A Preliminary Investigation of the Reproductive Biology of the Blind Shark, *Brachaelurus waddi* (Orectolobiformes: Brachaeluridae)

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Although the focus on shark conservation has increased in recent years, small, economically unimportant species are often overlooked. The blind shark, *Brachaelurus waddi*, is endemic to eastern Australia and is commonly encountered in commercial fisheries. However, this is the first study of the species' reproductive biology. Males were sexually mature at 520-540 mm total length (TL) and all females ≥ 563 mm TL were sexually mature. Only the right ovary was functional and two distinct groupings in follicle size indicated that the reproductive cycle is at least biennial. Reproductive output may be smaller than previously suggested, with an average of four pups per gravid female in this study.

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INTRODUCTION

The focus on elasmobranch (sharks, rays and skates) conservation and management is increasing as populations decrease worldwide mainly due to overfishing and other anthropogenic impacts (Peres and Vooren 1991; Stevens et al. 2000; Kyne et al. 2011). Many sharks adopt a K-selected life history strategy and consequently have low rebound potentials (Cortés 2000; Stevens et al. 2000). As predators at or near the highest trophic levels, their removal may have cascading effects on marine ecosystems (Cortés 1999; Stevens et al. 2000). Hence, knowledge of their biology and ecology, especially reproductive strategies, is crucial to elasmobranch conservation and management.

Most studies focus on large species (e.g. Pratt 1979; Mollet et al. 2000; Lucifora et al. 2005), whilst smaller, rare or non-targeted species are often overlooked, although they may be equally important ecologically, and knowledge gaps may hamper effective conservation and fisheries management (Kyne et al. 2011). The blind shark, *Brachaelurus waddi*, is a small (max. 1200 mm TL), cryptic and economically unimportant coastal shark endemic to eastern Australia (Jervis Bay to Moreton Bay; 0-137 m) (Compagno 2002; Last and Stevens 2009; Fig. 1). There are no specific fishing regulations, and catch records are not maintained for blind sharks. However anecdotal reports indicate that they are commonly encountered as bycatch in trap fisheries within their range and, although often released alive, post capture mortality is not known. No previous scientific studies are known and existing knowledge is limited and anecdotal. Despite being listed as "Least Concern" on the IUCN Red List, based mainly on the assumption that the species is common and on the absence of commercial exploitation, the need for research is acknowledged (Kyne and Bennett 2003). This is the first investigation of the reproductive biology of *B. waddi*, and provides important biological data and the foundation for further research.

MATERIALS AND METHODS

Samples were obtained from the bycatch of a commercial trap fishery operating between Killcare (33°32'S, 151°21'E) and Lion Island (33°33'S, 151°19'E), New South Wales, Australia (Fig. 1). A total of 66 sharks (38 males, 28 females) were collected between January and May 2011. Total length (TL) (Compagno 2002) was measured to the nearest 1 mm.

Male size at sexual maturity was estimated utilising three common indices (e.g. Pratt 1979; Peres and Vooren 1991; Walker 2005; Huveneers et al. 2007; Kyne et al. 2011). Inner clasper length (Compagno 2002) was measured to the nearest 1 mm. Clasper calcification status was categorised as uncalcified (soft and flexible), partially calcified (partially hardened) and calcified (fully hardened). The testis index was determined visually and assigned as immature (testes not differentiated from epigonal gland); maturing (partially differentiated); and mature (enlarged and dominating the epigonal gland). The proportion of mature males was determined by logistic regression using maximum likelihood probit analysis (Walker 2005) and the total length at which 50% (TL_{50}) were mature was calculated for each index.

Ovary index and oviducal gland index, both determined visually, were used to determine sexual maturity in females (Walker 2005). Ovaries were categorised as immature (undifferentiated from epigonal gland); maturing (differentiated but lacking vitellogenic follicles); and mature (contained vitellogenic follicles ≥ 2 mm diameter). The oviducal gland was categorised as immature (undifferentiated from the oviduct); maturing (differentiated but lacked visible zonation); or mature (differentiated with visible zonation). However, no immature females were captured.

To assess female ovarian fecundity, the number of vitellogenic ovarian follicles (≥ 2 mm diameter) were recorded and measured to the nearest 1 mm diameter. The temporal size distribution of maturing follicles was tested using a non-parametric Kruskal-Wallis one-way analysis of variance by rank. From the size distribution of maturing follicles, ovarian fecundity was estimated. Uteri were examined for the presence of embryos (measured to the nearest 1 mm), with intact yolk sacs measured to the nearest 1 mm. Uterine fecundity was defined as the total number of uterine eggs or embryos (Peres and Vooren 1991). A non-parametric Spearman's rank correlation was used to investigate whether fecundity was correlated with TL.

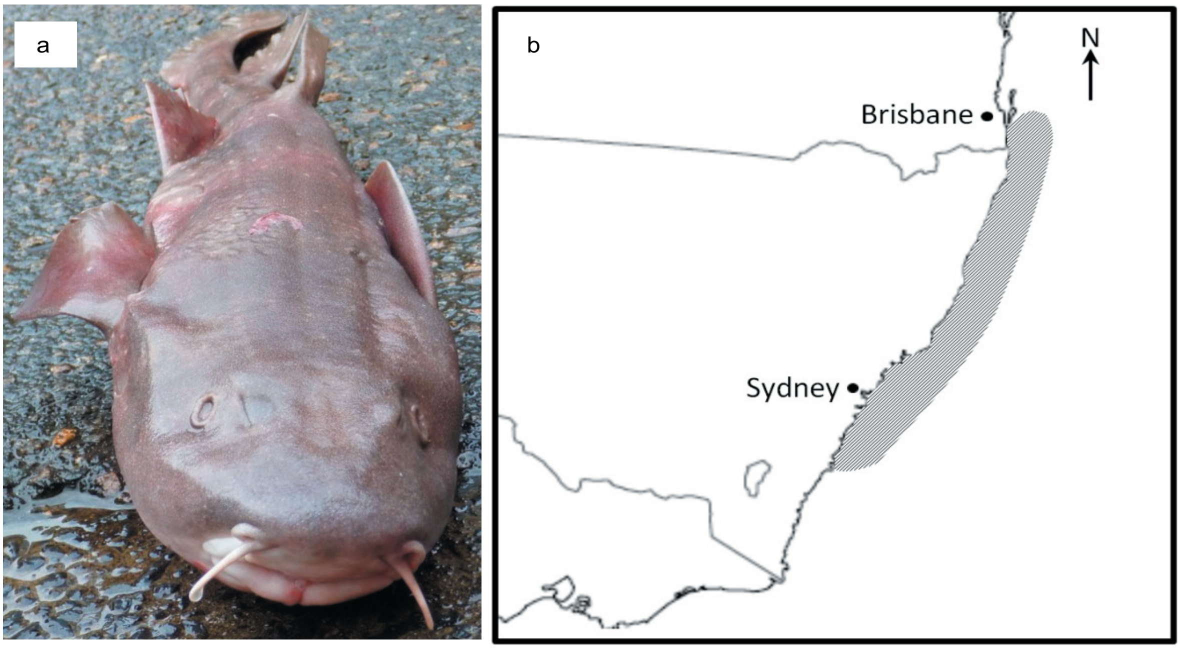

Figure 1. (a) Photograph of *Brachaelurus waddi* and (b) map of distribution (map modified from Geoscience Australia (http://www.ga.gov.au/corporate_data/61755/61755.pdf)).

RESULTS

Males reached sexual maturity (TL_{50}) between 519.9 mm and 542.1 mm TL based on the three indices ($n = 38$, Fig. 2). All females (563 to 720 mm TL; $n = 28$) were mature using both indices. Consequently, size at maturity and at maternity was ≤ 563 mm, as the smallest female was also gravid. Only the right ovary was functional in mature females.

Two gravid females, 610 and 583 mm TL, were captured on January 13, carrying four and five embryos, respectively (20.5 mm ± 2.6 mm TL; mean ± s.d.), with one intact yolk sac (42 mm diameter). Two females, 587 and 563 mm TL, captured on May 13, had three and four embryos, respectively (143.9 mm ± 2.9 mm TL) with a mean yolk sac diameter of 24.8 mm (± 1.0 mm, n = 7). It was not possible to determine gender in embryos caught in January. Of the seven embryos caught in May, three (43%) were male. The uteri of gravid females were fully extended.

There was no significant correlation between the number of follicles ≥ 7 mm diameter and TL in non-gravid females (ovarian fecundity; Spearman's rho = 0.41, $p = 0.05$, n=24). Follicle diameter increased significantly over time in non-gravid females (Kruskal-Wallis = 92.9, $p < 0.001$, df = 3; Fig.3). Only small (≤ 7 mm) ovarian follicles were present in gravid females. These small follicles were also present in all non-gravid females, but they also possessed larger, maturing follicles which increased in size and number over time to a maximum diameter of 31 mm by May (Fig. 3). Hence two distinct follicle size distributions occurred in gravid and non-gravid females, respectively.

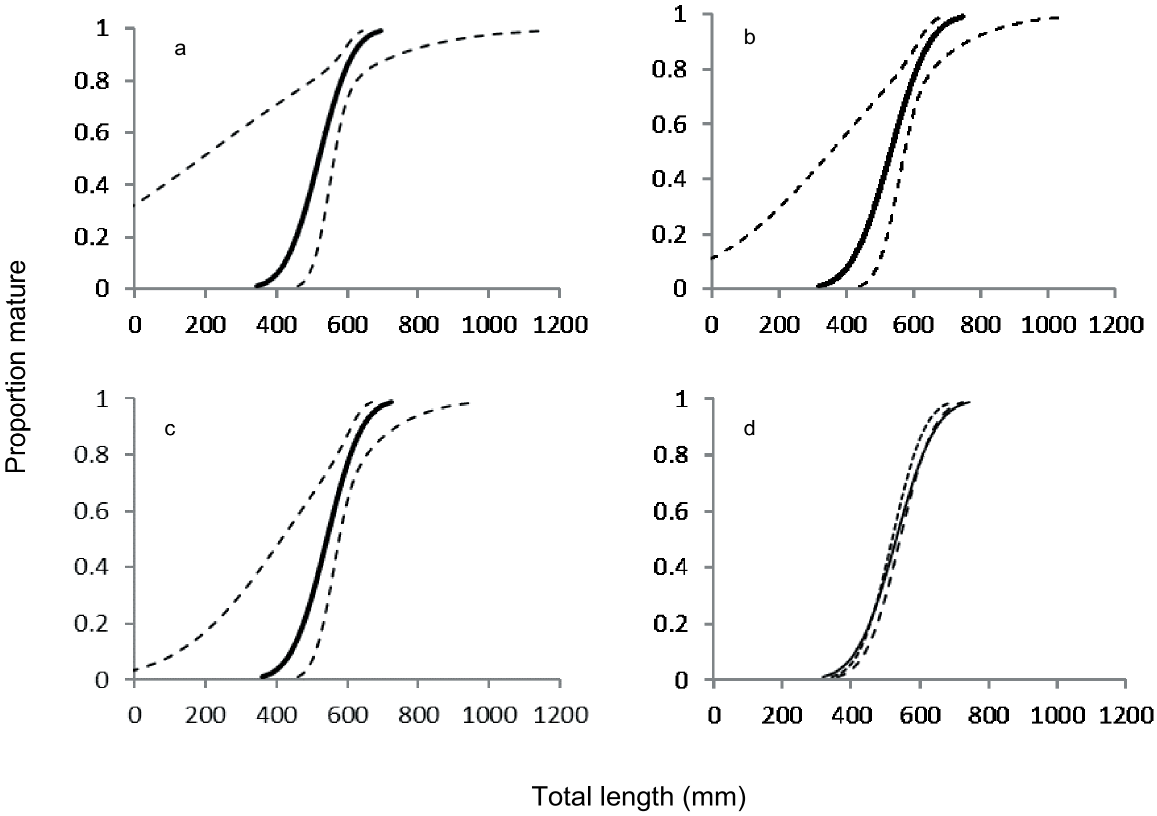

Figure 2. Proportion of mature male *Brachaelurus waddi,* given as (a) clasper length, (b) clasper calcification, (c) testes index (± 95% confidence interval; dashed line) and (d) combined (clasper length=dotted line; clasper calcification=solid line; testes index=dashed line).

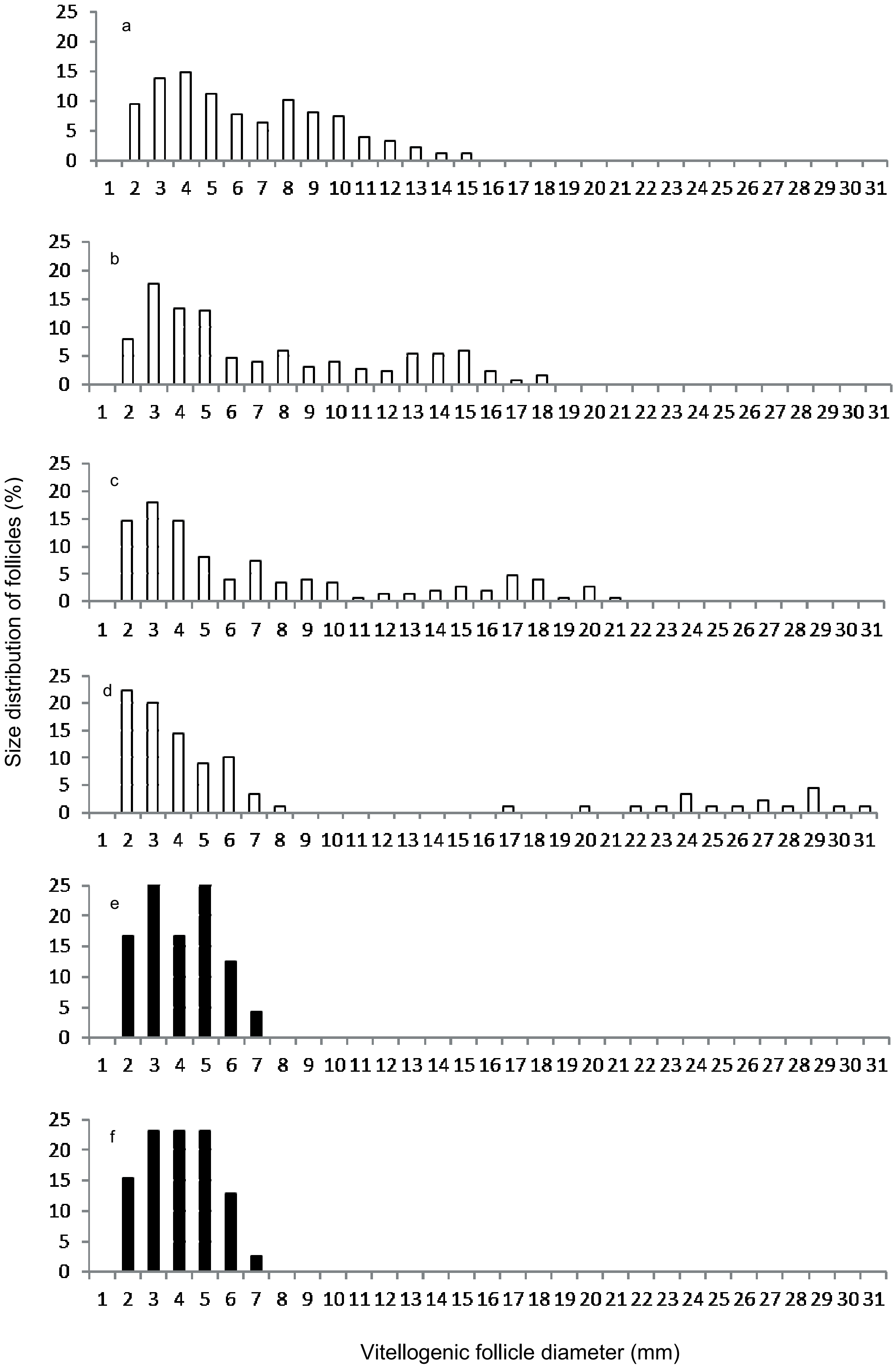

Figure 3. Size distribution of vitellogenic ovarian follicles in non-gravid female *Brachaelurus waddi* (open bars) captured in 2011 on (a) 13 January; (b) 8 February; (c) 15 February; and (d) 13 May; and gravid females (solid bars) captured on (e) 13 January; and (f) 13 May.

DISCUSSION

Although these results are preliminary and further study is required, the previously reported reproductive parameters for *B. waddi* appear questionable. Size at maturity was smaller than previously reported in both sexes. Males reached sexual maturity at approximately 520-540 mm TL, as opposed to the 600 mm (Last and Stevens 2009) and 620 mm (Compagno 2002) previously reported. The size at maturity and maternity of females in this study was ≤ 563 mm, compared with the previously reported 660 mm (Compagno 2002; Last and Stevens 2009), and, given that the uteri of all gravid females were fully distended, uterine fecundity is likely to equal maximum potential litter size (Compagno 2002; Last and Stevens 2009). However, the small sample size warrants caution.

Two distinct distributions in follicle size in combination with the low proportion of gravid females (12.5%) indicates at least a biennial reproductive cycle and not an annual cycle as previously assumed (Kyne and Bennett 2003). This is further supported by maturing follicles reaching a maximum diameter of 31 mm by May, well before the November mating season (Compagno 2002), and a 42 mm yolk-sac in a gravid female in January. In benthic elasmobranchs, follicles > 40 mm are generally associated with biennial or triennial ovarian cycles, while follicles < 30 mm are typically associated with annual ovarian cycles (Huveneers et al. 2007). However, the small proportion of gravid females (12.5%) may suggest a triennial cycle, but further data is required to establish this. Based on a biennial cycle and estimated fecundity, the reproductive potential of *B. waddi* may be as little as four pups every two years, or 25% of previous estimates (Compagno 2002; Last and Stevens 2009).

Although not targeted by commercial or recreational fishers, *B. waddi* is commonly caught by both, with most presumed to be released alive (Kyne & Bennett 2003). However unconfirmed reports from commercial fishers suggest some may be killed, as a nuisance which occupies traps and consumes target fish/bait, while others are released at sites remote from the trapping areas (D. Powter, field obs.). Post-capture survival is thought to be high, but not known definitively (Kyne & Bennett 2003). These factors and the more conservative life history found in this study, suggest the need for more research and new considerations for future fisheries management actions and conservation evaluations, such as those by the IUCN.

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REFERENCES

Compagno, L.J.V. (2002). 'Sharks of the world. An annoted and illustrated catalogue of shark species known to date. Volume 2: Bullhead, mackerel and carpet sharks (Heterodontiformes, Lamniformes and Orectolobiformes)'. Food and Agriculture Organization of the United Nations. FOA Species Catalogue for Fisheries Purposes No. 1

Cortés, E. (1999). Standardized diet compositions and trophic levels of sharks. *ICES Journal of Marine Science*, **56**, 707-717.

Cortés, E. (2000). Life history patterns and correlations in sharks. *Reviews in Fisheries Science* **8**, 299-344.

Huveneers, C., Walker, T.I., Otway, N.M. and Harcourt, R.G. (2007). Reproductive synchrony of three sympatric species of wobbegong shark (genus *Orectolobus*) in New South Wales, Australia: reproductive parameter estimates necessary for population modelling. *Marine and Freshwater Research* **58**, 765-777.

Kyne, P.M. and Bennett, M.B. (2003). *Brachaelurus waddi*. In: IUCN 2013. IUCN Red List of Threatened Species. Version 2013.2. SSG Australia & Oceania Regional Workshop, March 2003. Retrieved from www.iucnredlist.org on 05 January 2013.

Kyne, P.M., Compagno, L.J.V., Stead, J., Jackson, M.V. and Bennett, M.B. (2011). Distribution, habitat and biology of a rare and threatened eastern Australian endemic shark: Colclough's shark, *Brachaelurus colcloughi* Ogilby, 1908. *Marine and Freshwater Research* **62**, 540-547.

Last, P.R. and Stevens, J.D. (2009). 'Sharks and rays of Australia. Second edition.' (CSIRO Publishing, Australia).

Lucifora, L.O., Menni, R.C. and Escalante, A.H. (2005). Reproduction and seasonal occurrence of the copper shark, *Carcharhinus brachyurus*, from Patagonia, Argentina. *ICES Journal of Marine Science*, **62**, 107-115.

Mollet, H.F., Cliff, G., Pratt, H.L. and Stevens, J.D. (2000). Reproductive biology of the female shortfin mako, *Isurus oxyrinchus* Rafinesque, 1810, with comments on the embryonic development of lamnoids. *Fisheries Bulletin* **98**, 299-318.

Peres, M.B. and Vooren, C.M. (1991). Sexual development, reproductive cycle, and fecundity of the school shark *Galeorhinus galeus* off Southern Brazil. *Fishery Bulletin* **89**, 655-667.

Pratt, H.L. (1979). Reproduction in the blue shark, *Prionace glauca*. *Fishery Bulletin* **77**, 445-470.

Stevens, J.D., Bonfil, R., Dulvy, N.K. and Walker, P.A. (2000). The effects of fishing on sharks, rays, and chimaeras (Chondrichthyans), and the implications for marine ecosystems. *ICES Journal of Marine Science* **57**, 476-494.

Walker, T.I. (2005). Reproduction in fisheries science. In: ‘*Reproductive biology and phylogeny of Chondrichthyes: Sharks, batoids and chimaeras*’. (Ed W. C. Hamlett.) pp. 81-127. (Enfield, USA: Science Publishers).