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REPRODUCTIVE BIOLOGY OF *PORTUNUS PELAGICUS* IN A SOUTH-EAST AUSTRALIAN ESTUARY

Daniel D. Johnson, Charles A. Gray, and William G. Macbeth

(DJ, correspondence, Daniel.johnson@industry.nsw.gov.au; CG; WM) Cronulla Fisheries Research Centre of Excellence, PO Box 21, Cronulla, NSW, 2230, Australia

ABSTRACT

Portunus pelagicus (blue swimmer crab) is widely distributed and fished throughout the indo-west Pacific, but little is known of its biology and ecology in southeast Australia. In this study, the reproductive biology of *P. pelagicus* inhabiting Wallis Lake, a large coastal lake that supports the largest regional commercial fishery for the species was investigated. Males and females with mature gonads occur throughout the fishing season (November to July), however, ovigerous females are most prevalent in November and December. The mean size at which 50% of females reached maturity is estimated at 46 mm carapace length (CL). Fecundity increased linearly with CL and females are capable of producing up to 3 broods of eggs within the observed spawning season, with crabs of 60-69 mm CL producing approximately 76% of the estimated total egg production. Increasing the current minimum carapace length above 60 mm CL would potentially provide greater protection to mature females and increase total egg production, but this would reduce total retained catches in the fisheries.

KEY WORDS: blue crab, fecundity, maturity, *Portunus pelagicus*, reproduction

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INTRODUCTION

The blue swimmer crab, *Portunus pelagicus* (Linnaeus, 1758), occurs in shallow, tropical and temperate coastal and estuarine waters throughout the Indo-West Pacific from Africa to India, southeast Asia and Australia (Smith and Sumpton, 1989; Chande and Mgaya, 2003). Throughout its distribution, it is important in many commercial and recreational fisheries (Sukumaran and Neelakantan, 1997; Sumpton et al., 2003). In Australia, commercial and recreational fishers harvest approximately 3000 metric tons of *P. pelagicus* each year (Henry and Lyle, 2003).

Knowledge of the reproductive biology of a species is one of the most important aspects in evaluating the harvesting strategies of exploited populations (Campbell and Eagles, 1982; Addison and Bennet, 1992). Studies investigating aspects of the reproductive biology of *P. pelagicus* have reported regional and area-specific differences in the timing and length of spawning season (4 to 9 months), size at sexual maturity (31 to 49 mm carapace length) and fecundity (270,000 to 1,880,000 eggs per brood) (Sukumaran and Neelakantan, 1997, 1998; de Lestang et al., 2003a, b; Kumar et al., 2003; Smith et al., 2004; Xiao and Kumar, 2004). There have been no studies on the reproductive biology of *P. pelagicus* in southeastern Australia, even though it supports substantial fisheries. The life history of *P. pelagicus* in southeastern Australia may differ from populations elsewhere. Local data pertaining to the reproductive biology of *P. pelagicus* is therefore required to help determine appropriate management options for this species in southeast Australia.

The specific aims of this study were to investigate: 1) length of spawning period; 2) gonad and ovarian development; 3) size at sexual maturity; 4) relationship between size and fecundity; and 5) the relative contribution that each size class makes to total egg production; for a population of *P. pelagicus* in southeastern Australia. This work was done in Wallis Lake, New South Wales (NSW) as it supports the largest (40% of total landings) *P. pelagicus* fishery in NSW (NSW DPI unpublished data).

MATERIALS AND METHODS

Study Site and Collection of Samples

Wallis Lake (32°17'S, 152°52'E) is a large (water surface area of 86 km^2) barrier estuary comprising a shallow central lagoon with three main, and numerous smaller, tributaries, and with a single opening to the sea (Roy et al., 2001). Much of the lagoon contains areas of dense seagrass (*Posidonia australis* and *Zostera capricorni*) as well as shallow unvegetated habitats (< 2 m in depth).

Samples of *P. pelagicus* from Wallis Lake and adjacent inshore coastal waters were obtained via three different sources. Crabs were collected from commercial trap catches each month between November 2002 and July 2003, after which time the trap-fishing season had ended. The commercial trap fishery for *P. pelagicus* is managed by spatial closures, gear restrictions and a minimum legal size for retained crabs (carapace length [CL] of 60 mm). This size limit was introduced without quantitative data from NSW *P. pelagicus* populations. Fishers operating in Wallis Lake are permitted to set a maximum of 30 crab traps per day. Commercial fishers are permitted to trap in all months, however, greatest reported landings and effort predominately occur between late summer and autumn (January to April) each year. Low catches during the winter period prevent commercial fishers from targeting crabs.

Crabs were also collected from commercial prawn-seine (see Macbeth and Gray, 2008), and research beam-trawl catches (see Rotherham et al., 2008 for a description of gear) during February and March 2003. All crabs were measured for carapace length (CL, nearest mm), weighed (nearest g), and sexed. Samples were also retained for further examination in the laboratory.

Gonad and Ovarian Development

Each month a total of 70 crabs (35 males and 35 females) were randomly selected from commercial trap catches and macroscopically examined to determine their stage of gonad development. Six stages were used to classify females and three stages to classify males based on the reproductive staging criteria developed by Sukumaran and Neelakantan (1998) (Table 1).

Table 1. Stages of female ovary and male gonad development (based on Sukumaran and Neelakantan, 1998).

Maturity stage	
	Macroscopic appearance of female ovary
I	Colourless ovary: thread like in appearance.
II	Immediately after ovulation the ovary returns to the immature stage before rematuration. The ovary is yellow brown in colour and thick and translucent.
III	The ovary is ivory or yellow in colour and slightly enlarged
IV	The colour of the ovary varies from yellow to orange. The ovary at this stage is swollen with pronounced lobulations.
V	Mature ovaries are deep orange in colour and the swollen lobes obscure the underlying hepatopancreas.
VI	The ovary is ivory or yellow orange in colour and very flaccid.
	Macroscopic appearance of male gonad
I	Testes and vasa deferentia not clearly differentiated: vas deferentia are thin translucent straight tubes.
II	Testes and vasa deferentia well developed, testes are a large coiled tube spreading laterally and posteriorly in the stomach. Vasa deferentia opaque or white coiled mass extending to both sides of the heart.
III	Testes further enlarged, vasa deferentia are thick and white milky mass extending to fill most of the body cavity

Size at Maturity

Juvenile and adult female crabs collected from the beam trawl (159 individuals) and prawn seine (283 individuals) were used to examine size at maturity. Compared with trap catches, these relatively less size-selective fishing methods provide a wider size range of crabs, and therefore a potentially unbiased estimate of size at maturity (Smith et al., 2004). We used the definition of Smith et al. (2004) to determine if a female crab was mature. A female crab was deemed mature when the oval shaped pleonal flap could be separated from the carapace. During the pubertal moult, the pleonal flap of the female portunid species changes from triangular to oval shape and becomes loosely fixed to the carapace. The size at which 50% (L_{50}) of females were sexually mature was estimated by fitting a logistic regression curve to the proportion of mature *P. pelagicus* for each sequential 1-mm CL size class as described by King (1995) and Oh and Jeong (2003).

Fecundity

We collected a total of 30 ovigerous female crabs with undamaged egg batches from trap catches in November 2002 and February 2003. Prior to the removal of the egg batch and pleonal flap, the stage of egg development was determined and the whole weight of the crab (nearest 0.1g) and its CL (nearest 0.1 mm) were measured. Only crabs with stage I eggs (bright yellow egg batch, Svane and Cheshire, 2005) were included in the analysis of batch fecundity.

The total egg batch (including the pleonal flap) was removed from the crab and immersed in 400 ml of 1M KOH for 12 h to dissolve the funiculae that attach the eggs to the setae. Following the separation process, the pleonal flap was removed, the pleopods scraped clean and all setae removed from the separated egg batch. The wet weight of the total separated egg batch was recorded and five replicate 0.02 g sub-samples were taken. The average number of eggs per sub-sample was then scaled up to estimate the total number of eggs per egg batch. The relationship between size of crab (CL) and fecundity was estimated separately for each month by fitting linear regressions for CL vs fecundity. To investigate whether fecundity varied between different sample months, the slopes and y-intercepts of the regressions for November and February were compared using analysis of covariance (ANCOVA).

Multiple Batches

The potential total number of egg batches produced by mature females during a single breeding season was estimated by first determining the proportion of ovigerous females within each 5 mm size class. Using these data and estimates of spawning period (number of days that > 5% of mature females are ovigerous) and brood period (number of days carrying an egg batch, see Meagher, 1971), the CL vs number of batches relationship was determined by fitting a modified logistic curve ranging from one batch to a maximum of 1 + number (Nb) maximum batches as described by de Lestang et al. (2003b).

Index of Reproductive Potential

To determine the relative contribution that each size class made to total egg production of the entire population, an index of reproductive potential (IRP) was developed according to the methods of Kanciruk and Herrnkind (1976) and Sukumaran and Neelakantan (1997). We estimated the reproductive potential for each size class using the size-fecundity relationship, proportion of females that are ovigerous in each size class, and the size-frequency distribution of the population (based on trap catches; Johnson and Gray, submitted). The class index of the newly mature females (54-59 mm CL) was standardised at a value of 100.

Results

Gonad and Ovarian Development

Female crabs representative of all gonad stages were present during each month of the sampling period (Fig. 1a). The monthly mean CL for male crabs increased from 64.16 (± 0.28) mm in November to 69.62 (± 0.36) mm in April. Similarly, the mean size of females increased from 62.78 (± 0.34) to 64.67 (± 0.94) mm in CL during the sampling period. The highest proportion of female crabs with mature (stage V) ovaries was during November (49%), while during all the other months crabs with stage V ovaries accounted for 17-25% of all individuals sampled. Female crabs with spent (stage V1) ovaries were most common in December (31%) and July (29%). The primary spawning period was concluded to be between November and February, as at least 5% of mature crabs were ovigerous during this period (Fig. 2). Male crabs displayed no distinct changes in development stage throughout the sampling period, with 25-40% of crabs reproductively mature (stage III gonads) each month (Fig. 1b).

Female Size at Maturity

The smallest mature female recorded from seine and beam-trawl catches was 34 mm CL. The size at which 50% of female *P. pelagicus* were mature was estimated to be 46 mm CL (Fig. 3), while 95% were estimated to be mature at 56 mm CL. Overall, 85% of female crabs (33-80 mm CL) in seine and beam-trawl catches were mature.

Fecundity

The estimated fecundity for individual crabs varied from approximately 463,000 (± 13,200) to 1,751,000 (± 32,300) eggs per batch during November and between 620, 000 (± 23,500) and 1,781,000 (± 40,200) eggs per batch during February. There was no significant difference ($P > 0.05$) between the slopes ($P = 0.46$) and y-intercepts ($P = 0.66$) of the fecundity vs CL regression lines fitted for November and February. Consequently, these data were combined, providing an overall fecundity vs CL regression relationship of: Fecundity = $(0.4056\ CL - 16.116) \times 10^4$ (Fig. 4). The mean fecundity estimates for crabs in each 5 mm CL size class (months combined) is given in Table 2.

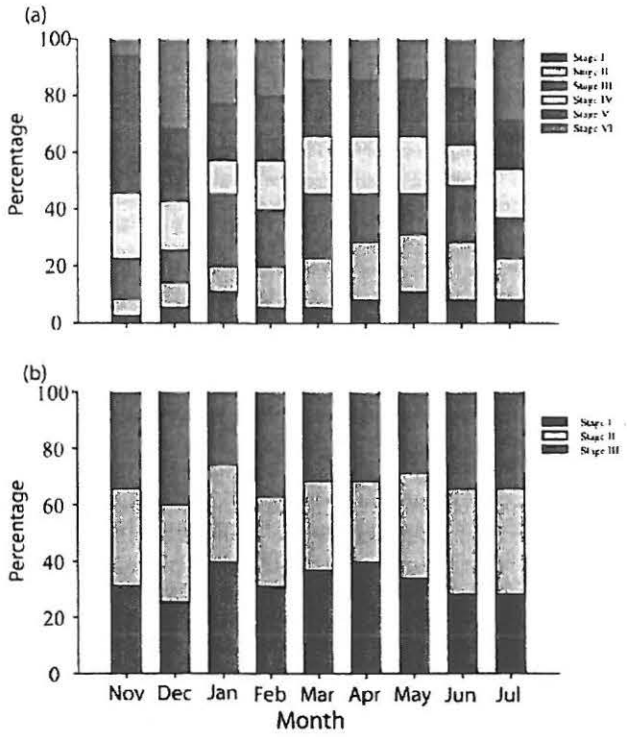

Fig. 1. The proportion of each gonad maturity stage for (a) female and (b) male *P. pelagicus*.

Multiple Batches

Fifty-three percent of ovigerous female crabs ($n = 69$) had stage IV to stage V ovaries, indicating they were capable of producing multiple batches from a single mating per spawning season. The estimated number of batches produced (NBj) by female crabs in each size class ranged from approximately one in crabs of 50-54 mm CL, to approximately three in crabs 75-79 mm CL (Fig. 5). The estimated CL-batch relationship is: NBj = 1 + 2/(1 + 0.810 exp (CLj − 57)), where the spawning and brood periods were estimated as 120 and 19 days, respectively.

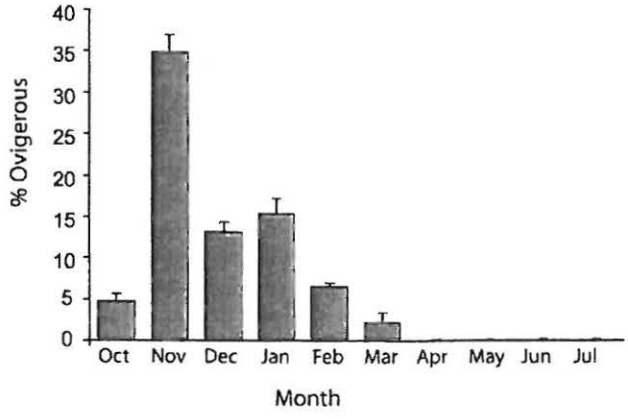

Fig. 2. The proportion of ovigerous females observed in commercial trap catches.

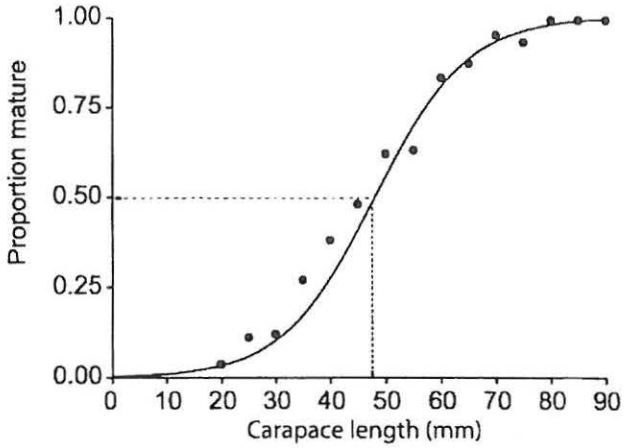

Fig. 3. Logistic curve showing the proportion of mature female *P. pelagicus* in each size category.

Index of Reproductive Potential

Females in the size class immediately below the current legal minimum CL of 60 mm (55-59 mm) represented 21.9% of all females, yet produced only 13.5% of estimated total egg production and had an estimated reproductivity of 0.62 (Table 3). The estimated reproductivity of crabs was greatest (1.56) in the 65-69 mm size class, while for larger crabs (i.e., 75-79 mm CL) it was considerably lower (0.32). Crabs measuring 60-69 mm CL represented 64% of the observed population and produced 76% of the estimated total egg production.

Discussion

The reproductive biology of *P. pelagicus* sampled in Wallis Lake was sufficiently different to that of *P. pelagicus* from other parts of the world to support the hypothesis of strong regional differences in biology of *P. pelagicus* (Table 4). More specifically, our estimates of fecundity differed to other studies in several ways despite similar methods. For example, our estimates of batch fecundity (463,000-1,781,000) were greater than that reported for individuals

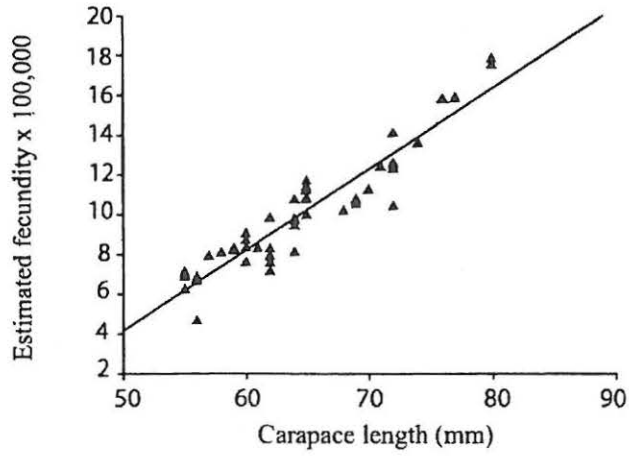

Fig. 4. Carapace length-fecundity relationship for female *P. pelagicus* pooled across months (November and February).

Table 2. Mean carapace length (CL), weight, egg batch weight and estimates of fecundity of *P. pelagicus* for each 5 mm size class (± 1 SE). Data pooled for November and February.

CL range (mm)	Number of individuals	Mean CL (mm)	Weight (g)	Egg mass weight (g)	Total no. of eggs per individual
55-59	15	56.9 (0.42)	132.9 (3.36)	41.6 (3.16)	730,828 (25,943)
60-64	17	61.9 (0.39)	175.58 (3.60)	50.15 (3.50)	866,468 (24,520)
65-69	12	66.6 (0.60)	219.39 (5.90)	59.1 (2.40)	1,081,701 (15,120)
70-74	10	71.9 (0.39)	273.82 (4.61)	74.6 (7.31)	1,237,008 (41,401)
75-79	6	76.6 (0.27)	333.70 (2.86)	94.2 (8.08)	1,579,011 (182,60)

of similar sizes in Western Australia (75,000-325,000; de Lestang et al., 2003b), and India (250,000-750,000, Sukumaran and Neelakantan, 1997), but comparable to estimates of fecundity for *P. pelagicus* in Queensland (Shields and Wood, 1993). We also found that individual fecundity increased with increasing CL over the size range examined (55-79 mm CL), with the greatest number of eggs per batch carried on the largest female—an observation shared by Sukumaran and Neelakantan (1997) with respect to *P. pelagicus* off the coast of India. In contrast, Kumar et al. (2003) and de Lestang et al. (2003b) reported that fecundity peaked at approximately 61 mm and 71 mm CL respectively, then declined with further increase in size. Finally, we found no significant temporal difference in the relationship between size of crab (CL) and fecundity, while Kumar et al. (2003) reported that fecundity increased from October to December, after which it declined.

Although we can not isolate mechanisms for each of the observed differences in fecundity listed above, biotic and abiotic factors such as water temperature fluctuations, growth rate (Prager et al., 1990), and the population density and size-structure can influence fecundity in crustaceans (Mohan, 1997; DeMartini et al., 2003). For example, the fecundity of the blue crab *Callinectes sapidus* (Rathbun, 1896) in Chesapeake Bay was estimated to be greater in 1987 than in 1986, an observation attributed to favourable climatic conditions coupled with increased growth rates (Prager et al., 1990).

Our estimate for the size at which 50% of female *P. pelagicus* attain maturity in Wallis Lake (i.e., 46 mm CL) was similar to corresponding estimates for females in Shark Bay (45 mm CL, Smith et al., 2004), and the Peel Harvey and Leschenault estuaries (43 mm CL, de Lestang et al., 2003b) in Western Australia, but much greater than for females in Spencer Gulf, South Australia (29 mm CL, Xiao and Kumar, 2004). This difference may simply reflect inter-regional differences in the biology of *P. pelagicus*, but may also be attributable to differences in the selectivity of the gears used to obtain samples. Trap catches are often biased towards large sexually mature crabs, resulting in an overestimation of the proportion of mature crabs in each size class and, therefore, an underestimation of the mean size at maturity (Smith et al., 2004). Our estimated mean size at 50% maturity was derived using samples from seine and beam trawls, whereas that of Xiao and Kumar (2004) was derived using samples from trap catches. Similarly, place of capture (e.g., estuary vs ocean) may bias the estimation of mean size at maturity of female *P. pelagicus* (de Lestang et al., 2003b). For example, emigration of mature females from estuaries to the ocean might increase the proportion of immature crabs in each size class in the estuary, leading to an over estimation of the overall mean size at 50% maturity for estuary-based samples (de Lestang et al., 2003b). For this reason, crabs used to estimate mean size at 50% maturity during our study were collected in February and March; prior to emigration to ocean waters by sexually mature females.

Despite the apparent inter-regional differences in fecundity and size at maturity, other aspects of the reproductive biology of *P. pelagicus* in Wallis Lake appear similar to that reported elsewhere. For example, length of spawning period of *P. pelagicus* appears to be influenced by water temperature, with extended spawning observed in waters with higher temperatures (de Lestang et al., 2003b). Reproductively mature *P. pelagicus* of both sexes (including ovigerous females) were found in Wallis Lake in all of the 9 months sampled, demonstrating their capability for having a lengthy spawning period in south-eastern

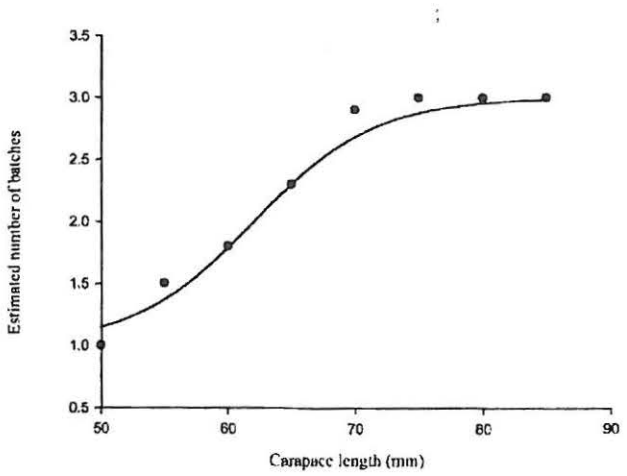

Fig. 5. Estimated number of egg batches produced during the observed spawning period.

Table 3. Index of reproductive potential of *P. pelagicus* for each 5 mm size class from commercial trap catches.

	Size class (CL mm)				
	55-59	60-64	65-69	70-74	75-79
% of total female catch (A)	21.86	32.91	30.84	12.08	2.31
% ovigerous	16.49	19.08	21.13	8.55	2.60
Estimated total potential fecundity (× 100,000)	14.62	17.32	28.67	37.11	47.37
Index of reproductive potential	100.00	206.37	354.54	72.73	5.39
% of total egg production (B)	13.53	27.92	47.97	9.84	0.73
Reproductivity (B/A)	0.62	0.84	1.56	0.81	0.32

Table 4. Comparative findings of the reproductive biology of *Portunus pelagicus*. Location: New South Wales (NSW), Western Australia (WA), Queensland (QLD), South Australia (SA).

Location	Size at maturity (Min CL mm)	Size at maturity (Max CL mm)	Fecundity (Eggs × 10^5)	Seasonal peaks in		Source
				Ovary condition	% ovigerous	
NSW	38	56	0.46-1.78	Nov-Dec	Nov-Jan	Present study
WA	38	43	-	-	-	de Lestang et al (2003b)
WA	42	47	-	-	-	Smith et al (2004)
WA	28	37	0.27-0.85	-	Jan-Feb	Potter et al (1983)
QLD	34	49	0.24-1.88	Jun-Mar	Aug-Mar	Shields and Wood (1993)
SA	28	49	0.48-1.60	-	Oct-Apr	Smith (1982)
India	38	47	-	-	Sep-Mar	Prasad and Tampi (1953)
India	-	-	0.25-0.75	Jan-Apr	Aug-Feb	Sukumaran and Neelakantan (1997)
Egypt	31	44	0.75-0.81	Apr-Sep	Mar-Aug	Razek (1988)

Australia. This concurs with observations indicating that *P. pelagicus* can spawn over several months (up to 10) in other sub-tropical and temperate regions (Potter et al., 1983; de Lestang et al., 2003b). Further, during our study, ovigerous females were most prevalent (36%) in late spring/early summer (November and December), which coincides with observations from estuaries and embayments in temperate south-western Australia (de Lestang et al., 2003b).

Female *P. pelagicus* can produce several batches of eggs from a single mating (Meagher, 1971) and our estimates of the relationship between CL and number of batches of eggs produced were similar to that reported by de Lestang et al. (2003b). Crabs < 55 mm CL tended to produce only one batch, whereas crabs > 75 mm CL produced up to three batches. The greater number of egg batches produced by larger crabs can be explained by their longer intermolt period between copulation and egg extrusion (de Lestang et al., 2003b).

Female *P. pelagicus* in Wallis Lake attain sexual maturity below the current minimum legal CL for retention by commercial and recreational fishers of 60 mm. The lower fecundity of newly matured females (55-59 mm CL), combined with the small proportion of ovigerous females observed in this size class (Johnson and Gray, submitted), means that these sized crabs probably make only a small contribution to the total egg production of the entire population. Similarly, because of their low abundances, the largest sized crabs (75-79 mm CL) probably do not contribute greatly to the estimated total egg production of the population, despite their potentially greater overall total fecundity compared with other size classes. Egg production in the Wallis Lake population appears to be heavily dependent on crabs between 60-69 mm CL, which are subject to the highest level of fishing pressure (Johnson and Gray, submitted). Increased fishing effort for, or catchability of, crabs in this size class could potentially result in large reductions in egg production and, depending on environmental conditions, could lead to reduced levels of recruitment.

A possible mechanism to increase the total reproductive output of *P. pelagicus* populations in Wallis Lake might be to increase the minimum legal CL. Increasing the current minimum legal CL from 60 mm to 65-70 mm could potentially protect 55-86% of the estimated egg producing females from harvesting and increase total egg production by 14%-34% respectively. A legal CL of 70 mm would potentially enable female crabs in the 65-70 mm size class to produce a greater number of egg batches prior to harvesting. Such a change would, however, probably also result in a large reduction in total retained catches in the commercial trap fishery and would impact on the burgeoning recreational fishery in NSW. Before any change in the legally retainable size of crabs is implemented, further information on growth and mortality, and spawner-recruitment relationships would also be required to properly assess the status of the *P. pelagicus* stocks of southeastern Australia and their susceptibility with respect to harvesting under such a regime.

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