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Notoraja hirticauda, a new species of skate (Chondrichthyes: Rajoidei) from the south-eastern Indian Ocean

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Abstract Last P.R. and McEachran J.D. 2006. *Notoraja hirticauda*, a new species of skate (Chondrichthyes: Rajoidei) from the south-eastern Indian Ocean. *Memoirs of Museum Victoria* 63(1): 65–75.

A new skate, *Notoraja hirticauda* sp. nov., is described from off central Western Australia in the south-eastern Indian Ocean. It is distinguished from its congeners in some proportional measurements, the distributions of dermal denticles and bristle-like thorns, the absence of oronasal pits, and several skeletal structures. The new species has a relatively long snout, multiple irregular rows of short thorns on the dorsal and lateral surfaces of the tail, and dermal denticles on the ventral surface of the tail. Its rostral cartilage, which is longer than the nasobasal length, has appendices that are subtriangular in cross-section posteriorly and abut the rostral shaft. Within *Notoraja*, *N. hirticauda* most closely resembles *N. subtilispinosa* Stehmann from the Philippines and Indonesia.

Keywords Chondrichthyes, Rajidae, new species, skate, *Notoraja hirticauda,* south-eastern Indian Ocean

Introduction

The highly diverse and endemic rich skate faunas of Australia and New Zealand are represented by at least 62 species, of which all but two appear to be restricted to the Australasian region (Last and Yearsley, 2002). Similarly, of the 40 or so Australian species (Last and Stevens, 1994), only one also occurs off New Zealand. Several new species have been identified from recent exploratory, trawl-fishing catches in Australian seas but most of these remain undescribed. For example, the rajoid fauna off the western coast of Australia consists of at least 14 species of which only three have been described (Last and Stevens, 1994). Many of these appear to have narrow depth and geographic ranges. Among the least well-known skates, at both specific and supraspecific levels within the suborder, are Australian members of the *Notoraja*-like skates.

McEachran and Miyake (1990) presented a cladogram dividing rajoids into two major clades: Group I consisting of nine supraspecific taxa including the pavorajine subgroups *Pavoraja* Whitley, *Notoraja* Ishiyama and a recently described genus, *Brochiraja* (Last and McEachran, 2006; formerly as an unnamed taxon “Subgenus A” of *Pavoraja*, *sensu* McEachran, 1984); and Group II consisting of 11 supraspecific taxa including “typical” rajine subgroups such as *Raja* and *Dipturus*. Group I skates are well represented in the western Pacific with at least 30 species occurring off Australasia (Last and Yearsley, 2002). However, relationships within the clade, which includes the pavorajine subgroups and *Insentiraja* Yearsley and Last, are not fully understood. McEachran and Last (1994) have suggested that *Brochiraja* (as Subgenus A) is a subgroup of *Notoraja* rather than *Pavoraja*, as originally suggested by McEachran (1984). However, elucidation of the relationships within this generic complex is dependent on descriptions of other members within the clade. *Notoraja* was resurrected by Stehmann (1989) and presently contains four valid nominal species, *N. laxipella* (Yearsley & Last) and *N. ochroderma* McEachran and Last from north-eastern Australia, *N. tobitukai* (Hiyama) from Japan, and *N. subtilispinosa* Stehmann from the Philippines and Indonesia, although other species are known to occur in the Indo-west Pacific (McEachran and Last, 1994). A new species of *Notoraja* is described below based on material from the continental slope off Western Australia.

Several different methods for taking external measurements of skates have been proposed. This has caused considerable confusion in the past, so our methods are explained here in some detail. We used the point-to-point approach proposed by Hubbs and Ishiyama (1968), but raw data are finally expressed as proportions of total length rather than disc width. The preoral length is defined as the measurement from the snout tip to the anterior median edge of the upper jaw rather than to the mouth proper. Mouth width is the greatest dimension across the tooth band of the upper jaw rather than visible width of the upper jaw between the inner margins of integument (Yearsley and Last, 1992). Spiracular measurements refer to distances around the main depression and do not include the anterior secondary depression. The maximum and minimum widths of the nasal curtain refer to the greatest dimensions across the curtain (usually across the lobes) and the width between the innermost insertions of the curtain immediately before the mouth respectively. The nasal lobe dimension is the greatest width of the lobe from the insertion of the curtain to its lateral margin. Pelvic-fin lobe lengths are taken from the point of articulation of the anterior lobe as described by McEachran and Stehmann (1984) and Stehmann (1985) rather than from the haemal spine (Hubbs and Ishiyama, 1968). The width of the pelvic-fin base is the minimum distance between these points of articulation. Measurements to the cloaca originate from near its posterior margin (i.e. approximated from the origin of the first haemal spine) rather than at its midpoint. Skeletal measurements and counts follow Hubbs and Ishiyama (1968) and McEachran and Compagno (1979, 1982).

Some mature paratypes were dissected to reveal the structure of the neurocranium, scapulocoracoid and clasper; skeletal elements were highlighted with Alcian blue eight GS cartilage stain. All specimens were radiographed to verify anatomical dissections, to count vertebrae, teeth and pectoral-fin radials, and to determine the shape of the pelvic girdle. Specimens examined in this study were obtained from the Australian National Fish Collection, Commonwealth Scientific and Industrial Research Organisation, Hobart (CSIRO).

Notoraja hirticauda sp. nov.

Figures 1–8, Tables 1–3

Notoraja sp. C — Last and Stevens, 1994: 312, figs 33, 34.5, Pl 50 (all fig. captions incorrect, as N. sp B).

Material examined. Holotype. Australia: CSIRO H1816–02, 446 mm TL, mature male, west of Shark Bay, Western Australia, 26°36'S, 112°09'E, 760 m, 28 December 1989, RV "Akebono Maru", sta. 41.

Paratypes (n=8): Australia: CSIRO CA2820, 312 mm TL, female, CSIRO CA2821, 264 mm TL, female, north of Nickol Bay, Western Australia, 18°38'S, 116°54'E, 600 m, 7 Apr 1982, FRV "Soela", Cr. 2, sta. 30; CSIRO CA2822, 241 mm TL, female, CSIRO CA2823, 277 mm TL, female, north of Nickol Bay, Western Australia, 18°41'S, 116°45'E, 596 m, 6 Apr 1982, FRV "Soela", Cr. 2, sta. 28; CSIRO CA2824, 361 mm TL, immature male, north of Nickol Bay, Western Australia, 18°43'S, 116°33'E, 612 m, 7 Apr 1982, FRV "Soela", Cr. 2, sta. 29; CSIRO H1816-03, 448 mm TL, mature male, captured with holotype; CSIRO H1822-01, 372 mm TL, female, west of Shark Bay, Western Australia, 26°44'S, 112°19'E, 735 m, 28 Dec 1989, RV "Akebono Maru", sta. 40; CSIRO H2574-06, 428 mm TL, female, west of Freycinet Estuary, Western Australia, 26°38'S, 112°30'E, 500 m, 30 Jan 1991, FRV "Southern Surveyor", Cr. 1, sta. 37.

Diagnosis. A small species of *Notoraja* with the following combination of characteristics: preoral snout 13.5–15.2% TL; preorbital snout 12.3–13.8% TL; mutiple irregular rows of small, bristle-like thorns and large dermal denticles present on both surfaces of tail; single preorbital thorn present; no oronasal pits; rostral cartilage about 1.25 in nasobasal length; rostral appendices about 62% of nasobasal length, subtriangular in cross-section posteriorly and evenly abutting rostral shaft; pectoral radials 61–66; trunk vertebrae 24–27, precaudal tail vertebrae 71–76; and both surfaces of body pale.

Description. Disc heart-shaped, 1.11 times as broad as long in holotype (1.11–1.16 times in paratypes); maximum angle in front of spiracles 73–75° in adult males, 93–97° in females and juveniles; anterior margin initially straight, slightly more convex in females and immatures, moderately concave opposite spiracles in mature male holotype; posterior margin and corners broadly convex (figs 1, 2). Snout to axis of greatest width 61.5% (57.7–60.9%) of disc length. Snout tip with prominent fleshy and laterally flattened apical process; process rather broad-based and almost continuous with anterior profile of disc in mature males, more lobe-like in immatures and adult females. Pelvic fins deeply incised, anterior lobe moderately long, narrow at base and tapering to blunt point; posterior lobe relatively short, with strongly convex lateral margins; anterior lobe length 95.7% (93–113%) of posterior lobe. Tail narrow at base, tapering gradually posteriorly, very slender toward tip; moderately depressed over length, width 1.42 (1.44–1.72) times height at axil of pelvic fin; slightly convex on ventral surface; lateral skin folds originating well behind posterior pelvic-fin lobes, extending to below mid-length of epichordal caudal-fin lobe and broadening distally (only slightly narrower than height of epichordal lobe); length of tail from rear of cloaca 1.40 (1.40–1.50) times distance from tip of snout to rear of cloaca; predorsal tail length 78.1% (78.2–81.4%) of tail length; width at midlength of tail 2.06 (1.99–2.72) in orbit diameter; width at axils of pelvic fins 0.80 (0.85–1.00) in orbit diameter. Dorsal fins of similar shape and size; rather short and moderately tall with evenly convex anterior margin; posterior margin straight or slightly convex; tip pointed or acutely rounded; fins separated by short interspace. Epichordal caudal-fin lobe relatively well developed, separated by short interspace from and distinctly longer than 2nd dorsal-fin base; hypochordal caudal lobe very low, originating near end of lateral fold, not confluent with epichordal lobe. Preorbital snout length 4.02 (3.15–3.50 in females and immatures) times orbit diameter; preoral snout length 2.29 (1.98–2.35) times internarial distance. Orbit diameter 1.17 (1.11–1.45) times interorbital distance; 1.87 (2.02–3.08) times length of spiracles. Lateral nasal fold expanded slightly, with weak triangular process along lateral margin, posterior margin smooth or with a weak fringe; nasal curtain moderately well developed, broadly rounded and weakly fringed (often hardly detectable) along posterior margin. Oronasal pits absent. Upper and lower jaws slightly arched on either side of symphysis; upper jaw of holotype indented at symphysis, not indented in females and immatures. Teeth in 36 (35–40) series in upper jaw, 34 (32–39) series in lower jaw; plate-like with short cusps in females, cusps acutely pointed in males, arranged quincuncially. Distance between 1st gill slits 1.72 (1.63–1.91) times distance between nostrils; distance between 5th gill slits 1.07 (1.04–1.27) times distance between nostrils; length of 1st gill slit 6.7 (4.7–8.4) times mouth width.

Dorsal surface of disc, posterior lobe of pelvic fin, dorsal fins, epichordal lobe of caudal fin, and lateral skin folds densely

Table 1. Morphometric data for the holotype of *Notoraja hirticauda* sp. nov., with ranges and means for paratypes. Measurements are expressed as percentages of total length

	Holotype CSIRO H1816–02	Paratypes n=8		
		Min	Max	Mean
Total length (mm)	446	241	448	
Disc width	48.7	47.3	51.3	48.7
Disc length	43.7	41.8	45.2	43.0
Head length (dorsal)	17.8	16.9	17.7	17.4
Head length (ventral)	25.1	23.1	25.7	24.3
Snout length (preorbital)	13.8	12.3	13.2	13.0
Snout length (preoral)	15.2	13.5	15.0	14.6
Prenasal length	11.1	10.1	11.0	10.5
Snout to maximum width	26.9	24.5	26.6	25.7
Orbit diameter	3.3	3.8	4.2	3.9
Distance between orbits	2.8	2.7	3.5	3.0
Orbit and spiracle length	4.3	4.2	5.0	4.5
Spiracle length	1.8	1.3	2.1	1.7
Distance between spiracles	5.4	5.4	6.3	5.7
Mouth width	7.2	5.7	6.6	6.3
Nare to mouth	4.3	3.6	4.7	4.2
Distance between nostrils	6.1	6.0	6.4	6.2
Width of first gill slit	1.0	0.8	1.2	1.0
Width of third gill slit	0.8	0.9	1.3	1.1
Width of fifth gill slit	0.7	0.9	1.1	0.9
Distance between first gill slits	10.6	10.4	11.7	11.1
Distance between fifth gill slits	6.5	6.4	7.8	7.2
Length of anterior pelvic-fin lobe	13.7	13.1	15.0	14.4
Length of posterior pelvic-fin lobe	12.2	12.3	14.5	13.4
Tail width at axil of pelvic fins	4.1	4.0	4.5	4.2
Tail height at axil of pelvic fins	2.9	2.5	3.1	2.7
Tail width at tips of pelvic fins	3.9	3.2	3.9	3.6
Tail height at tips of pelvic fins	2.4	2.1	2.6	2.3
Width of tail across its midpoint	1.6	1.5	2.0	1.7
Distance—snout to cloaca	41.7	40.1	42.4	41.0
Distance—cloaca to 1st dorsal fin	45.3	45.6	48.4	46.8
Distance—cloaca to 2nd dorsal fin	50.0	50.2	52.2	50.8
Distance—cloaca to caudal-fin origin	54.5	54.0	56.0	55.0
Distance—cloaca to caudal-fin tip	58.3	58.4	61.0	59.5
Number of tooth rows (upper jaw)	36	35	40	38.2
Number of tooth rows (lower jaw)	34	32	39	35.6
Number of trunk vertebrae	26	24	27	25.4
Number of precaudal tail vertebrae	72	71	76	73.0
Number of pectoral-fin radials	63	61	66	64.2

Table 2. Morphometric data fotr the neurocranium of paratype (CSIRO H1822–01) of *Notoraja hirticauda* sp. nov. Measurements are expressed as percentages of nasobasal length

	Neurocranium	% length
Nasobasal length (mm)	31.4	
Cranial length	72.8	231.8
Rostral cartilage length	39.3	125.2
Rostral cartilage width	1.6	5.2
Prefontanelle length	33.1	105.4
Cranial width	39.0	124.2
Interorbital width	10.1	32.3
Rostral base	3.8	12.0
Anterior fontanelle length	14.4	45.9
Anterior fontanelle width	3.9	12.5
Rostral appendix length	19.3	61.5
Rostral appendix width	5.4	17.2
Rostral cleft length	10.8	34.4
Cranial height	7.4	23.5
Width across otic capsules	19.0	60.5
Width of basal plate	9.0	28.7
Greatest width of nasal aperture	16.4	52.1
Least width of nasal aperture	7.0	22.4
Internasal width	3.9	12.5

Table 3. Morphometric data for the scapulocoracoid of paratype (CSIRO H2574–06) of *Notoraja hirticauda* sp. nov. Measurements are expressed as percentages of scapulocoracoid length

	Scapulocoracoid	% length
Scapulocoracoid length (mm)	22.7	
Scapulocoracoid height	17.2	75.5
Premesocondyle	9.0	39.6
Postmesocondyle	13.7	60.4
Postdorsal fenestra length	6.5	28.8
Postdorsal fenestra height	5.2	23.0
Anterior fenestra length	2.9	13.0
Anterior fenestra combined height	6.5	28.8
Base length	20.6	90.6
Anterior corner height	16.4	71.9
Posterior corner height	12.8	56.1

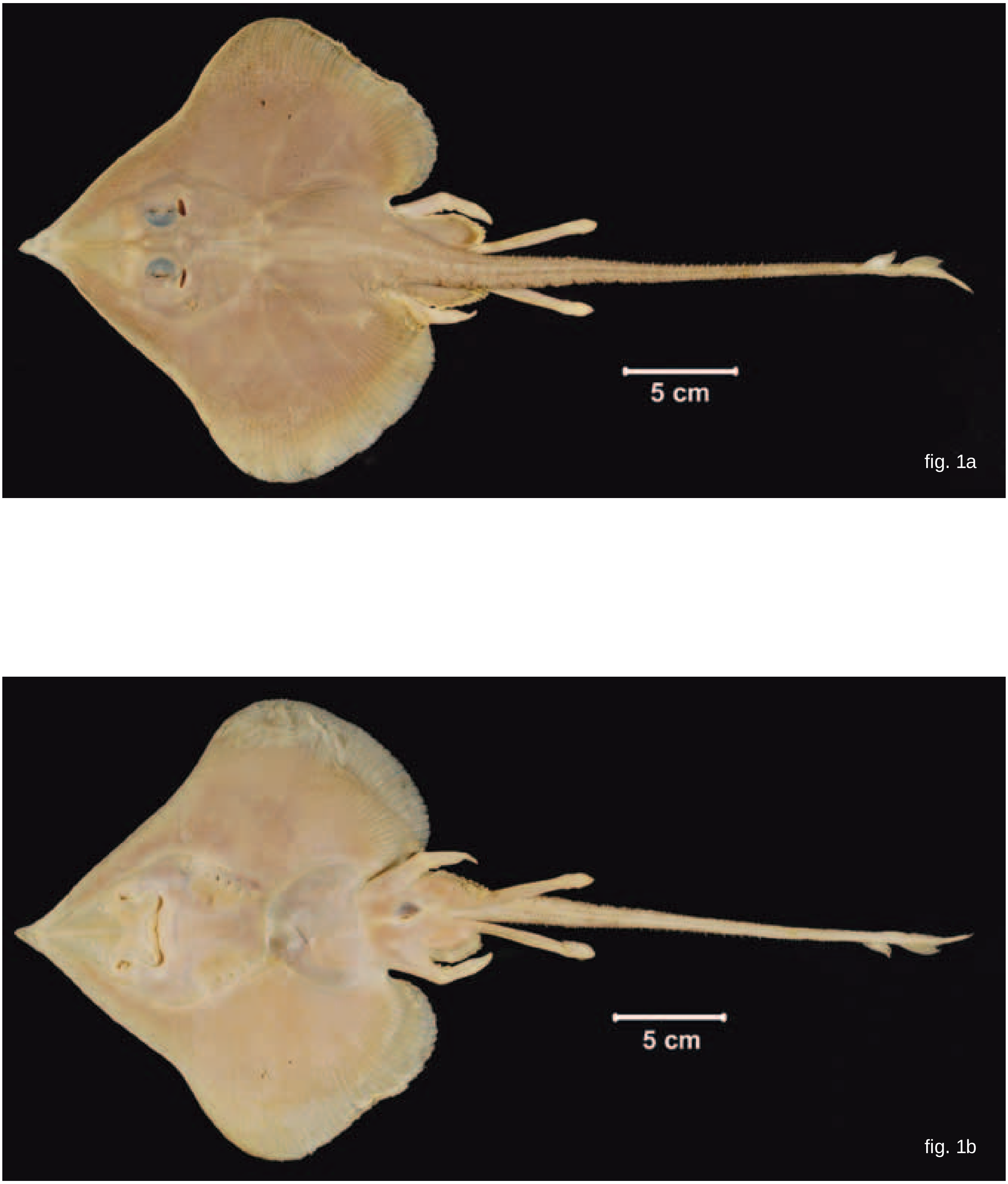

Figure 1. *Notoraja hirticauda* sp. nov. Holotype (CSIRO H1816–02, 446 mm TL, male). a. Dorsal view; b. Ventral view.

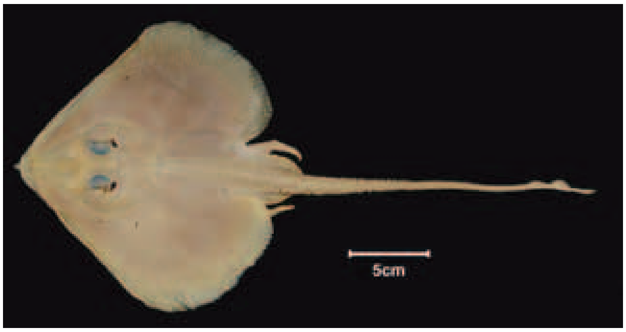

Figure 2. *Notoraja hirticauda* sp. nov. Paratype (CSIRO CA2824, 361 mm TL, female). Dorsal view.

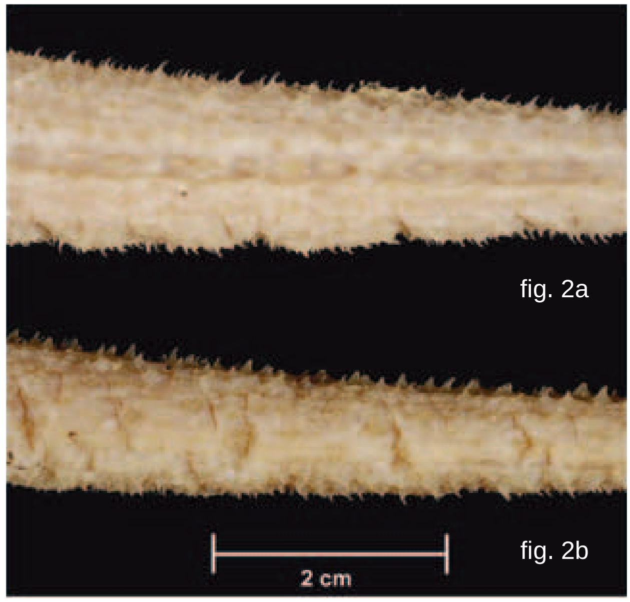

Figure 3. Squamation on the mid-tail of *Notoraja hirticauda* sp. nov. Holotype (CSIRO H1816–02, 446 mm TL, male). a. Dorsal view; b. Lateral view.

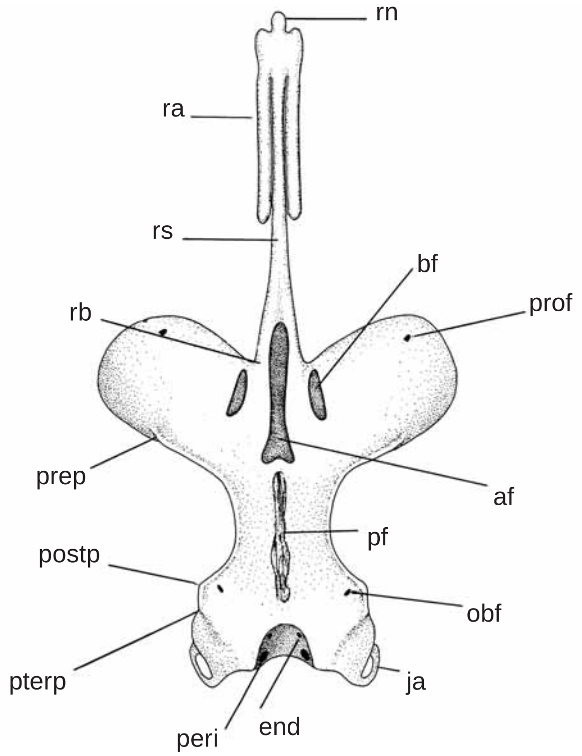

fig. 4a

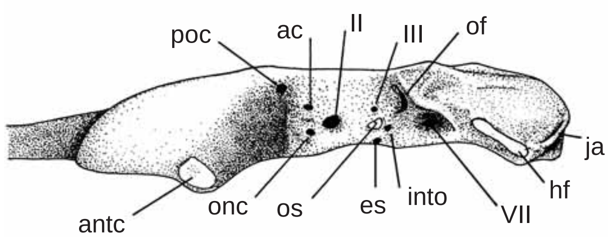

fig. 4b

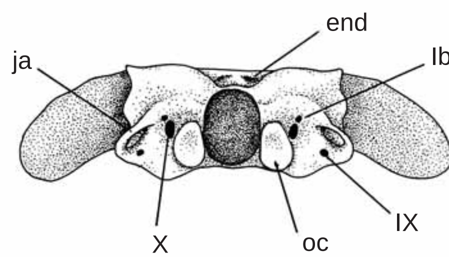

fig. 4c

Figure 4. Neurocranium of *Notoraja hirticauda* sp. nov. Paratype (CSIRO H1822–01, mature female, 372 mm TL: a. dorsal view; b. lateral view; c. posterior view). fig. abbreviations: ac–anterior cerebral vein foramen, af–anterior fontanelle, antc–antorbital condyle, bf–basal fenestra, end–endolymphatic foramen, es–efferent spiracular artery foramen, hf–hyomandibular facet, into–intercerebral vein foramen, ja–jugal arch, lbX–lateralis branch of vagus nerve foramen, obf–otic branch of facial nerve foramen, oc–occipital condyle, of–orbital fissure, onc–orbitonasal canal foramen, os–optic stalk, peri–perilymphatic nerve foramen, pf–posterior fontanelle, poc–preorbital canal, postp–postorbital process, prep–preorbital process, prof–profundus nerve foramen, pterp–pterotic process, ra–rostral appendix, rb–rostral base, rn–rostral node, rs–rostral shaft, II–optic nerve foramen, III–oculomotor nerve foramen, VII–hyomandibular branch of facial nerve foramen, IX–glossopharyngeal nerve foramen, X–vagus nerve foramen.

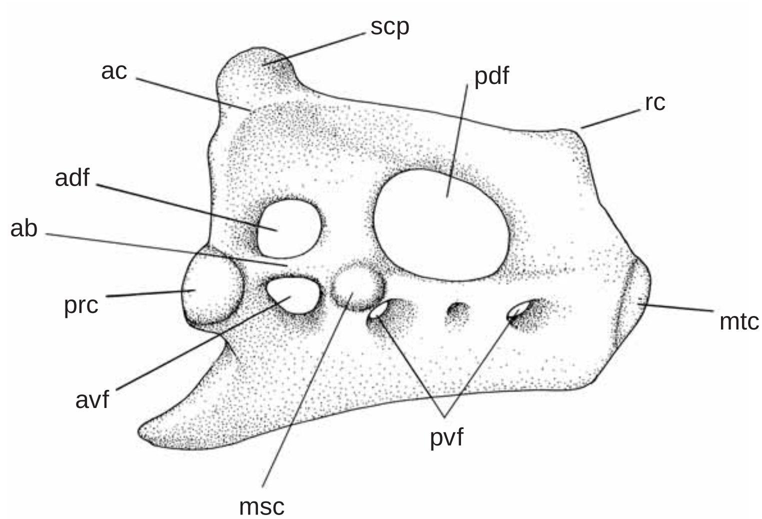

Figure 5. Lateral view of left scapulocoracoid of *Notoraja hirticauda* sp. nov. Paratype (CSIRO H2574–06, mature female, 428 mm TL). fig. abbreviations: ab–anterior bridge, ac–anterior corner, adf–anterodorsal fenestra, avf–anteroventral fenestra, msc–mesocondyle, mtc–metacondyle, pdf–postdorsal fenestra, prc–procondyle, pvf–postventral foramina, rc–rear corner, scp–scapular process.

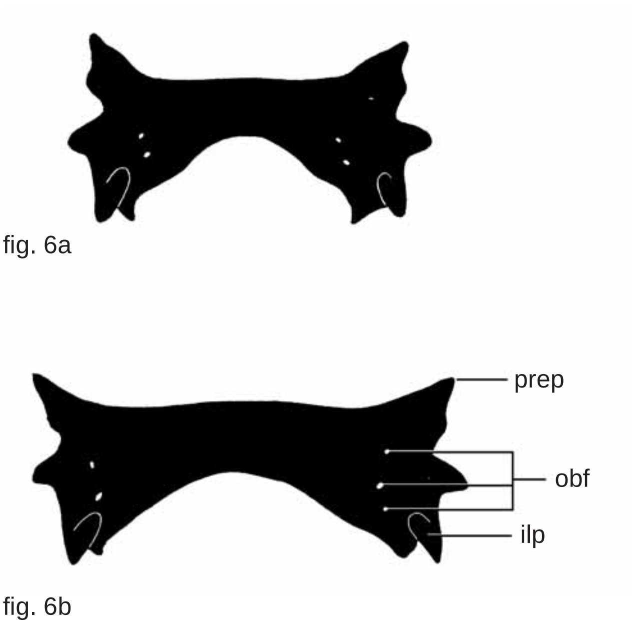

Figure 6. Ventral view of pelvic girdle of *Notoraja hirticauda* sp. nov. a. Holotype, (CSIRO H1816–02, male, 446 mm TL); b. Paratype (CSIRO H2574–06, female, 428 mm TL). fig. abbreviations: ilp–iliac process, obf–obturator foramina, prep–prepelvic process.

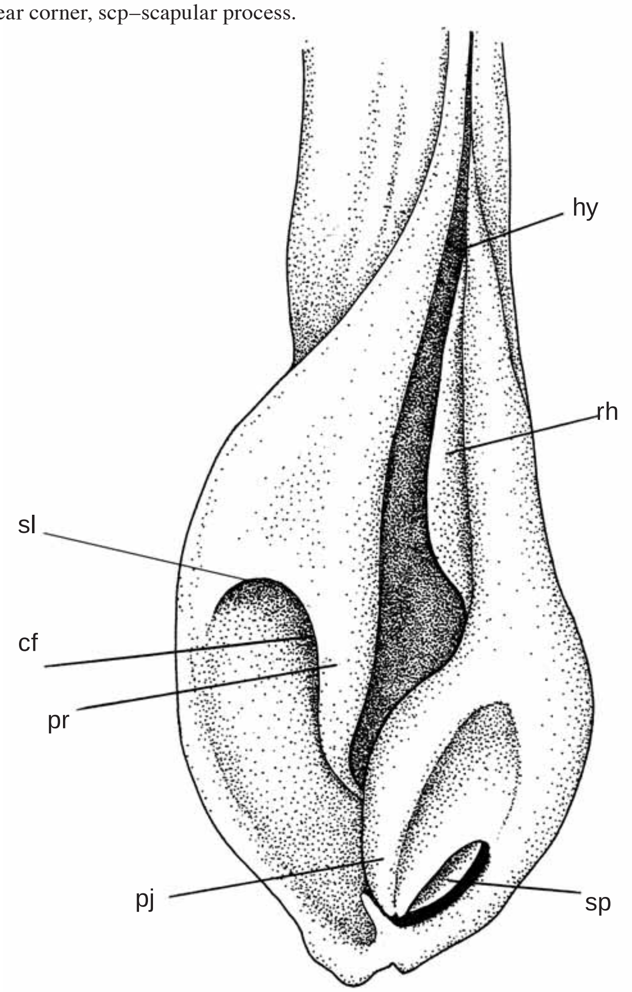

Figure 7. Lateral view, partially expanded, of right clasper of *Notoraja hirticauda* sp. nov. Holotype (CSIRO H1816–02, 446 mm TL, male). fig. abbreviations: cf–cleft, hy–hypopyle, pj–projection, pr–pseudorhipidion, rh–rhipidion, sl–slit, sp–spike.

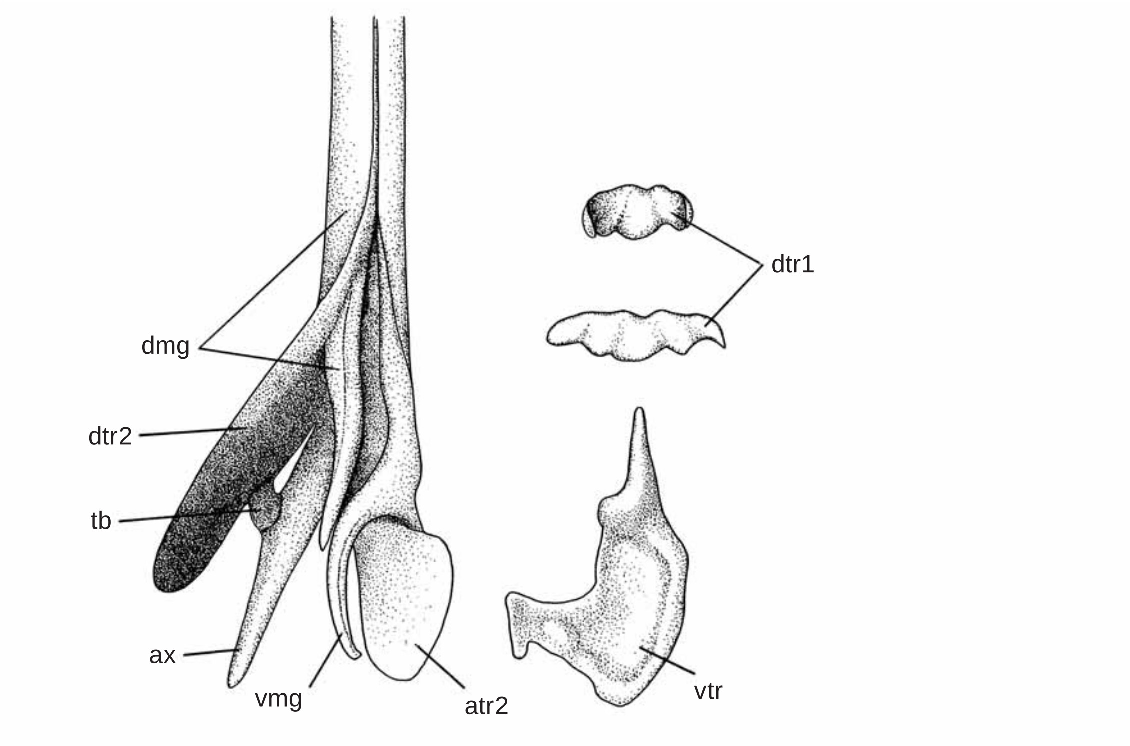

fig. 8a

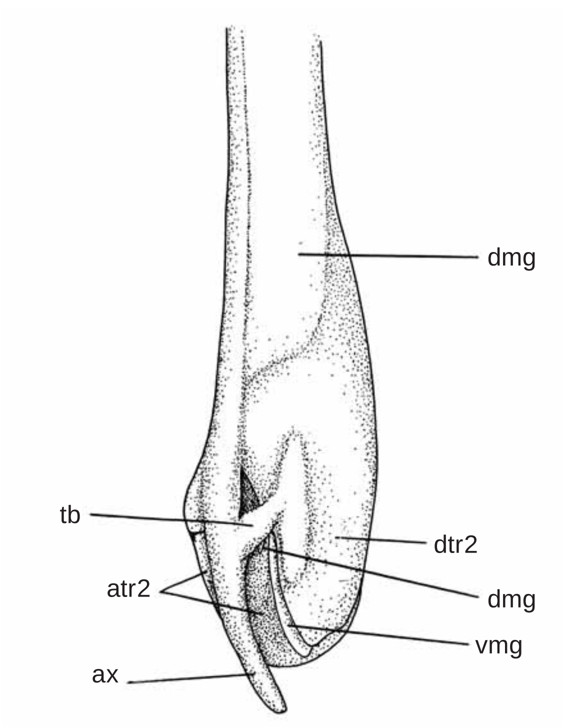

fig. 8b

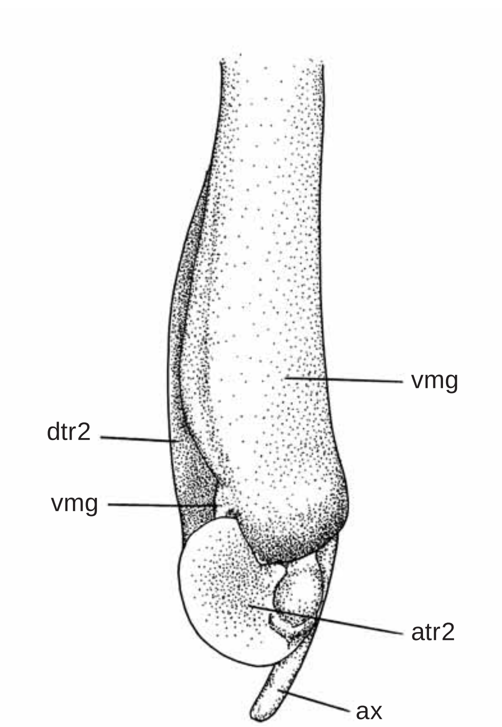

fig. 8c

Figure 8. Right clasper cartilages of *Notoraja hirticauda* sp. nov. Holotype (CSIRO H1816–02, 446 mm TL, male): a) lateral view; b) dorsal view; c) ventral view. fig. abbreviations: atr2–accessory terminal 2 cartilage, ax–axial cartilage, dmg–dorsal marginal cartilage, dtr1–dorsal terminal 1 cartilage, dtr2–dorsal terminal 2 cartilage, tb–terminal bridge, vmg–ventral marginal cartilage, vtr–ventral terminal cartilage.

covered with fine, more or less evenly spaced dermal denticles; thorns (fig. 3) small, delicate, confined to tail and preorbit, and alar regions of mature males. Denticle cusps on disc very slender, erect and slightly recurved; bases quadriradial, radii arranged more or less at right angles, anterior radius generally shortest (sometimes barely detectable). Both surfaces of tail densely covered with denticles and small, bristle-like thorns; thorns variable in size, scattered, interspersed with denticles; median thorns in an almost linear series, other thorns distributed randomly or in irregular series; largest thorns long-based, somewhat compressed, sharply pointed distally, upright and triangular or with narrow recurved tips; most numerous dorsally on centre of tail; thorns on ventral surface of tail generally smaller than those dorsally but much larger than denticles of disc. Single, rather short preorbital thorn present. Alar thorns strongly recurved and directed postero-medially, central group in indistinct rows and merging with a cluster of smaller thorns near anterior outer margin of pectoral fin; holotype with about 5–6 central rows, each with 1–4 thorns (mature male paratype with about 9–12 rows, each with 1–2 thorns); all thorns non-depressible, obliquely oriented to surface of disc, not fitting into slits in integument. Claspers, anterior lobes of pelvic fins, and ventral surfaces of disc and posterior pelvic-fin lobes naked; integument of ventral surface rather delicate.

Skeletal morphology. Neurocranium with nasobasal length 20.7% of distance from snout to posterior margin of cloaca and 80.5% of cranial width. Rostral shaft slender, of moderate length, about 125% of nasobasal length; rostral base 12% of nasobasal length (fig. 4, Table 2); rostral appendices long, flattened anteriorly, subtriangular in cross-section and abutting (rather than fused to) rostral shaft posteriorly; propterygia of pectoral girdle reaching rostral node; nasal capsules very large, ovoid, set at about 26° to transverse axis of neurocranium; foramen for profundus nerve near antero-lateral margin of nasal capsules; preorbital process poorly developed; postorbital process poorly developed and barely distinct from pterotic process; anterior fontanelle very narrow, with acutely rounded apex and bilobed posterior margin, extending to leading edge of nasal capsule; posterior fontanelle indistinct (not visible in radiographs and only detectable after staining and dissection), irregularly notched due to broad margin of acellular perichondrial tissue, fontanelle covered with dense fibrous connective tissue; basal fenestra kidney-shaped; anterior cerebral vein foramen antero-dorsal to optic nerve foramen and above orbito-nasal canal foramina; oculomotor nerve foramen dorsal to optic stalk; jugal arches weak; basal plate and internasal plate relatively narrow, about 28.7% and 12.5% of nasobasal length respectively.

Scapulocoracoid of female moderately short, longer than deep, tapering slightly posteriorly; lateral face expanded slightly between mesocondyle and metacondyle (fig. 5, Table 3); anterior bridge wide, thin, strongly depressed; anterior dorsal fenestra slightly larger than anterior ventral fenestra; scapular process elevated above antero-dorsal margin; anterior corner weakly angular, antero-lateral margin very slightly convex; rear corner not extended distally; mesocondyle slightly depressed; postdorsal fenestra moderately expanded, oval; 3 postventral foramina, central smallest.

Pelvic girdle with short prepelvic processes (fig. 6); iliac processes moderately well developed, strongly recurved; ischiopubic region relatively narrower in males than in females, with straight anterior margin in males and weakly convex margin in females, but with strongly concave posterior margins in both sexes; iliac region with 2–3 obturatorial foramina.

Claspers long, very slender, proximal to and not expanded at origin of glans (fig. 7); without dermal denticles or pseudosiphon; glans weakly depressed, moderately expandable. Inner dorsal lobe with pseudorhipidion extending from level of hypopyle and medial to slit, to about distal quarter of glans; continuing distally almost to glans margin as a fold of integument; lobe with deep cleft lateral to pseudorhipidion; slit proximal to cleft; spur and flag absent. Ventral lobe without shield; pela well developed, extending from level of hypopyle into distal half of glans; projection slightly curved laterally, extending for almost half length of glans from beneath pela to its pointed, naked distal tip near glans margin; spike disc-shaped with sharp, naked lateral and distal margins, ventral to projection, partly covered by sentina but disto-lateral margin visible. Axial cartilage with a slender conical tip; extending well beyond other cartilages (fig. 8). Dorsal marginal cartilage not expanded distally; with a truncate distal border (with the dorsal terminal 2 cartilage) and a long, slender, distomedial extension forming the pseudorhipidion. Dorsal terminal 1 cartilage relatively narrow and band-like with irregular anterior and posterior margins; located at about midlength of pela and enveloping axial cartilage. Dorsal terminal 2 cartilage rather broad, almost spatulate distally; connected to medial aspect of axial cartilage by well-developed terminal bridge and loosely connected to tip of axial by connective tissue. Ventral marginal cartilage not flared laterally at level of hypopyle; extending almost to distal margin of accessory terminal 2 (as component projection). Ventral terminal cartilage J-shaped; proximo-medial condyle articulating with ventral marginal cartilage, disto-medial extension articulating with tip of axial cartilage; inner limb seated near articulation of accessory terminal 2 and ventral marginal cartilages; acute proximal tip not forming component eperon; disto-lateral margin strongly curved inward and not forming component shield. Accessory terminal 1 cartilage lacking, possibly fused with ventral terminal cartilage to form component projection. Accessory terminal 2 cartilage with large disc-shaped distal extension forming component spike; articulating with postero-medial margin of ventral marginal cartilage.

Colour in preservative. Dorsal surface straw-coloured to pale greyish-yellow, minute melanophores scattered widely over most of surface; ventral surface whitish with translucent skin, palest near margins of disc, minute melanophores lightly scattered over tail. In life, paler, creamish to white above, pinkish over body cavity and head; eyes black; tail brilliant white; skin totally transparent ventrally, viscera distinct.

Size. A small skate attaining at least 448 mm TL and 222 mm disc width; males maturing larger than 360 mm TL.

Distribution. Known from the south-eastern Indian Ocean on the central western sector of the Australian continental slope (between Shark and Nickol Bays, Western Australia), in depths of 590–760 m. Apparent stenobathic and narrow geographic ranges may not be an artefact; trawl data from depths shallower and deeper, and in areas adjacent the geographic range, included other sympatric rajoid species, but excuded *N. hirticauda*.

Etymology. A combination of the Latin *hirtus* (rough or bristly) and *cauda* (tail) in allusion to the dense coverage of fine denticles on both surfaces of the tail. Known by the vernacular 'ghost skate'.

Remarks. *Notoraja hirticauda* fits the diagnosis of *Notoraja* as defined by Stehmann (1989) and McEachran and Last (1994), except that the tail is unusually thorny (compared to thorns absent or in a medial row in other *Notoraja* species), the rostral cartilage (including node) is distinctly longer than the nasobasal length (rather than about equal in length), and the rostral appendices are subtriangular posteriorly and abut the rostral shaft (rather than plate-like and running closely parallel to the shaft). *Notoraja hirticauda* is further distinguished from its nominal congeners *N. laxipella, N. ochroderma*, *N. subtilispinosa*, and *N. tobitukai*, in proportional measurements, lacking oronasal pits, coloration, and in some skeletal structures. Of these species, *Notoraja hirticauda* exhibits greatest overall similarity to *N. subtilispinosa*. It is also superficially similar to *N. laxipella* but has tail thorns (otherwise absent), a well-developed anterior bridge in the scapulocoracoid (rather than thin or absent), a robust terminal bridge in the clasper (rather than incomplete), and fewer precaudal vertebrae. The relatively long snout of *N. hirticauda* (preorbital snout length 12.4–13.7%) is more typical of *N. laxipella* (13.4–14.7% TL) than the other *Notoraja* species (10.8–12.5% TL). A longer snout is also evident from the prenasal length (10.1–11.0% vs. 8.9–10% TL in these other *Notoraja* species) and in the shape of the neurocranium (rostral cartilage length 125% in *N. hirticauda* vs. 88–92% of nasobasal length in *N. tobitukai* and *N. subtilispinosa*). *Notoraja ochroderma* has a relatively long rostral cartilage (ie. 104% of nasobasal length; McEachran and Last, 1994) but it is still much shorter than that of *N. hirticauda*. *Notoraja ochroderma* and *N. hirticauda* (combined orbit and spiracle lengths 3.5–4.7% TL), and *N. hirticauda* (4.2–5% TL), have smaller orbits and spiracles than *N. tobitukai* and *N. subtilispinosa* (5–5.7% TL).

Members of the genus *Notoraja* also exhibit significant interspecific variation in the mouth and tail sizes, the pelvic-fin shape, and the gill-slit size and interspacing. *Notoraja hirticauda* appears to have smaller gill slits (eg. first gill-slit width 0.8–1.2% vs. 1.2–1.5% TL) and narrower intergill distances (eg. width between first gill slits 10.4–11.7% vs. 11.5–13% TL) than *N. subtilispinosa*. The anterior pelvic-fin lobe varies greatly from slightly shorter in mature males (anterior 93–96% of posterior lobe) to slightly longer than the posterior lobe in most females (typically 104–110%) of *N. hirticauda*. The anterior lobe is subequal or longer in *N. subtilispinosa* and *N. tobitukai* (anterior 100–117% in posterior lobe) and shorter than the posterior lobe in *N. ochroderma* (anterior 76–90% in posterior lobe). *Notoraja hirticauda* and *N. tobitukai* (tail width at pelvic-fin tips 3.2–3.9% TL) have a slightly broader tail than *N. subtilispinosa* and *N. laxipella* (width at pelvic-fin tips 2.2–3.1% TL). The four *Notoraja* species appear to have larger mouths than *N. laxipella* (5.7–7.2 vs. 4.8–5.5).

The pectoral-fin radial and trunk vertebral counts of *N. hirticauda* closely resemble those of *N. subtilispinosa*, *N. tobitukai* and *N. laxipella* (ie. 24–27 and 61–67 for vertebral and radial counts respectively). Both counts are higher for *N. ochroderma* (30–32 and 87–89 for vertebral and radial counts respectively). Similarly, the scapulocoracoid of *N. hirticauda* is more similar to those of *N. subtilispinosa*, *N. tobitukai* and *N. laxipella* than to that of *N. ochroderma* which has a relatively more elongate scapulocoracoid with a very large, horizontally expanded post-dorsal fenestra. *Notoraja hirticauda* has three postventral foramina like female specimens of *N. subtilispinosa* and *N. laxipella* examined to date (four in *N. tobitukai* and five in *N. ochroderma*). The pelvic girdle of *N. hirticauda* most closely resembles that of *N. tobitukai*. In both species, the anterior contour of the ischiopubic bar is slightly convex and the prepelvic processes are short and rather robust. The prepelvic processes of *N. subtilispinosa* and *N. ochroderma* are much more slender and the anterior contour of the ischiopubic bar of the latter is straight (McEachran and Last, 1994). As discussed above, the neurocranium of *N. hirticauda*, like *N. laxipella*, has a relatively long rostral shaft and appendices compared to other species of *Notoraja* but the presence of jugal arches is shared by *N. laxipella* and all members of the genus except *N. ochroderma*.

The fontanelle structure of the neurocranium of *N. hirticauda* differs from the normal condition found in skates. A posterior fontanelle is well developed in most rajoids. Stehmann (1989) could not detect either anterior or posterior fontanelles in the neurocranium in radiographs of the holotype of *N. subtilispinosa*, and Ishihara and Stehmann (1990) observed only an anterior fontanelle in radiographs of a second specimen from Indonesia. Similarly, only the anterior fontanelle was detectable in X-rays of the neurocrania of *N. hirticauda* types, although an ill-defined, posterior aperture overlain with smooth uncalcified cartilage and dense connective tissue was evident from dissection. A similar, poorly-defined posterior fontanelle exits in *N. laxipella*. In comparison, the posterior fontanelles of other related Australasian skates (ie *Notoraja ochroderma*, *Irolita*, *Pavoraja* and *Brochiraja*) are sharply defined in radiographs (Last and McEachran, unpubl.).

The rostral appendices are considered to be important evolutionary characteristics (McEachran, 1984: McEachran and Miyake, 1990). Three *Notoraja* species (*N. tobitukai*, *N. subtilispinosa* and *N. ochroderma*) are considered to possess plate-like rostral appendices (Stehmann, 1989; McEachran and Last, 1994). These structures are thickened, almost triangular in cross-section distally in *N. hirticauda*, and more closely resemble the subconical appendices found in *N. laxipella* and *Brochiraja*. Further inspection of the neurocranium of *N. laxipella* revealed a relatively thinner, rostral cartilage separated slightly from its appendices (rather than continuously abutting them as in *N. hirticauda*).

The external form of the clasper of *N. hirticauda* is consistent with the general type found in *Brochiraja* and *Notoraja*, except for *N. ochroderma*, which has an eperon and a shield formed by the sharp proximal margin of the ventral terminal cartilage (McEachran and Last, 1994). The dorsal terminal 1 cartilage, small in *N. hirticauda*, is absent in *N. ochroderma* and sometimes absent in *N. tobitukai*. McEachran and Last (1994) suggested that the "rhipidion" of *Notoraja*, *Pavoraja* and *Irolita* is structurally different and probably not homologous with the rhipidion of Ishiyama (1958, 1967), Stehmann (1970) and Hulley (1972), that occurs in the majority of skate taxa in Group II (McEachran and Miyake, 1990). Ishiyama (1958, 1967) applied the terms pent and pela to this structure but since pent has been proposed for a separate component, the "rhipidion" of Group I should be called the pela to avoid further confusion.

Within *Notoraja*, only *N. ochroderma* and *N. hirticauda* are whitish on both dorsal and ventral surfaces. *N. ochroderma* possesses oronasal pits which are lacking in all other *Notoraja* species. The dorsal squamation of *N. hirticauda*, consisting of fine, erect but slightly recurved denticles, is similar to *N. subtilispinosa*, *N. ochroderma* and *N. laxipella*. Also, the tail of *N. hirticauda* and *N. ochroderma*, unlike the other two species, has irregular rows of small thorns. However, unlike *N. ochroderma*, the ventral surface of the tails of *N. hirticauda* and the other *Notoraja* species are covered in denticles.

Much of the pavorajine skate fauna of the Indo-Pacific remains undescribed. Within the known fauna, *N. hirticauda* appears to be much more similar to *N. subtilispinosa* and *N. laxipella* than either *N. ochroderma* or *N. tobitukai*, and the supraspecific structure of the *Notoraja* group needs further investigation. McEachran and Last (1994) noted that *N. ochroderma* did not fit the synapomorphy scheme of either *Notoraja* or *Pavoraja* but tentatively placed it in *Notoraja* as a conservative measure. Yearsley and Last (1992), who demonstrated similarities between the subgenus *Insentiraja* and *Notoraja*, temporarily placed the former in *Pavoraja* based on McEachran's earliest synapomorphy scheme (1984) and stressed the need for a review of Indo-Pacific pavorajines. A study of the relationships of Australian and New Zealand skates is now in progress by McEachran and Last (unpubl.).

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References

Hubbs, C. L. and Ishiyama, R. 1968. Methods for the taxonomic study and description of skates (Rajidae). *Copeia* 1968(3): 483–491.

Hulley, P. A. 1972. The origin, interrelationships and distribution of southern African Rajidae (Chondrichthyes, Batoidei). *Ann. S. Afr. Mus*. 60: 1–103.

Ishihara, H. and Stehmann, M. 1990. A second record of the deep-water skate *Notoraja subtilispinosa* from the Flores Sea, Indonesia. *Jap. J. Ichthyol*. 37: 182–186.

Ishiyama, R. 1958. Studies on the rajid fishes (Rajidae) found in the waters around Japan. *J. Shimonoseki Coll. Fish*. 7: 1–394.

Ishiyama, R. 1967. *Fauna Japonica: Rajidae (Pisces)*. Biogeographical Society of Japan: Tokyo, 84 pp.

Last, P. R. and McEachran J. D. 2006. New softnose skate genus *Brochiraja* from New Zealand (Rajidae: Arhynchobatinae) with description of four new species. *N. Z. J. Mar. Freshwater Res*. 40: 65-90.

Last, P. R. and Stevens, J. D. 1994. *Sharks and rays of Australia*. CSIRO: Melbourne, 513 pp.

Last, P. R. and Yearsley G. K. 2002. Zoogeography and relationships of Australasian skates (Chondrichthyes: Rajidae). *J. Biogeogr.* 29: 1627–41.

McEachran, J. D. 1984. Anatomical investigations of the New Zealand skates *Bathyraja asperula* and *B. spinifera*, with an evaluation of their classification within the Rajoidei (Chondrichthyes). *Copeia* 1984: 45–58.

McEachran, J. D. and Compagno, L. J. V. 1979. A further description of *Gurgesiella furvescens* with comments on the interrelationships of Gurgesiellidae and Pseudorajidae (Pisces, Rajoidei). *Bull. Mar. Sci*. 29: 530–553.

McEachran, J. D. and Compagno, L. J. V. 1982. Interrelationships of and within *Breviraja* based on anatomical structures (Pisces, Rajoidei). *Bull. Mar. Sci*. 32: 399–425.

McEachran, J. D. and Last, P. R. 1994. New species of skate, *Notoraja ochroderma*, from off Queensland, Australia, with comments on the taxonomic limits of *Notoraja*. (Chondrichthyes, Rajoidei). *Copeia* 1994: 413–421.

McEachran, J. D. and Miyake, T. 1990. Phylogenetic interrelationships of skates: a working hypothesis (Chondrichthyes: Rajoidei) in: Pratt Jr, H. L., Gruber, S. H. and Taniuchi, T. (eds). *Elasmobranchs as Living Resources: Advances in the Biology, Ecology, Systematics, and the Status of the Fisheries*. NOAA Technical Report 90.

McEachran, J. D. and Stehmann, M. 1984. A new species of skate, *Neoraja carolinensis*, from off the southeastern United States (Chondrichthyes, Rajoidei). *Proc. Biol. Soc. Wash*. 97: 724–735.

Stehmann, M. 1970. Vergleichend morphologische und anatomische Untersuchungen zur Neuordnung der Systematik der nordostatlantischen Rajidae. *Arch. Fischwiss*. 21: 73–164.

Stehmann, M. 1985. Ergebnisse der Forschungsreisen des FFS "Walther Herwig" nach Sudamerika. LXIV. *Bathyraja papilionifera* sp. n. (Pisces, Batoidea, Rajidae), eine weitere neue Rochenart aus dem Südwestatlantik vom nordargentinischen Kontinentalabhang. *Arch. Fischwiss*. 36: 195–211.

Stehmann, M. 1989. Resurrection of *Notoraja* Ishiyama, 1958 and description of a new species of deep-water skate from the South China Sea, *Notoraja subtilispinosa* sp. nov. (Pisces, Batoidea, Rajidae). *Mem. Mus. natn. Hist. nat*. (A)143: 247–260.

Yearsley, G. K and Last, P. R. 1992. *Pavoraja* (*Insentiraja*) *laxipella*, a new subgenus and species of skate (Chondrichthyes: Rajoidei) from the western Pacific. *Copeia* 1992: 839–850.