Running headline: Rhinobatid and urolophid reproduction

Reproductive parameters of rhinobatid and urolophid batoids taken as bycatch in the Queensland (Australia) East Coast Otter Trawl Fishery

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ABSTRACT

Reproductive parameters are provided for batoids regularly taken as bycatch in the East Coast Otter Trawl Fishery on the inner-mid continental shelf off the south-east and central coasts of Queensland, Australia. Size-at-maturity (L_{T50} and 95% C.I.) for the eastern shovelnose ray *Aptychotrema rostrata* was 639.5 mm (617.6–663.4 mm) for females and 597.3 mm (551.4–648.6 mm) for males. Litter size (n = 9) ranged from 9–20 (mean ± S.E. = 15.1 ± 1.2). This species exhibited a positive litter size-maternal size relationship. Size-at-maturity (W_{D50} and 95% C.I.) for the common stingaree *Trygonoptera testacea* was 162.7 mm (155.8–168.5 mm) for females and 145.9 mm (140.2–150.2 mm) for males. Gravid *T. testacea* (n = 6) each carried a single egg in the one functional (left) uterus. Size-at-maturity (W_{D50} and 95% C.I.) for the Kapala stingaree *Urolophus kapalensis* was 153.7 mm (145.1–160.4 mm) for females and 155.2 mm (149.1–159.1 mm) for males. Gravid *U. kapalensis* (n = 16) each carried a single egg or embryo in the one functional (left) uterus. A single female yellowback stingaree *Urolophus sufflavus* carried an embryo in each uterus. A global review of the litter sizes of shovelnose rays (Rhinobatidae) and stingarees (Urolophidae) is provided.

Key words: *Aptychotrema rostrata*; litter size; *Trygonoptera testacea*; *Urolophus kapalensis*; *Urolophus sufflavus*

INTRODUCTION

The batoids (order Rajiformes) are a large and diverse assemblage of chondrichthyan fishes comprising 23 families (Compagno, 2005) yet biological and ecological information on most species is lacking or very limited. Such basic biological information is essential to understanding a species' productivity, and hence their vulnerability to fishing activities. This is of particular importance given concern surrounding long-term sustainability of batoid populations and threats facing batoids globally (Dulvy *et al.*, 2014). As most batoids inhabit benthic environments they are a regular bycatch of benthic trawl fisheries including within Australian prawn trawl fisheries such as the Northern Prawn Trawl Fishery (Stobutzki *et al.*, 2002) and the Queensland East Coast Otter Trawl Fishery (ECOTF) (Courtney *et al.*, 2006; 2008). In tropical Australia, these species are typically discarded as bycatch although batoids can make up a large proportion of the product sold for consumption in other areas, *e.g.* Indonesia (White & Dharmadi, 2007).

The Queensland ECOTF is Australia's largest prawn trawl fishery which primarily targets benthic prawns (*Penaeus* spp., *Melicertus* spp. and *Metapenaeus* spp.) and saucer scallops (*Amusium balloti*). The fishery operates over a large geographic area along the Queensland continental shelf, and is divided into 'sectors' based on key target species and location. Fishing effort, reported catch and the number of licensed vessels have declined significantly over the last decade for a combination of reasons including management arrangements (effort reduction schemes, spatial closures) and reduced rates of participation (Courtney *et al.*, 2014). Bycatch has likely declined as a result of decreased effort, as well as the mandatory use of bycatch reduction devices, in addition to turtle exclusion devices (see Courtney *et al.*, 2006; 2008; 2014). While turtle excluders in Australian prawn trawl fisheries have reduced the catch of larger batoids, smaller species and individuals are still regularly caught (Brewer *et al.*, 2006; Courtney *et al.*, 2008; 2014).

In southern sectors of the ECOTF (those fishing on the south-east and central Queensland continental shelf for eastern king prawn *Melicertus plebejus* and saucer scallop), three of the most commonly encountered chondrichthyans are the eastern shovelnose ray *Aptychotrema rostrata* (Shaw & Nodder, 1794), the common stingaree *Trygonoptera testacea* Banks, in Müller & Henle, 1841 and the Kapala stingaree *Urolophus kapalensis* Yearsley & Last, 2006 (Kyne *et al.*, unpublished data). These three species are all endemic to the continental shelf of eastern Australia (Last & Stevens, 2009). *Aptychotrema rostrata* is a common species of inshore and shelf waters of south-east Queensland, and is the most numerically abundant chondrichthyan in the bycatch of both the eastern king prawn (shallow water) sector and the scallop sector of the ECOTF (Kyne *et al.*, unpublished data). *Trygonoptera testacea* and *U. kapalensis* represent the second and third most common chondrichthyans, numerically, in the bycatch of the eastern king prawn (shallow water) sector, but are not recorded in the scallop sector as south-east Queensland represents the northern-most extent of their ranges (Last & Stevens, 2009; Kyne *et al.*, unpublished data). Seasonally, the ECOTF targets eastern king prawns in deeper waters (> 90 m) with a shift in the chondrichthyan bycatch community to species more representative of the outer shelf and upper slope environment (*e.g.* skates and catsharks) (Courtney *et al.*, 2014). Both *A. rostrata* and *U. kapalensis* also occur on these deeper trawl grounds, as does the yellowback stingaree *Urolophus sufflavus* Whitley, 1929; another batoid endemic to eastern Australia (Last & Stevens, 2009). The extent of interactions between *U. sufflavus* and the ECOTF is more restricted than the afore-mentioned species as *U. sufflavus* is at the northern extent of its range off south-east Queensland and generally occurs in deeper water (Last & Stevens, 2009).

Guitarfishes (family Rhinobatidae) and stingarees (family Urolophidae) are viviparous; rhinobatids are lecithotrophic, exhibiting aplacental yolk sacs, while urolopids are matrotrophic, exhibiting placental analogues in the form of histotrophe and trophonemata

(Conrath, 2005). Kyne & Bennett (2002) provided a review of the reproductive cycles and litter sizes of the rhinobatids, and White & Potter (2005) and Trinnie *et al.* (2014; 2015) review the reproductive biology of the urolophids. Rhinobatids produce one litter annually and have gestation periods ranging from 3–4 months in the banded guitarfish *Zapteryx exasperata* (Jordan & Gilbert, 1880) to 12 months in some *Rhinobatos* species (Lessa, 1982; Wenbin & Shuyuan, 1993; Villavicencio-Garayzar, 1995). Litter size within the Rhinobatidae is often positively correlated with maternal body size (*e.g.* Kyne & Bennett, 2002; Marshall *et al.*, 2007; Kume *et al.*, 2009; Rocha & Gadig, 2013) with a maximum of 24 reported from the blackchin guitarfish *Rhinobatos cemiculus* St. Hilaire, 1817 (Seck *et al.*, 2004). Urolophids reproduce annually or biennially with parturition occurring after a 5–19 month (regularly 10–11 month) gestation period (see Trinnie *et al.*, 2014; 2015). Maximum litter size in urolophids is typically < 6, but for several species is as low as 1–2 (see White & Potter, 2005; Trinnie *et al.*, 2014; 2015).

This paper provides information on reproductive parameters, including size-at-maturity, litter size and size-at-birth, of three Australian endemic batoids from the families Rhinobatidae (*A. rostrata*), and Urolophidae (*T. testacea* and *U. kapalensis*) that are taken as bycatch on the east coast of the Australia. The study addresses knowledge gaps in the basic biology of these three species, provides a global review of litter sizes of rhinobatids and urolophids, and includes the first litter size information for *U. sufflavaus*.

MATERIALS AND METHODS

Specimens were collected between February 2001 and February 2004 from the inner- to mid-continental shelf off the south-east and central coasts of Queensland (22°42′–28°00′S, 150°57′–153°47′E) (Fig. 1). Capture depth ranged: 7–110 m for *A. rostrata*; 21–82 m for *T. testacea*; 33–128 m for *Urolophus kapalensis*; and, 150 m for the single *U. sufflavus*. All specimens were collected during fishery-independent and fishery-dependent sampling of the ECOTF eastern king prawn and saucer scallop sectors. Specimens were collected by otter trawlers utilizing three or four 2-seam Florida Flyer nets with net body mesh size 50.8 or 88.9 mm; codend mesh size 44.5 or 88.9 mm; and, headrope lengths of 10.97, 12.81 or 21.96 m, depending on the fishery sector. Full descriptions of the fishing gears deployed are provided in Courtney *et al.* (2006; 2008; 2014).

Total length (L_T) was used as the primary size measurement for *A. rostrata* and disc width (W_D) for *T. testacea*, *U. kapalensis* and *U. sufflavus*. The sex ratio of each species was analysed using a χ^2-test. Maturity stages were assessed for male and female *A. rostrata* in accordance with Kyne & Bennett (2002). Maturity assessments for *T. testacea* and *U. kapalensis* were based on White *et al.* (2001). For all species, males were classed as immature (possessing short, flexible, uncalcified claspers) or mature (rigid, calcified and elongated claspers, testes developed and lobular, epididymides highly coiled). For *A. rostrata*, females were classed as immature (possessing undifferentiated ovaries, undeveloped oviducal glands, thin uteri) or mature (developed ovaries with yellow vitellogenic follicles ≥5 mm diameter, fully developed oviducal glands and uteri, uterine eggs or embryos may be present). For urolophids, females were classed as immature (possessing small ovaries, both uteri thin and flaccid) or mature (left ovary developed with yellow vitellogenic follicles ≥2 mm diameter, left uterus expanded and enlarged in comparison to the right uterus, eggs or embryos may be present in the left uterus).

The ovaries of all three species were examined for follicles and uteri examined for the presence and number of eggs or embryos. The size of embryos (L_T for *A. rostrata* and W_D for *T. testacea* and *U. kapalensis*) and the maximum follicle diameter (D_{Fmax}) were measured to the nearest 1 mm. As most specimens were collected during fishery-independent surveys in October 2001 (eastern king prawn sector) and October 2002 (scallop sector), it was not possible to examine seasonal trends in reproductive cycles for any species.

The size at 50% and 95% maturity (L_{T50} and L_{T95} for *A. rostrata*, and W_{D50} and W_{D95} for *T. testacea* and *U. kapalensis*), together with 95% confidence intervals (C.I.) was estimated for each sex by applying logistic regression analysis to the data for the maturity status and size of individuals. Application of this procedure followed White & Potter (2005). The proportion of mature individuals, *P*, at a given size (L_T and W_D, respectively) is estimated as:

and,

$$P = \left\{1 + \exp\left[-\log_e(19)\frac{(L_T - L_{T50})}{(L_{T95} - L_{T50})}\right]\right\}^{-1}$$

This is a reparameterised form of the logistic equation using the parameters L_{T50} and L_{T95} or W_{D50} and W_{D95} (White & Potter, 2005). The Microsoft Excel routine SOLVER was used to

$$P = \left\{1 + \exp\left[-\log_e(19)\frac{(W_D - W_{D50})}{(W_{D95} - W_{D50})}\right]\right\}^{-1}$$

obtain maximum-likelihood estimates of the parameters L_{T50} and L_{T95} or W_{D50} and W_{D95} within the equation. Bootstrapping was used to randomly resample the data, with the reported parameters being the median values (and the 2.5 and 97.5 percentiles in the case of the 95% confidence intervals) of 200 bootstrap runs.

RESULTS

APTYCHOTREMA ROSTRATA (SHAW & NODDER, 1794)

Of 414 *A. rostrata* collected (Table I), females had a smaller modal value, but reached larger sizes than did males (Fig. 2a). The female to male sex ratio of 0.90:1.00 did not differ significantly from the expected ratio of 1:1 (χ^2, d.f. = 1, $P = 0.28$).

The largest immature female was 614 mm L_T and the smallest mature female was 665 mm L_T. There were no specimens collected between these sizes. The L_{T50} and L_{T95} for females was

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639.5 mm (95% C.I.: 617.6–663.4 mm) (Fig. 3a) and 642.1 mm (95% C.I.: 621.3–667.0 mm), respectively. The largest immature male was 658 mm L_T and the smallest mature male was 562 mm L_T. The L_{T50} and L_{T95} for males was 597.3 mm (95% C.I.: 551.4–648.6 mm) (Fig. 3b) and 608.7 mm (95% C.I.: 559.2–660.9 mm), respectively.

Of the 23 mature females, 9 (684–800 mm L_T) were gravid. Litter size ranged from 9–20 with a mean (± S.E.) of 15.1 ± 1.2. All gravid females were collected in the month of October. Large pre-ovulatory sized follicles were observed in three females collected in September (D_{Fmax} = 28, 28, 30 mm). Data combined with that from Kyne & Bennett (2002) produced an updated litter size-maternal size relationship; litter size was significantly correlated with maternal size (L_T) ($R^2 = 0.594$, $P < 0.001$, $n = 25$). Litter size = -38.76 + (0.069L_T) (Fig. 4).

Intra-uterine embryos of *A. rostrata* (all collected in October) were 24–57 mm L_T, the largest of which still possessed a large yolk-sac and were thus far from near-term. An accurate assessment of size-at-birth could not be determined, but the five smallest free-swimming individuals were 168, 170, 176, 178 and 183 mm L_T, suggesting a size-at-birth of < 170 mm L_T.

TRYGONOPTERA TESTACEA BANKS, IN MÜLLER & HENLE, 1841

Of 303 *T. testacea* collected (Table I), males dominated the smaller size classes (< 170 mm W_D) and females the larger size classes (> 190 mm W_D) (Fig. 2b). The female to male sex ratio of 0.86:1.00 did not differ significantly from the expected ratio of 1:1 (χ^2, d.f. = 1, $P = 0.19$).

The largest immature female was 187 mm W_D and the smallest mature female was 145 mm W_D. The W_{D50} and W_{D95} for females was 162.7 mm (95% C.I.: 155.8–168.5 mm) (Fig. 3c) and 192.2 mm (95% C.I.: 177.9–202.9 mm), respectively. The largest immature male was 160 mm W_D and the smallest mature male was 128 mm W_D. The W_{D50} and W_{D95} for males was 145.9

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mm (95% C.I.: 140.2–150.2 mm) (Fig. 3d) and 170.7 mm (95% C.I.: 164.8–177.5 mm), respectively.

Of the 82 mature females, 6 (198–270 mm W_D) were gravid. In each instance, a single egg was found in the left uterus. One non-gravid mature female possessed two large pre-ovulatory follicles (D_{Fmax} = 18 and 19 mm), suggesting that the species may be capable of carrying two embryos simultaneously. All other non-gravid mature females with large pre-ovulatory follicles (n = 5) (D_{Fmax} = 27 mm) had only a single large follicle.

While no embryos were observed from mature females, numerous small, free-swimming individuals (77–120 mm W_D), considered be to neonates, were caught in the trawls. Several of these (77, 78, 79, 83, 89 and 100 mm W_D) possessed internal yolk-sacs and were likely to be recently-pupped; size-at-birth was estimated to be between 77 and 100 mm W_D.

UROLOPHUS KAPALENSIS YEARSLEY & LAST, 2006

Of 100 *U. kapalensis* collected (Table I), females dominated almost all size classes (Fig. 2c). The female to male sex ratio of 1.00:0.30 differed significantly from the expected ratio of 1:1 (χ^2, d.f. = 1, $P < 0.001$).

The largest immature female was 167 mm W_D and the smallest mature female was 142 mm W_D. The W_{D50} and W_{D95} of females was 153.7 mm (95% C.I.: 145.1–160.4 mm) (Fig. 3e) and 168.6 mm (95% C.I.: 160.7–175.2 mm), respectively. The largest immature male was 162 mm W_D and the smallest mature male was 150 mm W_D. The W_{D50} and W_{D95} of males was 155.2 mm (95% C.I.: 149.1–159.1 mm) (Fig. 3f) and 164.1 mm (95% C.I.: 157.1–176.1 mm), respectively.

Of the 62 mature females, 16 (155–220 mm W_D) were gravid, with a single egg or embryo found in the left uterus. All gravid females were collected in October. Five non-gravid mature females each possessed two larger ovarian follicles (≥ 10 mm diameter; D_{Fmax} = 17 mm), suggesting that the species may be capable of carrying two embryos simultaneously. All other non-gravid mature females possessing larger follicles (n = 10) (D_{Fmax} = 17 mm) had only a single large follicle.

Uterine contents were observed in various stages of development. Seven gravid females carried a single egg with no discernible embryos, three females carried embryos in mid-stages of development (27, 38, 48 mm W_{D}), one female carried an embryo in a mid-late stage of development (64 mm W_{D}), and four females carried near-term embryos (75, 78, 78, 85 mm W_{D}). One additional female aborted a near-term embryo of 76 mm W_{D} and a second near-term embryo of 80 mm W_{D} (aborted from an unknown female) was found during catch sorting on board the trawler. The largest embryo thus observed was 85 mm W_{D}. The smallest free-swimming individuals caught were 97, 100 and 105 mm W_{D}; size-at-birth was estimated to be between 75 and 100 mm W_{D}.

UROLOPHUS SUFFLAVUS WHITLEY, 1929

A single female *U. sufflavus* of 180 mm W_{D} was collected. This individual, collected in July, was mature and gravid, with one early-stage embryo (21–23 mm L_{T}) in each uterus; pectoral fins had not yet formed and so W_{D} could not be measured.

DISCUSSION

This study provides an assessment of reproductive parameters for three batoid species that are common components of the Queensland ECOTF bycatch. It is the first study to provide such information for *U. kapalensis*, and expands on that previously published for *A. rostrata* from south-east Queensland (Moreton Bay; Kyne & Bennett, 2002) and for *T. testacea* from the central coast of New South Wales (van der Broek *et al.*, 2011). New, albeit limited information is also presented on the reproductive biology of *U. sufflavus.*

Aptychotrema rostrata displays a seasonal reproductive cycle with gravid females recorded in Moreton Bay from September to November (Kyne & Bennett, 2002). Females collected in October from the ECOTF bycatch had embryos in early-mid stages of development (24–57 mm L_T), which is in agreement with the period of pregnancy identified for the species in Moreton Bay. The capture of non-gravid mature females with large pre-ovulatory follicles in their ovaries in September also corresponds with the timing of ovulation (July–September) postulated by Kyne & Bennett (2002). While the gestation period of the species was estimated to be 3–5 months by Kyne & Bennett (2002), this estimate cannot be refined here with the data collected from specimens taken in the ECOTF.

Size-at-maturity for *A. rostrata* from Moreton Bay was previously reported as 540–660 mm L_T for females and 600–680 mm L_T for males (Kyne & Bennett, 2002). The L_{T50} values of 639.5 mm for females and 597.3 mm for males obtained here provide more robust estimates of size-at-maturity for the species. However, the female estimate could be further refined with additional sampling of individuals between the largest immature specimen (614 mm L_T) and the smallest mature specimen (665 mm L_T).

The mean litter size for *A. rostrata* was considerably larger than that reported by Kyne & Bennett (2002) (15.1 ± 1.2 *v*. 7.9 ± 0.9). In addition, the maximum litter size reported by Kyne & Bennett (2002) was 18, while maximum litter size in the present study was 20 (Table II). This species displays a positive relationship between litter size and maternal size (Fig. 4), and the higher mean litter size reported here is likely attributable to the predominance of larger gravid females; the mean size of gravid females examined by Kyne & Bennett (2002) was 699.3 ± 14.7 mm L_T (n = 16), whereas in the present sampling mean size was 738.3 ± 14.3 mm L_T (n = 9).

Broader comparisons of rhinobatid species showed that litter sizes within species is variable (Table II). This variation may be partially explained by the positive correlation between litter size and maternal size that many species display, including common guitarfish *Rhinobatos rhinobatos* (L. 1758) (Enajjar *et al.*, 2008), ringstraked guitarfish *Rhinobatos hynnicephalus* Richardson, 1846 (Wenbin & Shuyuan, 1993; Kume *et al.*, 2009) and southern fiddler ray *Trygonorrhina dumerilii* Castelnau, 1873 (Marshall *et al.*, 2007). Combining the litter size results from this study with data reported in Kyne & Bennett (2002), *A. rostrata* bears litters of 4–20 young (mean = 10.5 ± 1.0; n = 25), with the upper end of this range amongst the highest reported for any rhinobatid species (Table II).

An accurate estimate of size-at-birth remains unavailable for *A. rostrata*. Kyne (2000) estimated 130–150 mm L_T based on a comparison of *A. rostrata* embryo and yolk sac sizes with published accounts of the similarly-sized Atlantic guitarfish *Rhinobatos lentiginosus* Garman, 1880 (Hensley *et al.*, 1998), but cautioned that this was a preliminary estimate at best. The largest embryos recorded by Kyne (2000) were 105 mm L_T, but these retained large external yolk sacs. Embryos recorded in the present study were smaller (to 57 mm L_T), and as such provide no assistance in estimating size-at-birth. There were however, several free-swimming neonates captured and from the size of these animals, size-at-birth is suggested to be < 170 mm L_T.

Previous studies of the reproductive biology of urolophid batoids have shown that the majority have annual reproductive cycles with long gestation periods of 10–12 months (White *et al.*, 2001; 2002; White & Potter, 2005; Trinnie *et al.*, 2014; 2015). Biennial reproductive periodicity has however been reported in the sandyback stingaree *U. bucculentus* Macleay, 1884 (Trinnie *et al.*, 2012), banded stingaree *U. cruciatus* (Lacépède, 1804) (Trinnie, 2013) and spotted stingaree *U. gigas* Scott, 1954 (Trinnie *et al.*, 2014). The timing of reproductive events within the Urolophidae appears to vary both with respect to location and genus (Trinnie *et al.*, 2014). Off south-west Australia, *Trygonoptera* species typically give birth in mid-autumn to early winter (April-June), and *Urolophus* species in late spring/early summer

(October-December) (White & Potter, 2005). Trinnie *et al*. (2012) however suggests parturition during autumn (April–May) for *U. bucculentus* and *U. cruciatus* in south-east Australia. This could be attributed to these two species having biennial reproductive periodicity (Trinnie *et al*., 2012).

In the current study, all gravid *U. kapalensis* were collected during a 10-day period in mid-spring (October), and showed considerable variation in the stages of uterine development (*i.e.* from eggs with no visual embryos through to mid-late and near-term embryos). Neonate individuals were also collected at the same time, along with females without uterine contents but with large ovarian follicles. As specimens came from a short collection period, it was not possible to determine reproductive cycle characteristics for the species, although the parturition period for *U. kapalensis* may begin in spring (September-November) (as evidenced by near-term embryos and neonates) and last several months into summer (December-February) (as evidenced by smaller embryos observed in October). Given embryonic growth patterns recorded by White & Potter (2005) for the sparsely-spotted stingaree *U. paucimaculatus* Dixon, 1969, the smaller developing *U. kapalensis* embryos observed here in mid-spring could conceivably grow to term size by mid-summer. Females bearing only eggs without embryos may represent the following year's cohort of neonates. The examined uteri of gravid *T. testacea* carried only eggs with no visible embryos; thus it is not possible to speculate on this species' reproductive cycle. However, a number of neonate *T. testacea* (from 77 mm W_{D}), some with internal yolk sacs, were sampled in January (mid-summer), suggesting parturition in summer. This is earlier than the timing of parturition for *Trygonoptera* species off south-west Australia (March-June; White *et al.*, 2002; Trinnie *et al.*, 2009), although van den Broek *et al.* (2011) postulated a parturition period of February to April for *T. testacea* off New South Wales.

Litter sizes in urolophids are lower than rhinobatids with a maximum of 1–2 for several species (Table III). Litter sizes recorded here for *T. testacea* (1), *U. kapalensis* (1) and *U.*

sufflavus (2) are consistent with species from south-west Australia (White *et al.*, 2001; 2002; White & Potter, 2005). For these south-west Australian species, litter size was most often 1, and only occasionally 2 (*i.e.* mean litter sizes: western shovelnose stingaree *T. mucosa* (Whitley, 1939), 1.3 ± 0.10; masked stingaree *T. personata* Last & Gomon, 1987, 1.2 ± 0.12; lobed stingaree *U. lobatus* McKay, 1966, 1.3 ± 0.30; *U. paucimaculatus* 1.06 ± 0.05) (White *et al.*, 2001; 2002; White & Potter, 2005). Larger maximum litter sizes have been reported for several species off south-east Australia, including 6–7 for the eastern shovelnose stingaree *Trygonoptera imitata* Yearsley, Last & Gomon, 2008 (Trinnie *et al.*, 2009) and 11–13 for *U. gigas* (Trinnie *et al.*, 2014). For *U. paucimaculatus*, Trinnie *et al.* (2014) reported maximum litter sizes of 4–5 and 5–6 off two different regions of south-east Australia, while White & Potter (2005) reported 1–2 off south-west Australia, highlighting a general trend of higher litter sizes in urolophids off south-east Australia compared to south-west Australia (Trinnie *et al.*, 2014). White *et al.* (2001) demonstrated that in *U. lobatus* off south-west Australia, litter size declined during pregnancy, apparently due to embryos being aborted during the gestation period. Litter size declined from 2–6 embryos for early-term pregnancies, 1–4 for mid-term to 1–2 for late-term (White *et al.*, 2001). Trinnie *et al.* (2014) however, report that observations from south-east Australian urolophids show similar litter sizes during early and late-term, and as such, the higher reported litter sizes in that region are considered accurate by those authors.

White & Potter (2005) explained the small litter sizes of urolophids by the fact that they reach around 35–50% of their asymptotic disc width before birth. Such a large size-at-birth, relative to adult body size, is presumably advantageous for increasing juvenile survivorship, but limits litter size due to the morphological constraints of the maternal body. The largest *U. kapalensis* embryo observed (85 mm W_D) was 39% of the maximum size of the species collected during the present study (220 mm W_D), or 27% of the reported maximum size of the species (312 mm W_D; Yearsley & Last, 2006). By comparison, if a size-at-birth of 170 mm L_T

is assumed for *A. rostrata* (this is probably an overestimate), this represents 20% of maximum size observed in the present study (852 mm L_T), or 14% of the reported maximum size of the species (1200 mm L_T; Last & Stevens, 2009).

Gravid urolophids are known to readily abort their embryos upon capture (White *et al.*, 2001; *U. kapalensis* in the present study). Urolophids are common components of trawl bycatch where their range overlaps with that of fishing operations, including the eastern king prawn sector of the ECOTF, upper-mid slope trawl fisheries off New South Wales (Graham *et al.*, 2001) and demersal trawl fisheries off south-west Australia (Laurenson *et al.*, 1993). Even if trawl-caught stingarees are released alive, the induced embryonic mortality from abortion has the potential to reduce individual reproductive output. Evidently, this is an area of research that requires further investigation, not only for stingaree species but for batoids more generally.

K-selected reproductive parameters (*i.e.* low fecundity, long gestation period) have been demonstrated for many urolophid species (see White & Potter, 2005; Trinnie *et al.*, 2014; 2015; Table III). Despite these life history limitations on productivity, combined with their abortive behaviour, White & Potter (2005) commented that it was encouraging to see that large numbers of mature stingarees of all four species in their study off south-west Australia remained prevalent. In contrast, on the New South Wales upper continental slope Trawl surveys undertaken in 1976–77 and repeated in 1996–97 showed an overall decline in the catch rate of stingarees (four species of *Urolophus*) of 65.6%, while declines on individual trawl grounds were as high as 90.5% (Graham *et al.*, 2001). As these declines in stingaree catch rates may be attributable to a long history of trawling, it is recommended that stingaree catch rates be monitored in the ECOTF, particularly for the rarer *U. kapalensis*.

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TABLE I. Sample sizes, size ranges and mass ranges for *Aptychotrema rostrata*, *Trygonoptera testacea* and *Urolophus kapalensis* captured as bycatch in the Queensland East Coast Otter Trawl Fishery

Species	Total *n*	♀	♂	Size range (mean ± S.E.) mm L_T (*A. rostrata*) mm W_D (urolophids)	Mass range (mean ± S.E.) g
Aptychotrema rostrata	414	196	218	♀: 176–852 (465.3 ± 10.0)	♀: 19–2300 (435.7 ± 34.3)
				♂: 168–790 (470.5 ± 9.2)	♂: 15–1418 (396.5 ± 21.4)
Trygonoptera testacea	303	140	163	♀: 77–270 (170.6 ± 4.2)	♀: 13–942 (274.5 ± 17.8)
				♂: 78–222 (147.2 ± 2.5)	♂: 13–469 (147.7 ± 7.1)
Urolophus kapalensis	100	77	23	♀: 97–220 (170.5 ± 2.8)	♀: 30–463 (216.4 ± 9.5)
				♂: 126–203 (154.7 ± 3.3)	♂: 57–308 (141.9 ± 10.5)

L_T, total length; W_D, disc width.

568 TABLE II. Litter sizes for species of the family Rhinobatidae

Species	Location	Litter size		Source
		Range	Mean (± S.E. or S.D.)	
Aptychotrema rostrata	Moreton Bay, Queensland, Australia	4–18	7.9 ± 0.9 (± S.E.)	Kyne & Bennett 2002
	South-east/central Queensland, Australia	9–20	15.1 ± 1.2 (± S.E.)	This study
Aptychotrema vincentiana	Southern Australia	14–16	--	Haacke 1885
Glaucostegus granulatus	Madras, India	6–10	--	Prasad 1951
Glaucostegus typus	Captivity	11*	--	Timm *et al.* 2014
Rhinobatos cemiculus	Tunisia	5–8	7	Capapé *et al.* 1976
	Gulf of Gabès, southern Tunisia	5–12	7.52	Capapé & Zaouali 1994
	Cape Verde, Senegal	16–24	--	Seck *et al.* 2004
Rhinobatos horkelii	Rio Grande do Sul, Brazil	3–9	--	Lessa 1982
	Rio Grande do Sul, Brazil	4–12	--	Lessa *et al.* 1986
Rhinobatos hynnicephalus	Xiamen, Fujian, China	2–9	4.6	Wenbin & Shuyuan 1993
	Ariake Bay, Japan	1–9	4.4	Kume *et al.* 2009
Rhinobatos jimbaranensis	Eastern Indonesia	6–11	--	White & Dharmadi 2007
Rhinobatos lentiginosus	South Carolina, USA	5*	--	Jordan & Gilbert 1883
	Western North Atlantic	6*	--	Bigelow & Schroeder 1953
	Gulf of Mexico, USA	--	6.6 ± 0.557 (± S.E.)	Hensley *et al.* 1998
Rhinobatos leucorhynchus	Pacific Colombia	1–6	3.45 ± 1.15 (± S.D.)	Payán *et al.* 2011
	Pacific Ecuador	1–7	2.5 ± 1.5 (±S.D.)	Romero-Caicedo & Carrera-Fernández 2015
Rhinobatos penggali	Eastern Indonesia	2–13	--	White & Dharmadi 2007
Rhinobatos percellens	Santa Marta, Caribbean Colombia	2–4	--	Grijalba-Bendeck *et al.* 2008
	São Paulo, Brazil	2–13	5 ± 4 (± S.D.)	Rocha & Gadig 2013
	Isla de Margarita, Nueva Esparta, Venezuela	4^	--	Tagliafico *et al.* 2013
Rhinobatos productus	Bahía Almejas, Baja California Sur, Mexico	6–16	9	Villavicencio-Garayzar 1993
	Long Beach, California, USA	--	9	Timmons & Bray 1997
	Sonora, Gulf of California, Mexico	1–10	5 ± 2.24 (± S.D.)	Márquez-Farías 2007
Rhinobatos rhinobatos	Tunisia	4–6	5.3	Capapé *et al.* 1976
	Alexandria, Egypt	8–14	12	Abdel-Aziz *et al.* 1993
	Gulf of Gabès, southern Tunisia	6–8	--	Capapé *et al.* 1997
	Gulf of Gabès, southern Tunisia	1–13	5.34 ± 0.37#	Enajjar *et al.* 2008
Rhinobatos schlegelii	Penghu Islands, Taiwan	1–14	8.5 ± 4.8 (± S.D.)	Schluessel *et al.* 2015
Trygonorrhina dumerilii	Southern Australia	4–6	--	Haacke 1885
	Western Australia, Australia	2–5	3 ± 0.3 (± S.E.)	Marshall *et al.* 2007
	South Australia, Australia	4–7	5.33 ± 1.53 (± S.D.)	Izzo & Gillanders 2008
Zapteryx brevirostris	Rio de Janeiro, Brazil	1–6	--	Batista 1991

	São Francisco do Sul, Santa Catarina, Brazil	4–9	--	Abilhoa *et al.* 2007
	Uruguay/northern Argentina	3–6	3.8 ± 0.7 (± S.D.)	Colonello *et al.* 2011
Zapteryx exasperata	Bahía Almejas, Baja California Sur, Mexico	4–11	--	Villavicencio-Garayzar 1995
	Sonora, Gulf of California, Mexico	2–13	7 ± 3 (± S.D.)	Blanco-Parra *et al.* 2009
Zapteryx xyster	Pacific Costa Rica	1–8	--	Clarke *et al.* 2014

*Only one gravid female examined
^Only the maximum provided
#Not specified if S.E. or S.D.

TABLE III. Litter sizes for species of the family Urolophidae. All locations are in Australia

Species	Location	Litter Size		Source
		Range	Mean (± S.E.)	
Trygonoptera imitata	Victoria	1–7	--	Trinnie *et al*. 2009
Trygonoptera mucosa	Southern Western Australia	1–2	1.1 ± 0.10	White *et al*. 2002
Trygonoptera personata	Southern Western Australia	1–2	1.2 ± 0.12	White *et al.* 2002
Trygonoptera testacea	Off Newcastle, New South Wales	2*	--	van den Broek *et al.* 2011
	South-east Queensland	1	1.0	This study
Urolophus bucculentus	Victoria	1–5	--	Trinnie *et al.* 2012
Urolophus cruciatus	South-west Victoria	2	--	Treloar & Laurenson 2005
	Victoria	4	--	Trinnie *et al.* 2009^
Urolophus gigas	Victoria	11–13	--	Trinnie *et al.* 2014^
Urolophus kapalensis	South-east Queensland	1	1.0	This study
Urolophus lobatus	Southern Western Australia	1–6	#	White *et al.* 2001
Urolophus paucimaculatus	Port Phillip Bay, Victoria	2–6	--	Edwards 1980
	Southern Western Australia	1–2	1.06 ± 0.05	White & Potter 2005
	Victoria	1–6	--	Trinnie *et al.* 2014
Urolophus sufflavus	South-east Queensland	2*	--	This study
Urolophus virdis	Victoria	1–3	--	Trinnie *et al.* 2015

*Only one gravid female examined
^Referenced by authors as unpublished data
#Refer to Discussion

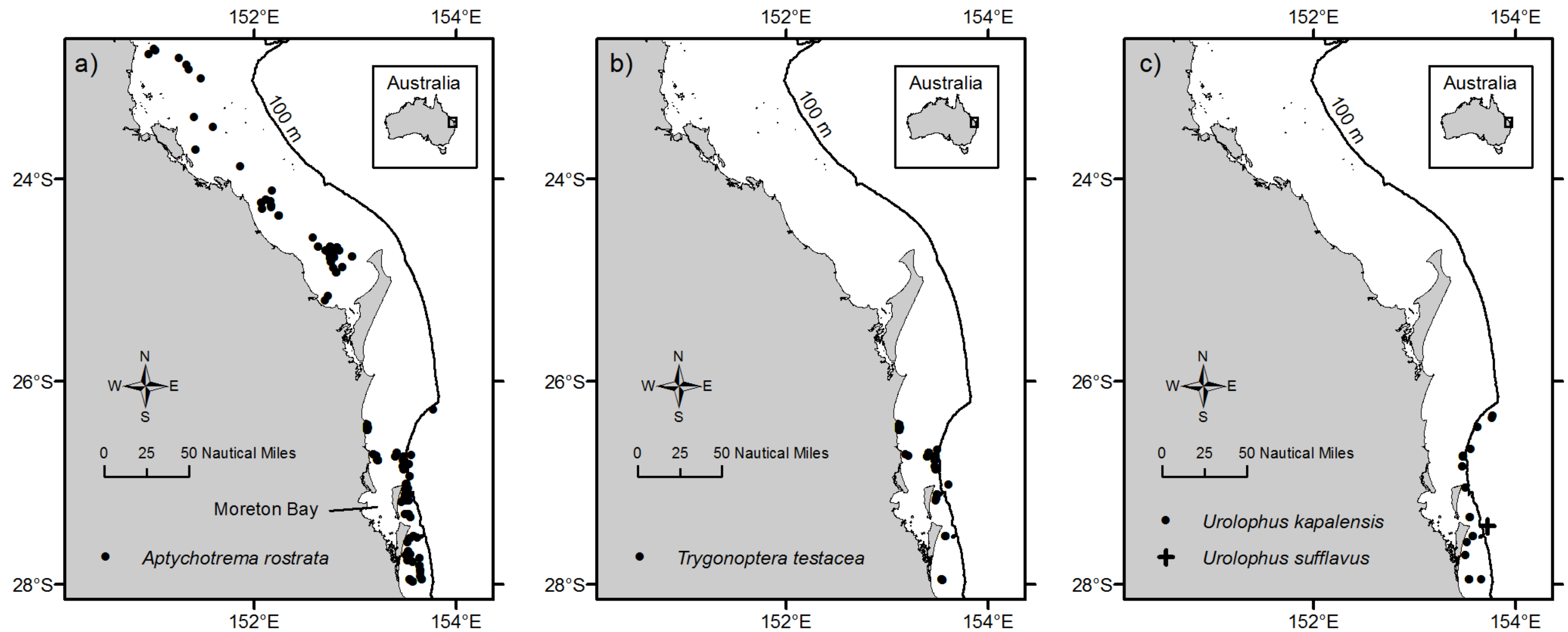

FIG. 1. Sample collection sites for (a) *Aptychotrema rostrata*, (b) *Trygonoptera testacea*, and (c) *Urolophus kapalensis* and *Urolophus sufflavus* from off the coast of south-east and central Queensland, Australia. Inset shows sample area circumscribed by a square.

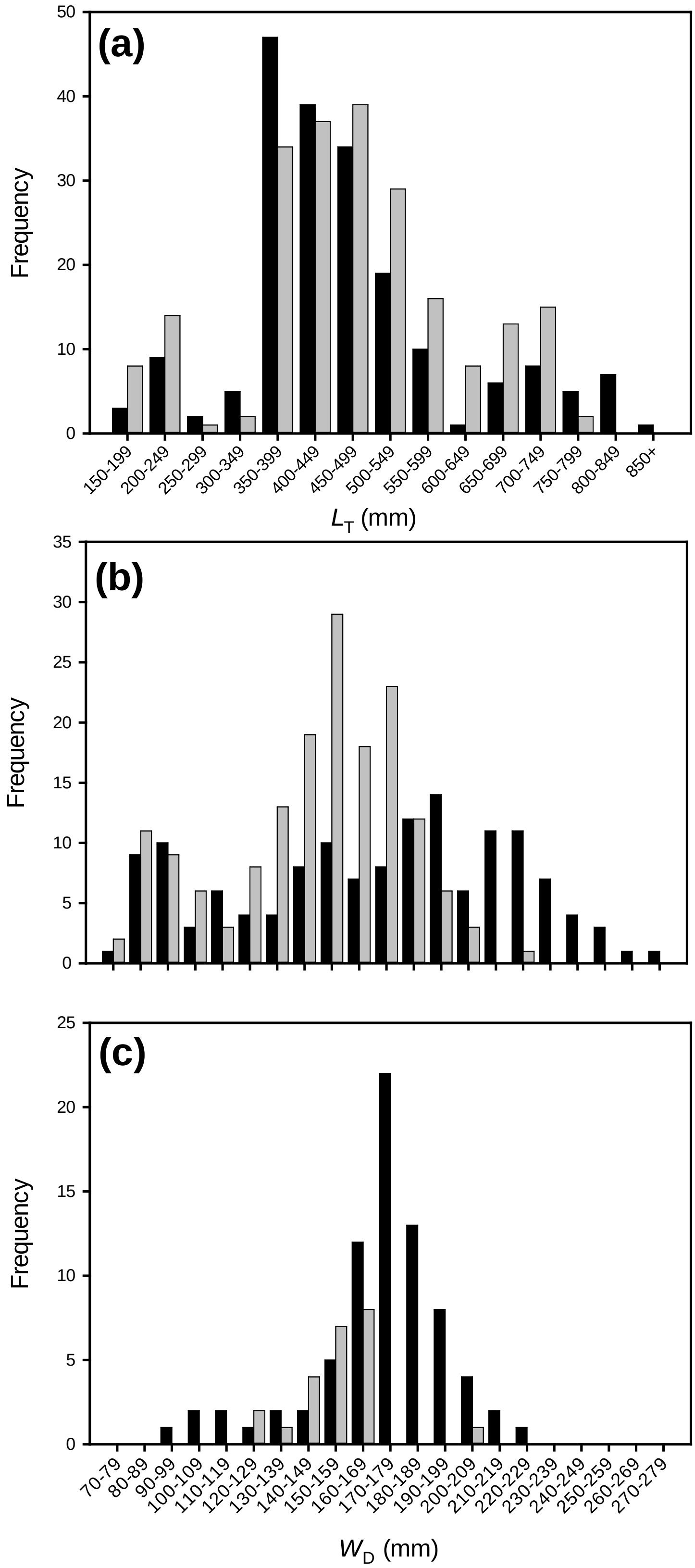
(a)
(b)
(c)
Frequency
L_T (mm)
W_D (mm)
150-199
200-249
250-299
300-349
350-399
400-449
450-499
500-549
550-599
600-649
650-699
700-749
750-799
800-849
850+
70-79
80-89
90-99
100-109
110-119
120-129
130-139
140-149
150-159
160-169
170-179
180-189
190-199
200-209
210-219
220-229
230-239
240-249
250-259
260-269
270-279

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FIG. 2. Size (L_T, total length; W_D, disc width)-frequency histogram of female (black bars) and male (grey bars) (a) *Aptychotrema rostrata*, (b) *Trygonoptera testacea*, and (c) *Urolophus kapalensis*.

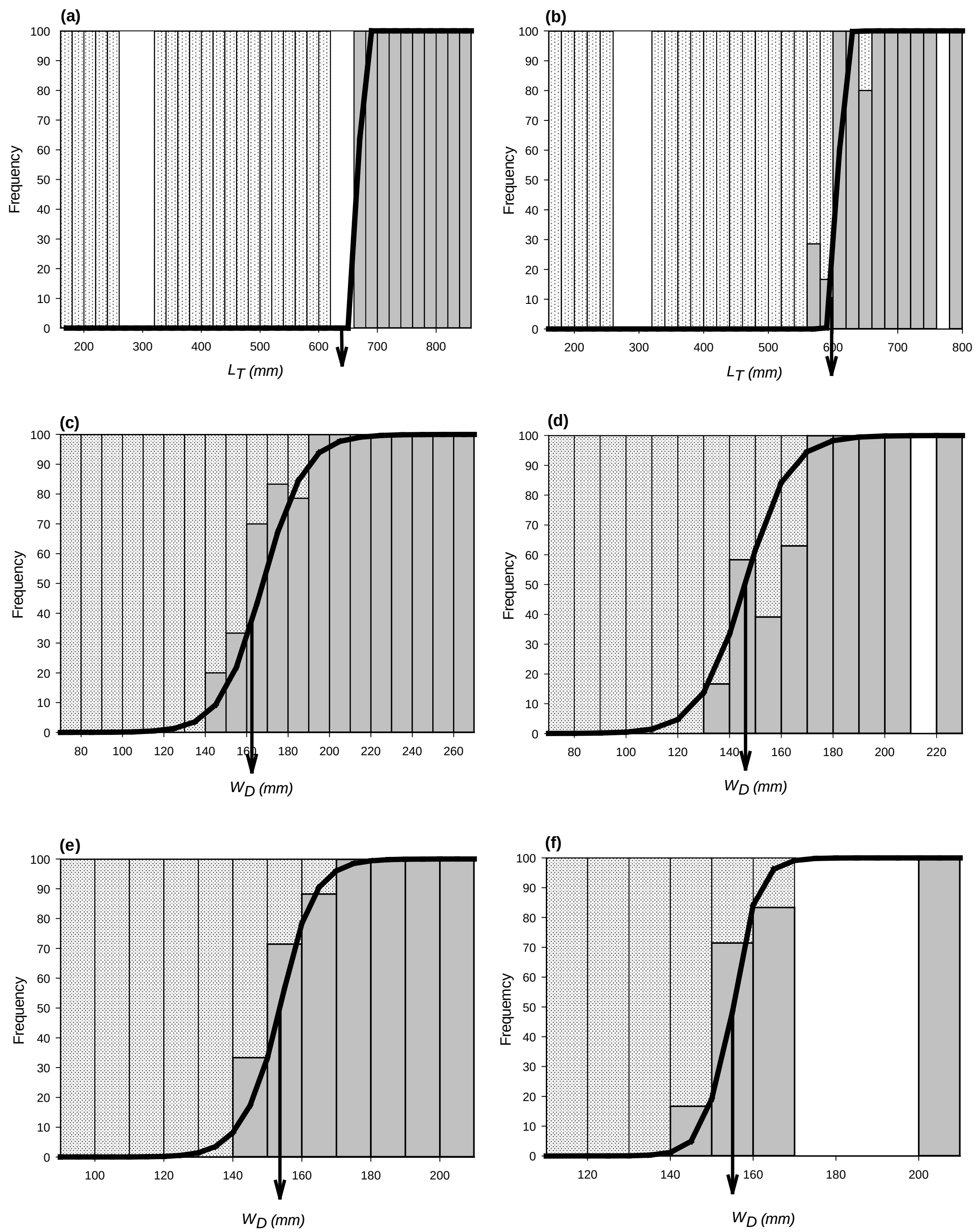

FIG. 3. Frequency of occurrence of immature (transparent grey bars) and mature (solid grey bars), and maturity curves for (a) female *Aptychotrema rostrata*, (b) male *Aptychotrema rostrata*, (c) female *Trygonoptera testacea*, (d) male *Trygonoptera testacea*, (e) female *Urolophus kapalensis*, and (f) male *Urolophus kapalensis*. Arrows denote L_{T50} and W_{D50}. White bars, no data. L_T, total length; W_D, disc width.

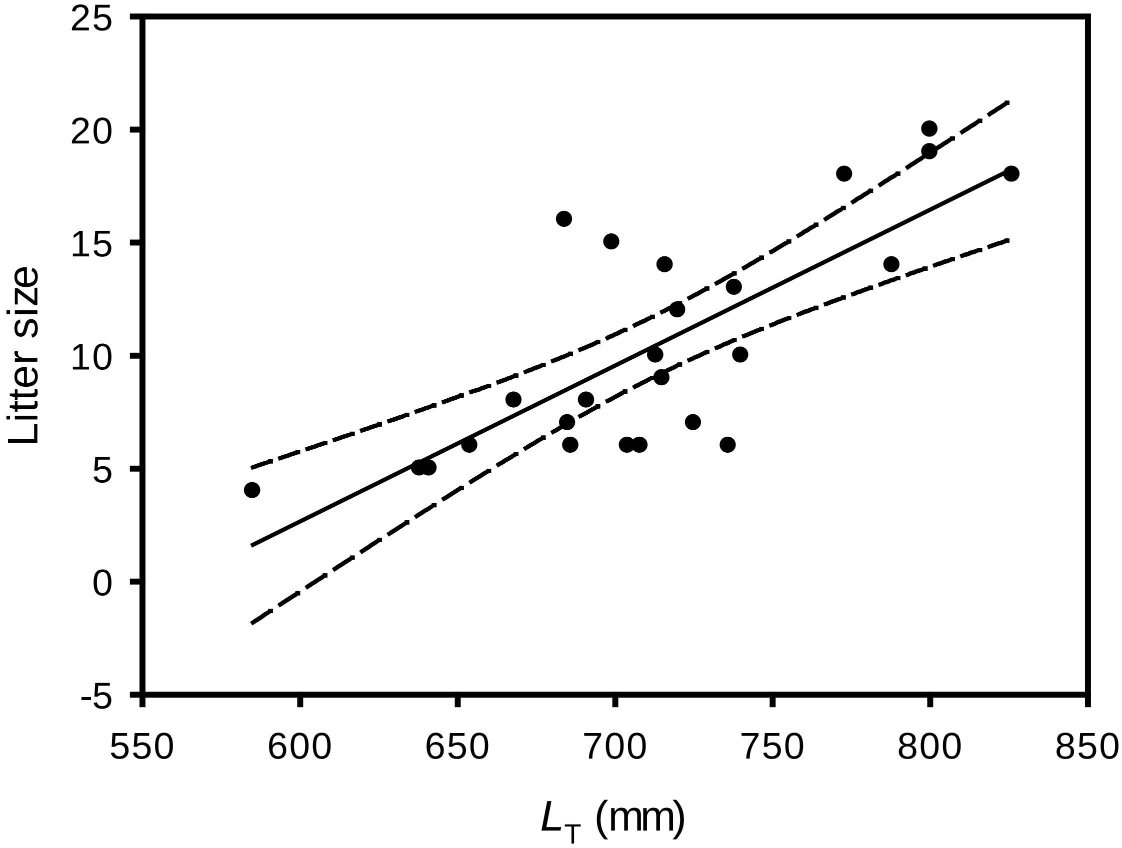

FIG 4. Linear regression analysis of litter size (R^2 = 0.594, P < 0.001, n = 25) with respect to maternal size (L_T, total length) of *Aptychotrema rostrata*. Data combined from present study and Kyne & Bennett (2002). Dashed lines show 95 % confidence intervals.