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SEX RATIO DATA FOR WESTERN NORTH ATLANTIC SWORDFISH

J. Hoey
National Fisheries Institute, 1525 Wilson Boulevard, Suite 500, Arlington, Virginia, U.S.A.

SUMMARY

Sex ratio-at-size information from over 2,000 swordfish will be described. Data are stratified by five geographical regions and 5 cm length increments. Differences in sex ratio at size associated with hypothesized latitudinal and temporal effects will be described. An hypothesis for a size-temperature mediated physiological mechanism related to feeding will be presented.

RESUME

L'information sur le sex ratio par taille sur plus de 2.000 espadons est décrite. Les données sont stratifiées selon 5 secteurs géographiques et des intervalles de taille de 5 cm. Les différences du sex ratio par taille associées à des effets hypothétiques latitudinaires et temporels sont décrites. L'hypothèse d'un mécanisme physiologique médiateur taille-température lié au trophisme est présentée.

RESUMEN

Trata acerca de la proporción de sexos por talla de más de 2000 peces espada. Los datos están estratificados en 5 zonas geográficas e incrementos de tallas de 5 cm. Se describen las diferencias en la proporción de sexos por tallas asociadas a efectos latitudinales y temporales hipotéticos. Se presenta una hipótesis sobre un mecanismo fisiológico mediatizado por la talla-temperatura y relacionado con la alimentación.

INTRODUCTION

Early studies of harpoon captured swordfish in the western North Atlantic indicated that they were primarily non-spawning females (Goode 1883, Lee 1942, Rich 1947). Tibbo, Day and Doucet (1961) noted that for the Canadian fishery, "most, if not all, of the present catch is of females". Exploratory longline fishing by the U.S. Bureau of Commercial Fisheries in the late 1950's and early 1960's captured significant numbers of males for the first time (Wilson and Bartlett 1967, National Science Foundation Grant Report G-1906). Data from the northwest coast of Cuba (Guitart-Manday 1964) indicated differences in sex ratios by size and between areas and seasons. Subsequent studies (Berkeley and Houde 1981, Berkeley and Irby 1982, Hurley 1982, Radtke and Hurley 1983, Stillwell and Kohler 1985, Wilson and Dean 1983) confirmed variable sex ratios in the western North Atlantic and summarized observations in either numbers or percentages by length or weight intervals. Hoey (1986) combined original data from the preceding studies with unpublished records from NMFS sampling and observer programs for use in assessment analyses. Comparable data were collected from the Spanish longline fishery in the eastern North Atlantic by Garcia and Mejuto (1988).

The predominance of females at larger sizes has been attributed to sexually dimorphic growth, differential mortality, differential availability, or a combination of these factors. Analytical assessments developed by ICCAT have relied on generalized growth equations to assign ages to the catch, rather than separate functions for each sex (Anonymous 1990). This has raised concern about the accuracy of fishing mortality and population size estimates from Virtual Population Analyses (VPA), given that errors in age assignments result from the simplified growth model. Suzuke and Miyabe (1989) developed separate catch at age tables by sex and the resulting estimates of fishing mortality were lower than those derived using the average growth model. The results were confounded with changes in age selectivity patterns. Restrepo (1990) investigated the effect of aging errors and bias in VPA's using simulated data. Results indicate that the amount of bias is sensitive to the degree of dimorphic growth.

Sex ratio size data from the western North Atlantic will be updated (Hoey 1986), including additional records from the central North Atlantic and initial reports from the Caribbean fishery. Differences in sex ratio at size by area and season will be emphasized and compared with eastern Atlantic data (Garcia and Mejuto 1988). The sex ratio size data will provide insight for VPA interpretation.

MATERIALS AND METHODS

Observations were collected by scientists from the National Marine Fisheries Service (NMFS), the Bureau of Commercial Fisheries (BCF-NMFS predessor), and Sea Grant funded biologists from Universities in Florida and South Carolina. Additional records were obtained from the Canadian Department of Fisheries. Samples were opportunistically collected on research and commercial fishing vessels and at recreational fishing tournaments. Although data was collected in 1970 and 1972, most sampling occurred from 1977 through 1986.

For each fish sampled, the date, location and year were recorded along with up to 7 length and 2 weight measurements, sex, and other notations. Original measurements and appropriate units (lbs., kg., inches, cm.) were recorded. Records were used if they included either a measured lower jaw forks length (LJFL) or a measured dressed weight (head, gills, fins, viscera removed). Dressed weights were converted to LJFL using the following equation developed by Turner (1986):

LJFL = 44.2237 x (DWT) xx .29257

Numbers of swordfish sampled were compiled by 5cm intervals of LJFL. Results are presented for 5 areas in the western North Atlantic. The boundaries for the areas are as follows:

1. Caribbean Sea - Latitude <20 N - Longitude <82 W
2. Gulf of Mexico - Latitude >20 N - Longitude >82 W
3. Southeast U.S. - Latitude >20 N and <35 N - Longitude <82 W
4. Northeast U.S. - Latitude > 35N - Longitude >65 W
5. Northwest Azores - Latitude >35 N - Longitude <65 W

RESULTS

Length (LJFL) or weight measurements were recorded for 2,206 swordfish with 52% male and 48% female. Although the observed overall male: female ratio is not significantly different from 1:1, variability was noted by area (Table 1). Males were predominant in the Caribbean and off the Southeast U.S., while females were predominant in the Gulf of Mexico and off the Northeast United States. Northwest of the Azores (Grand Banks) the ratio of males to females was not significantly different from 1:1 (47% vs 53%) based on chi squared tests.

Sample observations are generally clustered across years and areas (Table 2). The 1970 first quarter sample dominates the data from the Gulf of Mexico, although the sex ratio for more recent data (38% male; 61% female) is consistent with the overall ratio. The 1970 sample was associated with the first year of commercial exploitation in the Gulf, and larger individuals were apparently more abundant than current data indicates.

Size affects sex ratios as evident in Table 3, which lists numbers of males, females, and the percent female by 5 cm intervals (LJFL) for the total sample and the numbers of males and females by area. Numbers of males and females observed by 5 cm intervals for all areas are displayed in histogram format in Figure 1. Proportions of females by 5 cm intervals are plotted in Figure 2. At sizes below 135 cm, the sex ratios in this sample are variable. Between 135 cm and 170 cm males are predominant in this sample, although the ratios may not be statistically different from 1:1 based on chi-squared tests. The consistency of the pattern however supports this general trend. Beyond 170 cm the proportion of females in the sample increases reaching 100% beyond 250 cm.

Proportions of females by size differ between areas (Figure 3). Males are more abundant at sizes less than 170 cm in the Caribbean compared to other areas. In the Gulf of Mexico and off the southeast U.S., the ratios are highly variable for sizes less than 135 cm. The pattern for swordfish <135cm from the southeast US region is similar to the overall sample pattern. Off the southeast U.S., males are predominant between 135 cm and 175 cm as in the Caribbean. Off the northeast U.S. and in the northwest Azores areas, female proportions are not consistently reduced below 50% in the 135cm to 175cm range. This pattern differentiates profiles from areas north of 35 N from those ofareas south of 35 N.

Seasonal changes in profiles are illustrated for the southeast U.S. in Figure 4. In the second quarter, males predominate between 135 cm and 170 cm, but ratios at smaller sizes are highly variable. Females account for 38% and 39% of the sample <135cm during the 2nd and 3rd quarters respectively. Ratios between 135 cm and 170 cm are similar between the second and third quarters. At sizes >175cm the proportions of females declines from 64% in the second quarter to 48% in the third quarter. Large males might therefore be more prevalent in the third quarter. The fourth quarter profile differs from the second and third in that the prevalence of males between 130 cm and 170 cm is not as clearly evident. Quarterly samples for other areas are limited, or as in the case of the third and fourth quarters for the northeast region (Figure 5), the profiles are highly variable. The quarterly profiles for the northeast US samples do show a tendency for far fewer 5cm interval ratios to occur below the level of 50% female.

The largest male recorded was 246 cm LJFL and 395 pounds dressed weight while the largest female was between 290 and 294cm and weighed 537 pounds dressed weight. The previous review (Hoey 1986 n=1,560) included 17 males greater than 200 pounds dressed weight (approximately 200 cm LJFL). The addition of 646 observations, primarily from the Caribbean and northwest Azores areas, added 21 males greater than 200 pounds dressed weight. These observations may provide evidence of a preferred offshore distribution for large males and highlights the importance of increased sex ratio size sampling. The fact that males account for 24% of the 260 observations of swordfish larger than 200 cm LJFL, may indicate that dimorphic growth is not as divergent as previous studies have indicated. Beyond 250 cm however, all 24 measured swordfish were females.

DISCUSSION

Because of the limited and clustered nature of the observations, comparisons with sex ratios reported by area and season from other fisheries in the north Atlantic are informative. Cuban size composition data (Guitart - Manday 1964) accounts for 242 swordfish sampled off the northwest coast of Cuba in the early 1960's. Males were predominant (72% male: 28% female) especially at smaller sizes, while most female were larger. The southeast U.S. sample described in this report indicates a lower overall male percentage (62% vs. 72%). In the cuban fishery the winter (October-March -4th and 1st quarters - N=130) sample was 78% male: 22% female while, the summer (April-September - 2nd and 3rd quarters - N=57) sample was 67% male; 33% female. Whereas the cuban study documented a decreasing proportion of males from colder to warmer months, the present study indicated the opposite trend with increasing proportions of males. The later trend would be compatible with a dominant female migration to the colder feeding grounds in the north, while male movements are less extensive and may be more inshore - offshore oriented.

Hurley (1980) provides length frequency histograms for 288 swordfish sampled on 4 cruises between Cape Hatteras and the Grand Banks from August 5 to October 8, 1980. Data from the first cruise (August 5-18) is included in the current report. Original records from the remaining cruises were not available. Females were more abundant than males (75% female) in the total sample and there was "an east to west trend of decreasing size in both sexes and an increasing proportion of females in the catch". The data presented in this report supports this trend with the sample recording 53% females in the northwest Azores area (Grand Banks) compared to 63% female for areas off the northeast United States. It would appear that male abundance is higher where warm offshore Gulf Stream water is available, whereas along the colder areas near the continental shelf break, especially within the Canadian EEZ, females predominate.

The only additional information on sex ratios available for the western north Atlantic was collected during exploratory longline cruises by the Bureau of Commercial Fisheries in the early 1960's. Most of the effort was conducted off the northeast U.S. from Cape Henry, Virginia to the northeast part of Georges Bank. Data from the cruise reports are summarized in Table 4. As in this study, the records clearly indicate female predominance north of Cape Hatteras and seasonal variability in sex ratios with increased proportions of males noted for warmer months.

Garcia and Mejuto (1988) examined 977 swordfish from the eastern north Atlantic. Females were predominant (56% female vs. 44% male) in this sample and the overall sex ratio agreed closely with data from the northwest Azores area. The profile of proportions of females was similar to the total western north Atlantic profile indicating a predominance of males at intermediate sizes and female predominance beyond 170 cm LJFL.

Physiological and anatomical adaptations for withstanding the diversity of temperatures encountered by swordfish during feeding excursions differentially distribute the sexes based on size-temperature preferences. Temperature preferences reflect an animals metabolic sensitivity to internal temperatures in the face of ambient environmental conditions. Internal temperatures can be maintained (quasi-regulated) by insulating muscle mass or fat layers (thermal inertia), or by conservation of metabolic heat through circulatory adaptations such as; restricted lateral blood flow or countercurrent heat exchange rates. Countercurrent exchangers have been documented in bluefin and bigeye tuna, swordfish, mako, porbeagle, and white sharks (Carey and Teal 1969, Carey 1973, Carey and Robison 1981, Carey 1982). Carey (1982) considered swordfish to be creatures of semidarkness, spending the night near the surface, but going deep (600m) during daylight hours. As stalkers and sprinters, their feeding pattern and vertical excursions subject them to dramatic temperature changes, as much as 19 C in two hours (Carey and Robison 1981). Size influences the rate at which internal temperatures decrease upon movement into colder water. It would seem logical that smaller swordfish would not be able to spend as much time feeding in colder water in comparison to larger swordfish. Differences in the ability to hunt in cold temperatures would produce size segregation. As suggested in the early BCF study, as seasonal warming occurs males and females move northward with the slightly larger females moving into the northern grounds before the males. Winter sampling south of Cape Hatteras documents a latitudinal gradient with the percentage of females increasing from south to north. Larger females seem to prefer colder temperatures as noted in many of the previously cited studies on the harpoon and canadian longline fisheries. Further verification of this hypothesis requires comprehensive sampling at sea. Differences in summer sex ratio size data between the Scotian Shelf and the Grand Banks undoubtedly reflects distances to warm water in the Gulf Stream. Sex ratio size data north of Cape Hatteras will require accurate sea surface temperature and watermass data associated with the biological samples. This hypothesis of size-temperature mediated sexual segregation does however provide a reasonable explanation for the highly variable sex ratio data presented and it corresponds well with the seasonal abundance and size composition data available for the U.S. fishery.

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Table 1. Numbers of swordfish sampled by area and the percentages of females. Numbers sampled by quarter and the percentage of females observed in parenthesis.

AREA	TOTAL NUMBER	PERCENT FEMALE	NUMBERS SAMPLED BY QUARTER (% FEMALE) QTR1	QTR2	QTR3	QTR4
CARI	242	33%	242 (33)	–	–	–
GOMX	315	63%	255 (63)	21 (52)	21 (76)	18 (56)
SEUS	902	38%	41 (46)	380 (38)	368 (35)	113 (46)
NEUS	336	63%	9 (78)	1 (100)	167 (59)	159 (65)
NWAZ	411	53%	–	–	411 (53)	–

Table 2. Numbers of swordfish sampled by year and area.

YEAR	CARI	GOMX	AREA SEUS	NEUS	NWAZ	TOTAL
1970		237				237
1972				130		130
–						
1977			41			41
1978			128	35		163
1979		3	214	6	1	224
1980		4	304	68		376
1981		4	132	26		162
–						
1983		4		1		5
1984		7		2	199	208
1985		38	83	68	211	400
1986	242	18				260

Table 3. Numbers of males and females and the percentage female by 5cm intervals of LJFL for all areas and numbers of males and females by area.

LJFL	ALL AREAS			CARI		GOMX		SEUS		NEUS		NWAZ	
cm	M	F	%F	M	F	M	F	M	F	M	F	M	F
80	4	1	20			2	0	1	1	1	0		
85	6	17	54	1	0	1	3	4	2	0	2		
90	9	11	55			1	5	4	1	2	3	2	2
95	13	6	32			4	2	7	4	2	0		
100	16	15	48			2	3	12	11	2	1		
105	37	34	48	0	1	7	3	22	20	7	10	1	0
110	53	36	40			9	3	39	23	3	10	2	0
115	51	39	43	3	0	9	5	29	23	6	9	4	2
120	63	40	39	5	1	5	6	36	21	12	6	5	6
125	56	53	49	4	2	4	8	28	23	10	13	10	7
130	62	67	52	8	5	13	13	24	20	11	17	6	12
135	74	46	38	12	0	5	17	38	11	7	14	12	4
140	81	46	36	9	2	6	10	48	14	10	11	8	9
145	85	51	38	16	2	11	11	37	5	9	21	12	12
150	72	40	36	14	4	7	7	33	5	7	11	11	13
155	66	35	35	17	2	4	2	30	5	8	19	7	7
160	64	41	39	14	2	6	7	23	6	5	10	16	16
165	78	39	33	18	6	4	8	34	5	6	5	16	15
170	43	42	49	10	2	6	9	14	9	3	8	10	14
175	47	50	52	14	7	3	17	20	8	1	4	9	14
180	35	43	55	7	5	1	12	15	8	4	7	8	11
185	34	42	55	3	2	3	10	16	14	1	8	11	8
190	26	38	59	2	3	2	7	11	12	1	3	10	13
195	19	30	61	1	2	1	11	10	10	1	3	6	4
200	12	29	71	1	5	0	6	4	9	1	3	6	6
205	15	30	67	1	7	1	4	8	12	1	1	4	6
210	11	27	71	0	2	0	2	7	15	1	0	3	8
215	5	20	80	0	5	0	2	3	7	0	1	2	5
220	6	17	74	0	1	0	1	1	9	2	2	3	4
225	3	13	81	0	3			1	4	0	1	2	5
230	5	12	71	0	2			1	4	1	1	3	5
235	3	8	73	1	1			1	3	0	3	1	1
240	1	10	91					0	4	0	2	1	4
245	1	8	89	0	1	0	2	0	3	0	1	1	1
250	0	7	100	0	1	0	1	0	3			0	2
255	0	5	100	0	1			0	1	0	1	0	2
260	0	2	100	0	1			0	1				
265	0	4	100	0	3							0	1
270													
275	0	1	100					0	1				
280	0	3	100			0	1	0	2				
285	0	1	100					0	1				
290	0	1	100					0	1				

Table 4. Cruise results from Bureau of Commercial Fisheries exploratory longline fishing in the early 1960's.

CRUISE #	MONTHS	MALES	FEMALES	UNSEXED	% FEMALES
CB 62-1	OCT	3	3	11	50%
CB 62-2	OCT	22	27	51	55%
CB 62-3	NOV	18	28	40	61%
CB 62-4	NOV	18	44	17	71%
CB 63-1/GOS	JAN-FEB	8	19	4	70%
CB 63-2	FEB	6	53	0	90%
CB 63-3	MARCH	3	27	0	90%
DEL 63-4	JUNE	5	16	0	76%
CF 63-1	JUNE	3	15	0	83%
CF 63-2	JULY	12	45	1	79%
CB 63-5	SEPT	51	66	0	56%
CB 63-6	SEPT-OCT	120	214	12	64%

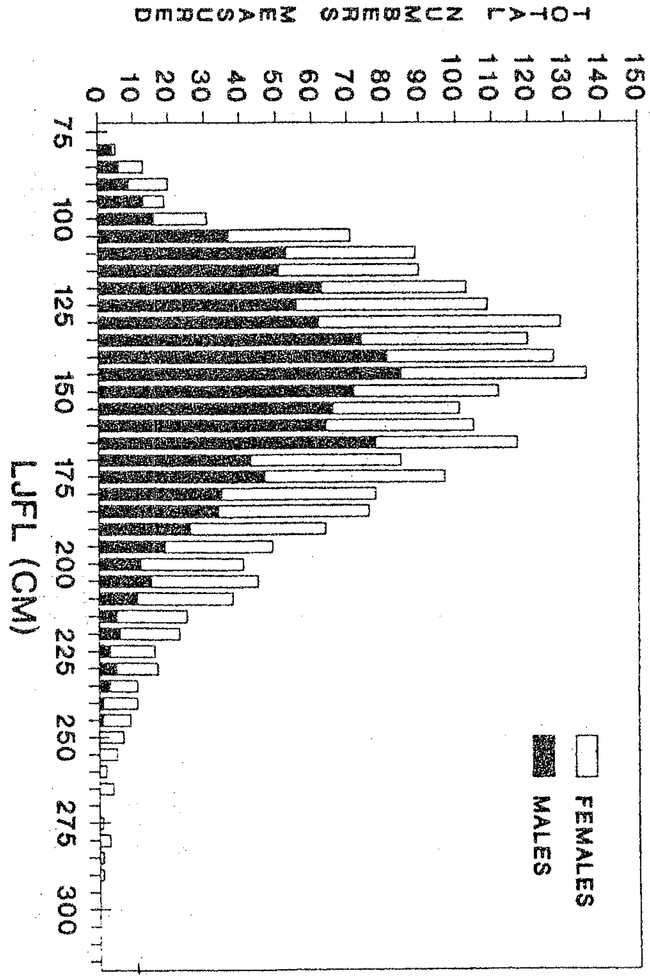

Figure 1. A histogram of the total numbers of male and female swordfish sampled from all areas by 5cm intervals of LJFL.

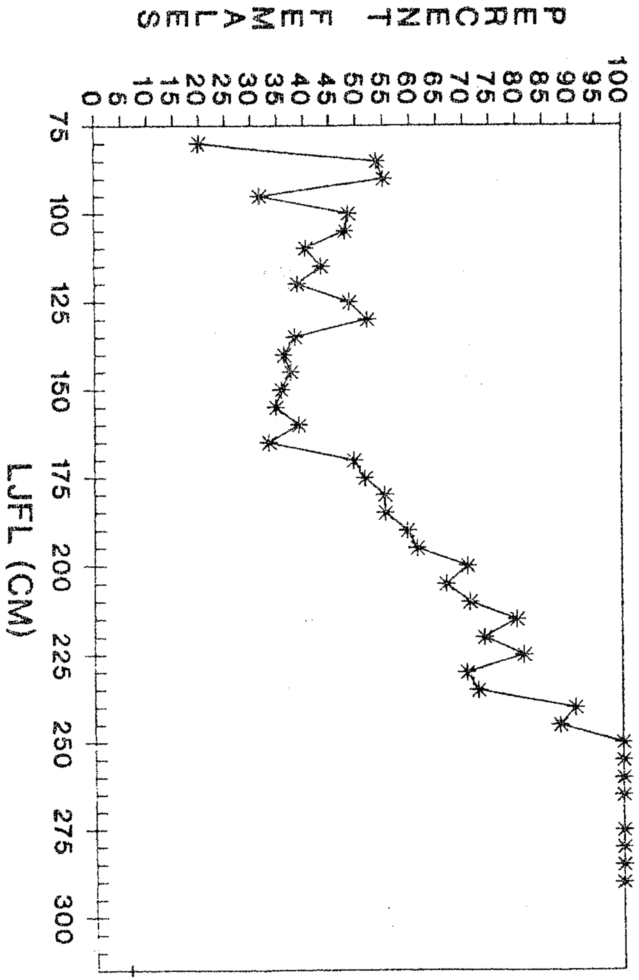

Figure 2. Proportions of females by 5 cm intervals of LJFL for 1,206 swordfish sampled in the western North Atlantic.

Figure 3. Proportions of females by 5 cm intervals of LJFL for the Caribbean (area 1), Gulf of Mexico (area 2), southeast US (area 3), northeast US (area 4), and northwest Azores (area 5) regions.

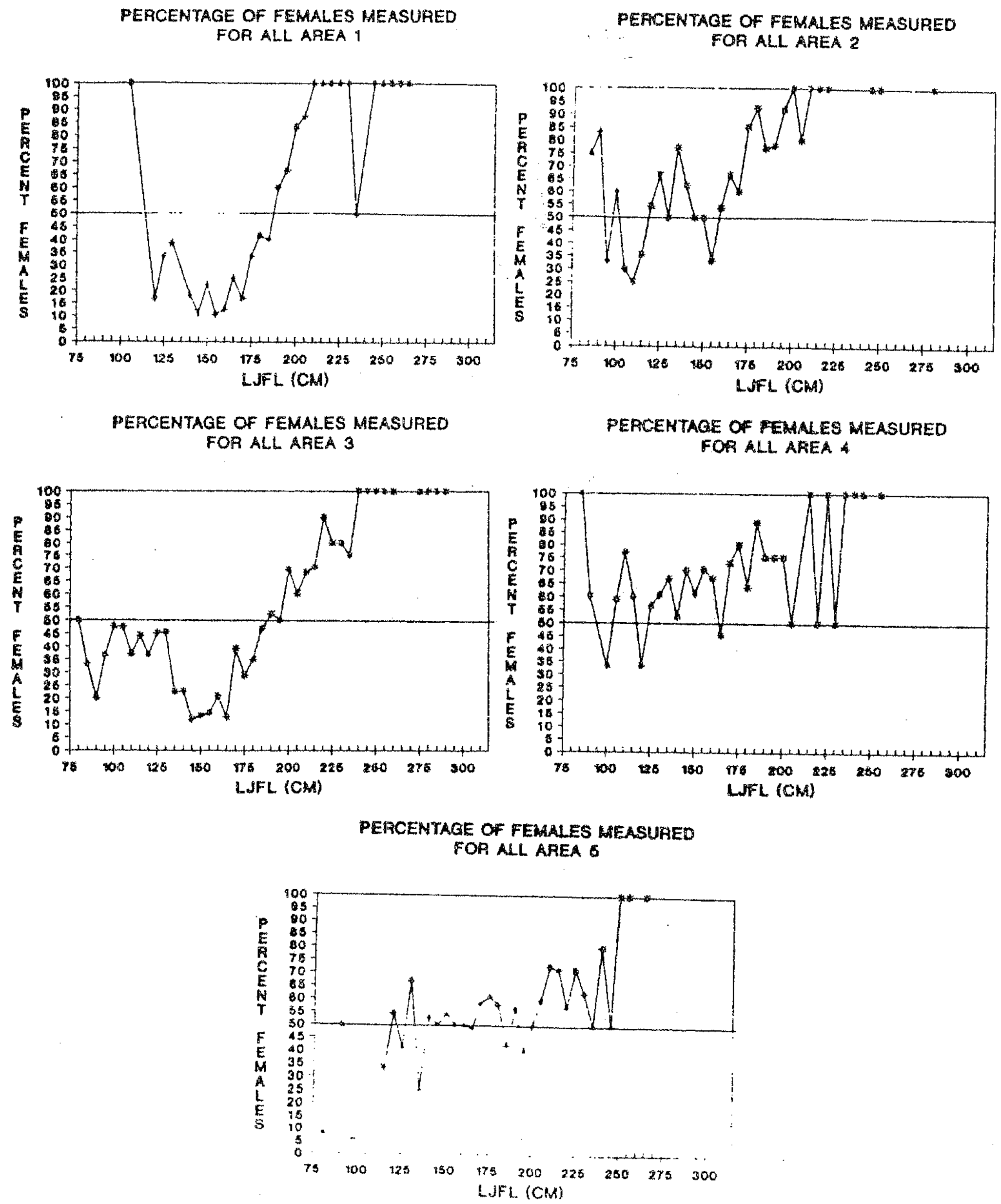

Figure 4. Proportions of females by 5cm intervals of LJFL for the second, third, and fourth quarter samples from the southeast US area.

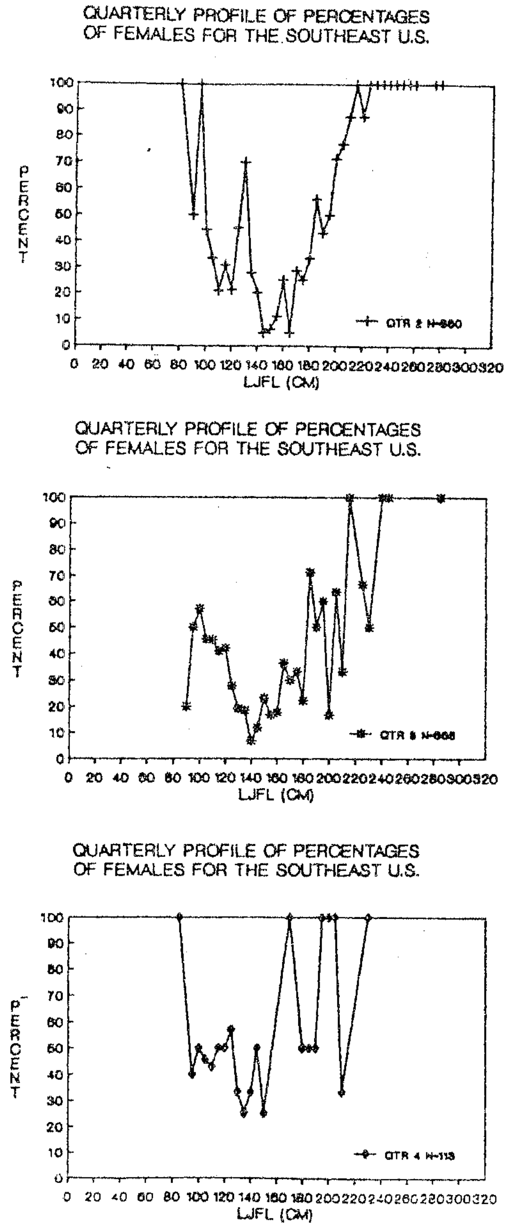

Figure 5. Proportions of females by 5cm intervals fo LJFL for the third and fourth quarter samples from the northeast US area.