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FIRST RECORDS OF *NOTOTODARUS HAWAIIENSIS* (BERRY, 1912) (CEPHALOPODA: OMMASTREPHIDAE) FROM NORTHERN AUSTRALIA WITH A RECONSIDERATION OF THE IDENTITY OF *N. SLOANI PHILIPPINENSIS* VOSS, 1962

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Abstract

Dunning, M., 1988. First records of *Nototodarus hawaiiensis* (Berry, 1912) (Cephalopoda: Ommastrephidae) from northern Australia with a reconsideration of the identity of *N. sloani philippinensis* Voss, 1962. *Memoirs of the Museum of Victoria* 49: 159-168.

Nototodarus hawaiiensis (Berry, 1912) is reported for the first time from northern Australian continental slope waters and distribution and life history are discussed. Re-examination of the holotype of *N. sloani philippinensis* Voss, 1962 confirms that this subspecies is a junior synonym of *N. hawaiiensis* and that the paratype is referrable to *Todarodes pacificus* Steenstrup, 1880.

Introduction

Recent exploratory trawling for deep-water crustaceans in north-western and north-eastern Australian continental slope waters yielded significant numbers of a large ommastrephid squid, assigned to the genus *Nototodarus* Pfeffer, 1912 on the basis of the simple foveola in the funnel groove, absence of light organs and hectocotylization of both ventral arms in males. Additional specimens were identified from off the New South Wales coast in the collections of the Australian Museum, Sydney.

Brief review of the distribution of Nototodarus *species*

Six nominal forms of the genus *Nototodarus* have been described from continental shelf and slope waters of the Indo-Pacific region.

N. gouldi (McCoy, 1888) is the dominant squid in continental shelf waters of southern Australia. Its known distribution extends as far north as 27°S off the east coast and at least as far as 25°S off the west coast (Lu and Dunning, 1982). Berry (1918) provided a detailed morphological description of post-juvenile growth stages of this species.

N. hawaiiensis (Berry, 1912) has been reported from the Hawaiian and Midway Islands (Berry, 1912, 1914; Wormuth, 1976; Young, 1978), and the South China Sea (Dong, 1963). Its distribution throughout the island chains of the central Pacific remains unclear although Okutani and Kuroiwa (1985) tentatively assigned to this species specimens taken on jigs at a seamount off the coast of Chile.

N. nipponicus Okutani and Uemura, 1973 was described from jig-caught specimens from southern Honshu, Japan. *N. nipponicus* was characterised by "rough" skin, a very broad fin relative to mantle length and large fin angle. In a recent paper, Okutani and Kuroiwa (1985) considered *N. nipponicus* to be a junior synonym of *N. philippinensis*.

The identity of a fourth nominal species, *N. insignis* (Gould, 1852), described from "Feejee Islands; Antarctic Seas" remains to be clarified. Pfeffer (1912) erected the genus *Nototodarus* based on a single male specimen assigned to *Ommastrephes insignis* from the south-east coast of New Zealand. However, Gould's type specimen was not examined by Pfeffer. It has not been redescribed and its present location is unknown.

Names of the two (or according to some authors, three) forms of *Nototodarus* occurring in New Zealand waters are confused (Tung, 1977; Kawakami and Okutani, 1981; Smith et al., 1981). The nomenclature currently is being reviewed (R.H. Mattlin, pers. comm.), but the morphological characteristics of the dominant forms and their distributions are well defined (Smith, 1985). The form predominating off the north-west coast of new Zealand is morphologically identical to the southern Australian *N. gouldi*, with the form from the east coast of New Zealand referred to as *N.*

sloani (Gray, 1849) showing the characteristics clearly described and illustrated by Pfeffer (1912) for *N. insignis* (R.H. Mattlin, pers. comm.).

N. sloani philippinensis Voss, 1962 has been recorded from slope waters around the Philippines and Hong Kong (Voss, 1963; Voss and Williamson, 1971). Perera (1975) assigned squid specimens taken by jig from off Sri Lanka to this subspecies. However the sessile arm and tentacular club suckers illustrated in figure 10, p. 58, are characteristic of the subfamily Ommastrephinae rather than Todarodinae casting doubt on the validity of this identification.

Differences between *N. gouldi* and the form currently identified as *N. sloani* are clearly presented by Smith et al. (1981, Fig.2, p. 249) and Kawakami and Okutani (1981: 22-28, Fig. 1). With the exception of the structure of the hectocotylus, characters that separate *N. hawaiiensis* and *N. gouldi* were well described by Berry (1918: 242-243). However, morphological differences between *N. hawaiiensis* and *N. sloani philippinensis* remain unclear. In light of our recent understanding of morphological characters useful in separating species of the genus *Nototodarus* (Smith et al., 1981; R.H. Mattlin, pers. comm.; M.A. Roeleveld, pers. comm.), the types of these nominal species were re-examined for the present study.

Material examined

Specimens from northern Australian waters examined during this study were collected by the CSIRO Research Vessel "Soela" and New South Wales Fisheries RV "Kapala" with demersal fish and deep-water lobster trawls, the commercial trawlers FV "Craigmin" and FV "Iron Summer" with prawn trawls and from the Japanese RV "Hoyo-maru" No. 81 using a hand held scoop net. Collecting locations are shown in Figure 1 and details presented in Appendix 1.

The majority of measurements and indices used in this study follow Wormuth (1976). Counts of arm suckers were made using a binocular dissecting microscope and indices are expressed as a proportion of dorsal mantle length (ML) unless otherwise specified. Interpretation of tentacular club structure agrees with that proposed by Roeleveld (1982) and the criteria described in Dunning and Brandt (1985) were used to assess reproductive condition.

Results and discussion

Reconsideration of N. sloani philippinensis *Voss, 1962*

The structure of the hectocotylus has been shown to be of major taxonomic importance within the family Ommastrephidae and particularly within the genus *Nototodarus* (Adam, 1960; M.A. Roeleveld, pers. comm.). However, both *N. hawaiiensis* and *N. sloani philippinensis* were originally described from female specimens. Wormuth (1976) described the hectocotylus of *N. hawaiiensis*, but the form of the modification of the ventral arms of *N. philippinensis* has not been described in detail in the literature. The general description given by Voss and Williamson (1971: 70) is nonspecific, viz. "the left arm is modified only basally by the enlargement of the protective membrane supports. The right arm is modified similarly basally but on the distal half the suckers are modified into long papillae forming a comb-like structure."

Voss (1962) distinguished *N.sloani philippinensis* from *N. hawaiiensis* and *N. gouldi* (which he considered as subspecies of *N. sloani*) on the basis of the dentition of the arm and tentacular suckers. *N. sloani philippinensis* differs from the form from the east coast of New Zealand currently referred to as *Nototodarus sloani* (Kawakami and Okutani, 1981; Smith et al., 1981; R.H. Mattlin, pers. comm.) (Table 1). These differences are sufficiently significant to recognize *N. sloani* and *N. philippinensis* as distinct species.

Comparison of N. philippinensis *with* N. hawaiiensis

To clarify the morphological differences between them, the holotype and paratype of *N. philippinensis* and the holotype and one additional specimen of *N. hawaiiensis* described by Berry (1914) were re-examined (Table 2).

In the holotypes of both species, approximately 20 pairs of suckers are present on the right dorsolateral arms. Sucker rings in both progress from being almost smooth in row one through the development of slightly raised low ridges on the distal half in row two to separate conical teeth in row three, a single much larger medial tooth being flanked by three to four smaller teeth. Low ridges appear on row four which by row six are developed as low triangular rather than conical teeth. Largest suckers are in rows seven and eight and possess 19 to 21 teeth in both specimens. From these rows distally, the proximal triangular tooth margins of the rings begin to degenerate and the distal conical teeth become more equal in size. From row nine onward,

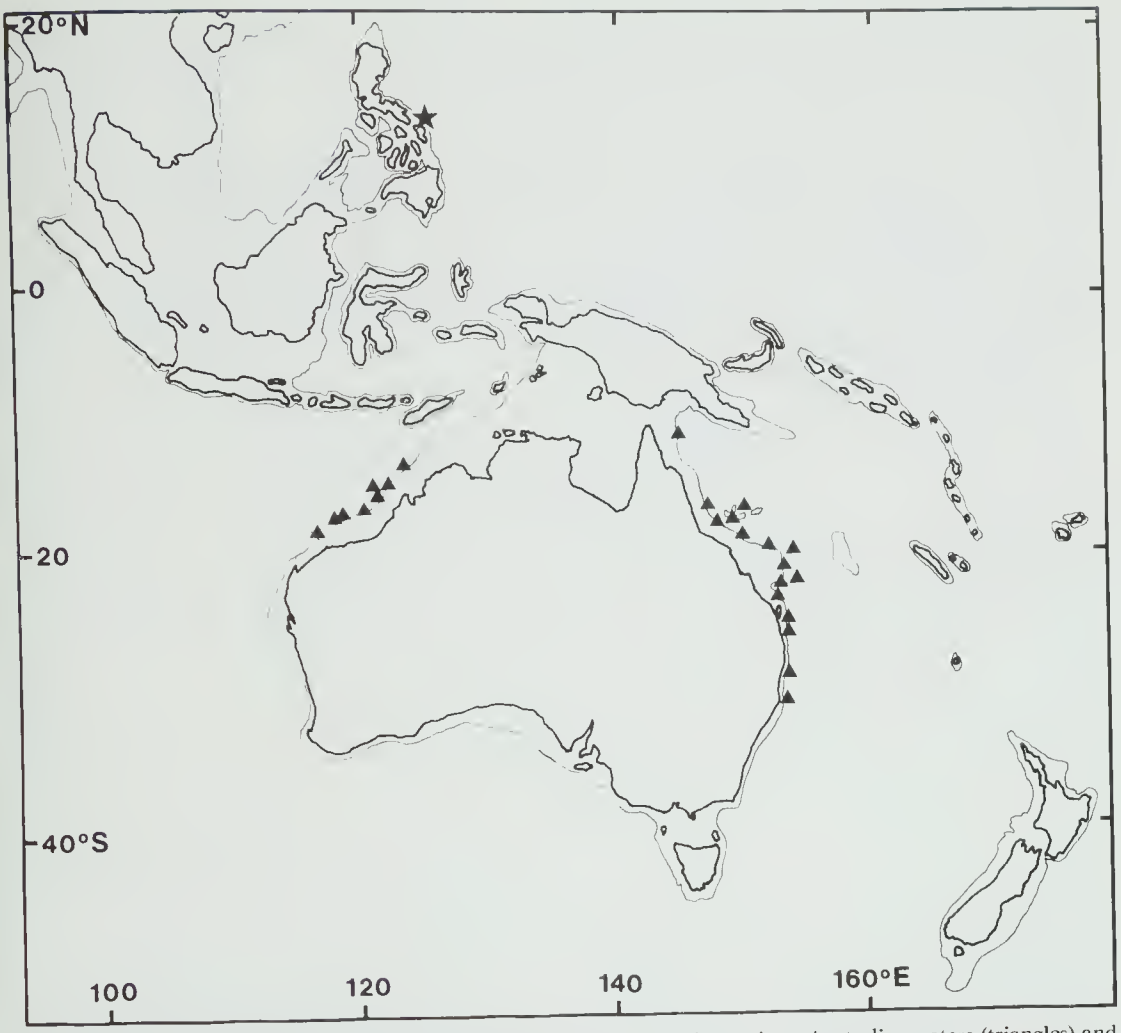

Figure 1. Capture localities of *Nototodarus hawaiiensis* (Berry, 1912) in northern Australian waters (triangles) and of the type specimen of *N. sloani philippinensis* Voss, 1962 (star) off the east coast of Luzon, Philippines.

only the conical teeth on the distal margin remain and curve more markedly inward.

Minute denticles interspersed among the distal teeth are rare and not consistently present even between the partners in an arm sucker row in the holotype of *N. hawaiiensis* and do not occur in the additional specimen examined (Berry No. 383; USNM 214617). (An additional specimen, Berry No. 248 (USNM 214632) is not a *Nototodarus*. Although poorly preserved, knobs of the fixing apparatus are evident on both tentacles and evidence exists of side pockets in the funnel groove. These characters place this specimen in the subfamily Ommastrephinae).

No differences between the holotypes are evident in the tentacular sucker dentition. Both have median manus sucker rings with 13 to 18 acutely pointed inwardly curved teeth, triangular proximally and more conical on the distal margin with a single much larger tooth distalmost. These teeth regularly alternate with low, wide curved plates in both specimens. Largest marginal manus suckers in each specimen have 19 to 21 equal pointed teeth alternating with small sometimes sharp denticles.

Sucker rings in the carpal region of the tentacles of both holotypes have an identical structure to those of the distal arm suckers. The sucker arrangement in both is left: 1,2,1 and right: 2,2,1;

Table 1. Measurements and counts for the holotype and paratype of *N. sloani philippinensis* Voss, 1962 and the holotype and an additional specimen (Berry No. 383) of *N. hawaiiensis* (Berry, 1912).

	Holotype *N. s. philippinensis* USNM 575451*	Paratype *N. s philippinensis* USNM 575452	Holotype *N. hawaiiensis* USNM 214382	Berry No. 383 *N. hawaiiensis* USNM 214617
ML (mm)	180	101	138	116
Sex	F	F	F	F
MWI	25	19	24	–
FLI	36	33	38	32
FWI	55	45	55	45
FA	52°	52	51°	–
HLI	24	19	20	28
HWI	28	20	27	24
IRAI	33	28	45	37
SR(IRA)I	2	1.4	2	2
ISC	19	16	19	19
HSC	21	19	18	20
SR(RT)I	3.3	2.4	3.4	3.0
CHI	47	31	–	–
MaSC (rows)	10	9	11	11
Arm Formula	3>2>1>4	2=3>1>4	2>3>1>4	2=3>1=4

* United States National Museum of Natural History.

Table 2. Morphological comparison of *Nototodarus sloani philippinensis* and *N. sloani*

	*N. sloani**	*N. philippinensis*†
Arm sucker count	>60	22
Head length index	<20	24
Head width index	<24	28
Arm I sucker index	<1.2	1.6
Tentacle sucker index	<2.5	3.3
Fin length index	>42	35.5
Arm and tentacular sucker teeth	approximately equal	single much larger tooth
Teeth largest medial manus sucker	12-15	14-18
Quadriserial rows of manus	12-13	10
Skin	"smooth"	"rough"

* Includes values from Kawakami and Okutani (1981) and Wormuth (1976).
† Values for the holotype.

the basic pattern in ommastrephids according to Roeleveld (1982). Voss' holotype has ten quadriserial manus rows and the holotype of *N. hawaiiensis* eleven. (Three specimens of *N. hawaiiensis* from Hawaiian waters had either ten or eleven manus rows.)

The paratype of *N. philippinensis* differs from the holotype as noted in the original description (viz. 18 to 20 equal conical teeth in the medial manus suckers compared with 14 to 18 with one much larger in the holotype; arm suckers without variation in tooth ring structure), the "rough" skin present in the holotypes of *N. philippinensis* and *N. hawaiiensis* (Figure 2) (also characteristic of *N. nipponicus*) is absent. Suckers of the arms and tentacles are proportionally smaller and mantle and fin proportions are different. I conclude that this specimen is referrable to *Todarodes pacificus* Steenstrup, 1880.

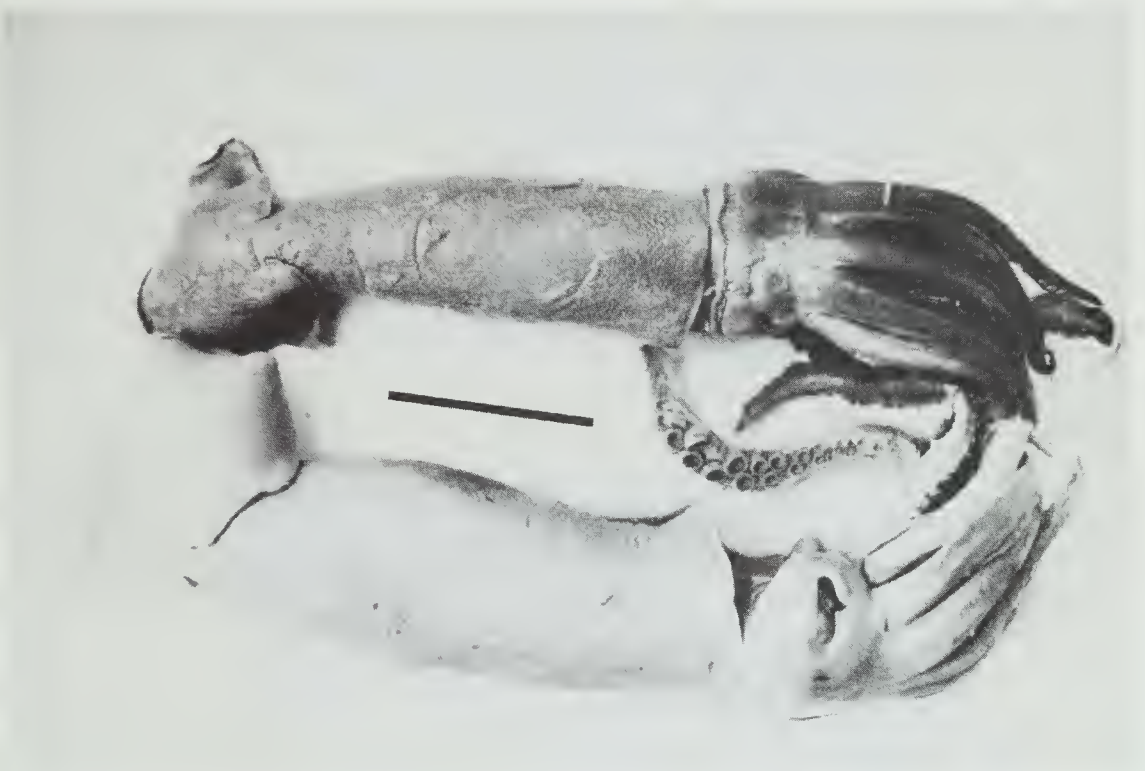

Figure 2. Holotypes of *Nototodarus sloani philippinensis* and *N. hawaiiensis* showing the "rough" skin of the mantle and head. (Scale = 50 mm)

I do not consider the morphological differences between the holotype of *N. philippinensis* and the holotype and an additional specimen of *N. hawaiiensis* examined by Berry (1914) sufficient to justify their separation into separate species. *N. philippinensis* Voss, 1962 therefore is a junior synonym of *N. hawaiiensis* (Berry, 1912).

These conclusions are summarised in the following synonymy:

?Ommastrephes sloanei.—Schauinsland, 1899: 92.

Ommastrephes sagittata near *sloanei.*—Berry, 1909: 418.

?Ommastostrephes sloanei sloanei.—Pfeffer, 1912: 458-9 (in part).

Ommastrephes hawaiiensis Berry, 1912: 434, 437.

Nototodarus sloani philippinensis Voss, 1962: 175.

Nototodarus sloani hawaiiensis.—Voss, 1962: 175.

Nototodarus hawaiiensis.—Wormuth, 1976: 2, 17-21, Fig. 3.

Northern Australian Nototodarus

Measurements and counts of representative specimens from northern Australian waters are compared with data from Table 1, from the literature for *N. hawaiiensis* and *N. gouldi* and from additional specimens from Hawaiian waters in Table 3. The form of hectocotylization in males was compared with that described by Wormuth (1976) for *N. hawaiiensis,* by Berry (1918) for *N. gouldi* and Smith et al. (1981) for *N. sloani.*

The northern Australian *Nototodarus* specimens differ from *N. gouldi* (McCoy, 1888), the common ommastrephid of southern continental shelf waters, and from the so-called *N. sloani* in the larger size of its head relative to mantle length, the smaller number of sucker rows on the sessile arms in specimens of similar size, the dentition of the suckers of the arms and tentacles and the structure of the hectocotylus in males as shown in Table 3 and Figure 3.

All specimens from northern Australian waters have "rough" skin both in the fresh as well as preserved specimens. This condition has not been observed by the author in several hundred fresh and

Table 3. Comparison of measurements and counts for *Nototodarus* specimens from northern Australian waters, New Zealand *N. sloani*, southern Australian and New Zealand *N. gouldi* and additional specimens of *N.hawaiiensis* from Hawaii

	N. hawaiiensis (Northern Australia)	*N. hawaiiensis*† (Hawaii)	*N. sloani**	*N. gouldi**
Arm I sucker count	21-28	19-27	>60	35-50
Head length index	19-28	23-31	<20	16-20
Head width index	23-30	21-30	<24	18-22
Arm I sucker index	1.7-2.2	1.5-2.3	<1.5	<1.5
Tentacle sucker index	3.0-3.7	2.8-3.6	<2.5	<3.0
Fin length index	35-43	35-40	>42	>40
Arm and tentacular sucker teeth	single much larger tooth	single much larger tooth	approximately equal	approximately equal
Teeth largest medial manus sucker	14-18	14-16	12-15	12-15
Quadriserial rows of manus	10-11	10-11	12-13	12-13
Skin	"rough"	"rough"	"smooth"	"smooth"
Hectocotylus				
Proximal sucker bases enlarged as cushions	≈4-5 pairs	≈4-5 pairs	≈10 pairs	≈5-6 pairs
Normal sucker rows	1-6	1-5	≈5	≈5
Ventral protective membrane	wide with attenuated supports to tip of arm	wide with attenuated supports to tip of arm	present only on distal ⅓ of arm	wide with attenuated supports to tip of arm
Ventral sucker bases	modified as thin papillae	modified as thin papillae	rapidly diminish in height distally	rapidly diminish in height distally
Dorsal sucker bases	modified as broad based papillae extending to tip of arm equal in length to ventral papillae	modified as broad based papillae extending to tip of arm equal in length to ventral papillae	modified as distally flattened papillae extending to tip of arm	modified as broad based papillae extending to tip of arm

† Synthesis of values from Wormuth (1976) and material examined for this study.
* Synthesis of values from Kawakami and Okutani (1981) and material examined for this study.

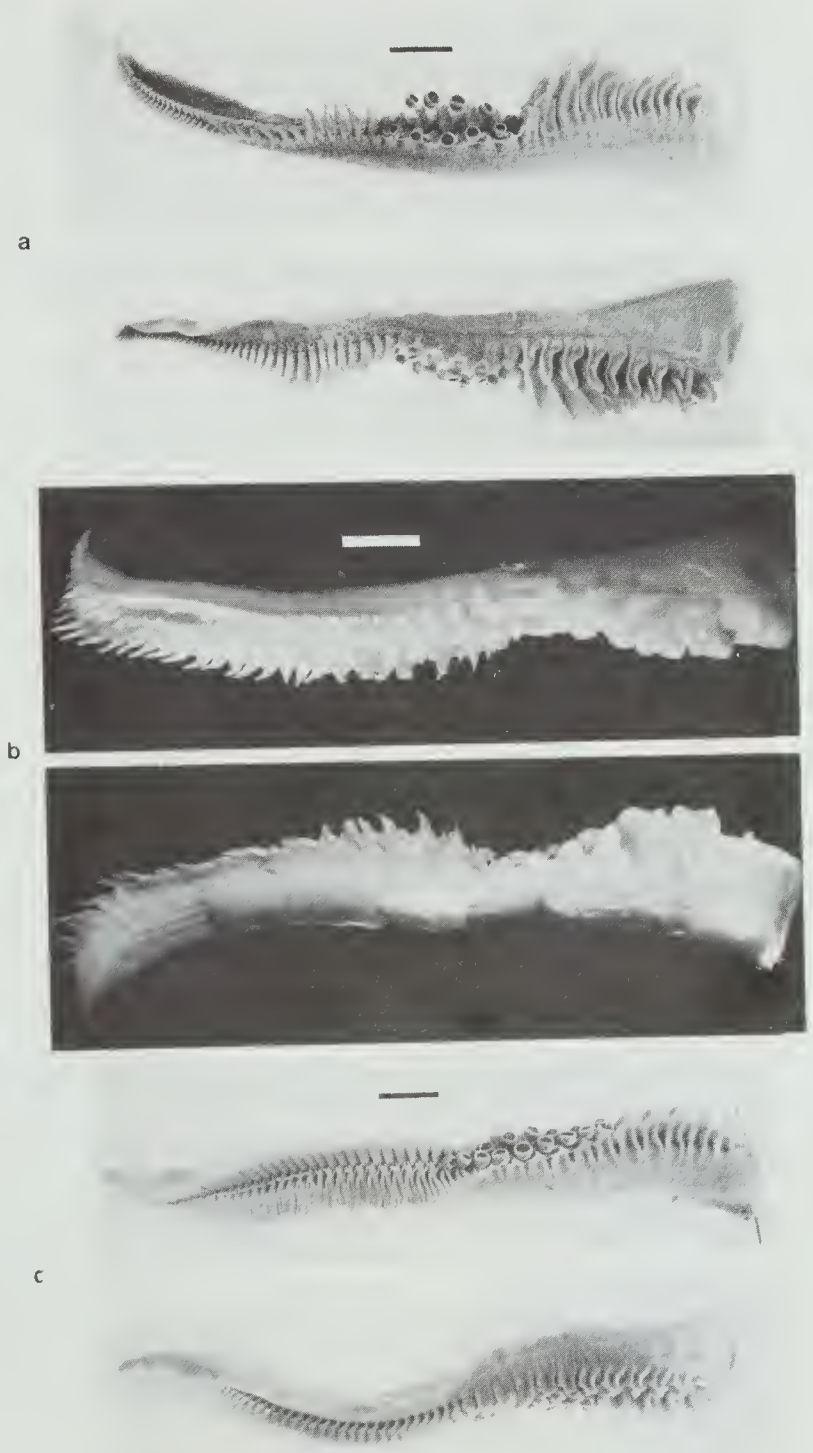

Figure 3. Right hectocotylized arms of a 256 mm ML male *Nototodarus sloani* from Taranaki Bight, central New Zealand (a), a 210 mm ML male *Nototodarus hawaiiensis* from off the northern Queensland coast (b) and a 266 mm ML male *Nototodarus gouldi* from off eastern Tasmania (c). Left ventral arms show a mirror reflection of the modified sucker bases seen on the proximal portion of the right arms in all species. (Scale = 10 mm)

preserved specimens of both *N. gouldi* and *N. sloani*, and represents a useful feature for rapid field identification. Regularly spaced thickenings in the dermis produce this "rough" texture.

On the basis of the size, number and dentition of arm and tentacular suckers (Figure 4), the structure of the hectocotylus in males and the "rough" texture of the skin, the northern Australian specimens are assigned to *N. hawaiiensis* (Berry, 1912).

Sexual dimorphism

While making measurements of the Australian *N. hawaiiensis* for the above morphometric comparisons, it became apparent that this species exhibits pronounced sexual dimorphism in body characteristics in larger specimens. A preliminary comparison of selected characters was undertaken for 25 males and 25 females between 120 and 231 mm ML trawled off the Great Barrier Reef in November 1985.

Larger head and arms, particularly of mature males are confirmed by significant differences in mean AIII length and head length indices (males: 66.9, 26.8 and females: 60.9, 23.7). No differences between males and females were found in fin proportions. (Mean fin length and fin width indices—males: 36.9, 60.6; females: 37.5, 61.1) [Mann-Whitney U-tests $p \geq 0.05$ (Siegel, 1956)].

Distribution and life history

The largest individuals of *N. hawaiiensis* examined were a fully mature female, 248 mm ML taken by demersal trawl in 376 m off the North-west Shelf in August 1982 and a mature male of 215 mm ML caught in 555 m off southern Queensland in May 1983. A 36 mm ML juvenile taken at night in a scoop net off Lady Elliot Island, southern Queensland in April 1981 was the smallest specimen examined. Off the north-western coast, this species was collected south to 19°20′S in depths of between 200 and 500 m in water temperatures of less than 12.4°C and off the east coast to 32°34′S in depths of 100 to 600 m.

Nototodarus hawaiiensis has been taken around Hawaii in shrimp trawls and occasionally on jigs over depths of from 230 to 710 m (Young, 1978; R. Harman, pers. comm.) and Dong (1963) examined specimens of up to 140 mm ML caught at a depth of 290 m off Hainan. The holotype of *N. sloani philippinensis* was trawled in 565 m in soft mud where the bottom temperature was 7.4°C (Voss, 1963). Around Hong Kong, *N. philippinensis* has been caught on the bottom in depths of 275 to 650 m, reaching a maximum size of 180 mm ML (Voss and Williamson, 1971).

Among Australian specimens of *N. hawaiiensis*, the smallest mature female was 154 mm ML and the smallest mature male 152 mm ML. Mature squid were present off both the north-west and north-east coasts at all times when samples were collected (Appendix 1) which, together with the broad size range of specimens in all samples indicates a prolonged spawning period in Australian waters. No significant size disparity was observed

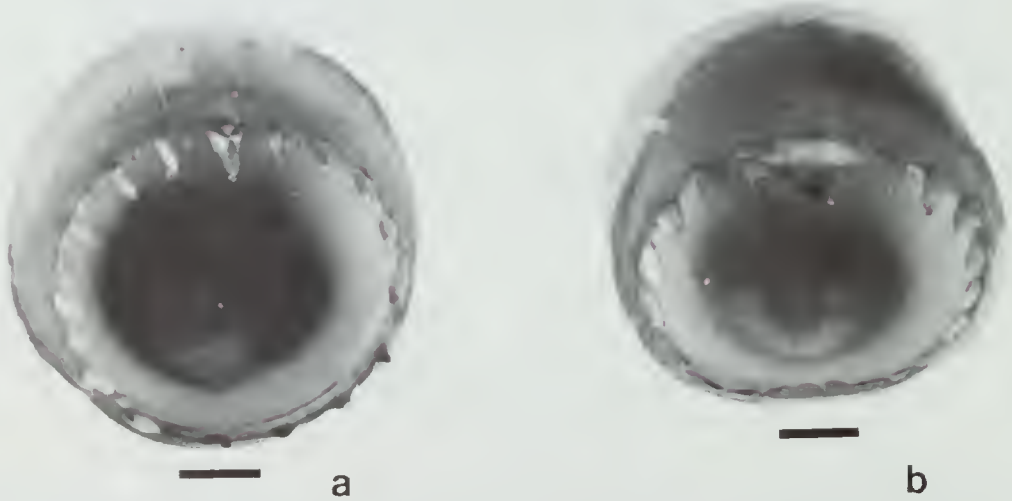

Figure 4. Arm III(a) and tentacular (b) suckers of a 205 mm female *Nototodarus hawaiiensis* from off northern Queensland. (Scale = 1 mm)

between females and males with an almost equal sex ratio evident in large samples (North-west Shelf, February 1983—60 females: 68 males; January 1984—314 females: 301 males).

In Hawaiian waters, male *N. hawaiiensis* reach maturity at less than 120 mm ML and females at less than 150 mm ML. Squid larger than 160 mm ML have not been reported in the literature from Hawaiian waters. Larvae of this species are present throughout the summer months (Harman and Young, 1986).

Off the eastern Australian coast between 28°S and 32°S, *N. hawaiiensis* and *N. gouldi* have been occasionally caught together on the upper continental slope and off the northern Queensland coast, the former species has been caught together with small numbers of *T. pacificus pusillus* (Dunning, 1988). The latter two species however are more abundant in shallower shelf waters. The distributions of *Todaropsis eblanae* (Ball, 1841) (Lu, 1982) and *N. hawaiiensis* show a major overlap in tropical Australian slope waters with *N. hawaiiensis* more abundant in all mixed samples I have examined.

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Appendix 1. Details of *Nototodarus* material examined. For each lot data for vessel, cruise number, date, latitude, longitude, depth range, size range in mm, museum and registration number are given in that order. Locations of material are as follows: NMV, Museum of Victoria, Melbourne; QM, Queensland Museum, Brisbane; AM, The Australian Museum, Sydney. For samples marked * only representative material was examined.

Northern Australian *Nototodarus*

"Soela", 2/82, Apr 1982, 18°-18°20′S, 118°20′E, 298-404 m, 83-157, NMV F51639 *

"Soela", 4/82, Aug 1982, 18°-18°46′S, 117°-118°30′E, 368-400 m, 53-248, QM Mo16363-4 *

"Soela", 1/83, Feb 1983, 17°41′S, 119°02′E, 318-360 m, 66-161, QM Mo16367*

"Soela", 2/83, Apr 1983, 18°30′-45′S, 117°19′-37′E, 340-400 m, 56-197,NMV F52539*

"Soela", 1/84 Jan-Feb, 1984, 13°17′-19°15′S, 115°38′-120°33′E, 224-600 m, 44-218, NMV F52541*

"Soela", 5/85, Nov-Dec 1985, 17°10′-23°13′S, 146°40′-154°25′E, 162-646 m, 55-231, NMV F52533-34*

"Iron Summer", Nov 1982-Jun 1983, 27°10′-27°20′S, 153°50-154°E, 180-600 m, 135-238, QM Mo16361-2*

"Hoyo-maru", Apr 1981, 23°58′S, 152°42′E, 120 m, 36, NMV F52531

"Craigmin", Nov 1980, 23°33′-26°S, 152°43′-153°53′E, 300-320 m, 79-157, NMV F52532*

"Kapala", Mar 1977, 37°25′S, 150′15′E, 329 m, 106, AMC 140403

"Kapala", Mar 1978, 32°34′S, 152°49′E, ~250 m, 77-85, AM C119659

"Kapala", Aug 1978, 29°32′S, 153°48′E, 410 m, 177-182, AM C137098

"Kapala", Feb 1979, 11°35′S, 144°02′E, 275 m, 94-102, AM C137097

"Kapala", Jul 1982, 29°54′S, 153°39′E, 274 m, 142, AM C135502

Nototodarus hawaiiensis

"Hokusei-maru", 7 Feb 1983, Off Hilo, Hawaiian Islands, depth not known, 116-156, NMV F52554

Nototodarus sloani

"Ryoun-maru", 18 Jan 1983, 39°56′S, 172°422′E, depth not known 256, NMV F52537

Nototodarus gouldi

"Hoyo-maru", 6 Apr 1981, 41°07′S, 148°29′E, 100 m, 266, QM Mo16368