Aquatic Mammals 2009, *35*(1), 72-81, DOI 10.1578/AM.35.1.2009.72

Ossification Patterns of Cranial Sutures in the Florida Manatee (*Trichechus manatus latirostris*) (Sirenia, Trichechidae)

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Abstract

Although morphological skull characters are used to identify species or subspecies of the genus *Trichechus*, little information is available on the growth of the manatee skull. We examined the ossification of the skull of the Florida manatee (*Trichechus manatus latirostris*) with regard to its growth pattern. We observed ten sutures in 137 crania (70 males and 67 females). Based on these results, the sutures can be classified into two groups by their ossification pattern. The first group contains the maxilloincisive suture, median palatine suture, frontal suture, and coronal suture. This group begins to ossify early in growth. The age of suture closure does not differ among the sexes. The second group consists of sutures related to the basicranium. This group is characterised by slower ossification compared to the first group. Suture ossification in this group proceeds from anterior to posterior. In this suture series, ossification occurred at later ages in males than in females. A notable feature is the formation of the occipital bone. Ossification of the spheno-occipital synchondrosis occurred earlier than that of the occipital condyle. This pattern is unique among mammals, including the dugong. Osteological maturity was determined by the status of the sutures. The sutures of the basicranium ossify slowly, and thus they are more valuable in evaluating the growth status of the skull than those of the viscerocranium and calvaria. The supraoccipital-exoccipital synchondrosis was the last to begin ossification, starting when individuals were more than 15 y old and 11 y old in males and females, respectively. We conclude that the ossification of the basicranium exhibits a unique pattern in the Florida manatee and that it is possible to determine the osteological maturity of the skull from the ossification of the supraoccipital-exoccipital synchondrosis.

Key Words: Florida manatee, *Trichechus manatus latirostris*, osteological maturity, cranial sutures, age-related growth

Introduction

The family Trichechidae includes three living species, the West Indian manatee (*Trichechus manatus*), the African manatee (*T. senegalensis*), and the Amazon manatee (*T. inunguis*). The West Indian manatee is classified into two subspecies: (1) the Antillean manatee (*T. m. manatus*) and (2) the Florida manatee (*T. m. latirostris*). Although morphological skull characters are useful in identifying species and subspecies of the genus *Trichechus* (Domning & Hayek, 1986), few data on growth patterns and osteological maturity have been published. Todd & Todd (1938) described the osteological growth pattern of the West Indian and African manatees. They examined the growth of the forelimb and the cervical vertebrae in 19 specimens; no data were collected on cranial characters, however. Odell (1981) studied the growth of the body length, weight, and some external morphological characters of the West Indian manatee, and Marmontel (1995) estimated sexual maturity in female manatees by an anatomical study of carcasses. By contrast, some studies have described the skull growth of the dugong (*Dugong dugon*), which belongs to the same order (Sirenia) as the manatees. Spain & Heinsohn (1974) analysed the size allometry of the dugong skull, while De Beer (1971) studied the development of the osteocranium.

The sirenians occupy an interesting phylogenetic position. They are usually considered close living relatives of the proboscideans by both morphological and molecular studies (Springer & Kirsch, 1993; Savage et al., 1994; Arnason et al., 2002). The Sirenia have evolved as the only herbivorous mammals that spend their entire lives in water. Thus, the bones of sirenians are also specialised. For example, the ribs and long bones of the West Indian manatee possess a characteristic growth pattern. Endochondral ossification is slow, while perichondral ossification proceeds at a more normal rate. This accounts for their delayed skeletal maturation (Fawcett, 1942). The skulls of sirenians also possess specific characters (e.g., the stretched premaxilla contacts the frontal bone, enlarged external nares extend beyond the anterior side of the orbit, and there is no sagittal crest). However, no information is available on the growth or ossification of the skull. Suture ossification is an important physiological event because bone growth is terminated by it. If skull characters are important in biological studies, we must understand how these characters change during growth. The elucidation of suture ossification is one way to investigate this.

Here we examined ossification in the skull of the Florida manatee in order to understand its growth patterns. We noted the ossification of the cranial sutures. Based on these data, we estimated the timing of osteological maturity in the Florida manatee. We also discuss skull development in this species and the peculiar characters of the order Sirenia.

Materials and Methods

We examined 137 crania of Florida manatees (70 males and 67 females). All specimens are deposited in the National Museum of Nature and Science, Tokyo, Japan (Appendix 1). The animals were collected from the Florida Peninsula, USA, between 1984 and 1996. Their ages were estimated by counting the number of growth layers in the dome portion of the tympanic bone complex (Marmontel et al., 1996). Their ages ranged from 0 to 27 y (males) and 0 to 33 y (females).

Mitchell (1973) described the sutures observed in a sirenian skull. She noted the ossification of three sutures surrounding the brain case (spheno-occipital synchondrosis, intersphenoidal synchondrosis, and supraoccipital-exoccipital synchondrosis) in the dugong. We found an additional seven sutures in our study of the growth pattern of the whole skull. The observed ten cranial sutures were as follows (see Figure 1): (1) intersphenoidal synchondrosis, (2) spheno-occipital synchondrosis, (3) basioccipital-exoccipital synchondrosis, (4) interexoccipital suture, (5) supraoccipital-exoccipital synchondrosis, (6) spheno-squamosal suture, (7) maxilloincisive suture, (8) median palatine suture, (9) frontal suture, and (10) coronal suture.

We referred to the methods of Stevenson (1924). He recognized four stages of epiphyseal union. We added one stage between the third and forth

Observed sutures
1. Intersphenoidal synchondrosis
2. Spheno-occipital synchondrosis
3. Basioccipital-exoccipital synchondrosis
4. Interexoccipital suture
5. Supraoccipital-exoccipital synchondrosis
6. Spheno-squamosal suture
7. Maxilloincisive suture
8. Median palatine suture
9. Frontal suture
10. Coronal suture

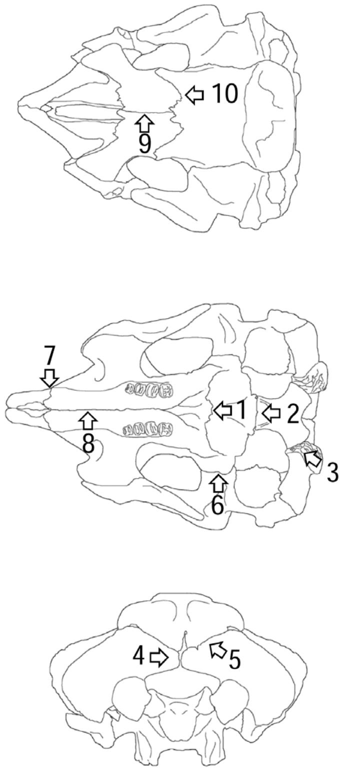

Figure 1. Examined sutures and their positions on the skull; the skull images are from NSMT-M34626 (1-y-old female).

in his study. The sutures were visually classified into five stages of suture closure (Figure 2): Stage I, suture open with no ossification; Stage II, suture partially ossified and bridging; Stage III, suture closed but still clearly observed; Stage IV, suture partially obscured by ossification; and Stage V, suture fully ossified and completely obliterated. Missing or damaged sutures in partially damaged specimens were excluded from the observations of the relevant suture.

Results

The ossification patterns of the ten observed sutures with respect to age are shown in Figures 3 & 4. The intersphenoidal synchondrosis was the first to ossify. The sutures in specimens of both sexes less than 1 y old were already at Stage II. Those of all the females older than 1 y were at Stage II or later. Those in males more than 4 y old were at Stages II to V. The closure of this suture continued until 4 and 6 y in females and males, respectively. The specimens older than this were at Stage V, except for one specimen of each sex (11-y-old female, NSMT-M34582, and 9-y-old male, NSMT-M35002; Figure 3a).

The closure of the sutures of the constituent elements of the occipital (spheno-occipital synchondrosis, basioccipital-exoccipital synchondrosis, interexoccipital suture, and supraoccipital-exoccipital synchondrosis) started late (Figures 3b to 3e). The spheno-occipital synchondrosis began ossification earliest (Figure 3b). Stage IV was observed in a 3-y-old female and a 4-y-old male. There were no specimens at Stage I among males and females over 7 y old and 8 y old, respectively, and all specimens of both sexes that were more than 10 y old were at Stage V.

Without exception, the closure of the basioccipital-exoccipital synchondrosis begins after the closure of the spheno-occipital synchondrosis. The occipital condyle is completed by the closure of this suture. Initial ossification of this suture was observed at 6 y in females and 10 y in males. In females, most specimens older than 11 y had completed the formation of the occipital condyle (Figure 3c).

The closure of the interexoccipital suture began a little later than that of the spheno-occipital synchondrosis. The youngest specimen showing initial closure of this suture was almost the same age as that for spheno-occipital synchondrosis; however, the age at which Stages IV or V were reached in all specimens was older than 11 y for females and 15 y for males (Figure 3d).

The closure of the supraoccipital-exoccipital synchondrosis was the latest among the sutures of the occipital region. The closure of this suture

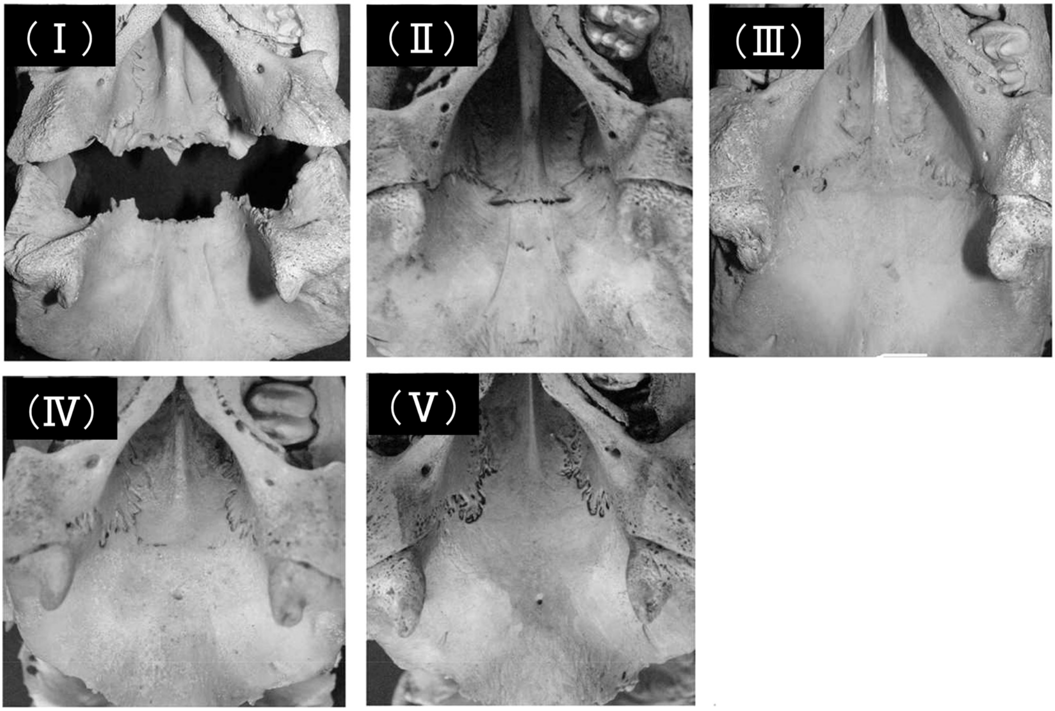

Figure 2. Representations of each stage of suture closure of the intersphenoidal synchondrosis; stages are described in the text.

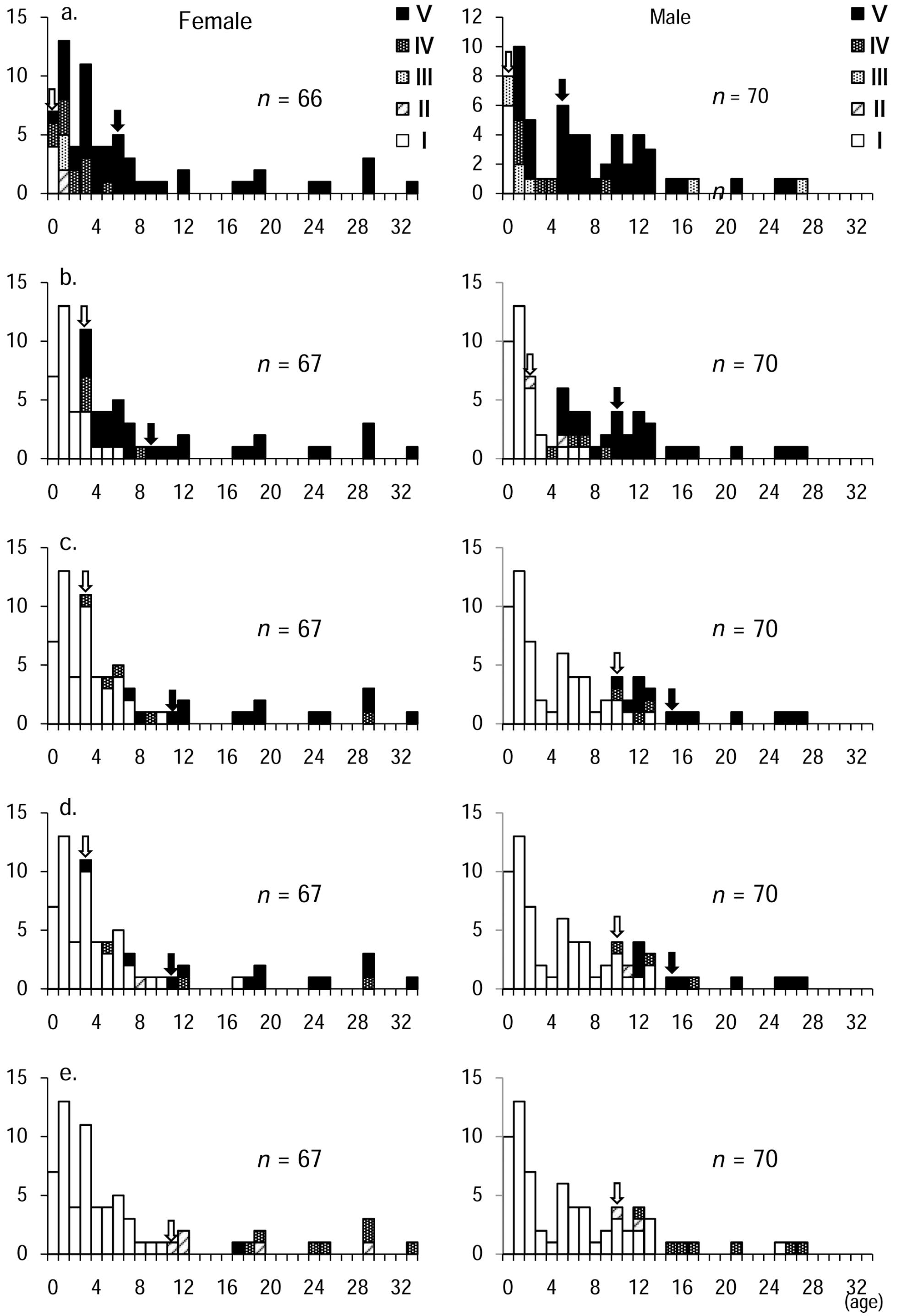

Figure 3. Status of the closure of the basicranial sutures at each age: a: intersphenoidal synchondrosis; b: spheno-squamosal suture; c: basioccipital-exoccipital synchondrosis; d: interexoccipital suture; and e: supraoccipital-exoccipital synchondrosis. The white arrows indicate the onset of fusion in each suture, and the black arrows indicate completion of ossification in each suture.

completes the development of the occipital bone. The stage of closure of the supraoccipital-exoccipital synchondrosis was definitely less advanced than that of the interexoccipital suture at the same age (e.g., female and male over 11 y old; Figures 3d & 3e). In addition, only one 17-y-old female specimen (NSMT-M35012) was at Stage V, and the oldest specimens of both sexes were still progressing through Stage IV.

In all specimens, the spheno-squamosal suture was persisted Stage I (not fused), except in one female (NSMT-M34715, 12 y old; Figure 4a).

The closure of the median palatine suture also begins at a young age. Some specimens under 1 y of age were at Stage III, and all specimens were at Stage III by 10 y in females and 17 y in males; however, this suture maintained Stage III and never disappears in older specimens (Figure 4b).

The maxilloincisive suture, the frontal suture, and the coronal suture had patterns of fusion similar to the median palatine suture (Figure 4). The maxilloincisive suture of most specimens under 1 y of age was at Stage I. Stage II begins at 1 to 7 y in females and 1 to 6 y in males (Figure 4c).

The closure of the frontal suture also begins before the end of the first year in both sexes. Females over 7 y old and males 9 y old were categorised as Stage III (Figure 4d).

For the coronal suture, Stages II and III were observed in specimens less than 1 y old. There were no specimens at Stage II older than 4 y among females and 5 y among males (Figure 4e). However, the latter two sutures were maintained at Stage III to adulthood, just like in the median palatine suture.

Discussion

Based on the above results, the observed sutures can be divided into two groups by their ossification patterns. The first group contains the maxilloincisive suture, median palatine suture, frontal suture, and coronal suture. These sutures reached Stage II in juveniles, and no sexual difference was observed in the age of suture closure (see Figure 4). In addition, these sutures became interdigitated more complexly with growth and persisted in older specimens, except in a few exceptional individuals. In this group, the frontal and coronal sutures begin closing at less than 1 y of age (Figures 4d & 4e). These sutures are formed between the bones that constitute the calvaria (see Figure 1). These bony elements should be subject to pressure from the rapidly growing brain. The growth of the brain occurs rapidly and shortly after birth (in humans, brain size increases rapidly between the time of birth and 3 y of age; Sperber, 1989). The maxilloincisive and median palatine sutures then start to ossify (Figures 4b & 4c).

The other group relates mainly to the basicranium. This group is characterised by slower closure than the first group and a gradual progression of suture closure. Ossification proceeds anterior to posterior. This pattern is found in both sexes; however, sutures close later in males than in females.

The advance of suture closure appears to be rather regular, with a few exceptions (see Figure 3). The spheno-occipital synchondrosis closed between 3 and 6 y. The ossification of the basioccipital-exoccipital synchondrosis to form the occipital condyle occurred after closure of the spheno-occipital synchondrosis between 10 and 15 y in males and 6 and 11 y in females. Finally, the supraoccipital part of the occipital bone fuses to the exoccipital part by the supraoccipital-exoccipital synchondrosis.

These results indicate that the growth of the cranial base is relatively regular and more readily defines growth stages than does the calvaria and viscerocranium as in other mammals. A remarkable feature is the ossification of the occipital bone. This pattern is unique when compared to other mammals. In mammals, the development of the occipital region generally begins relatively early starting with the dorsal region and the ossification of the supraoccipital (Novacek, 1993). For example, in humans, the supraoccipital begins to fuse with the exoccipitals at 2 to 3 y; the occipital condyle begins to form at 3 to 4 y; and, finally, the squama, exoccipital, and basioccipital bones fuse together and complete the occipital bone at approximately 7 y (Sperber, 1989). In addition, in the dugong, the ossification of the occipital condyle occurs faster than the ossification of the spheno-occipital synchondrosis (Mitchell, 1973). Perrin (1975) also reported that cetaceans are slower to ossify the occipital bone of the basicranium than the dorsal calvaria. We conclude that the ossification of the basicranium follows a particular pattern in the Florida manatee (see Figure 5). The growth of the basicranium decides the final size of the skull and plays an important role in the outcome of the shape of the whole skull (Sperber, 1989). In particular, closure of the spheno-occipital synchondrosis occurs slowly and continues over a long period in other mammals, whereas the Florida manatee is unique in that the spheno-occipital synchondrosis is the earliest to fuse in the occipital region.

Manatees and dugongs share a phylogenetic history, and thus they share some unique features. The replacement of cheek teeth is one of these characteristic features. The cheek teeth of the recent sirenians, manatees and dugongs, are replaced horizontally; the new tooth erupts from the rear of the tooth row, pushing the anterior tooth out of the tooth row. Generally, the number

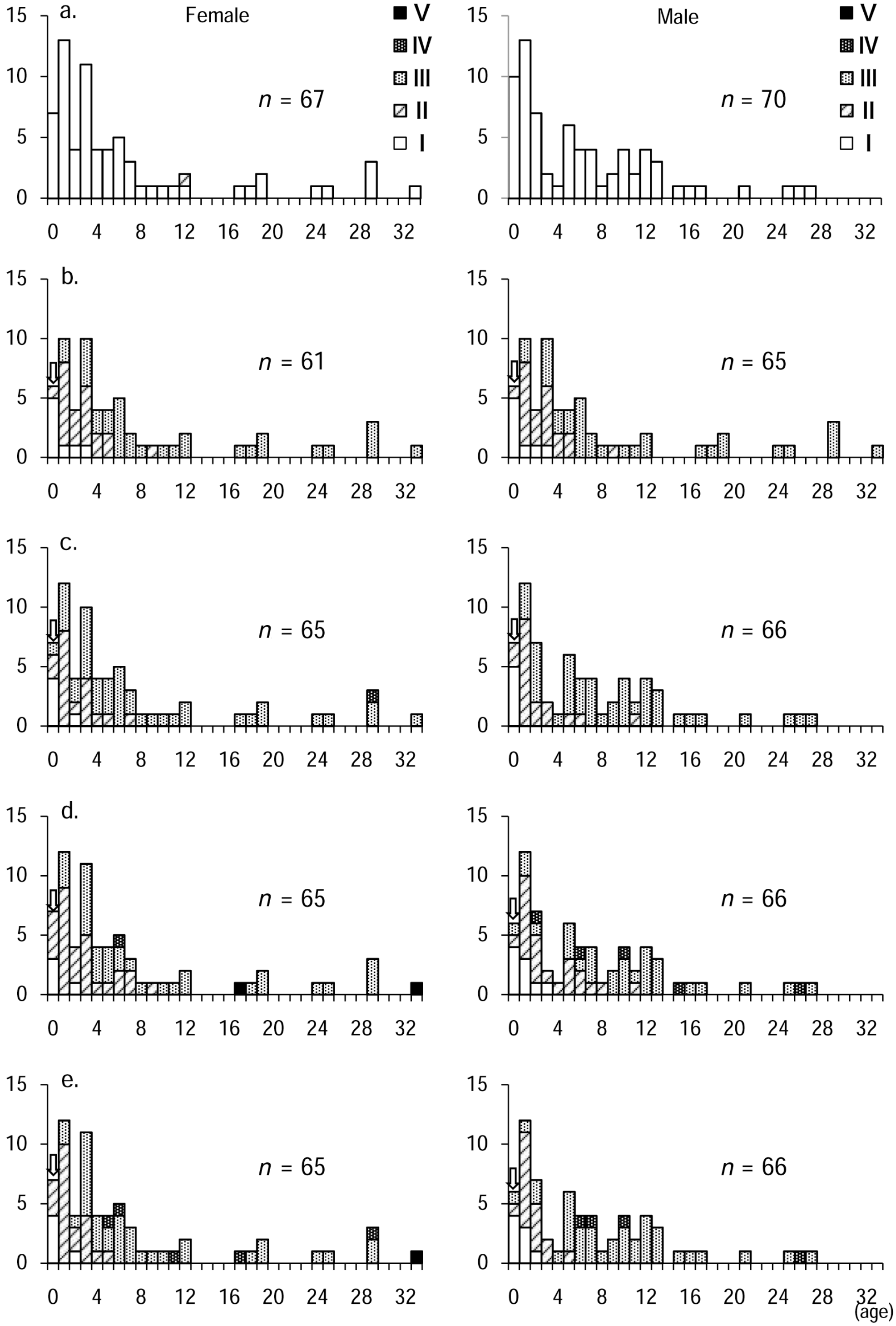

Figure 4. Status of the closure of the sutures of the calvaria and viscerocranium at each age: a: spheno-squamosal suture; b: maxilloincisive suture; c: median palatine suture; d: frontal suture; and e: coronal suture. The white arrows indicate the start of suture closure.

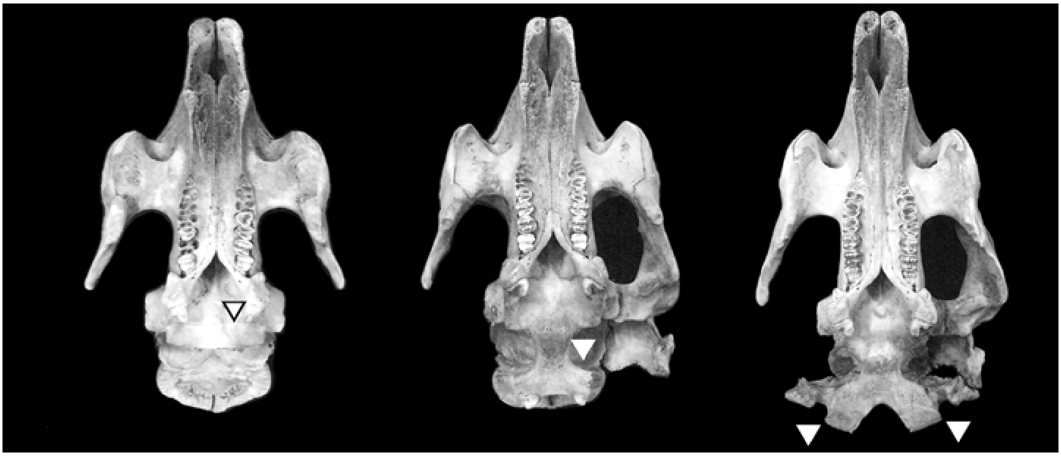

Figure 5. Progression of ossification in the basicranium; triangles indicate the sutures that define the criteria for determination of each grade. Left: a cranium of the second grade; the closure of only the intersphenoidal synchondrosis. Centre: a cranium of the third grade; the ossification of the spheno-occipital synchondrosis. Right: a cranium of the fourth grade; basioccipital-exoccipital synchondrosis.

of cheek teeth in mammals is not more than seven, and in the dugong, six cheek teeth erupt. The manatee is the only exception in that the molar number is not defined, and the estimated lifetime number of erupted molars in each jaw quadrant is as high as 20 to 30 (Thomas & Lydekker, 1897; Domning & Hayek, 1984). In addition, the manatee has another peculiar feature with regard to the neck, having only six cervical vertebrae. This characteristic also separates the manatees from the dugongs. In addition to differences in the number of teeth and cervical vertebrae, there also are obvious differences in the ossification of the basicranium between manatees and dugongs. Domning (2000) suggested that the shortened neck of marine mammals is an advantage in controlling buoyancy due to the anterior positioning of the flippers, and Buchholtz et al. (2007) followed this suggestion by measurements of vertebrae. However the mechanisms and processes of decreasing cervical vertebrae are not yet elucidated. Hence, the unique ossification pattern of the occipital bone of the Florida manatee may have some relationship to the unique replacement of molars and number of cervical vertebrae. Studies of the evolutionary development of these features and confirmation of effect on growth of skull proportions by this unique closure pattern in sutures are necessary.

The progression of suture closure in the basicranium is more easily evaluated than that of the viscerocranium and calvaria. As shown in Figures 3 & 4, the complete ossification of the viscerocranium and calvaria seems to continue for a long time. On the other hand, the sutures of the basicranium are fused earlier than those of the calvaria and viscerocranium, despite the later start of their closure. Therefore, the basicranium is the most useful in determining osteological maturity. Our findings show that the closing sequence of sutures related to the basicranium is more stable. The last suture to close is the supraoccipital-exoccipital synchondrosis. Thus, osteological maturity in the skull is achieved by the closure of this suture.

These suture closures can be used for supplementary relative age estimates as the closures progress following a certain sequence, without exception. Thus, five grades of osteological age-related growth in the skull can easily be defined by the closure of the basicranial sutures. The first grade is defined by the first grade, all basicranial sutures open with no ossification at 0 y old. The second grade is defined by the closure of only the intersphenoidal synchondrosis at approximately 0 to 2 y old. The third grade is defined by the ossification of the spheno-occipital synchondrosis at approximately 3 to 7 y old. The fourth grade is defined by the ossification of the basioccipital-exoccipital synchondrosis at approximately 7 to 10 y old in females and 7 to 14 y old in males. Finally, the fifth grade is defined by the start of the ossification of the supraoccipital-exoccipital synchondrosis at over 11 y in females and 15 y in males. We conclude that skulls of the Florida manatee of the fifth grade are osteologically mature.

Acknowledgments

We thank the National Museum of Nature and Science for permission to use their Florida manatee specimens, and are particularly grateful to Drs. Tadasu K. Yamada and Yuko Tajima of the Department of Zoology of said museum.

These specimens were originally collected by the Marine Mammal Pathobiology Laboratory of the Florida Marine Research Institute, We thank Drs. Tom Pitchford, John E. Reynolds III, Sentiel A. Rommel, and Alex Costidis. We also thank Dr. Nozomi Kurihara for advice in writing this report.

Literature Cited

Arnason, U., Adegoke, J. A., Bodin, K., Born, E. W., Esa, Y. B., Gullberg, A., et al. (2002). Mammalian mitogenomic relationships and the root of the eutherian tree. *Evolution*, *99*(12), 8151-8156.

Buchholtz, E. A., Booth, A. C., & Webbink, K. E. (2007). Vertebral anatomy in the Florida manatee, *Trichechus manatus latirostris*: A developmental and evolutionary analysis. *The Anatomical Record, 290*, 624-637.

De Beer, G. (1971). *Development of the vertebrate skull.* Oxford, UK: Oxford University Press. 580 pp.

Domning, D. P. (2000). The readaptation of Eocence sirenians to life in water. *Historical Biology*, *14*, 115-119.

Domning, D. P., & Hayek, L. C. (1984). Horizontal tooth replacement in the Amazonian manatee (*Trichechus inunguis*). *Mammalia*, *48*(1), 105-127.

Domning, D. P., & Hayek, L. C. (1986). Interspecific and intraspecific morphological variation in manatees (Sirenia: *Trichechus*). *Marine Mammal Science*, *2*(2), 87-144.

Fawcett, D. W. (1942). The amedullary bones of the Florida manatee (*Trichechus latirostris*). *American Journal of Anatomy*, *71*(2), 272-309.

Marmontel, M. (1995). Age and reproduction in female Florida manatees. In T. J. O'Shea, B. B. Ackerman, & H. F. Percival (Eds.), *Population biology of the Florida manatee (*Trichechus manatus latirostris*)* (National Biological Service, Information and Technology Report 1) (pp. 98-119).

Marmontel, M., O'Shea, T. J., Kochman, H. I., & Humphrey, S. R. (1996). Age determination in manatees using growth-layer-group count in bone. *Marine Mammal Science*, *12*(1), 54-88.

Mitchell, J. (1973). Determination of relative age in the dugong *Dugong dugon* (Müller) from a study of skull and teeth. *Zoological Journal of the Linnean Society*, *53*, 1-23.

Novacek, M. J. (1993). Patterns of diversity in the mammalian skull. In J. Hanken & B. K. Hall (Eds.), *The skull, Vol. 2* (pp. 438-545). Chicago: University of Chicago Press.

Odell, D. K. (1981). Growth of a West Indian manatee, *Trichechus manatus*, born in captivity. In R. L. Brownell, Jr., & K. Ralls (Eds.), *The West Indian manatee in Florida* (Proceedings of a workshop held in Orlando, Florida) (pp. 131-140). Tallahassee: Florida Department of Natural Resources.

Perrin, W. F. (1975). Variation of spotted and spinner porpoise (genus *Stenella*) in the Eastern Pacific and Hawaii. *Bulletin of the Scripps Institution of Oceanography University of California, San Diego*, *21*. 206 pp.

Savage, R. J. G., Domning, D. P., & Thewissen, J. G. M. (1994). Fossil Sirenia of the West Atlantic and Caribbean region. V. The most primitive sirenian, *Prorastomus sirenoides* Owen, 1855. *Journal of Vertebrate Paleontology*, *14*, 427-449.

Spain, A. V., & Heinsohn, G. E. (1974). A biometric analysis of measurement data from a collection of North Queensland dugong skulls, *Dugong dugon* (Müller) *Australian Journal of Zoology*, *22*, 249-257.

Sperber, G. H. (1989). *Craniofacial embryology* (4th ed.). London: Butterworth-Heinemann Ltd. 256 pp.

Springer, M. S., & Kirsch, J. A. W. (1993). A molecular perspective on the phylogeny of placental mammals based on mitonchondrial 12s rDNA sequence, with special reference to the problem of the Paenungulata. *Journal of Mammalian Evolution*, *1*, 149-166.

Stevenson, P. H. (1924). Age order of epiphyseal union in man. *American Journal of Physical Anthropology*, *7*(1), 53-93.

Thomas, O., & Lydekker, R. (1897). On the number of grinding-teeth possessed by the manatee. *Proceedings of the Zoological Society of London*, 595-600.

Todd, T. W., & Todd, A. W. (1938). The epiphysial union pattern of the ungulates with a note on Sirenia. *The American Journal of Anatomy*, *63*(1), 1-34.

Appendix 1. The specimens used for observations of suture closure

Collection number	Field ID	sex	age	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
NSMT-M34562	MSW088	F	0	I	I	I	I	I	I	I	I	I	I
NSMT-M34588	MJAV9003	F	0	I	I	I	I	I	I	I	II	I	I
NSMT-M34589	MJAV9004	F	0	I	I	I	I	I	I	I	I	I	I
NSMT-M34590	UCF9007	F	0	V	I	I	I	I	I		II	II	I
NSMT-M34601	UCF9025	F	0	I	I	I	I	I	I	II	I	II	II
NSMT-M34615	MJAV9035	F	0	IV	I	I	I	I	I	I	III	II	II
NSMT-M34638	MNE9110	F	0	IV	I	I	I	I	I	I	I	II	II
NSMT-M34554	SWFTM8519	F	1	V	I	I	I	I	I	II	II	II	II
NSMT-M34556	M8608	F	1	IV	I	I	I	I	I	II	II	II	II
NSMT-M34563	MSW099	F	1	V	I	I	I	I	I	II	II	III	III
NSMT-M34565	MSW103	F	1	II	I	I	I	I	I	II	III	II	II
NSMT-M34569	MSE8801	F	1	IV	I	I	I	I	I	II	II	II	II
NSMT-M34574	MSE8901	F	1	IV	I	I	I	I	I	III	III	III	II
NSMT-M34583	MSW243	F	1	II	I	I	I	I	I	II	III	II	II
NSMT-M34585	MJAV9002	F	1	III	I	I	I	I	I	III	II	II	II
NSMT-M34633	UCF9111	F	1	III	I	I	I	I	I				
NSMT-M34634	UCF9113	F	1	V	I	I	I	I	I		II	III	III
NSMT-M34641	UCF9122	F	1	V	I	I	I	I	I		II	II	II
NSMT-M34656	MSW9132	F	1	V	I	I	I	I	I	II	II	II	II
NSMT-M34714	MEC9420	F	1	III	I	I	I	I	I	I	III	II	II
NSMT-M34555	M8604	F	2	IV	I	I	I	I	I	II	II	II	II
NSMT-M34558	MSW080	F	2	V	I	I	I	I	I	II	III	II	II
NSMT-M34592	UCF9017	F	2	V	I	I	I	I	I	II	III	II	III
NSMT-M34707	MSE9409	F	2	IV	I	I	I	I	I	I	I	I	I
NSMT-M34561	SWFTM8630	F	3	V	IV	I	I	I	I	II	III	II	III
NSMT-M34567	MSW119	F	3	IV	IV	I	I	I	I	II	II	III	III
NSMT-M34612	MSW271	F	3	V	V	I	I	I	I	II	III	III	III
NSMT-M34621	MSE9022	F	3	V	V	I	I	I	I	II	III	III	III
NSMT-M34639	UCF9119	F	3	V	IV	I	I	I	I			II	II
NSMT-M34648	MNW9116	F	3	V	V	IV	V	I	I	III	III	III	III
NSMT-M34722	MEC9439	F	3	IV	I	I	I	I	I	I	II	III	III
NSMT-M34982	MSW9529	F	3	V	I	I	I	I	I	II	II	II	III
NSMT-M34984	MNW9512	F	3	IV	I	I	I	I	I	III	III	III	II
NSMT-M35008	MEC9629	F	3	V	V	I	I	I	I	III	III	II	II
NSMT-M35010	MEC9651	F	3	V	I	I	I	I	I	III	II	II	II
NSMT-M34597	UCF9021	F	4	V	V	I	I	I	I	II	III	III	III
NSMT-M34647	MSE9113	F	4	V	V	I	I	I	I	III	III	III	III
NSMT-M34696	MNE9310	F	4	V	V	I	I	I	I	III	III	III	III
NSMT-M34987	MSW9540	F	4	V	I	I	I	I	I	II	II	II	II
NSMT-M34553	SWFTM8518	F	5	V	V	I	I	I	I	II	III	III	IV
NSMT-M34640	MSE9110	F	5	V	V	I	I	I	I	III	III	III	III
NSMT-M34643	MSE9111	F	5	V	V	IV	IV	I	I	III	III	III	III
NSMT-M35014	MEC9658	F	5	IV	I	I	I	I	I	II	II	II	II
NSMT-M34619	MSE9023	F	6	V	V	IV	I	I	I	III	III	III	III
NSMT-M34635	MSW9109	F	6	V	I	I	I	I	I	III	III	II	III
NSMT-M34718	MEC9430	F	6	V	V	I	I	I	I	III	III	III	III
NSMT-M35013	MSE9622	F	6	V	V	I	I	I	I	III	III	II	III
NSMT-M35015	MSE9623	F	6	V	V	I	I	I	I	III	III	IV	IV
NSMT-M34609	MSE9012	F	7	V	V	V	V	I	I	III	III	III	III
NSMT-M34637	MSW9112	F	7	V	V	I	I	I	I	III	III	II	III
NSMT-M34651	MSW9124	F	7	V	V	I	I	I	I		II	II	III
NSMT-M34991	MNW9517	F	8	V	IV	V	II	I	I	III	III	III	III
NSMT-M34559	MSW081	F	9	V	V	IV	I	I	I	II	III	II	III
NSMT-M35018	MEC9664	F	10	V	V	I	I	I	I	III	III	III	III
NSMT-M34582	MSE9001	F	11	III	V	V	V	II	I	III	III	III	IV
NSMT-M34620	MSW288	F	12	V	V	V	V	II	I	III	III	III	III
NSMT-M34715	MEC9422	F	12	V	V	V	IV	II	II	III	III	III	III
NSMT-M35012	MSW96216	F	17	V	V	V	I	V	I	III	III	V	IV
NSMT-M34631	MSW9103	F	18	V	V	V	V	IV	I	III	III	III	III
NSMT-M34577	KDL8947	F	19	V	V	V	V	II	I	III	III	III	III
NSMT-M34616	MSW279	F	19	V	V	V	V	IV	I	III	III	III	III
NSMT-M34579	MJAV8922	F	24	V	V	V	V	IV	I	III	III	III	III
NSMT-M34632	UCF9107	F	25	V	V	V	V	IV	I	III	III	III	III
NSMT-M34564	M8626	F	29	V	V	V	V	IV	I	III	III	III	IV
NSMT-M34649	MSW9120	F	29	V	V	IV	IV	I	I	III	IV	III	III
NSMT-M35016	MSE9624	F	29	V	V	V	V	IV	I	III	III	III	III
NSMT-M34694	MEC9320	F	33	V	V	V	V	IV	I	III	III	V	V

Appendix 1 (cont.). The specimens used for observations of suture closure

Collection number	Field ID	sex	age	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
NSMT-M34550	MSW032	M	0	I	I	I	I	I	I	I	I	I	I
NSMT-M34572	MSW169	M	0	III	I	I	I	I	I	II	II	III	III
NSMT-M34595	UCF9020	M	0	I	I	I	I	I	I				
NSMT-M34623	MSE9024	M	0	I	I	I	I	I	I	I	I	I	I
NSMT-M34625	UCF9101	M	0	I	I	I	I	I	I	I	I	I	I
NSMT-M34626	UCF9102	M	0	II	I	I	I	I	I				
NSMT-M34628	UCF9104	M	0	III	I	I	I	I	I				
NSMT-M34645	UCF9123	M	0	II	I	I	I	I	I	I	II		
NSMT-M34662	MSE9125	M	0	I	I	I	I	I	I	I	I	II	II
NSMT-M35005	MNE9608	M	0	I	I	I	I	I	I	I	I	I	I
NSMT-M34551	MSW049	M	1	II	I	I	I	I	I	I	II	I	I
NSMT-M34560	SWFTM8623	M	1	V	I	I	I	I	I	II	II	III	III
NSMT-M34568	KDL8803	M	1	V	I	I	I	I	I	II	II	II	II
NSMT-M34581	MSW236	M	1	IV	I	I	I	I	I	III	III	I	I
NSMT-M34587	MNW9001	M	1	III	I	I	I	I	I	II	II	II	II
NSMT-M34591	UCF9011	M	1	V	I	I	I	I	I	II	II	I	II
NSMT-M34594	MSW247	M	1	IV	I	I	I	I	I	II	II	II	II
NSMT-M34596	UCF9018	M	1	IV	I	I	I	I	I	III	II	III	II
NSMT-M34604	UCF9033	M	1	III	I	I	I	I	I				
NSMT-M34627	UCF9103	M	1	II	I	I	I	I	I		II	II	II
NSMT-M34655	MSW9130	M	1	II	I	I	I	I	I	II	III	II	II
NSMT-M34659	UCF9137	M	1	V	I	I	I	I	I	II	II	II	II
NSMT-M34994	MSW9544	M	1	V	I	I	I	I	I	II	III	II	I
NSMT-M34607	UCF9044	M	2	V	I	I	I	I	I	II	II	II	II
NSMT-M34608	UCF9046	M	2	V	I	I	I	I	I	III	III	IV	III
NSMT-M34652	MSE9116	M	2	V	I	I	I	I	I	II	III	II	II
NSMT-M34708	MSW9412	M	2	II	I	I	I	I	I	I	III	II	II
NSMT-M34978	MNE9505	M	2	III	II	I	I	I	I	II	III	III	II
NSMT-M34986	MEC9521	M	2	II	I	I	I	I	I	II	II	II	III
NSMT-M34993	MNW9518	M	2	V	I	I	I	I	I	III	III	I	I
NSMT-M34999	MSW9607	M	3	II	I	I	I	I	I	II	II	II	II
NSMT-M35011	MEC9652	M	3	IV	I	I	I	I	I	I	II	I	II
NSMT-M34989	MNW9515	M	4	IV	IV	I	I	I	I	II	III	II	III
NSMT-M34576	MSE8911	M	5	V	II	I	I	I	I	III	III	II	III
NSMT-M34593	UCF9016	M	5	V	V	I	I	I	I	III	II	II	III
NSMT-M34598	UCF9019	M	5	V	V	I	I	I	I	III	III	II	III
NSMT-M34614	MJAV9031	M	5	V	V	I	I	I	I	III	III	III	III
NSMT-M34646	MNE9113	M	5	V	V	I	I	I	I	III	III	III	III
NSMT-M34732	MSW9502	M	5	V	I	I	I	I	I	II	III	III	II
NSMT-M34573	KDL8850	M	6	V	V	I	I	I	I	II	III	III	III
NSMT-M34704	MNW9402	M	6	V	I	I	I	I	I	II	II	IV	IV
NSMT-M34985	MSW9532	M	6	V	V	I	I	I	I	II	III	II	III
NSMT-M35000	MSW9606	M	6	V	IV	I	I	I	I	II	III	II	III
NSMT-M34557	MSW078	M	7	V	V	I	I	I	I	III	III	III	IV
NSMT-M34605	MJAV9018	M	7	V	IV	I	I	I	I	III	III	III	III
NSMT-M34650	UCF9129	M	7	V	I	I	I	I	I	III	III	II	III
NSMT-M35003	MSW9614	M	7	V	V	I	I	I	I	II	III	III	III
NSMT-M34698	MSE9314	M	8	V	V	I	I	I	I	II	III	II	III
NSMT-M34630	UCF9105	M	9	V	IV	I	I	I	I	III	III	III	III
NSMT-M35002	MSW9612	M	9	IV	V	I	I	I	I	III	III	III	III
NSMT-M34575	MSE8906	M	10	V	V	V	IV	II	I	III	III	III	III
NSMT-M34622	MSW291	M	10	V	V	I	I	I	I	III	III	III	III
NSMT-M34992	MSE9522	M	10	V	V	I	I	I	I	III	III	III	III
NSMT-M34995	MSW9549	M	10	V	V	IV	I	I	I	III	III	IV	IV
NSMT-M34990	MNW9516	M	11	V	V	V	II	I	I	III	III	III	III
NSMT-M35019	MEC9665	M	11	V	V	I	I	I	I	II	II	II	III
NSMT-M34566	M8710	M	12	V	V	V	V	IV	I	III	III	III	III
NSMT-M34571	MJAV8802	M	12	V	V	V	V	II	I	III	III	III	III
NSMT-M34654	MNE9122	M	12	V	V	V	V	I	I	III	III	III	III
NSMT-M34695	MEC9322	M	12	V	V	IV	I	I	I	III	III	III	III
NSMT-M34606	MJAV9021	M	13	V	V	I	I	I	I	III	III	III	III
NSMT-M34719	MNW9415	M	13	V	V	IV	IV	I	I	III	III	III	III
NSMT-M34996	MSE9525	M	13	V	V	V	I	I	I	III	III	III	III
NSMT-M34644	MSE9112	M	15	V	V	V	V	IV	I	III	III	IV	III
NSMT-M34570	MSE8803	M	16	V	V	V	V	IV	I	II	III	III	III
NSMT-M34979	MSE9514	M	17	III	V	V	IV	IV	I	III	III	III	III
NSMT-M34642	MNE9112	M	21	V	V	V	V	IV	I	III	III	III	III
NSMT-M34584	MSE9002	M	25	V	V	V	V	I	I	III	III	III	III
NSMT-M34624	MSW9101	M	26	V	V	V	V	IV	I	III	III	IV	IV
NSMT-M34629	MSE9105	M	27	III	V	V	V	IV	I	III	III	III	III