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NOTE

Taxonomic resolution of sawfish rostra from two private collections

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ABSTRACT: Management and recovery of endangered sawfishes are challenged by the uncertainty of species determination. Frequently, dried rostra (saws) are the only material available to represent an historical occurrence, yet traditional methods of species identification of data-deficient rostra (rostral tooth counts) are unreliable. We evaluated the utility of morphometric characters for the identification of specimens from 2 private collections totaling 41 rostra and representing 4 species: *Anoxypristis cuspidata*, *Pristis pectinata*, *P. pristis*, and *P. zijsron*. Rostra were acquired as available and the sample is likely representative of sawfishes globally. Data on 9 morphometric and meristic variables were collected, 5 of which were evaluated using principal component analysis (PCA). PCA of the mensural data accounted for 87% of the variance with the first 2 principal components. Principal component 1 (PCI) was explained by 4 variables and PCII by a single variable. This indicated that all 5 variables were taxonomically important. Spatial relationships of points were consistent with putative identifications based on available data. Knifetooth sawfish (*A. cuspidata*), smalltooth sawfishes (*P. pectinata* and *P. zijsron*), and largetooth sawfishes (*P. pristis*) formed 3 distinct clusters with minimal overlap along PCI. *P. pectinata* and *P. zijsron* were separated from each other along PCII, as were the *P. microdon* (nom. dub.) (Indian and Pacific) and *P. perotteti* (nom. dub.) (Atlantic) populations of *P. pristis*. The results demonstrate the utility of analyzing private collections of historically traded rostra. Cumulatively, such collections represent a global fauna sampled over many decades with potential for characterizing phenotypic variation in sawfish at interspecific and intraspecific levels on a greater geographic and temporal scale than targeted modern sampling of specific populations. Further, PCA provides an objective way of classifying data-deficient rostra to species, greatly increasing the research value of these specimens.

KEY WORDS: Pristidae · *Anoxypristis* · *Pristis* · Taxonomy · Species identification · Morphometrics · Principal component analysis · Conservation

INTRODUCTION

Prior to protection of all species of sawfishes under CITES (September 13, 2007; http://checklist.cites.org/#/en) and the Endangered Species Act (January 12, 2015; NMFS 2014), sawfish rostra were long traded among dealers and collectors of natural history objects. Traffic in these distinctive curios was common for nearly 2 centuries (Norman & Fraser 1938, Migdalski 1960, Hoover 2008). Specimens imported from the Indo-Pacific were commonplace as late as the 1960s in retail shell shops and souvenir stores in coastal towns of the United States. Once dried, sawfish rostra were well suited for long-term storage due in part to being composed primarily of cartilage reinforced with calcium. As a result, despite

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the current rarity of sawfishes in many areas of the world, the collectability, historical availability, and durability of dried rostra contribute to their frequent representation in both public and private collections. Unfortunately, rostra in private collections often lack the supporting data, such as non-rostral characters and locality of capture, needed to make species-level determinations, yet their relative availability makes them potentially useful in research. This is because fresh specimens are difficult to obtain and whole preserved specimens are uncommon in public collections due to their large sizes and the logistical challenges of transportation, preservation, and storage. Sawfish rostra can provide important insights on morphology (e.g. variation in shape), rostrum tooth number, historic population status (e.g. geographic distribution, relative abundance), and genetics.

The characters used to discriminate species of sawfishes include rostral tooth counts, position of teeth along rostrum, shape of rostrum, dorsal fin position, and development of the lower caudal lobe (Faria et al. 2013). However, taxonomic resolution based exclusively on rostral characters is also possible, as demonstrated for 4 species of Australian sawfishes for which supporting data were available (Whitty et al. 2014). Given the wide range of sizes and overlap in rostrum tooth counts for sawfish specimens, there is some uncertainty in species-level identifications based exclusively on rostral morphology. Such identifications are necessary, however, for specimens obtained from commercial trade as these typically lack supporting data. For these reasons, we undertook a morphological analysis of sawfish rostra from 2 private collections to address 3 specific questions: (1) Are taxonomic determinations based exclusively on rostral morphology consistent with those based on additional information? (2) Can rostral morphology be used as a stand-alone tool to objectively discriminate among species? (3) Do private collections of <50 specimens allow insight into interspecific and intraspecific taxonomic diversity?

Our study differs in 2 respects from previous studies by Faria et al. (2013) and Whitty et al. (2014). It is based exclusively on privately traded specimens, requiring no targeted sampling of sawfish populations, but providing no supporting data on other diagnostic features (e.g. fin position and shape) and limited supporting data on locality (i.e. 18 of 41 specimens). It employs a taxonomically conservative technique for multivariate analysis, i.e. principal component analysis (PCA), which is less biased than previous similar studies as it requires no previous assignment of specimens to taxonomic groups and sorts specimens based on variables with the greatest variation, not necessarily the greatest discrimination. As a result, our study serves as a test case for subsequent (and larger scale) evaluations of historically traded specimens, in private and public collections, that do not impact living sawfishes and are cost-effective because they require no fieldwork.

MATERIALS AND METHODS

Material examined

Sawfish rostra from 2 private collections were studied. One collection (belonging to J. C. Seitz) consists of 30 specimens acquired between 1980 and 2014, mainly through donations and exchanges with other collectors. Of these, 29 were suitable for analysis, 18 of which have supporting locality data. The other collection (belonging to J. J. Hoover) consists of 12 specimens acquired between 2003 and 2011, principally by eBay auction, but none having locality data. All rostra were obtained on an 'as available' basis and specific taxa were not targeted for acquisition. Time of collection is unknown for the majority of specimens but documented ages for a few are >50 yr, and we assume that most were collected during the 20th century.

We have a follow-up project planned that necessitates retention of these specimens in our respective private collections but we intend to donate these to museums when our work is complete. In the interim, our specimens will continue to be available to researchers as needed and we will provide photographs on request. See Table 1 for a list of our specimens and associated data.

Characters

Counts and measurements were made according to protocols in Faria et al. (2013) and Whitty et al. (2014). Measurements were made to the nearest mm using a tape measure or calipers, depending on the size of the rostrum and sizes of individual characters. Characters included (1) left rostral tooth count; (2) right rostral tooth count; (3) total rostrum length (TRL), from mid-point of tip to mid-point at confluence of the rostrum with the head (where the rostrum begins to flare); (4) standard rostrum length (SRL), from mid-point of tip to mid-point adjacent to posterior edge of the proximal-most left rostral tooth; (5) standard rostrum width, which we refer to as proximal rostrum width (PRW), from base of proximal-most left rostral tooth to opposite edge of rostrum; (6) rostral tip width, which we refer to as distal rostrum width (DRW), from anterior edges of distal-most rostral teeth; (7) proximal tooth gap (PTG), from anterior edge of proximal-most right tooth to posterior edge of the next tooth; (8) distal tooth gap (DTG), from posterior edge of the distal-most right tooth to anterior edge of the tooth behind it. Rostral teeth were occasionally missing in some specimens but were included in tooth counts based on the presence of alveoli. In 6 specimens, the rostrum–head juncture was not apparent and overall length was assumed to be equivalent to TRL.

Table 1. Sawfish rostral material used in this study. The 4 species represented were *Anoxypristis cuspidata*, *Pristis pectinata*, *P. pristis*, and *P. zijsron*. Measurements are in mm and consist of: overall length (tip to cut end), total rostrum length (TRL), standard rostrum length (SRL), proximal rostrum width (PRW), distal rostrum width (DRW), proximal tooth gap (PTG), and distal tooth gap (DTG). Specimen ID prefix (i.e. JCS, JJH) indicates owner of specimen. These materials are available for non-destructive sampling upon request to J. C. Seitz (floridasawfish@gmail.com) or J. J. Hoover (jan.j.hoover@usace.army.mil)

Specimen ID	Species	Overall length	TRL	SRL	PRW	DRW	Rostral tooth count		PTG	DTG	Locality
							Left	Right			
JCSAC231109	*A. cuspidata*	773	710	550	54	30	21	22	26	8	Undetermined
JCSAC221106	*A. cuspidata*	662	633	457	45	28	18	19	22	7	Phuket, Thailand
JCSAC301206	*A. cuspidata*	213	175	133	16	12	17	18	8	4	Undetermined
JCSAC031009	*A. cuspidata*	174	163	114	15	10	19	18	7	2	Undetermined
JCSACXXXX8X	*A. cuspidata*	494	–[a]	355	36	21	18	21	25	5	Undetermined
JCSAC260707	*A. cuspidata*	492	447	335	36	20	23	21	18	5	Undetermined
JCSAC260707B	*A. cuspidata*	454	442	324	36	18	19	18	20	5	Undetermined
JCSAC260707C	*A. cuspidata*	449	424	332	34	20	23	22	20	5	Undetermined
JJH004	*A. cuspidata*	637	633	493	54	27	26	27	29	7	Undetermined
JJH005	*A. cuspidata*	614	603	538	52	31	28	26	23	7	Undetermined
JJH006	*A. cuspidata*	489	–[a]	404	43	20	21	21	27	7	Undetermined
JJH007	*A. cuspidata*	597	–[a]	523	54	33	19	22	32	9	Undetermined
JCSPPXX1200	*P. pectinata*	816	812	750	101	44	23	23	56	14	Southwestern Florida, USA
JCSPP211202	*P. pectinata*	848	774	746	102	45	24	26	50	13	Southwestern Florida, USA
JCSPPXX1003	*P. pectinata*	659	643	601	86	38	25	25	36	12	Undetermined
JCSPP221106	*P. pectinata*	232	222	207	34	17	26	25	12	5	Tampa Bay, Florida, USA
JCSPP061007	*P. pectinata*	378	342	319	48	24	27	28	11	7	Florida Keys, Florida, USA
JCSPPXX0702	*P. pectinata*	187	176	168	27	14	25	26	8	4	Undetermined
JJH001	*P. pectinata*	849	825	803	118	53	27	27	47	9	Undetermined
JJH002	*P. pectinata*	351	–[a]	330	59	30	24	24	19	8	Undetermined
JJH003	*P. pectinata*	548	543	527	94	46	21	21	28	13	Undetermined
JJH012	*P. pectinata*	835	797	764	113	61	26	26	42	12	Undetermined
JCSPM180807	*P. pristis*	1175	1051	997	216	87	17	17	75	41	Bangladesh
JCSPM281005	*P. pristis*	1377	1290	1246	261	102	16	18	71	54	Bangladesh
JCSPM070707	*P. pristis*	1365	1345	1272	268	99	17	16	77	47	Bangladesh
JCSPP270103	*P. pristis*	685	–[a]	664	131	45	17	16	57	27	Texas, USA
JCSPMXX1206	*P. pristis*	654	614	580	116	47	17	16	41	25	Bangladesh
JCSPPXX0104	*P. pristis*	578	567	528	105	35	16	17	37	24	Lake Nicaragua, Nicaragua
JCSPX260812	*P. pristis*	694	686	636	131	51	14	14	48	30	Undetermined
JCSPMXX1206B	*P. pristis*	1224	1134	1058	204	80	18	19	60	44	Bangladesh
JCSPP241009	*P. pristis*	994	951	919	181	62	19	19	61	35	Brownsville, Texas, USA
JCSPM281005B	*P. pristis*	877	865	772	153	57	19	20	42	30	Bangladesh
JCSPMXX0702	*P. pristis*	350	341	327	61	29	19	20	19	12	Western Australia
JJH008	*P. pristis*	473	–[a]	463	98	55	16	18	20	23	Undetermined
JJH009	*P. pristis*	942	923	881	187	83	19	17	61	43	Undetermined
JCSPZXX1003	*P. zijsron*	1018	1015	988	112	51	37	35	53	8	Undetermined
JCSPZXX0805	*P. zijsron*	1164	1150	1000	120	54	28	28	89	16	Makran, Pakistan
JCSPZ070809	*P. zijsron*	452	449	416	54	27	25	25	41	7	Great Barrier Reef, Australia
JCSPZ301214	*P. zijsron*	1065	1065	1009	106	66	26	27	62	15	Northern Territory of Australia
JJH010	*P. zijsron*	900	858	805	118	53	25	25	44	13	Undetermined
JJH011	*P. zijsron*	1497	1470	1263	153	73	29	29	80	16	Undetermined

[a] Could not be measured. TRL was assumed to be equal to overall length for these specimens for the purpose of this study

Each specimen was assigned to a putative taxon based on appearance, tooth counts, and, when available, collection records. Until recently, 7 (or more) species of extant sawfishes were recognized, but recent morphologic and genetic data recognize only 5 species belonging to 3 species groups (Faria et al. 2013). Two forms of knifetooth sawfish *Anoxypristis cuspidata* have been documented: one from the Indian Ocean averaging 25.6 (typically ≥23) rostral teeth per side and another from the western Pacific averaging 21.2 (typically <23) teeth per side. The smalltooth sawfishes, comprising dwarf sawfish *Pristis clavata* from the eastern Indian and western Pacific, smalltooth sawfish *P. pectinata* from the Atlantic, and green sawfish, *P. zijsron*, from the Indo-Pacific, are each considered distinct and monospecific. Known rostral tooth counts per side are 18–27 for *P. clavata*, 20–30 (typically >22) for *P. pectinata*, and 23–37 for *P. zijsron*. The group of largetooth sawfishes was, until 2013, generally considered to consist of 2 or 3 species that were morphologically identical but geographically isolated: freshwater sawfish, *P. microdon* (nom. dub.) (hereafter *P.* '*microdon*') from the Indo-Pacific, largetooth sawfish formerly *P. perotteti* (nom. dub.) (hereafter *P.* '*perotteti*') from the Atlantic (Faria et al. 2013), and possibly a Mediterranean species, *P. pristis* (Ferretti et al. 2016). Genetic studies indicate that largetooth sawfishes represent a single wide-ranging species, *P. pristis*, and that there are no appreciable morphological differences among largetooth sawfishes from adjacent oceans. Tooth counts per side for *P. pristis* are 14–24 (Whitty et al. 2014). To be taxonomically conservative, we assigned each rostrum to 1 of 6 series: (1) *A. cuspidata* with ≥23 rostral teeth (either side); (2) *A. cuspidata* with <23 teeth (either side); (3) *P. zijsron*; (4) *P. pectinata*; (5) *P.* '*microdon*'; and (6) *P.* '*perotteti*'. The collections lacked examples of *P. clavata* and the possible Mediterranean form of *P. pristis*. Three rostra could not be confidently identified and were assigned to *Pristis* sp.

Analysis

Data were compiled and analyzed using SAS 9.3 (SAS Institute). A derived character, rostral narrowing (RN) was calculated as the ratio PRW/DRW to describe the degree to which rostra tapered from the base to the tip. Values for other rostral characters were standardized as ratios: character measurements (in mm) divided by TRL (in mm) and multiplied by 100. Values cannot exceed 100 (because no single measurement can exceed the total length of the rostrum) and represent percentages of the value for TRL.

To identify morphologically important variables and to quantify degree of morphological similarity within and between groups, PCA was performed using 5 standardized rostral characters: SRL, PRW, DRW, PTG, and DTG. PCA is well suited for databases consisting entirely of standardized morphological measurements and is often used to evaluate morphology of phenotypically similar individuals within and among species or populations of individuals (e.g. Mayden & Kuhajda 1996, Kuhajda et al. 2007, Murphy et al. 2007, Hoover et al. 2009). We used it here because the limited availability of supporting data prohibited certainty in the corroboration of species-level identifications. Unlike some other techniques, PCA is 'objective', requiring no prior identification of groups (i.e. species) for analysis. Instead, it derives ordination scores exclusively from the data matrix for characters, plotting points (i.e. individual rostra) in a space of low dimensions (e.g. 2 or 3 components) while preserving as much of the original structure of the data as possible (e.g. 5 standardized rostral characters) (Gaugh 1982). The first axis (PCI) accounts for the greatest amount of data variance, expressed as an eigenvalue, the second component (PCII) the second greatest amount, the third axis (PCIII) the next greatest. Direction and strength of associations of the original characters with components are expressed as eigenvectors.

Following ordination, we coded rostra based on the taxa to which they had been assigned during data collection. Individual points at the periphery of taxon-delineated clusters were used to define polygons. Spatial proximity of each rostrum (point) or clusters of rostra (polygons) represented the degree of morphological similarity.

To evaluate potential bias from our assumption that 6 specimens with no apparent flare at the base represented TRL, we re-ran PCA with those specimens deleted and compared outputs from the 2 analyses. These outputs were: eigenvalues (and proportion of variance) represented by each principal component; direction, rank order, and magnitude of each variable loading for the first 2 components and position of different taxa in morphological space.

RESULTS

The 2 combined collections were numerically dominated by *Anoxypristis cuspidata* (n = 12), followed by *Pristis pectinata* (10), *P.* '*microdon*' (7), *P. zijsron*

Table 2. Sample size, total rostrum length (TRL), and rostral characters for 2 combined private collections of sawfish rostra. Rostral tooth data are counts (teeth and empty alveoli). Measurements, in mm, were made according to techniques by Faria et al. (2013) and Whitty et al. (2014). Upper row of data for each character represents the mean (±SD). Lower row represents the range of values for that character. Characters in **bold** were used in principal component analysis (values are given as percentages of TRL)

	Anoxypristis cuspidata	*Pristis zijsron*	*P. pectinata*	*P.* '*microdon*'	*P.* '*perotteti*'
Number of rostra (*N* = 38[a])	12	6	10	7	3
Total rostrum length (TRL), mm	484.5 (172.9) 163–710	988.8 (322.1) 449–1407	549.7 (258.1) 176–835	948.6 (366.7) 350–1377	734.3 (196.7) 567–951
Number of rostral teeth on left side	21.0 (3.4) 17–28	28.3 (4.5) 25–37	24.8 (1.9) 21–27	17.6 (1.1) 16–19	17.3 (1.5) 16–19
Number of rostral teeth on right side	21.2 (2.9) 18–27	28.1 (3.7) 25–35	25.1 (2.0) 21–28	18.0 (1.7) 16–20	17.3 (1.5) 16–19
Standard rostrum length (SRL), % TRL	77.5 (6.1) 69.9–89.2	92.7 (3.9) 87.0–97.3	94.7 (1.6) 92.4–96.5	94.1 (2.4) 89.2–96.6	95.6 (2.1) 93.1–96.9
Proximal rostrum width (PRW), % TRL	8.3 (0.7) 7.1–9.1	11.4 (1.4) 9.9–13.9	14.6 (1.6) 12.4–17.3	19.0 (1.2) 17.7–20.5	18.9 (0.3) 18.5–19.1
Distal rostrum width (DRW), % TRL	4.8 (0.8) 4.1–6.6	5.6 (0.7) 4.7–6.3	7.1 (1.1) 5.4–8.5	7.6 (0.7) 6.6–8.5	6.4 (0.2) 6.2–6.6
Proximal tooth gap (PTG), % TRL	4.4 (0.7) 3.47–5.5	6.5 (1.6) 5.2–9.1	5.4 (1.0) 3.2–6.9	5.8 (0.8) 4.8–7.1	7.1 (1.1) 6.4–8.3
Distal tooth gap (DTG), % TRL	1.3 (0.3) 1.0–2.2	1.3 (0.3) 0.8–1.6	1.9 (0.4) 1.1–2.5	3.8 (0.3) 3.5–4.2	3.9 (0.3) 3.7–4.2
Rostral narrowing (PRW/DRW)	1.7 (0.2) 1.4–2.1	2.1 (0.2) 1.6–2.2	2.1 (0.2) 1.8–2.3	2.5 (0.2) 2.1–2.7	2.9 (0.00) 2.9–3.0

[a] Three rostra could not be confidently identified to species prior to PCA and therefore were excluded from this table

(6), *and P.* '*perotteti*' (3) (Table 2), excluding the 3 taxonomically unassigned specimens. Rostra ranged from 163 to 1407 mm TRL. Tooth counts were consistent with previously published data for all species (Faria et al. 2013, Whitty et al. 2014). On average, *A. cuspidata* had rostra with relatively parallel margins (RN < 2.0), *P. pectinata* and *P. zijsron* had broader bases (RN » 2.0), and *P.* '*microdon*' and *P.* '*perotteti*' had the broadest bases relative to tip width (RN > 2.0).

PCA indicated that the first 2 principal components and all 5 standardized rostral characters accounted for 87% of the dataset variation (Table 3). PCI accounted for 68.5% of the variation and was positively associated with PRW, followed by DTG, DRW, and SRL. PCII accounted for 18.4% of the variation and was positively associated with PTG. PCIII and higher accounted for <9% of the variation and were excluded from analysis.

The plotting of individual specimens along PCI (*x*-axis) and PCII (*y*-axis) was informative (Fig. 1). The 3 species groups (knifetooth, smalltooth, and largetooth) were well separated along PCI: *A. cuspidata* with values of PCI < −1, *P. zijsron* and *P. pectinata* with values of PCI = −1 to 1, and *P.* '*microdon*' and *P.* '*perotteti*' with values of PCI > 1. Overlap between the knifetooth and smalltooth groups did not occur, and overlap between the smalltooth and largetooth groups was negligible: 1 individual of each species in the area where polygons overlapped. Within the knifetooth group, specimens with high numbers of rostral teeth (23–28) occurred central to those with lower tooth counts (17–22), suggesting that higher count specimens had comparable rostrum shapes to

Table 3. Eigenvalues and eigenvectors from principal component analysis of sawfish rostrum data from 2 private collections. High-loading characters (eigenvectors >|0.45|) are indicated in **bold**

	PCI	PCII	PCIII
Eigenvalue	3.426	0.921	0.445
Variance	0.685	0.184	0.089
Eigenvectors			
Standard rostrum length	**0.452**	0.175	**−0.744**
Proximal rostrum width	**0.526**	−0.092	0.119
Distal rostrum width	**0.463**	−0.411	−0.155
Proximal tooth gap	0.275	**0.874**	0.204
Distal tooth gap	**0.478**	−0.167	**0.606**

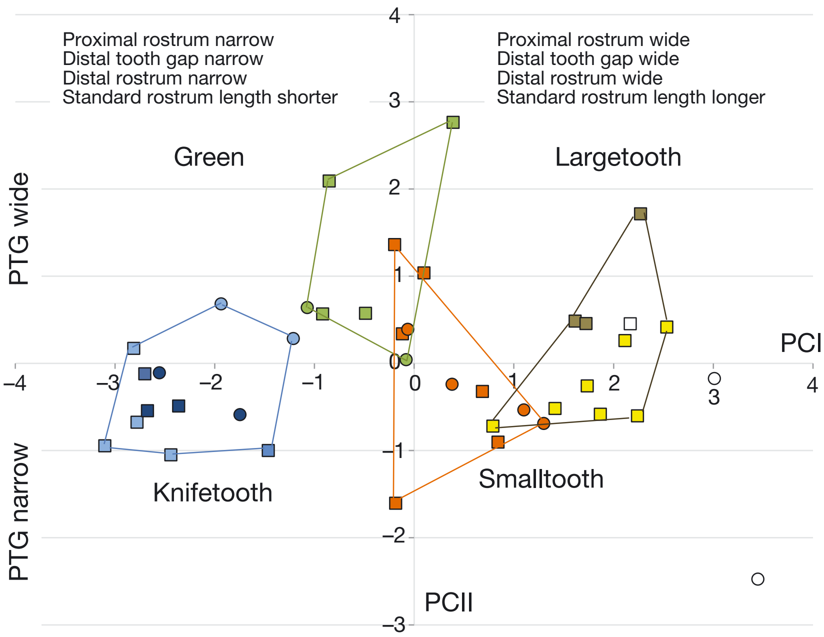

Fig. 1. Principal component ordination of morphological data from 2 private collections of sawfish rostra belonging to the authors: J. C. Seitz specimens, squares; J. J. Hoover specimens, circles. Six series represented are *Anoxypristis cuspidata* with ≤23 rostral teeth (either side), light blue; *A. cuspidata* with ≥23 rostral teeth (either side), dark blue; *Pristis zijsron*, green; *P. pectinata*, orange; *P.* '*microdon*', yellow; *P.* '*perotteti*', brown; unidentified species, white. Knifetooth and largetooth groups are shown as blue and brown polygons, respectively; *P. zijsron* and *P. pectinata* are shown separately as green and orange polygons, respectively. PTG: proximal tooth gap

those with lower tooth counts. Within the smalltooth group, 67 % of the *P. zijsron* specimens plotted lower than any of the *P. pectinata* specimens, and the two that did not were close to minimal values for the opposing species. SRL, PRW, DRW, and DTG, then, provide taxonomic resolution at the species-group level and, to a lesser degree, resolution among species in the smalltooth group.

No group or species separated cleanly along PCII but there was substantial variation within species and groups (Fig. 1). All 6 *P. zijsron* plotted higher than 60 % of the *P. pectinata* specimens, reflecting higher PTG values for *P. zijsron* (Table 2). Similarly, all 3 *P.* '*perotteti*' specimens plotted higher than 86 % of the *P.* '*microdon*' specimens, suggesting that PTG could be different between these 2 populations. However, the low number of specimens of *P.* '*perotteti*' prevents a definitive conclusion.

Polygon area and shape are comparable for *A. cuspidata*, *P. pectinata*, *P. zijsron*, and the *P.* '*perotteti*'–*P.* '*microdon*' group (Fig. 1). All 4 are similar in size and orientation and are taller than they are wide, suggesting greater variation in PTG than other characters for all taxa.

Of the 3 taxonomically unassigned specimens, all were unusual in certain respects; one plotted central to the *P.* '*perotteti*'–*P.* '*microdon*' group and another just outside of the polygon, but the third specimen was an outlier to the group and to all other individuals. The first specimen was consistent (within range) in all mensural characters with other individuals of the group. It had, however, an unusually low tooth count, 14 on each side, which is the minimum value documented for the group in Australia (Whitty et al. 2014) and globally (Faria et al. 2013). The second specimen had values that were within our range for SRL, PTG, and RN but greater than maximum values documented for PRW, DRW, and DTG in other specimens. Tooth counts were typical (19 left and 17 right) and we believe that the specimen probably represents a largetooth sawfish. The third specimen was outside the range of standardized relative values for all mensural characters for other individuals in the largetooth group: SRL = 98.1 % vs. SRL ≤ 96.9 % TRL, PRW = 20.8 % vs. PRW ≤ 20.5 % TRL, DRW = 11.7 % vs. DRW ≤ 8.5 % TRL, PTG = 4.2 % vs. PTG ≥ 4.8 % TRL, DTG = 4.9 % vs. DTG ≤ 4.2 % TRL, and RN = 1.78 vs. RN ≥ 2.1. Because the third specimen had evenly spaced rostral teeth along its length (PTG ≈ DTG), and because the SRL/TRL ratio is only negligibly greater than the range of values documented by Whitty et al. (2014) (SRL/TRL = 91–98 %), it is possible that this specimen represents a morphological extreme for the group. We conclude then that all unidentified specimens were members of *P. pristis*.

For the 5 specimens with no apparent flare to indicate the juncture with the head, the assumption that overall length was equivalent to TRL was supported by re-analysis of the data. PCA output of the 41 specimens (Table 3, Fig. 1) was comparable to PCA output with those specimens deleted (N = 36). Changes in eigenvalues (and proportion of variance) were negligible: for PCI, 3.426 (0.685) to 3.475 (0.695); for PCII, 0.921 (0.184) to 0.814 (0.163); and for PCIII, 0.445 (0.089) to 0.487 (0.097). Directions (+ or −) were identical for all loadings. Rank order of variable loadings was identical for PCI; first-, second-, and fifth-ranked variables were the same for

PCII. Differences in magnitude of loading were low: <0.045 with 8 of 10 values <0.020. Scatterplots were not appreciably different for the 2 PCAs. *A. cuspidata* specimens had low scores on PCI, moderate scores on PCII, and the polygon was disjunct from all other specimens. *P. pectinata* and *P. zijsron* had moderate scores on PCI; *P. zijsron* had moderate to high scores on PCII, *P. pectinata* low to moderate scores on PCII, and overlapped with 5 specimens (1 *P. zijsron* and 4 *P. pectinata*). *P.* '*perotteti*' and *P.* '*microdon*' had high scores on PCI; *P.* '*perotteti*' had moderate to high scores on PCII, *P.* '*microdon*' low to moderate scores. The polygon for the 2 largetooth species combined overlapped the *P. pectinata* polygon with 2 specimens (1 *P. pectinata*, 1 *P.* '*microdon*'). Because differences in the 2 PCAs were inconsequential, we base our interpretations on the first analysis of all 41 specimens.

DISCUSSION

Our results are similar to those of previous studies in which ordination analyses showed that 2 morphologically-based axes could separate sawfish species (Faria et al. 2013, Whitty et al. 2014), and that taxonomic resolution of 4 sawfish species was possible based on overall morphology (Faria et al. 2013) or a combination of rostral characters, including standard length, relative width, and inter-dental spaces of rostra (Whitty et al. 2014). This is noteworthy considering the disparities between the previous studies and this project in sample size (N > 800 vs. N = 41), supporting data (rostral and non-rostral characters vs. rostral-only characters), and analytical approach. Faria et al. (2013) used canonical variate analysis and Whitty et al. (2014) used discriminant analysis. Both of these techniques are classification-based approaches designed to maximize discrimination among groups. The groups (species) are identified beforehand for these approaches. In contrast, PCA used here is a classification-free ordination depicting maximum variation among individuals with no prior identification of groups (species). PCA provided a comparable level of discrimination, suggested that intra-specific variation was similar among species, and verified the utility of rostral measurements as informative characters. Recent morphological studies of other elasmobranch groups have also used PCA to discriminate among phenotypically similar confamilial and congeneric species (Lonardoni et al. 2009, Veríssimo et al. 2014, Orlando et al. 2015). Our results compared well with those of previous studies and enabled us to answer the 3 questions prompting this study.

Are taxonomic determinations based exclusively on rostrum morphology consistent with those based on additional information? Our data suggest 'yes' and that 5 morphological measurements can confirm or refute identifications based on other kinds of information. Four taxa represented herein showed complete separation or only slight overlap (i.e. *Pristis pectinata* with *P. zijsron* and with *P. pristis*) (Fig. 1). The pattern of separation along the primary ordination axis in this study was the same as that observed in Australian sawfish rostra (Whitty et al. 2014): knifetooth group, low; smalltooth group, moderate; largetooth group, high. It was similar to that observed for sawfishes globally in which largetooth were distinct (spatially remote) from smalltooth species, but in which there was no overlap among any taxa, possibly attributable to the use of different and non-rostral characters (Faria et al. 2013).

Can rostral morphology be used as a stand-alone tool to objectively discriminate species? The low degree of overlap among groups indicates that these or similar analyses objectively classify rostra for which identifications are uncertain or contentious. Two of the 3 specimens for which we were reluctant to provide identifications were positioned central and proximate to the largetooth group polygon (Fig. 1). Morphological measurements of the third specimen, an apparent outlier, were still consistent with previously published data for *P. pristis*. This specimen likely represents a morphologically extreme individual.

Do private collections of <50 specimens allow insight into interspecific and intraspecific taxonomic diversity? Our data suggest 'yes'. Comparable and substantial point spread for each of the 4 species examined in this study may be attributable to morphological variation in taxa with extensive geographic ranges and, presumably, locally adapted populations, which is supported by the previous ordination studies. Globally, morphological variation based on data for the rostrum and body of sawfishes, and on the number of rostral teeth, exclusive of *Anoxypristis cuspidata*, was also comparable and substantial for *P. pectinata* and *P. zijsron*, although *P. pristis* from the Atlantic Ocean, the Indo-West Pacific, and Eastern Pacific showed relatively low point spread (Faria et al. 2013). In Australia, however, as in our study, rostral morphology of *A. cuspidata*, *P. zijsron*, and *P. pristis* showed comparable point spread (Whitty et al. 2014).

Similarity in results between this study of 2 private collections and previous studies based on extensive regional and global surveys may have biological and anthropogenic explanations. It could reflect characteristic morphological plasticity among highly similar species within the family. It could also reflect long-term, geographically extensive harvest and far-ranging trade of durable specimens. In either case, there is high research value in the logistically conservative and cost-effective analysis of privately held rostra. The authors are currently investigating the possible use of rostral tooth and canal morphometric analysis for taxonomic resolution of sawfish rostra.

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