

TAIL SPINE CHARACTERISTICS OF STINGRAYS (ORDER MYLIOBATIFORMES) FREQUENTING THE FAO FISHING AREA 61 (20°N 120°E - 50°N 150°E) OF THE NORTHWEST PACIFIC OCEAN

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ABSTRACT. – Tail spine characteristics were examined in 46 stingray species (171 males, 252 females) with intact spines from the Northwest Pacific Food and Agriculture Organization (FAO) fishing area 61 (located between 20°N 120°E - 50°N 150°E). Of these, 34 species possessed tail spines, 10 did not and two species either had all their spines broken (*Dasyatis navarrae*) or were not examined (*D. gigantea*). The distribution, spine length, base length, total number of serrations per spine, the prebase / total spine length percentage ratio and the presence of a dorsal spine groove are discussed for each species. The number of spine serrations appears to be related to the specific habitat frequented by each species: 1) open water and highly-active swimming species (eight species) possessed total spine serrations exceeding 100; 2) active midwater species (12 species) possessed 70 - 100 total spine serrations; 3) benthopelagic species (seven species) possessed 50 - 70 total serrations and 4) benthic species (seven species) possessed 25 - 50 total spine serrations. Spine total lengths (STL) varied widely and were not correlated with disk widths (DW). For example, *Aetobatis narinari*, a large (300 cm DW), active species had spine lengths of 60 - 78 mm with 102 - 112 serrations while the benthic species *Dasyatis ushieii* (38 cm DW) had a comparable spine length of 92 mm but only 46 serrations. Likewise, the length of the serrations varied in length from minute in *D. ushieii* (38 cm DW), to stout in *D. izuensis* (32 cm DW) and long in *D. bennetti* (30 cm DW) although they were of similar disk widths. Some spines also had serrations on the sides of the spine base. Thus, stingray spine characteristics are good indicators of the species and its habitat preference. Spine morphologies can aid ichthyologists, paleontologists and physicians in species identification and elucidating fossil relationships.

KEY WORDS. – Stingrays, Myliobatiformes, tail spine morphology, Northwest Pacific Ocean.

INTRODUCTION

The Pacific Ocean is the largest and deepest ocean on earth. It is made up of the Pacific Plate, the Philippine Plate, deep ridges and troughs and islands (Springer, 1982) that are subjected to volcanism (Packham & Falvey, 1971). This paper reports on the tail spine characteristics of 46 species of stingrays found in waters of Food and Agriculture Organization (FAO) fishing area 61 located between 20°N 120°E and 50°N 150°E (Garibaldi & Limongelli, 2002). This area includes China, Japan, the Japan Sea, Korea, the South China Sea, Taiwan, the Ryukyu, Penghu and Ogasawara (Bonin) Islands and Okinawa.

Humans have long been aware of the venomous and toxic aspects of stingray spines (Halstead, 1970). However, it has not been regarded as a taxonomic character. This paper reports on the tail spine serrations of 34 species of stingrays frequenting the Northwest Pacific Ocean. Synonyms, geographic distribution of the species, the existence of

bilateral spine serration asymmetry by sex (Schwartz, 2003, Leamy & Klingenberg, 2005), total, base and prebase spine lengths, the presence of dorsal grooves, percentage spine dorsal groove length, the presence of lateral serrations or spaces on the spine base and the number of tail spines per species were examined.

MATERIALS AND METHODS

Preserved stingray specimens (171 males, 252 females) with intact tail spines were examined at the Chinese Academy Sciences (Beijing), Hokkaido University (Hokodate, Japan), the University of Tokyo (Tokyo, Japan), the National Sciences Museum (Tokyo, Japan), the Taiwan National Museum (Taipei, Taiwan), the Commonwealth Scientific and Industrial Research Organisation, CSIRO, (Hobart, Tasmania, Australia), the Australian Museum (Sydney, Australia), the Cape Town Museum (South Africa), Rhodes University (J. L. B. Smith Laboratory, Grahamstown, South Africa),

Naturhistorisches Museum (Vienna, Austria), the U.S. National Museum (Washington, DC, USA), the California Academy of Sciences (San Francisco, CA, USA) and the Scripps Institution of Oceanography (La Jolla, CA, USA).

Geographic localities, by species, are designated as follows: China (C), Japan and Japan Sea (J), Korea (K), Taiwan (T), South China Sea (SC), Penghu (P), Ryukyu (R), Ogasawara (Bonin) Islands (O) and Okinawa (OK). The use of common names of the stingrays discussed follows Compagno (1999).

Most of the spines of the stingrays examined while still attached to the tail, while a few were excised at the base of the spine by teasing the skin loose to expose serrations or spaces (in mm) on the sides of the base. All large and small serrations occurring from the tip to the spine base were counted for each side of the spine. Spine total length (STL) was the spine length from its attachment to the tip of the spine. Spine base (pb) was the STL minus the length of the spine tip to the point where the spine was attached to the tail. Spine base / spine total length (pb / STL) ratios were expressed in terms of percentages. Percent length of the dorsal groove was the length of the groove from the basal end of the spine to the spine tip. Body disk widths (DW) are expressed in centimeters (cm).

The order of the species presented in Table 1 is on the basis of serration numbers and not generic relationships.

OBSERVATIONS

***Himantura fai* Jordan & Seale**, pink whipray: A species (150 cm DW) that occurs from the waters off Japan Southward to the Indo-Pacific area and Australia (Last & Stevens, 1994; Randall & Lim, 2000) (Table 1). The STL averages 184 mm and it possessed the most highly-serrated spine of all the North Pacific stingrays (183 serrations). No serrations or blank spaces occurred on the base. The pb / STL was 70% and a dorsal groove extended an average of 70% of the length of the spine. *Himantura fai* is an active species that frequents a range habitats from open water to atolls (Randall & Earle, 2000).

***Pteroplatytrygon violacea* Bonaparte**, pelagic stingray: One of the largest (Last & Stevens, 1994) stingrays with an average 210 cm DW frequenting the waters of the China Sea, off Japan, Taiwan, Korea, the South China Sea and the Ryukyu Islands (Ishihara, 1990; Nishida & Nakaya, 1990; Last & Stevens, 1994; Randall & Lim, 2000) (Table 1). It has been placed in the genus *Dasyatis* by some authors (Nishida & Nakaya, 1990). It is dark both dorsally and ventrally. Its anterior disk profile is arched. The spine of the female was slightly longer than that of the male (121 mm STL vs. 109 mm STL) (Table 1). Average total spine serrations of the males were 166 while the females had 169. There were 3 - 20 serrations on each side of the spine base. The average pb / STL was 72% for the males and 75% for the females. A dorsal groove extended an average of 20% of the spine's

length. The most distinguishing feature of the spine was the cul-de-sacs located medially, between each spine serration.

***Pastinachus sephen* Forsskael**, cowtail stingray: A species (180 cm DW) with a conspicuous lower tail fin fold is found across the world from the Red Sea, South Africa, China, Taiwan, Korea, Indonesia, the Ryukyu Islands, Japan, the South China Sea and Okinawa (Fowler, 1941; Nishida & Nakaya, 1990; Last & Stevens, 1994; Randall & Lim, 2000) (Table 1). The tail spine was long, with the STL averaging 157 mm in males and 159 mm in females. The average total spine serrations were 124 for both sexes and 5 to 26 serrations occurred on the sides of the spine base. The average pb / STL was 75% for males and 76% for females. No dorsal groove was evident in this multi-spined species.

***Dasyatis izuensis* Nishida & Nakaya**, Izu stingray: A species (37 cm DW) that is found off Japan and Taiwan (Nishida & Nakaya, 1990) (Table 1). The average STL of males was 68 mm and 79 mm in females. The spine was stout and had an average of 112 serrations in males and 130 in females with 10 to 33 serrations occurring on the sides of the spine base. The average pb / STL was 69% for males and 74% for females. A dorsal groove extended an average of 10% of the spine's length.

***Himantura granulata* Macleay**, mangrove whipray: A species (90 cm DW) that occurs in the South China Sea and is widespread in the Indo-West Pacific (Last & Stevens, 1994; Randall & Lim, 2000) (Table 1). The average STL was 52 mm in both sexes. The average total spine serrations were 124 in males and 97 in females. There were 2 - 13 serrations on the sides of the spine base. The average pb / STL was 72% for males and 81% for females. A dorsal groove extended an average of 70% of the spine's length.

***Aetobatis narinari* Euphrasen**, spotted eagle ray: An active, open water species (300 cm DW) that is found off China, Japan, Taiwan, Korea, the Ryukyu and Ogasawara Islands and in the South China Sea (Fowler, 1941; Shen, 1984; Ishihara, 1990; Last & Stevens, 1994; Randall et al., 1997; Randall & Lim, 2000) (Table 1). The average total spine serrations were 102 for males and 112 for females with 4 - 16 serrations occurring on the sides of the spine base. The average pb / STL was 76% for males and 66% for females. A dorsal groove extended an average of 50% of the spine's length in some specimens and there were up to 8 tail spines per specimen.

***Plesiobatis daviesi* Wallace**, giant stingaree: A species (200 cm DW) that is found off China, Taiwan, the Ryukyu Islands, Okinawa and in the South China Sea (Ishihara, 1990; Last & Stevens, 1994; Randall & Lim, 2000; Chen, 2004) (Table 1). It possessed a long serrated spine with an STL average of 114 mm in males and 81 mm in females. The average total spine serrations were 114 for males and 87 for females. On the sides of the spine base, either 6 - 15 serrations or a space of 2 to 18 mm occurred. The average pb / STL was 71% for males and 74% for females. No dorsal groove was evident.

***Dasyatis lata* Garman**, brown stingray: A species (52 cm DW) that occurs off China, Japan, Taiwan and in the South China Sea (Nishida & Nakaya, 1990; Randall & Lim, 2000) (Table 1). The total serrations averaged 83 mm in males and 122 mm in females. The spine base had 1 - 13 serrations or an 8 mm space on each side. The average pb / STL was 56% for males and 58% for females. A dorsal groove extended 50 - 80% of the spine's length.

***Rhinoptera javanica* Müller & Henle**, Javanese cownose ray: An active (114 cm DW) mid- and benthic swimming species found off China, Taiwan, the Ryukyu and Ogasawara Islands and in the South China Sea (Fowler, 1941; Ishihara, 1990; Randall & Lim, 2000) (Table 1). STL averages 52 mm in males and 112 mm in females. The average total spine serrations were 36 for males and 72 for females with 2 - 10 serrations occurring on the sides of the spine base. The average pb / STL was 69% for males and 64% for females. A dorsal groove extended an average of 40% of the spine's length. A specimen labeled as a Hainan cownose ray (*Rhinoptera hainanensis*) that Chu (1960) examined in Beijing, was found to be *R. javanica*.

***Dasyatis bennetti* Müller & Henle**, frilltailed stingray: A species (30 cm DW) frequenting the waters off China, Taiwan, the Ryukyu and Ogasawara Islands and the South China Sea (Shen, 1984; Ishihara, 1990; Nishida & Nakaya, 1990; Randall & Lim, 2000) (Table 1). It possesses a long tail which is upturned at the tip. There were only male specimens available for examination. The average STL was 51 mm, total serrations were 95 and 8 serrations usually occurred on the sides of the spine base. The average pb / STL was 77% and a dorsal groove extended an average of 60% of the spine's length.

***Dasyatis ushieii* Jordan & Hubbs**, cow stingray: A species (38 cm DW) that is found off China, Japan, Taiwan, Korea, the Ryukyu and Ogasawara Islands and in the South China Sea (Fowler, 1941; Ishihara, 1990; Nishida & Nakaya, 1988b, 1990; Randall & Lim, 2000) (Table 1). Only one female specimen was available for examination. Its STL was 74 mm, 46 right serrations and 46 left serrations and many small serrations (92 in total) occurred on the base. The average pb / STL was 59%. No dorsal groove was present.

***Dasyatis matsubarai* Miyosi**, pitted stingray: A species (44 cm DW) that is known from the waters off China, Japan and Taiwan (Nishida & Nakaya, 1990) (Table 1). The STL averaged 65 mm in males and 77 mm in females. The average total spine serrations were 90 for males and 87 for females and a 6 - 27 mm space occurred on the sides of the spine base sometimes extending on to the beginning of the spine proper. The average pb / STL was 70% for males and 71% for females. No dorsal groove was present.

***Taeniura meyeni* Müller & Henle**, fantail stingray: A wide-ranging (118 cm DW) species found off China, Japan, Korea, Taiwan, the Ryukyu and Ogasawara Islands and in the South China Sea (Fowler, 1941; Last & Stevens, 1994; Randall & Lim, 2000; Randall & Lim 2000; Chen, 2004) (Table 1). The

average STL was 60 mm in males and 61 mm in females. The average total spine serrations were 111 for males and 65 for females. On the spine base, either 5 - 10 serrations or a space of 1 - 23 mm may occur on each side. The average pb / STL was 72% for males and 74% for females. A dorsal groove extended an average of 80% of the spine's length.

Hexatrygon* sp. H, *H. sp. I*, *H. brevisrostra (Shen, 1986b), ***H. longirostrum*** (Chu et al., 1981), ***H. taiwanensis*** (Shen, 1986a, 1993) and ***H. yangi*** (Shen & Liu, 1984) may all be ***H. bickelli*** Heemstra & Smith, 1980 (Table 1). There was difficulty in confirming the identity of the species as the spine of the ***H. bickelli*** type specimen described by Heemstra and Smith (1980) and examined at Grahamstown (as well as others in Taipei, Taiwan and CSIRO, Hobart, Tasmania) were broken. Most of the *Hexatrygon* spp. (long-nosed stingrays) (44 - 80 cm DW) occur off China, Taiwan, Okinawa and Southward to Australia (Last & Stevens, 1994; Randall & Lim, 2000) (Table 1). The STL varied between 64 and 124 mm. Total serrations varied between 61 and 139. Spaces up to 22 mm in size may occur on the sides of the spine base depending on the specimen and/or 'species'. The pb / STL varied between 58 and 79%. A dorsal groove extended 40 - 60% of the spine's length. All the specimens examined except for *H. sp. I* may be of the same species.

***Himantura uarnak* Forsskael**, leopard ray: A highly dangerous (125 cm DW) species whose broad range extends from the waters off China, Taiwan, the Ryukyu Islands, the South China Sea and the Mediterranean (Ishihara, 1990; Last & Stevens, 1994; Randall & Lim, 2000) (Table 1). The STL averaged 63 mm in males and 55 mm in females, although other specimens may possess longer, narrower spines. The average total spine serrations were 92 for males and 73 for females and 2 - 12 serrations occurred on the sides of the spine base. The average pb / STL was 65% for males and 64% for females. A dorsal groove extended an average of 25% of the spine's length.

***Himantura imbricata* (= *walga*) Bloch & Schneider**, dwarf stingray: A species (23 cm DW) that is found from the Yellow Sea to the South China Sea (Ishihara, 1990; Randall & Lim, 2000) (Table 1). The average STL was 45 mm in males and 40 mm in females. The average total spine serrations were 76 for males and 75 for females. On the sides of the spine base, either 11 serrations or a 4 - 6 cm space occurred. A dorsal groove extended an average of 79% of the spine's length.

***Aetobatus flagellum* Bloch & Schneider**, longheaded eagle ray: A large, active species (97 cm DW) found off China and in the South China Sea (Ishihara, 1990; Randall & Lim, 2000) (Table 1). There was only one female specimen available for examination for this species. Its STL was 42 mm and possessed 115 serrations. On the sides of the spine base, 2 - 4 serrations occurred. The average pb / STL was 67%. No dorsal groove was present.

***Dasyatis microps* Annandale**, thickspine giant stingray: A species (22 cm DW) that is found in the South China Sea

(Fowler, 1941; Randall & Lim, 2000) (Table 1). Only one female specimen was available for examination. Its STL was 91 mm and total serrations were 75. Twenty-five serrations occurred on the sides of the spine base. The pb / STL was 74%. A dorsal groove extended an average of 75% of the spine's length.

***Himantura jenkinsii* Annandale**, pointed-nose stingray: A species (105 cm DW) that is found in the waters off China and the South China Sea (Fowler, 1941; Last & Stevens 1994; Randall & Lim, 2000) (Table 1). The STL averaged 40 mm in males and 34 mm in females. The average total spine serrations were 69 for males and 73 for females and an 8 - 30 mm space occurred on the sides of the spine base and often extended onto the spine proper. The average pb / STL was 88% for males and 89% for females. A dorsal groove extended an average of 55 - 87% of the spine's length.

***Dasyatis akajei* Müller & Henle**, red stingray: A species (30 cm DW) that is found off China, Japan, Taiwan, the Ryukyu and Ogasawara Islands and in the South China Sea (Fowler, 1941; Okamura & Kitajima, 1984; Shen, 1984; Ishihara, 1990; Nishida & Nakaya, 1990; Randall et al., 1997; Randall & Lim, 2000; Chen, 2004) (Table 1). The STL averaged 42 mm in males and 41 mm in females. The average total spine serrations were 68 for males and 72 for females and 2 - 19 serrations occurred on the sides of the spine base. The average pb / STL was 54% for males and 61% for females. A dorsal groove extended an average of 20% of the spine's length.

***Himantura* sp. A**: A species (30 cm DW) that is found off China and the South China Sea (Last & Stevens, 1994; Randall & Lim, 2000) (Table 1). The STL averaged 46 mm in males and 41 mm in females. The average total spine serrations were 45 for males and 44 for females. On the sides of the spine base, 6 - 11 serrations occurred. The average pb / STL was 67% for males and 63% for females. No dorsal groove was present.

***Taeniura lymma* Forsskael**, blue-spotted ribbontail: A wide-ranging species (30 cm DW) that occurs from the Red Sea to China, Taiwan and in the South China Sea (Fowler, 1941; Last & Stevens, 1994; Ishihara, 1990) (Table 1). The STL averaged 58 mm in males and 37 mm in females. The average total spine serrations were 68 for males and 69 for females. At the spine base, 4 - 21 serrations or a 4 - 13 mm space may occur on the sides. The average pb / STL was 79% for males and 85% for females. A dorsal groove extended 59 - 96% the length of the spine.

***Dasyatis kuhlii* Müller & Henle**, blue-spotted stingray: A wide-ranging species (38 cm DW) that is found off China, Japan, Taiwan, Korea, the Ryukyu and Ogasawara Islands and in the South China Sea (Fowler, 1941; Ishihara, 1990; Nishida & Nakaya, 1990; Last & Stevens, 1994; Randall et al., 1997; Randall & Lim, 2000; Chen, 2004) (Table 1). The STL averaged 49 mm in males and 65 mm in females. The average total spine serrations were 60 for males and 73 for females. At the spine base, either 4 - 5 serrations or a 16 - 18 mm space may occur on the sides. The average pb / STL was

71% for males and 65% for females. A dorsal groove extended an average of 80% the length of the spine.

***Himantura gerrardi* Gray**, bluntnose whiptail ray: A species (45 cm DW) that inhabits the waters off China, Southern Japan, Taiwan and the South China Sea (Fowler, 1941; Ishihara, 1990; Randall & Lim, 2000; Chen, 2004) (Table 1). Two forms may be encountered, one with a banded tail and the other with a uniformly-coloured tail. Average STL was short: 23 mm in males and 37 mm in females. The average total spine serrations were 41 for males and 83 for females with a space 2 - 24 mm in size occurring on the sides of the spine base that extended on to the spine proper. The average pb / STL was 71% for males and 52% for females. A dorsal groove extended some 50% of the spine's length.

***Dasyatis laevigata* Chu**, Yantai stingray: A species (19 cm DW) that is found off China, Taiwan and in the South China Sea (Ishihara, 1990; Nishida & Nakaya, 1990; Randall & Lim, 2000) (Table 1). The STL averaged 42 mm in males and females. The average total spine serrations were 60 for both sexes and a 6 mm space occurred on each side of the spine base. The average pb / STL was 61% for males and females. A dorsal groove extended an average of 63% of the length of the spine.

***Dasyatis zugei* Müller & Henle**, pale-edged stingray: A species (29 cm DW) that is found in fairly deep waters off China, Japan, Taiwan and in the South China Sea (Fowler, 1941; Shen, 1984; Ishihara, 1990; Randall & Lim, 2000) (Table 1). The STL averaged 53 mm in males and 49 mm in females. The average total spine serrations were 54 for males and 64 for females. A space 8 - 30 mm occurred on each side of the base and extended on to the spine proper. The average pb / STL was 62% for males and 61% for females. No dorsal groove was present.

***Dasyatis acutirostra* Nishida & Nakaya**, sharpnose stingray: A species (52 cm DW) that is found off Japan and Taiwan (Ishihara, 1990; Nishida & Nakaya, 1990) (Table 1). The average STL was 39 mm in males and 34 mm in females. The average total spine serrations were 52 for males and 56 for females with a small space occurring at the forward edge of the spine base. The average pb / STL was 66% for males and 65% for females. No dorsal groove was present.

***Myliobatis tobijei* Bleeker**, kite ray: A species (≥ 35 cm DW) that is found off China, Japan, Taiwan, Korea, the Ryukyu and Ogasawara Islands, Okinawa and in the South China Sea (Fowler, 1941; Shen, 1984, 1988; Randall et al., 1997; Randall & Lim, 2000; Chen, 2004) (Table 1). The STL averaged 42 mm in males and 28 mm in females. The average total spine serrations were 60 for males and 42 for females. Six serrations or a 5 - 8 mm space may occur on sides of the base of spine. The average pb / STL was 74% for males and 60% for females. A dorsal groove extended an average of 20% of the spine's length.

***Himantura* (= *Trygon*) *pastinacoides* Bleeker**, round whiplay: This species (35 cm DW) is found in the South China

Table 1. Tail spine characteristics of 34 species of stingrays captured in the Northwest Pacific Ocean in FAO fishing area 61 (20°N 120°E to 50°N 150°E) listing species distributions and spine morphology.

Species	n (Sex)	Distribution	Average Total Serrations (Range)		Total	Average STL (Range), mm	pb / TL (% Range), %	Barbs (B)/ Spaces (S) on Base	Dorsal Groove (% of STL)
			R	L					
<i>Himantura fai</i>	1F	J,S,C	88	95	183	184	70	No	70
<i>Pteroplatyrygon violacea</i>	15M	C,J,T,K,R	78 (58 - 104)	88 (50 - 139)	166	109 (111 - 139)	72 (64 - 77)	3 - 20B	20
	23F	SC	76 (58 - 147)	93 (57 - 156)	169	121 (75 - 156)	75 (69 - 92)		
<i>Pastinachus sephen</i>	6M	C,T,R,SC,	62 (51 - 71)	62 (37 - 68)	124	157 (49 - 80)	75 (66 - 93)	5 - 26B	
	4F	OK	68 (50 - 72)	62 (37 - 69)	124	159 (62 - 300)	76 (66 - 86)		
<i>Dasyatis izuensis</i>	5M	J,T	57 (29 - 101)	56 (33 - 77)	112	68 (45 - 104)	69 (67 - 73)	10 - 33B	10, stout spine
	2F		69 (37 - 101)	61 (37 - 81)	130	79 (57 - 106)	74 (71 - 77)		
<i>Himantura granulata</i>	1M	SC	52	72	124	52	72	2B on base	70, stout spine
	1F		45	52	97	52	81		
<i>Aetobatis narinari</i>	7M	C,J,T,K,	52 (25 - 78)	50 (28 - 71)	102	60 (38 - 95)	76 (67 - 92)	4 - 16B	50 on some
	25F	R,O,SC	62 (16 - 87)	50 (24 - 87)	112	78 (36 - 166)	66 (35 - 93)		
<i>Plesiobatis daviesi</i>	1M	C,T,R,OK,	69	66	114	114	71	6 - 15B or	no
	2F	SC	43 (41 - 44)	44 (42 - 46)	87	81 (69 - 93)	74 (69 - 78)	2 - 18S	
<i>Dasyatis lata</i>	9M	C,J,T,SC	27 (21 - 51)	66 (8 - 39)	83	36 (21 - 80)	56 (47 - 66)	1 - 13B or 8S	50 - 80
	1F		56	66	122	108	58		
<i>Rhinoptera javanica</i>	1M	C,T,R,O,	29	36	65	52	69	2 - 10B	40
	1F	SC	55	72	127	112	64		
<i>Dasyatis bennetti</i>	5M	C,T,R,O, SC	47 (35 - 53)	48 (32 - 52)	95	51 (42 - 54)	77 (60 - 85)	8B	60 long, up at tip
<i>Dasyatis ushiei</i>	1F	C,J,T,K, O,R,SC	46	46	92	74	59	42 small barbs	no
<i>Dasyatis matsubarai</i>	6M	C,J,T	48 (30 - 84)	42 (34 - 84)	90	65 (41 - 98)	70 (60 - 79)	6 - 27S	no
	11F		44 (30 - 62)	43 (30 - 62)	87	77 (41 - 98)	71 (52 - 84)		
<i>Taeniura meyeni</i>	2M	C,J,T,K, R,O,SC	61 (36 - 98)	50 (24 - 92)	111	60 (45 - 163)	72 (66 - 76)	5 - 10B or	80 longest spine 210 mm
<i>Hexatrygon</i> sp. H	3F		33 (14 - 49)	32 (19 - 55)	65	61 (47 - 87)	74 (52 - 67)	1 - 23S	
	2M	C,T	29	45	84	92	64	S	40 - 60
<i>H. sp. I</i>	2F	OK,SC	34	27	61	93	79		
<i>H. sp. I</i>	1M		69	70	139	124	72	0 - 19S	
<i>H. taiwanensis</i>	2F		21	28	55	64	58 (51-69)	11S	
<i>H. yangi</i>	1M		34	36	71	75		22S	
<i>Himantura uarnak</i>	16M	C,T,R,SC	40 (25 - 87)	42 (35 - 77)	92	63 (41 - 87)	65 (55 - 92)	2 - 12B	25
	28F		36 (17 - 65)	37 (16 - 131)	73	55 (35 - 97)	64 (48 - 71)		
<i>Himantura imbricata</i> (= <i>walga</i>)	5M	SC	37 (30 - 44)	39 (29 - 48)	76	45 (16 - 93)	90 (87 - 92)	4 - 6S	75 - 79
	13F		37 (28 - 35)	38 (28 - 49)	75	40 (28 - 97)	90 (72 - 98)	11 - 11B	

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Table 1. (Continue).

Species	n (Sex)	Distribution	Average Total Serrations (Range)		Total	Average STL (Range), mm	pb / TL (%)	Barbs (B)/ Spaces (S) on Base	Dorsal Groove (% of STL)
			R	L					
<i>Aetobatis flagellum</i>	1F	C SC	39	76	115	67	2 - 4B	no	
<i>Dasyatis microps</i>	1F	SC	40	35	75	91	25 small	75, 25 in small	
<i>Himantura jenkinsii</i>	10M 9F	C SC	35 (27 - 49) 40 (23 - 61)	34 (27 - 38) 33 (22 - 61)	69 73	40 (27 - 49) 34 (23 - 61)	8 - 30S	55 - 87	
<i>Dasyatis akajei</i>	7M 6F	C,J,T,R, O,SC	34 37	34 35	68 72	42 41	2 - 19B	20	
<i>Himantura</i> sp. A	1M 2F	C SC	22 22	23 22	45 44	46 41	6 - 11S	no	
<i>Taeniura lymna</i>	11M 7F	C SC	34 (26 - 41) 36 (18 - 44)	34 (22 - 51) 33 (20 - 38)	68 69	58 (21 - 43) 37 (18 - 44)	4 - 13S 4 - 21B	59 - 96	
<i>Dasyatis kuhlii</i>	30M 31F	C,J,T,K, R,O,SC	30 (20 - 63) 37 (11 - 55)	30 (19 - 74) 36 (18 - 67)	60 73	49 (32 - 82) 65 (32 - 77)	6-18S 4 - 5B	80	
<i>Himantura gerrardi</i>	12M 36F	C,J,T, SC	25 (23 - 45) 33 (18 - 45)	16 (11 - 44) 50 (10 - 79)	41 83	23 (10 - 55) 37 (25 - 102)	2 - 24S	50	
<i>Dasyatis laevigata</i>	2M	C,T SC	38 (32 - 49)	32 (28 - 35)	60	42 (40 - 44)	6S	63	
<i>Dasyatis zugei</i>	2M 1F	C,J,T SC	28 (28) 36 (22 - 58)	26 (25 - 26) 31 (22 - 41)	54 64	53 (53 - 57) 49	8 - 30S	no	
<i>Dasyatis acutirostra</i>	3M 11F	J, T	27 (21 - 32) 26 (19 - 32)	25 (21 - 30) 30 (18 - 35)	52 56	39 (35 - 44) 34 (23 - 41)	1 spine paratype	no	
<i>Myliobatis tobijei</i>	1M 1F	R,O,OK SC	39 (39) 21 (20 - 22)	31 (31) 21 (19 - 31)	60 42	42 (42) 28 (26 - 30)	5 - 8 S 6B	20	
<i>Himantura</i> (= <i>Trygon pastinacoides</i>)	1M 1F	SC	36 36	29 40	65 76	59 60	3 - 15S	no	
<i>Urolophus auranitacus</i>	1F	C,J,T,R, OK,SC	19	22	41	42	Up at tip	no	
<i>Himantura microphthalma</i>	3M 8F	C,J,T SC	22 (14 - 25) 18 (18 - 29)	22 (17 - 25) 21 (11 - 32)	44 39	28 (26 - 32) 31 (24 - 38)	12S	no, long spine	
<i>Aetoplatea zonura</i>	1M 3F	C,T SC	25 17	25 14	50 28	15 17 (13 - 24)	2 - 7B	no, short serrations	
<i>Gymnura bimaculata</i>	3M	C,J,T,K, O,SC	15	16	31	15 (12 - 16)	13 - 15B	no	
<i>Gymnura japonica</i>	1M 2F	C,J,T,O, SC	11 13 (12 - 14)	10 8 (6 - 10)	21 21	8 15 (15)	4 - 6S 3 - 7B	30	

n = number of individuals; STL = spine total length; pb / TL = prebase length to total length percentage ratio; B = barbs present; S = spaces present; R = right side of spine; L = left side of spine; M = male; F = female; C = China; J = Japan and Japan Sea; K = Korea; T = Taiwan; SC = South China Sea; P = Penghu; R = Ryukyu Islands; O = Ogasawara (Bonin) Islands; OK = Okinawa

Sea (Randall & Lim, 2000) (Table 1). The spine is long and thin. The average STL was 59 mm in males and 60 mm in females. The average total spine serrations were 65 for males and 76 for females and a space 3 - 15 mm may occur on each side of the spine base. The average pb / STL was 69% for males and 66% for females. No dorsal groove was present.

***Urolophus aurantiacus* Müller & Henle**, sepia stingray: A species (28 - 37 cm DW) that is found in the waters off China, Japan, Taiwan, the Ryukyu Islands, Okinawa and the South China Sea (Shen, 1984, 1988; Okamura & Kitajima, 1984; Randall & Lim, 2000) (Table 1). Only one female specimen was available for examination. It possessed a long 42 mm STL spine whose tip is bent upward and 41 total serrations. The pb / STL was 75%. No dorsal groove was present.

***Himantura microphthalmia* Chen**, smalleye whipray: This small, long-spined (45 cm DW) species is found in the waters off China, Japan, Taiwan and the South China Sea (Ishihara, 1990; Randall & Lim, 2000) (Table 1). The STL was short and averaged 28 mm in males and 31 mm in females. The average total spine serrations were 44 for males and 39 for females with a 12 mm space occurring on each side of the spine base. The average pb / STL was 66% for males and 59% for females. No dorsal groove was present.

***Aetoplatea zonura* Bleeker**, zonetail butterfly ray: A species (85 cm DW) that is found off China, Taiwan and in the South China Sea (Shen, 1984; Ishihara, 1990; Randall & Lim, 2000) (Table 1). The STL averaged 15 mm in males and 17 mm in females. The average total spine serrations were 50 for males and 28 for females and 2 - 7 serrations occurred on the sides of the spine base. The average pb / STL was 33% for males and 46% for females. No dorsal groove was present.

***Gymnura bimaculata* Norman**, twin-spot butterfly ray: A species (39 cm DW) that is found off China, Japan, Korea, Taiwan, the Ogasawara Islands and in the South China Sea (Fowler, 1941; Randall et al., 1997; Randall & Lim, 2000) (Table 1). Only male specimens were available for examination. Average STL was 15 mm and total serrations were 31. At the spine base, 13 to 15 serrations occurred on each side. The pb / STL was 42%. A dorsal groove was not evident.

***Gymnura japonica* Schlegel**, Japanese butterfly ray: A species (77 cm DW) that is found off China, Japan, Taiwan, the Ogasawara Islands and in the South China Sea (Shen, 1984, 1988; Ishihara, 1990; Randall & Lim, 2000; Randall & Lim, 2000; Chen, 2004) (Table 1). The STL averaged 8 mm in males and 15 mm in females and the average total spine serrations were 21 in both sexes. On both sides of the spine base, 3 - 7 serrations or a space 4 - 6 mm in size may occur. The average pb / STL was 50% for males and 42% for females. A dorsal groove extended an average of 30% of the spine's length.

DISCUSSION

Elasmobranch classifications have had many interpretations (Compagno 1973, 1986, 1999; Nishida, 1990; Nishida & Nakaya, 1990; Lovejoy, 1996; McEachran et al., 1996; Dunn et al., 2003; McEachran & Aschliman, 2004). Nishida & Nakaya (1990) which have listed 17 species of stingrays frequenting FAO fishing area 61. Randall & Lim (2000) recorded 53 species from the South China Sea. Ishihara (1990) considered 56 stingray species of the genus *Dasyatis* to occur in the Northwest Pacific and further referred several stingrays to the genus *Dasyatis* (i.e. *Urolophoides*) and considered *D. ushieii* to be *D. matsubarai*. Other authors have also listed various members of stingrays from the area: Fowler (1941); Garman (1997, reprint); Randall et al. (1997); the genus *Mobula* by Notabartolo-di-Sciara (1987, 1988); Okinawa Trough species by Okamura & Kitajima (1984, Okinawa Trough); Australian species by Last & Stevens (1994); Penghu species by Chen (2004); species of the Okinawa and Ogasawara Islands by Randall et al. (1997) and the Taiwanese species by Shen (1988).

New species of stingrays described from the Northwest Pacific include: *Dasyatis acutirostra* (Nishida & Nakaya, 1988a) and *D. izuensis* (Nishida & Nakaya, 1988b). There was also ambiguity in nomenclature and identification. *Dasyatis cheni* being a synonym of *D. zugei*. *Raja africana* being a synonym of *Urogymnus asperrimus* (Eschmeyer, 1998). *Rhinoptera hainanensis* actually being *R. javanica* (see text). Isouchi (1977) considered *Gymnura bimaculata* to be a synonym *G. japonica*. Nishida & Nakaya (1988a) felt that *D. acutirostra* may be *D. zugei*. Compagno (1986) placed *D. sephen* in the genus *Hypolophus* which Ishihara (1990) considered to be *Dasyatis*. McEachran et al. (1996) removed several American species of stingrays from the Family Urolophidae. Also, *Pastinachus gruvelli* is *P. sephen* (Fowler, 1941).

The various spine characteristics of the 34 species of stingrays are described (Table 1). Ten additional species did not have tail spines: *Aetomylaeus maculatus*, *A. milvus*, *A. nichofii* (although Halstead, 1970 illustrates a specimen with a spine), *A. vespertilio*, *Urogymnus asperrimus*, *Manta birostris*, *Mobula eregoodootenkee*, *Mobula tarapacana*, *Mobula thurstoni* and *Dasyatis sinensis* (the 38 cm DW holotype examined in Vienna has no spine). The tail spines of all the *D. navarrae* specimens from Taiwan were broken. Also, the 178 cm DW taxidermized *D. gigantea* specimen from the Peter the Great Bay was not examined (Soldatov & Lindberg 1930; Lindberg & Ligeza, 1967).

Overall, eight stingrays (the pelagic stingray, pink whipray, cowtail stingray, Izu stingray, mangrove whipray, spotted eagle ray, giant stingaree and brown stingray) which had average total spine serrations > 100, were usually associated with open water habitats. The 12 species (the Javanese cownose ray, frilltailed stingray, cow stingray, pitted stingray, fantail stingray, various *Hexatrygon*, leopard stingray, dwarf stingray, long-headed eagle ray, thickspine giant stingray, pointed-nose stingray and red stingray) with average total of

between 70 and 100 total serrations were mid-water inhabitants. The seven species (the blue-spotted ribbontail, blue-spotted stingray, bluntnose whiptail ray, Yantai stingray, pale-edged stingray, sharpnose stingray and kite ray) with average total spine serrations of 50 - 70 were near-substrate or benthic inhabitants. Finally, the seven species (round whiplay, sepia stingray, smalleye whip ray, zonetail butterfly ray, *Himantura* sp. A, twin-spot butterfly and Japanese butterfly ray) with 25 - 50 average total spine serrations were benthic inhabitants.

Spine lengths varied and were not correlated with disk widths. *Aetobatis narinari* which is a large active (300 cm DW) species had spine lengths of 60 - 78 mm with 102 - 112 serrations while the benthic species *Dasyatis ushiei* had a 38 cm DW but a similar spine length (92 mm) with only 46 serrations. Likewise, the length of spine serrations varied in length and was dependent on species. It ranged from minute in *D. ushiei* (38 cm DW), to stout in *D. izuensis* (32 cm DW) and long in *D. bennetti* (30 cm DW). This was despite similar disk widths.

Rosenberger (2001a, b: 390) commented that "swimming behavior can be coordinated with habitat and life style". Benthic species employ undulating fin movements while pelagic species use oscillatory fin movements. However, little correlation exists between comparison of tail spine serration counts to habitat usage (present study) and swimming behaviour of the species [*Taeniura lymma* (benthic species), *Pteroplatytrygon violacea* (pelagic species), *Gymnura bimaculata* (benthic-pelagic species) and *Rhinoptera javanica* (benthic-pelagic species)] in Rosenberger (2001a, b). *Taeniura lymma* have 68 serrations, *P. violacea* has 166, *G. bimaculata* have 31 and *R. javanica* have 65. On the basis of undulation or oscillation swimming, *T. lymma* (1.4 fin waves) would be very different from *P. violacea* (0.7 fin waves) and *G. bimaculata* (0.6 fin waves) would be similar to *R. javanica* (0.4 fin waves). McEachran & Aschleiman (2004: 8 - 9) affirmed that the systematic proximity of *Gymnura* to *Rhinoptera* and that *Pteroplatytrygon* were closer to *Dasyatis* and *Taeniura*, yet their behaviour is very different. Thus, fin movements and spine serrations are not correlated. Furthermore, spine serration variation differs greatly within a species (e.g., *Dasyatis* spp. had spine serrations ranging from 52 to 112). Spine serrations also do not correlate to increasing evolutionary complexity (from primitive to advanced), i.e. *Dasyatis* - *Taeniura* - *Himantura* - *Gymnura* - *Myliobatis* - *Rhinoptera* - *Mobula*.

Stingray spines can now be used as an additional morphological character in defining a species and their habitat preferences. Spine morphology will aid ichthyologists, paleontologists and physicians in species identification and elucidating fossil relationships.

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LITERATURE CITED

- Chen, C.-H., 2004. Checklist of the fishes of Penghu. *Fisheries Research Institute Special Publication* 4: 1-175. (In Chinese with English abstract).
- Chu, Y.-T., Q.-W. Meng, A.-S. Hu & S. Li., 1981. Description of four new species, a new genus and a new family of elasmobranch fishes from the deep sea of the South China Sea. *Oceanology and Limnology Sinica*, **12**(2): 103-116.
- Compagno, L. J. V., 1973. Interrelationships of living elasmobranchs. *Zoological Journal of the Linnean Society, London*, **53**(Supplement 1): 15-61.
- Compagno, L. J. V., 1986. *Dasyatidae*. In: Smith, M. M. & P. C. Heemstra (eds.), *Smith's Sea Fishes*. Springer Verlag, New York. Pp. 135-142.
- Compagno, L. J. V., 1999. Systematics and body form. In: Hamlett, W. G. (ed.), *Sharks, Skates and Rays. The biology of elasmobranch fishes*. Johns Hopkins University Press, Baltimore. Pp. 1-42.
- Dunn, K. A., J. D. McEachran & R. L. Honeycutt, 2003. Molecular phylogenetics of Myliobatiform fishes (Chondrichthyes: Myliobatiformes), with comments on the effects of missing data on parsimony and likelihood. *Molecular Phylogenetics and Evolution*, **27**: 259-270.
- Eschmeyer, W. (ed.), 1998. *Catalog of fishes*. 3 Volumes. California Academy of Sciences Special Publication 1, Anaheim, California. 2905 pp.
- Fowler, H. W., 1941. Contributions to the biology of the Philippines and adjacent regions. *Bulletin of the United States National Museum*, **100**(13):1-879.

- Garibaldi, L. & L. Limongelli, 2002. *Trends in ocean captures and clustering of large marine ecosystems. Two studies based on the FAO capture database*. FAO Fisheries Technical Paper 435, Italy. 71 pp.
- Garman, S., 1997 (reprint). *The Plagiostoma (sharks, skates and rays)*. Benthic Press, California, 515 pp. + 75 plates.
- Halstead, B. W., 1970. *Poisonous and venomous marine animals of the world. Vol. 3. Vertebrates*. U.S. Govt. Printing Office, Washington, DC. 1006 pp.
- Heemstra, P.C. & M. M. Smith, 1980. Hexatrygonidae, a new family of stingrays (Myliobatiformes: Batoidea) from South Africa, with comments on the classification of Batoid fishes. *Ichthyological Bulletin J.L.B. Smith Institute Ichthyology*, **43**:1-17.
- Ishihara, H., 1990. The skates and rays of the western North Pacific, an overview of their fisheries, utilization and classification. In: Pratt, H. L. Jr., S. G. Gruber & T. Taniuchi (eds.), *Living resources: advances in the biology, ecology, systematics and status of the fisheries*. NOAA Technical Paper, NMFS 90, National Marine Fisheries Service. Washington, DC. Pp. 485-497.
- Isouchi, T., 1977. Butterfly ray, *Gymnura bimaculata*, a junior synonym of *G. japonica*. *Japanese Journal of Ichthyology*, **23**(4): 242-244.
- Last, P. R. & D. Stevens, 1994. *Sharks and rays of Australia*. CSIRO, Melbourne. 513 pp.
- Leamy, L. J. & C. P. Klingenberg, 2005. The genetics and evolution of fluctuating asymmetry. *Annual Review of Ecology, Evolution and Systematics*. **36**: 1-21.
- Lindberg, G. U. & M. I. Legeza, 1967. (Transl.). *Fishes of the Sea of Japan and the adjacent areas of the Sea of Okhotsk and the Yellow Sea*. Akademia Nauka Soyuzha Sovetche Sotsialisti Republica No. 68 pt. 1. Amphoxi. Petromyzones, Myxini, Elasmobranchii and Holocephali. Israel Program for Scientific Translation. Jerusalem, Israel.
- Lovejoy, N. R., 1996. Systematics of myliobatoid elasmobranchs: with emphasis on the phylogeny and historical biogeography of neotropical freshwater stingrays (Potamotrygonidae: Rajiformes). *Zoological Journal of the Linnean Society, London*, **117**(3): 207-257.
- McEachran, J. D. & N. Aschliman, 2004. Phylogeny of Batoidea. In: Carrier, J. C., J. A. Musick & M. R. Heithaus (eds.), *Biology of Sharks and their relations*. CRC Press, Florida. Pp. 79-113.
- McEachran, J. D., K. A. Dunn & T. Miyake, 1996. Interrelationships of batoid fishes (Chondrichthyes, Batoidei) In: Stiassny, M. L. J., L. R. Parenti & G.D. Johnson (eds.), *Interrelationships of fishes*. Academic Press, California. Pp. 63-84.
- Notabartolo-di-Sciara, G., 1987. A revisionary study of the genus *Mobula* Rafinesque, 1910 (Chondrichthyes: Mobulidae), with the description of a new species. *Zoological Journal of the Linnean Society, London*, **91**: 1-91.
- Notabartolo-di-Sciara, G., 1988. Natural history of the rays of the genus *Mobula* in the Gulf of California. *Fisheries Bulletin*, **68**(1): 45-66.
- Nishida, K., 1990. Phylogeny of the suborder Myliobatoidei. *Memoirs Faculty Fisheries Hokkaido University*, **37**(1.2): 1-108.
- Nishida, K. & K. Nakaya, 1988a. A new species of the genus *Dasyatis* (Elasmobranchii: Dasyatidae) from southern Japan and lectotype designation of *D. zugei*. *Japanese Journal of Ichthyology*, **35**(2): 115-123.
- Nishida, K. & K. Nakaya, 1988b. *Dasyatis izuensis*, a new stingray from the Izu Peninsula, *Japanese Journal of Ichthyology*, **25**(3): 227-235.
- Nishida, K. & K. Nakaya, 1990. Taxonomy of the genus *Dasyatis* (Elasmobranchii: Dasyatidae) from the north Pacific. In: Pratt, H. L. Jr., S. H. Gruber & T. Taniuchi (eds.), *Elasmobranchs as living resources: advances in the biology, ecology, systematics and the status of the fisheries*. NOAA Technical Paper NMFS 90. National Marine Fisheries Service. Pp. 327-346.
- Okamura, O. & T. Kitajima (eds.), 1984. Fishes of the Okinawa Trough and the adjacent waters. *Japanese Fisheries Research Conservation Association Vol. 1.*, Tokyo, Japan. 414 pp.
- Parkham, G. H. & D. A. Falvey, 1971. An hypothesis for the formation of marginal seas in the western Pacific. *Tectonophysics*, **11**: 79-109.
- Randall, J. E. & J. L. Earle, 2000. Annotated checklist of the shore fishes of the Marquesas Island. *Occasional Paper of the Bishop Museum*, **66**: 1-39.
- Randall, J. E. & K. P. Lim (eds.), 2000. A checklist of the fishes of the South China Sea. *The Raffles Bulletin of Zoology. Supplement No. 8*: 569-667.
- Randall, J. E., H. Ida, K. Kato, R. L. Pyle & J. L. Earle, 1997. *Annotated checklist of the inshore fishes of the Ogasawara islands*. National Science Museum, Tokyo. 74 pp. 19 pls.
- Rosenberger, L. J., 2001a. Phylogenetic relationships within the stingray genus *Dasyatis* (Chondrichthyes: Dasyatidae). *Copeia*, **2001a**(3): 615-627.
- Rosenberger, L. J., 2001b. Pectoral fin locomotion in batoid fishes: undulation versus oscillation. *Journal of Experimental Biology*, **204**: 379-384.
- Schwartz, F. J., 1990. Mass migratory aggregations and movements of several species of cownose rays, Genus *Rhinoptera*: a world-wide review. *Journal of the Elisha Mitchell Scientific Society*, **106**(1): 10-13.
- Schwartz, F. J., 2003. Bilateral asymmetry in the rostrum of the smalltoothed sawfish, *Pristis pectinatus* (Pristiformes: family Pristidae). *Journal of the North Carolina Academy of Science* **119**(2): 41-47.
- Shen, S.-C., 1984. *Coastal fishes of Taiwan*. National Taiwanese University, Taipei. 190 pp.
- Shen, S.-C., 1986a. A new species of stingray *Hexatrygon taiwanensis* from Taiwan Strait. *Journal of the National Taiwan Museum*, **39**: 175-180.

- Shen, S.-C., 1986b. A new species of stingray *Hexatrygon brevirostra* and a new record *Anacanthobatis borneensis* (Rajiformes) from Taiwan. *Journal of the National Taiwan Museum*, **39**: 105-110.
- Shen, S.-C., 1988. Catalogue of the fish specimens deposited in the Museum of the Department of Zoology, National Taiwan University. *Acta Zoologica Taiwansia*, **No. 2**: 1-161.
- Shen, S.-C., 1993. *Fishes of Taiwan*. Taipei, Taiwan. 960 pp.
- Shen, S.-C. & C.-S. Liu. 1984. A new stingray of the genus *Hexatrygon* from Taiwan. *Acta Oceanographica Taiwan*, **No. 18**: 201-206.
- Soldatov, V. K. & G. J. Lindberg, 1930. A review of the fishes of the far eastern seas. *Bulletin of the Far East Institute*, **5**: 1-576.
- Springer, V. G., 1982. Pacific plate biogeography with special reference to shore fishes. *Smithsonian Contribution to Zoology*, **367**: 1-182.