Maturation and Fecundity of Swordfish, *Xiphias gladius,* from Hawaiian Waters

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ABSTRACT

Sixteen swordfish, *Xiphias gladius,* ovaries ranging in weight from 39 to 20,000 g were examined. Fish size ranged from 47 to 246 kg. Based on the occurrence of ripe ovaries, spawning in Hawaiian waters was estimated to extend from April through July. The developmental stages of ova are described; the most advanced ova examined averaged 1.6 mm in diameter. The distribution of ova diameters within an ovary was found to be heterogeneous. Fecundity was estimated for eight swordfish. Some variability in fecundity was noted; a positive curvilinear relationship of increase in fecundity with increase in fish size was evident. Best estimates suggest that an 80 kg swordfish has 3.0 million ova (early ripe or ripe stages) and a 200 kg swordfish has 6.2 million ova.

The occurrence in Hawaiian waters of mature swordfish, *Xiphias gladius*, with ovaries in advanced stages of maturation has been observed in the past by longline fishermen and other members of the fishing industry. However, precise information of the spawning period and the fecundity of swordfish from the Hawaiian Islands area is lacking. Although swordfish are not taken in large numbers by the longline fishery (Fig. 1), the absence of studies on swordfish has been due principally to difficulty in obtaining adequate data. The large ovaries of swordfish along with ovaries of other billfishes and tunas are commercially valuable and considered as a food delicacy in Hawaii. Thus, in order to prevent damage to the gonads, the auction firms handling the sale of swordfish do not permit the fish to be cut open prior to sale. Since fish are often butchered outside of the auction area, we were unable to obtain the needed information on sex and maturity. Although very little data on swordfish were available during our six years of sampling (1961-66), we were able to collect 16 ovaries covering all seasons of the year. These samples and related data on swordfish were considered adequate to permit us to make a preliminary assessment of spawning and fecundity of swordfish; the results are presented in this paper.

OCCURRENCE OF SWORDFISH IN HAWAIIAN WATERS

Swordfish are taken exclusively with longline fishing gear in Hawaiian waters. The swordfish catch landed by the Hawaiian fishery is very small; the total annual catch did not exceed 120 fish during the six years of sampling (Fig. 1). Since fishing for

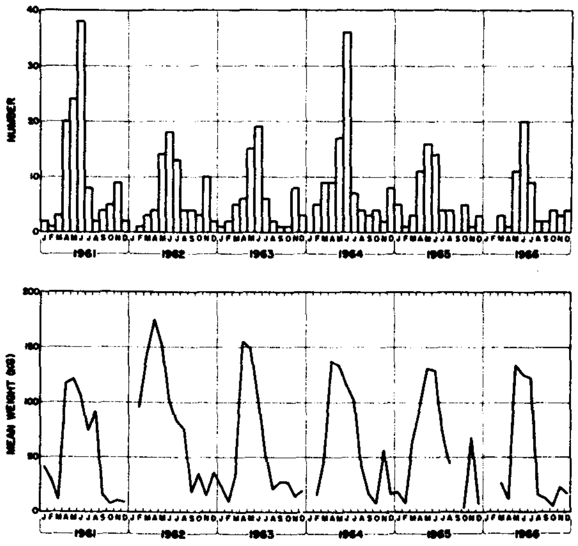

Figure 1.—Monthly landings of swordfish (upper panel) and average size of fish (lower panel) from 1961 to 1966.

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swordfish with longline gear is more successful during the night than day (Ueyanagi, 1974), the low catches may only be reflecting the fact that the Hawaiian fishery operates principally during daylight hours. Day fishing is carried out to maximize the catch of tunas and species of billfishes other than swordfish.

Figure 1 shows the monthly landings of swordfish for the period 1961-66. Although catches are small, there is a pronounced increase in landings during the summer months with the peak occurring in July. The increase is due to an increase in availability and not to an increase in fishing effort, since Yoshida (1974) showed that the catch rates (catch per trip) for blue marlin, *Makaira nigricans*, and striped marlin, *Tetrapterus audax*, in the Hawaiian longline fishery parallel the monthly landings, thus suggesting that the monthly catch data could be used as a general measure of availability.

The average size of swordfish also shows a peak during the summer period. As it will be discussed later, the increase in average size accompanied by the appearance of females in late stages of maturation may be related to a spawning migration.

MATERIALS AND METHODS

The 16 swordfish ovaries were collected at the Honolulu fish markets between June 1964 and May 1967 (Table 1). Since longline-caught fish are kept refrigerated with crushed ice, the ovaries were kept in an unfrozen condition until collected.

In the laboratory, excess connective tissue was removed from the external surfaces of the ovaries. The ovaries were weighed to the nearest gram and preserved in 10% Formalin. Detailed microscopic examination of the ovaries was undertaken only after the ovarian material had been thoroughly preserved, and shrinkage had stabilized. Generally, ova diameter measurements were taken after preservation had exceeded 6 mo.

For the maturation study, a small sample was extracted from the ovary with a cork borer and 100 randomly selected ova were measured to obtain mean diameter values for the most developed ova size group. Individual ova diameters obtained were not necessarily the maximum diameters. We followed the method developed by Yuen (1955) for measuring bigeye tuna ova and used by Otsu and

Table 1.—Summary of swordfish data used in maturation and fecundity study.

Sample number	Date of landing	Fish size (kg)	Paired ovary weights: Fresh (g)	Paired ovary weights: Preserved in 10% Formalin (g)	Maturity[1]	Most advanced mode: Mean diameter (mm)	Most advanced mode: Number measured	Fecundity (millions of ova)	Gonad[2] index
BB-1	6/24/64	187.2	11,566	10,033	ER, RS	1.019	153	2.24	6.18
BB-2	6/25/64	121.5	10,205	6,805	RP	1.205	257	3.84	8.40
BB-3	6/25/64	204.1	19,958	19,609	RP, RS	1.364	172	6.18	9.78
BB-4	7/ 3/64	156.5	9,389	(8,267)[3]	ER	0.986	228	4.80	6.00
BB-5	7/ 3/64	142.4	8,373	(7,332)[3]	ER	0.923	403	9.38	5.88
BB-6	7/ 6/64	246.3	1,542	1,430	ED, RS	0.101	100	—	0.63
BB-7	7/17/64	86.6	184	169	IM	0.060	100	—	0.22
BB-8	11/26/65	17.7	39	39	IM	0.057	100	—	0.22
BB-9	1/ 2/66	68.0	508	490	ED	0.141	100	—	0.75
BB-10	1/25/67	90.3	390	415	ED	0.154	100	—	0.43
BB-11	2/24/67	46.7	(Damaged)						
BB-12	4/ 5/67	54.4	172	174	ED	0.107	100	—	0.32
BB-13	4/13/67	76.6	163	176	IM	(poorly preserved)			0.21
BB-14	4/27/67	121.5	8,164	(7,187)[3]	RP	1.438[4]	113	3.73	6.72
BB-15	5/22/67	83.0	4,327	4,200	ER	0.990	306	3.21	5.21
BB-16	5/28/67	202.7	8,255	8,197	ER, RS	1.033	296	6.54	4.07

[1] Key: IM - Immature
ED - Early developing
ER - Early ripe
RP - Ripe
RS - Residual eggs present

[2] Gonad index is percentage of fresh ovary weight to fish size.

[3] Weight estimated from fresh-preserved conversion given in Figure 2.

[4] Ova diameters of fresh (non-preserved) samples placed in sea water averaged 1.571 mm.

Uchida (1959) for albacore. The measurement was the random diameter located parallel to the ruled lines marked on the measuring dish.

For ovaries in the early ripe or ripe stages, ova diameters were taken to obtain the mean diameter of the most advanced mode. A small sample of the ovarian tissue was extracted with a cork borer from the area near the lumen of the posterior region of the right ovary. Excess liquid was first blotted out and the sample weighed on an analytical balance. All ova in the most advanced stage were measured and counted, the latter to obtain fecundity estimates.

Weights of preserved ovaries from four fish were not recorded (Table 1). Since three of these samples were in the early ripe or ripe stages of maturity and could be used for fecundity estimates, we computed a conversion factor to correct for shrinkage due to preservation. Figure 2 shows the regression of fresh whole ovary weight on preserved (10% Formalin) ovary weight. The regression computed on the transformed data ($\log_e$) shows a very good fit for the 12 sets of data. The equation was used to estimate the preserved weights of the three samples (Table 1).

Sample BB-3 (Table 1) was used to test for homogeneity of ova diameters within a pair of ovaries. A cork borer (14.29 mm diameter) was used to obtain a core sample which extended from the outer surface of the ovary to the centrally-located lumen. The core was divided into an outer layer, a central layer located next to the lumen, and a middle layer. Separate cores were taken from the anterior, middle, and posterior region of both ovaries, thus providing a total of 18 subsamples. Ripe ova were teased from each sample and 200 randomly-selected ova were measured

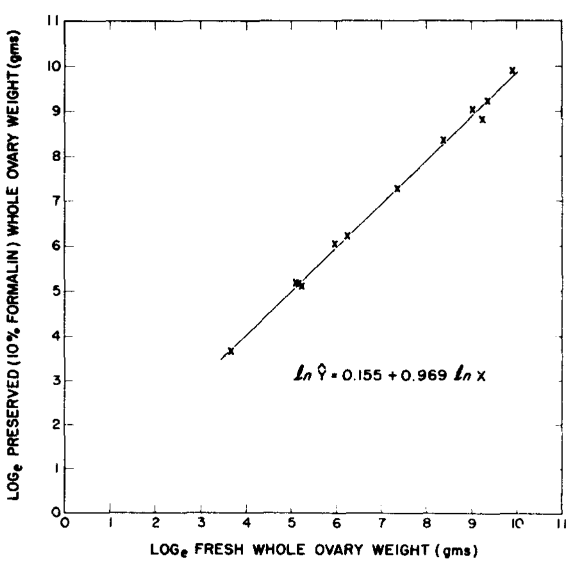

Figure 2.—Relationship of fresh ovary weight to preserved (10% Formalin) ovary weight for swordfish.

DEVELOPMENTAL STAGES OF OVA

An examination of the physical appearance of ova from swordfish showed that the ova could be classified easily into several developmental stages which were not dependent on ova diameters. The stages are described as follows:

1. Primordial Ova
   Ova are transparent, ovoid in shape, and diameters range from 0.01 to 0.05 mm. Primordial ova are present in all ovaries.
2. Early Developing Ova
   Ova are still transparent and ovoid in shape; diameters range from approximately 0.06 to 0.24 mm. A chorion membrane has developed around the ovum and an opaque yolk-like material has begun to be deposited within the ovum.
3. Developing Ova (Figure 3A)
   Ova are completely opaque, more wedge-shaped than ovoid, and diameters range between 0.16 to 0.96 mm. The chorion is stretched and not visible in this stage.
4. Advanced Developing Ova (Figure 3B)
   Ova are ovoid and diameters range from 0.47 to 1.20 mm. Ova have a translucent margin, a fertilization membrane, and a round yolk.
5. Early Ripe Ova (Figure 3C)
   Ova diameters range from 0.60 to 1.20 mm. The yolk material is translucent and oil globules have begun to form.
6. Ripe Ova (Figure 3D)
   Ova are transparent and with oil globules. Diameters range from 0.80 to 1.66 mm.
7. Residual Ova
   Ova in this stage show signs of degeneration. Ova are thin-walled and translucent and have shrunken and measure approximately 0.80 mm in diameter.

HETEROGENEITY OF OVA DIAMETERS

The distribution of ova diameters in sample BB-3 was examined critically to test for heterogeneity. A chi-square test of the normality of the size frequency distribution of ova diameters for the 18 samples (Appendix Table 1) showed significant differences for

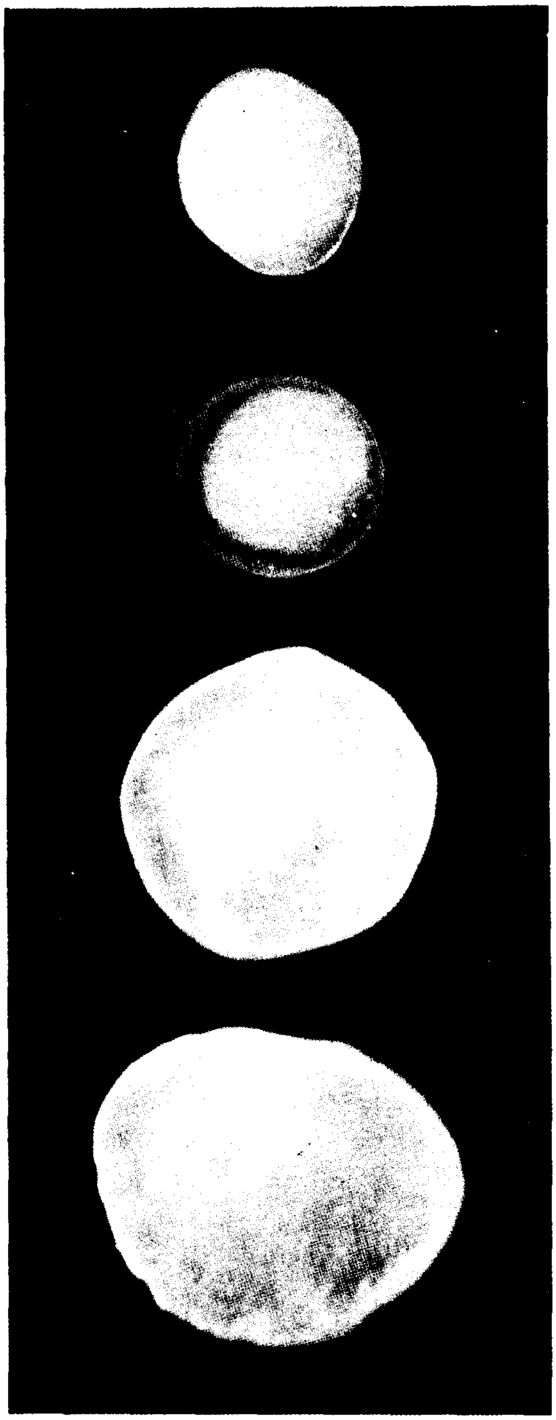

Figure 3.—Developmental stages of swordfish ova. **A.** Developing. **B.** Advanced developing. **C.** Early ripe. **D.** Ripe.

sample RMO (P = 0.01) and samples RMC and RPO (P = 0.05). An analysis of variance for one-way design was used to test for homogeneity (Table 2). The null hypothesis that the distribution of ripe ova was homogeneous throughout the ovaries was rejected ($P<0.05$; F ratio of 5.2821; $d.f.$ 17 and 3,582). An examination of the means showed no general trends with the different sections of each ovary and locations within each section. The lack of homogeneity in ova has also been demonstrated for bigeye tuna (Yuen, 1955) and albacore (Otsu and Uchida, 1959).

A further evidence of heterogeneity was indicated in a comparison of ripe and early ripe ova. Table 3 shows the number of ripe and early ripe ova from the nine locations sampled from the right ovary. The ratio of ripe to early ripe ova ranged from 0.5576 to 2.6792. Three samples, RPC, RPM, and RMC, had almost identical ratios; but no consistent pattern was evident.

SPAWNING

Swordfish with ovaries in a ripe condition have been reported in the Mediterranean Sea off Sicily (Sella, 1911), in the Gulf Stream off Cuba (LaMonte, 1944) and in the western Pacific Ocean in the seas adjacent to Minami Tori Shima located at long. 156°E, lat. 25°17'N (Nakamura et al., 1951). Yabe et al. (1959) reported the occurrence of swordfish with ripe ovaries in the North Pacific Ocean in waters extending from the Subtropical Convergence to the equator and in the South Pacific in the Coral Sea and near the Fiji Islands. Yabe et al. (1959) also reported on the occurrence of seven ripe ovaries taken from swordfish caught in the Indian Ocean.

The appearance in April through July (Table 1) of large swordfish in the late stages of maturity suggests that the movement into coastal waters of the Hawaiian archipelago may be part of a spawning migration. Matsumoto and Kazama (1974) identified swordfish larvae from plankton hauls taken in Hawaiian waters, thus confirming the indirect evidence based on our ovary maturation study. Cavaliere (1962) reported that embryos start to form in eggs with diameters between 1.60 and 1.80 mm. In our samples the mean ova diameters of the most advanced modes of the preserved material were 1.20 mm for sample BB-2, 1.36 mm for BB-3, and 1.44 mm for BB-14. Ova from sample BB-14, which had been immersed in seawater prior to preservation, had a mean diameter of 1.57 mm. Since the gonad

Table 2.—Test of ova diameters from selected locations from right and left ovary of sample BB-3; analysis of variance for one-way design.

Treatment[1]	Sample size	Mean micrometer units	Standard deviation	Mean (mm)
RAC	200	69.38500	6.133913	1.4223
RAM	200	69.93500	6.480799	1.4336
RAO	200	68.41500	7.441750	1.4025
RMC	200	67.51500	7.646705	1.3840
RMM	200	67.51000	7.418561	1.3839
RMO	200	67.93500	8.098684	1.3926
RPC	200	69.44500	7.664900	1.4236
RPM	200	69.94000	7.077913	1.4337
RPO	200	72.00000	6.587639	1.4760
LAC	200	68.96500	6.347853	1.4137
LAM	200	69.97000	6.592144	1.4343
LAO	200	70.19000	6.296197	1.4388
LMC	200	69.86000	5.928416	1.4229
LMM	200	68.19500	6.523783	1.3979
LMO	200	69.48500	6.331683	1.4244
LPC	200	69.41000	5.725012	1.4229
LPM	200	69.40500	6.811972	1.4336
LPO	200	69.80000	5.445941	1.4309

Analysis of Variance

	Sum of squares	*d.f.*	Mean square	*F* ratio
Between groups	4072.5925	17	239.5643	5.2821
Within groups	162458.1074	3582	45.3540	
Total	166530.6992	3599		

[1] RAC - Right anterior center
RAM - Right anterior mid-layer
RAO - Right anterior outer layer
RMC - Right middle region center
RMM - Right middle region mid-layer
RMO - Right middle region outer layer
RPC - Right posterior region center
RPM - Right posterior region mid-layer
RPO - Right posterior region outer layer
LAC - Left anterior center
LAM - Left anterior mid-layer
LAO - Left anterior outer layer
LMC - Left middle region center
LMM - Left middle region mid-layer
LMO - Left middle region outer layer
LPC - Left posterior region center
LPM - Left posterior region mid-layer
LPO - Left posterior region outer layer

index measures gonad size relative to fish size, it is not surprising to find that the highest gonad indices occurred during the apparent spawning period April to July (Table 1).

Since residual ova are remains from previous spawning (Yuen and June, 1957), all ovaries from our collection were examined for these ova. Residual ova were only evident in some of the samples collected in May, June, and July (Table 1). Although Yabe, et al. (1959), assumed that the ripe ova (modal diameter 1.2 mm to 1.6 mm) were spawned at one time, partial spawning of swordfish cannot be discounted as sample BB-3, which was judged ripe, also had residual ova.

Table 3.—Ratio of numbers of ripe to early ripe ova.

Sample[1]	Number of early ripe ova	Number of ripe ova	Ratio index
RAC	170	212	1.2470
RAM	195	291	1.4923
RAO	220	256	1.1636
RMC	303	269	.8877
RMM	319	212	.6645
RMO	477	266	.5576
RPC	194	172	.8865
RPM	280	248	.8857
RPO	106	284	2.6792

[1] RAC - Right anterior center
RAM - Right anterior mid-layer
RAO - Right anterior outer layer
RMC - Right middle region center
RMM - Right middle region mid-layer
RMO - Right middle region outer layer
RPC - Right posterior region center
RPM - Right posterior region mid-layer
RPO - Right posterior region outer layer

It is interesting to note that Sella (1911) reported that the swordfish ovary contracts after spawning and remains compact and firm. This differs from tunas, which tend to be noticeably flaccid (Yuen, 1955). Sample BB-6, which was collected in July, appeared to confirm the general condition described for swordfish. Although this ovary was in an early stage of maturity and was firm and compact, it also contained residual ova, suggesting recent spawning.

No early ripe or ripe ovaries were collected from August to April. To some extent this feature may only reflect absence of mature fish, since nearly all of the swordfish taken during this period were small in size (Table 1) and indicative of immature fish.

FECUNDITY

Fecundity estimates are presented in Table 1 and shown in Figure 4. Since homogeneity tests showed significant differences in the distribution of ova diameters within a single pair of ovaries, the estimates should be considered only as rough approximations of the true fecundity of the swordfish. It

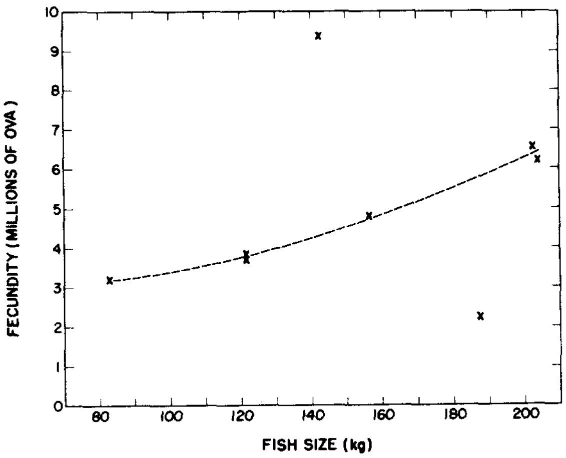

Figure 4.—Fecundity estimates for swordfish from Hawaiian waters.

should be pointed out, however, that while nonrandom distribution of ova diameters within an ovary may contribute to errors in fecundity estimates, other factors are equally important in making the current methods of measuring fecundity difficult. Other factors include inaccurate estimates of the true ovary weight due to varying amounts of connective tissue left on the ovary surface, and more important, the varying amount of excess fluids (primarily the preservative) removed from the ovary during the "draining" period. Possibly the most important error factor may be related to the point in maturation when the fecundity estimates are made. In species with multimodal frequency distributions of ova diameters (Yuen, 1955; Otsu and Uchida, 1959), the most advanced modal size group has fewer ova than the modal groups to the left (smaller ova). This suggests that resorption of some ova is taking place. Thus, the final number of ova extruded during spawning is less than the number with which the modal group started when the mode first differentiated from the primordial ova stock.

Fecundity estimates of the eight swordfish with early ripe or ripe ova are shown in Figure 4. As indicated in an earlier section, fecundity estimates from three of the fish were based on preserved ovary weights which were estimated from fresh-preserved ovary weight relationship. In Figure 4 two of the eight points appear to be displaced a considerable distance from the general curvilinear relationship of increasing fecundity with increasing fish size. Sample BB-5 with an estimated 914 million ova is considerably higher than the general trend, while sample BB-1 with 2.2 million ova is on the lower side.

From our limited fecundity data, and considering the error factors described above, we estimate the fecundity of swordfish to range from 3.0 million ova for a fish weighing 80 kg to 6.2 million ova for a fish weighing 200 kg. Yabe et al. (1959) estimated the fecundity of a 186 cm (orbit to fork) swordfish to be between 3 and 4 million ripe ova.

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APPENDIX: Table 1.—Frequency distribution of ripe ova diameters from selected parts of a swordfish ovary (sample BB-3).

Ocular micrometer units	Milli-meters	Subsamples[1] RAC	RAM	RAO	RMC	RMM	RMO	RPC	RPM	RPO	LAC	LAM	LAO	LMC	LMM	LMO	LPC	LPM	LPO
87	1.7835	1	—	1	2	—	—	2	—	1	—	—	—	—	—	—	—	—	—
86	1.7630	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
85	1.7425	—	2	—	—	—	—	1	—	—	—	—	1	—	—	—	1	—	—
84	1.7220	1	—	—	—	—	2	1	1	2	—	1	—	—	—	1	—	2	—
83	1.7015	—	—	1	1	—	2	3	2	5	1	1	1	—	1	—	—	1	1
82	1.6810	—	3	1	—	2	4	3	2	4	1	1	4	1	—	2	—	1	1
81	1.6605	2	2	1	3	2	3	2	4	2	3	3	2	3	2	1	1	1	2
80	1.6400	5	2	4	4	4	4	3	7	10	4	3	6	5	2	2	4	1	1
79	1.6195	4	4	6	3	4	3	2	2	7	—	5	2	2	4	4	3	8	3
78	1.5990	4	6	6	6	3	7	10	11	9	7	5	8	5	2	3	5	5	3
77	1.5785	4	6	9	1	8	2	13	14	12	5	8	8	10	4	8	11	9	11
76	1.5580	10	14	8	8	5	12	9	3	14	7	9	10	7	10	11	3	5	10
75	1.5375	4	11	8	12	8	10	5	13	7	11	6	3	10	5	12	9	13	12
74	1.5170	7	11	11	7	5	4	7	11	8	7	17	12	17	10	12	7	9	8
73	1.4965	11	13	7	10	12	7	10	13	20	16	20	15	13	11	13	14	14	11
72	1.4760	21	13	11	11	13	10	10	10	15	11	14	17	10	18	19	13	14	11
71	1.4555	18	16	6	4	7	8	9	6	7	16	16	18	11	9	11	14	18	16
70	1.4350	14	15	10	8	15	10	7	11	12	12	15	16	16	13	13	21	11	18
69	1.4145	10	5	11	6	7	7	8	8	10	7	11	4	9	14	8	13	6	12
68	1.3940	20	11	9	15	16	7	12	11	12	17	8	10	20	12	10	16	12	10
67	1.3735	14	11	19	11	8	13	11	8	14	12	5	12	12	10	16	10	11	21
66	1.3530	6	9	10	13	11	9	17	8	3	10	8	4	8	9	5	10	8	13
65	1.3325	7	6	12	11	10	16	6	7	3	5	7	12	9	8	6	5	5	6
64	1.3120	4	8	5	7	2	5	7	9	4	8	2	6	3	12	11	9	9	6
63	1.2915	10	4	8	13	6	9	4	9	4	6	7	6	4	9	5	7	5	6
62	1.2710	3	9	5	4	6	5	6	7	1	12	8	5	4	10	4	8	7	4
61	1.2505	3	3	3	3	6	8	9	2	2	4	5	4	4	3	2	4	9	2
60	1.2300	5	4	1	5	7	4	6	4	3	5	4	2	9	6	6	1	1	5
59	1.2095	2	3	2	4	5	3	2	5	2	1	—	1	1	1	3	2	1	1
58	1.1890	2	—	4	5	6	3	3	4	—	3	—	6	3	1	3	4	6	4
57	1.1685	1	2	6	6	5	9	2	2	1	2	2	—	—	4	2	1	1	1
56	1.1480	1	1	2	2	3	—	—	2	1	1	2	—	—	1	—	1	1	—
55	1.1275	2	1	1	2	6	4	1	1	1	1	—	1	2	2	2	—	1	—
54	1.1070	—	1	4	5	3	—	1	—	1	1	1	3	1	1	2	1	—	—
53	1.0865	2	—	2	2	1	1	1	1	—	1	1	—	—	1	1	1	1	—
52	1.0660	1	1	3	3	1	3	3	—	1	—	—	—	—	1	—	1	1	—
51	1.0455	—	1	—	1	—	2	1	—	2	2	2	1	—	1	1	—	—	—
50	1.0250	—	—	2	—	—	—	1	—	—	1	2	—	—	1	1	—	—	—
49	1.0045	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	1
48	.9840	1	—	—	1	1	—	—	1	—	—	—	—	1	2	—	—	—	—
47	.9635	—	—	—	—	1	1	—	1	—	—	—	—	—	—	—	—	1	—
46	.9430	—	—	1	1	1	2	—	—	—	—	—	—	—	—	—	—	2	—
45	.9225	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—
44	.9020	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

[1] RAC - Right anterior center
RAM - Right anterior mid-layer
RAO - Right anterior outer layer
RMC - Right middle region center
RMM - Right middle region mid-layer
RMO - Right middle region outer layer
RPC - Right posterior region center
RPM - Right posterior region mid-layer
RPO - Right posterior region outer layer
LAC - Left anterior center
LAM - Left anterior mid-layer
LAO - Left anterior outer layer
LMC - Left middle region center
LMM - Left middle region mid-layer
LMO - Left middle region outer layer
LPC - Left posterior region center
LPM - Left posterior region mid-layer
LPO - Left posterior region outer layer