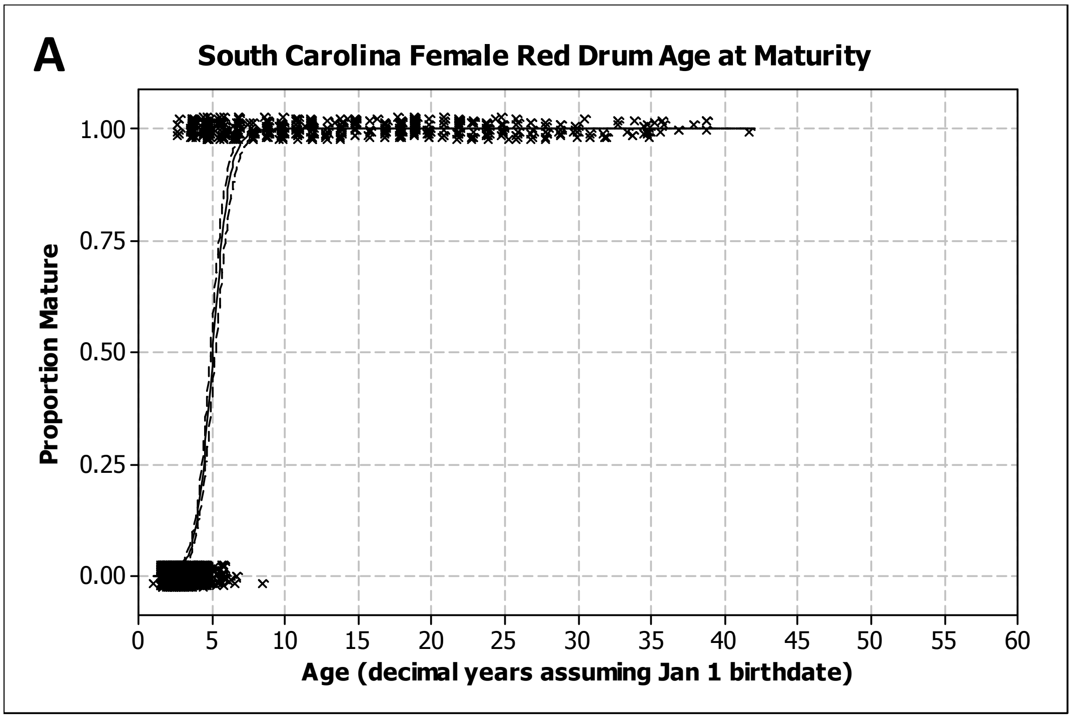


Fig 2.3 Female age at maturity for South Carolina red drum. (A) all data, and (B) zoomed in to show just ages 1-10 years. Data points represent individual fish (binary immature/mature data, jittered around 0 = immature and 1 = mature to reduce overlap). Fitted lines (± 95% CI) are from logistic regressions fitted to data from fish captured during any time of the year (January-December), although most of the older fish were captured during fall. Age is in decimal calendar years (i.e. assuming a Jan 1st birth date).



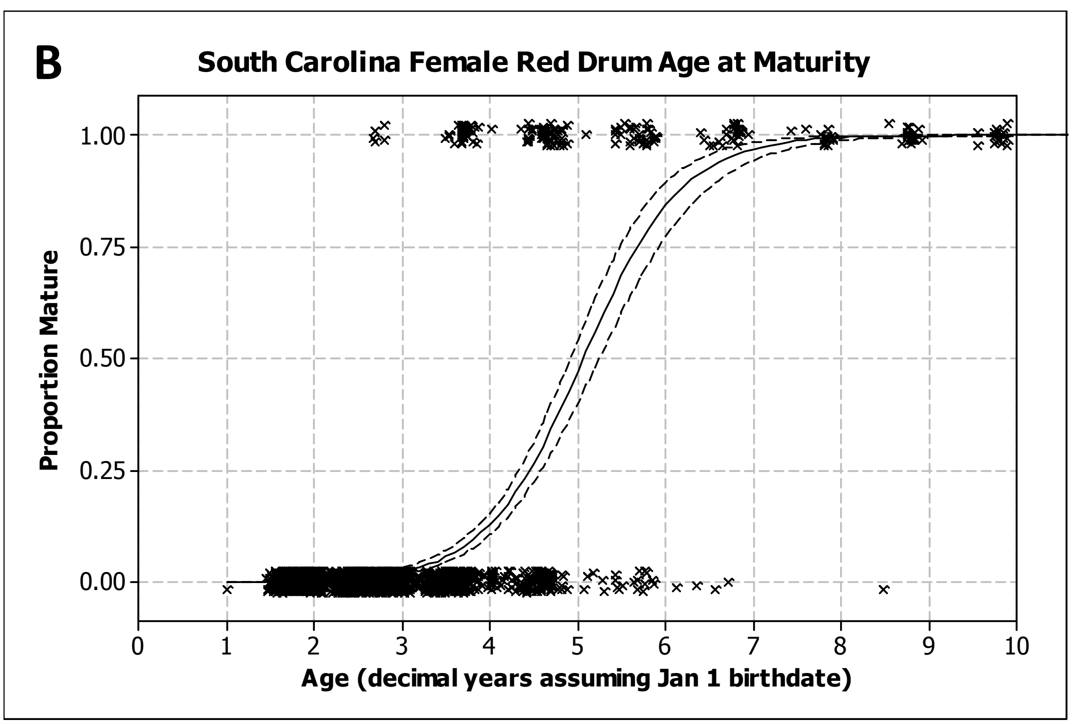
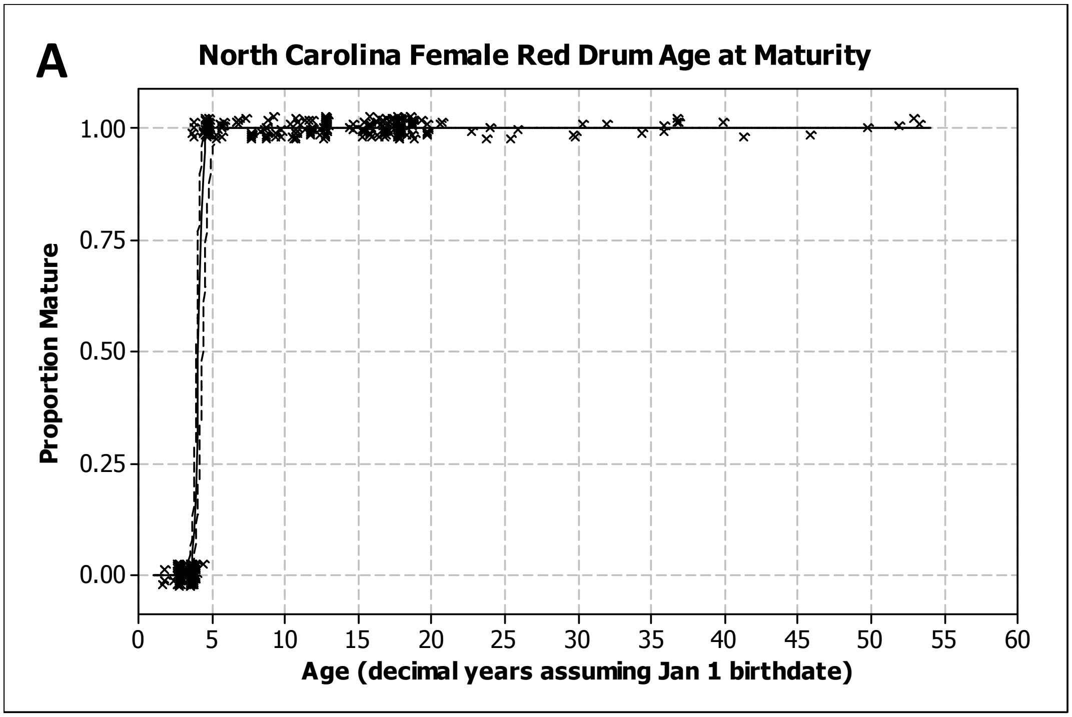


Fig 2.4 Female age at maturity for North Carolina red drum. (A) all data, and (B) zoomed in to show just ages 1-10 years. Data points represent individual fish (binary immature/mature data, jittered around 0 = immature and 1 = mature to reduce overlap). The fitted line (± 95% CI) is from a logistic regression fitted to data from fish captured during any time of the year (January-December), although most of the older fish were captured during fall. Age is in decimal calendar years (i.e. assuming a Jan 1st birth date).



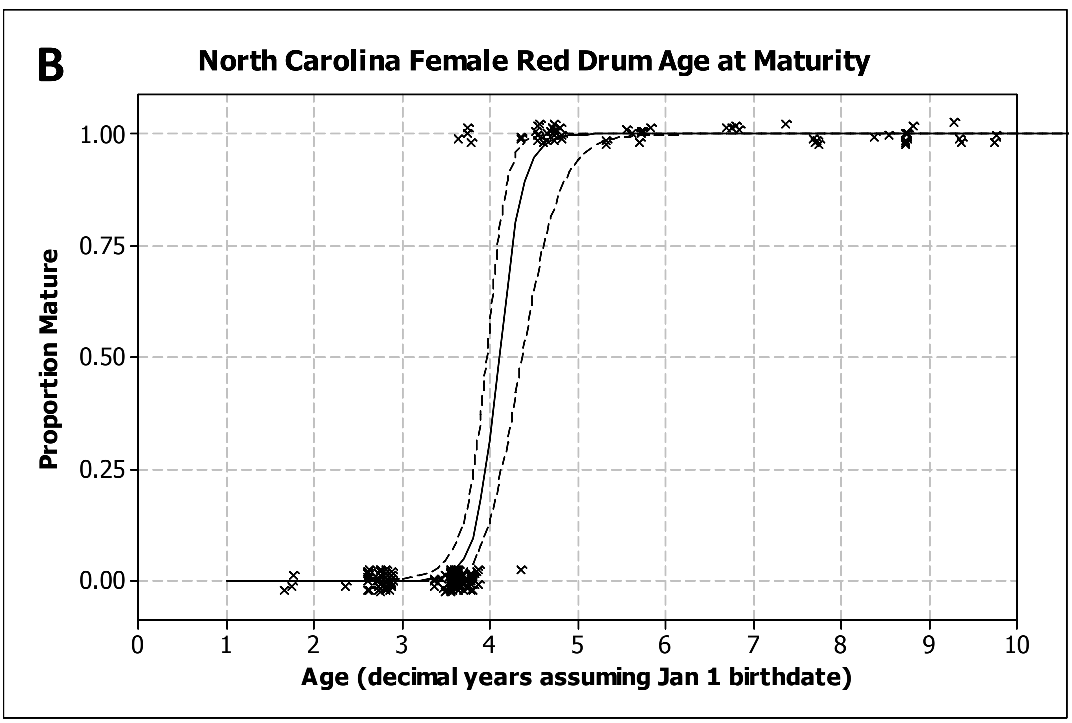


Fig 2.5 Male length at maturity for (A) South Carolina red drum, and (B) North Carolina red drum. Data points represent individual fish (binary immature/mature data, jittered around 0 = immature and 1 = mature to reduce overlap). Fitted lines (± 95% CI) are from logistic regressions fitted to data from fish captured during July-December.

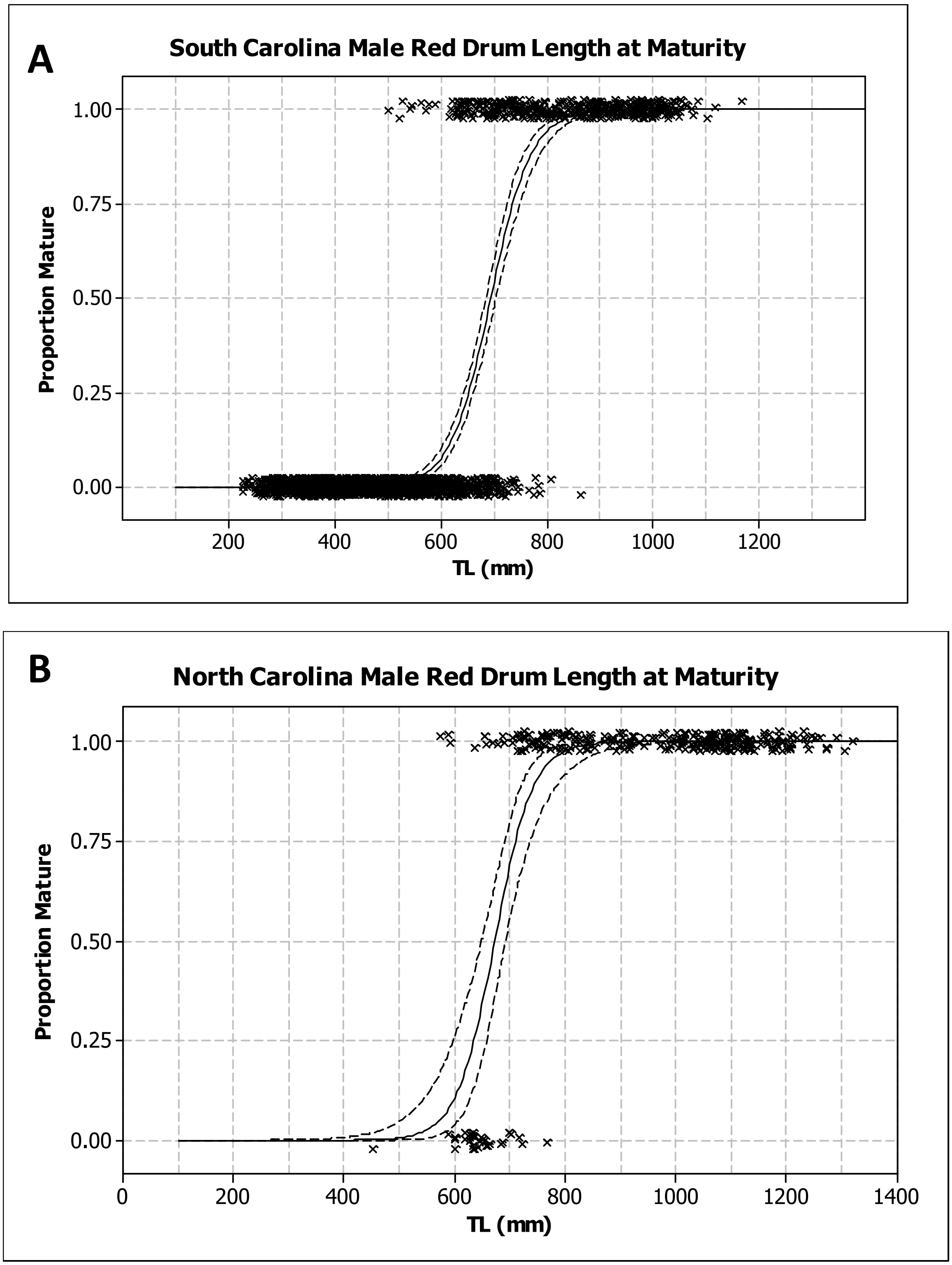
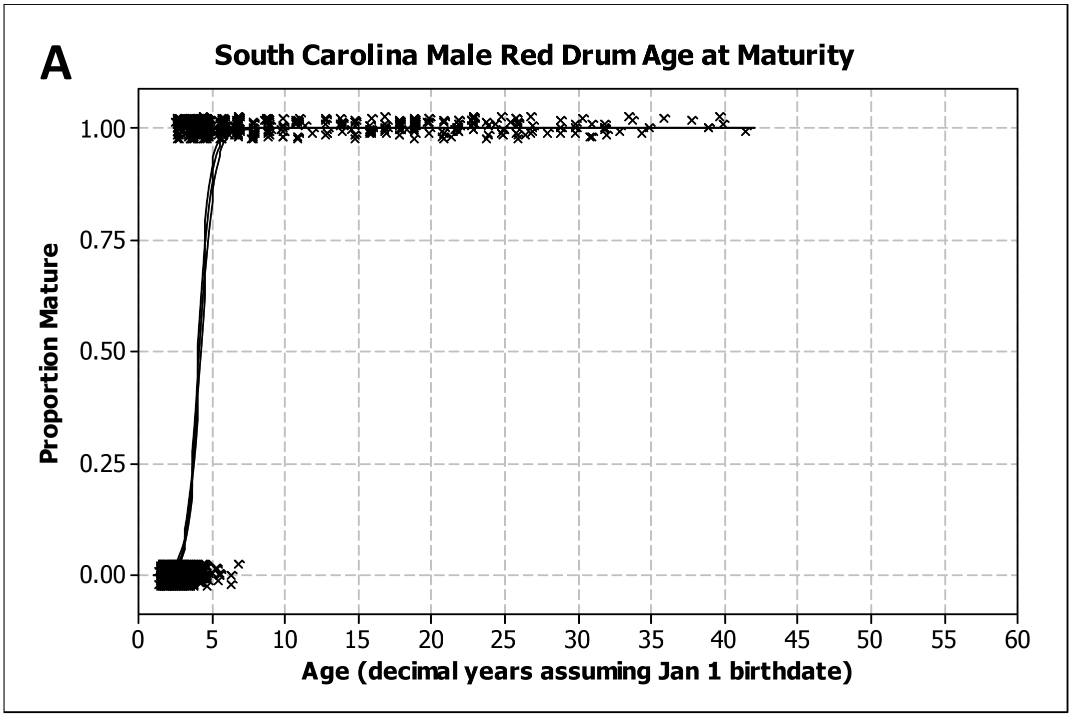


Fig 2.6 Male age at maturity for female South Carolina red drum. (A) all data, and (B) zoomed in to show just age 1-10 years. Data points represent individual fish (binary immature/mature fish jittered around 0 and 1 to reduce overlap). Fitted lines (± 95% CI) are from logistic regressions fitted to data from fish captured during any time of the year (January-December), although most of the older fish were captured during fall. Age is in decimal calendar years (i.e. assuming a Jan 1st birth date).



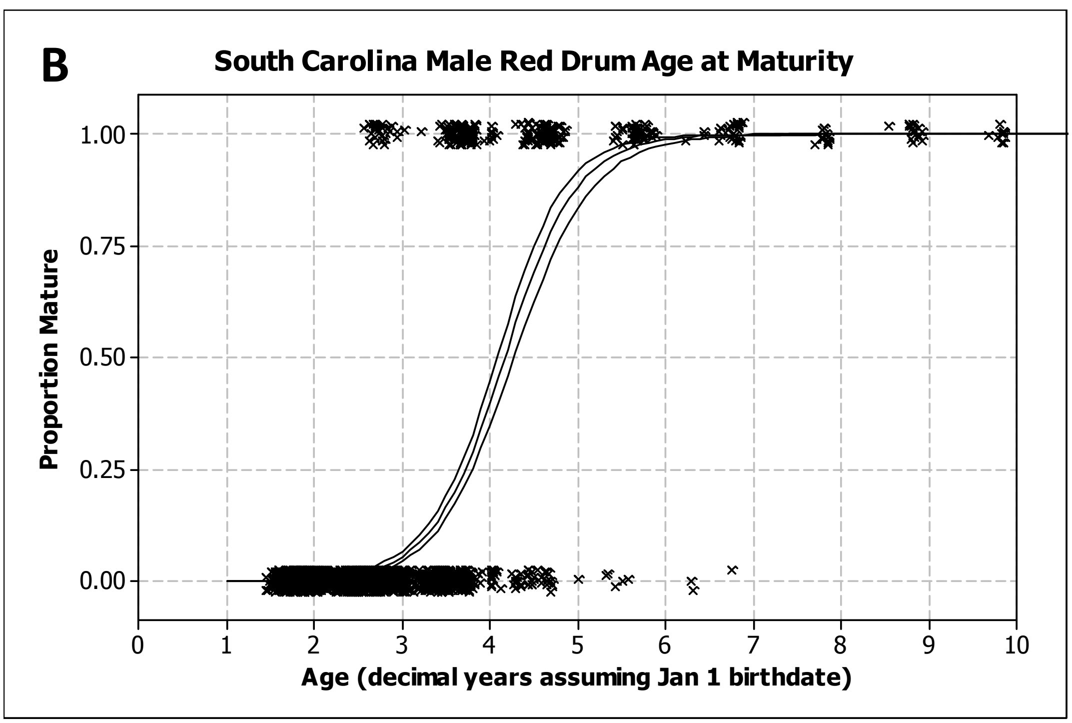


Fig 2.7 Male age at maturity for female North Carolina red drum. (A) all data, and (B) zoomed in to show just age 1-10 years. Data points represent individual fish (binary immature/mature data, jittered around 0 = immature and 1 = mature to reduce overlap). The fitted line (± 95% CI) is from a logistic regression fitted to data from fish captured during any time of the year (January-December), although most of the older fish were captured during fall. Age is in decimal calendar years (i.e. assuming a birthday of Jan 1st).