

Pre-recruit abundance indices for eastern king prawn, blue swimmer crab and snapper in south eastern Queensland

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Government

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1 Introduction

Abundance indicators are an important variable included in fishery stock assessments and are used to inform fishery management decisions using harvest strategies (Haddon 2011, Sloan et al. 2014). While fishery-dependent abundance indices are commonly available, these may be influenced by changing behaviors of fishers and may not accurately represent the abundance of the population (Mauder and Punt 2004; Ye and Dennis 2009). Fishery-independent abundance indices overcome these issues and are a valuable tool to investigate changes in population structure through time.

Pre-recruit abundance indicators have improved assessments and management of fisheries, both globally and in Australia (Fowler and Jennings 2003; Hamer and Jenkins 2004; Lowery and Geer 2000). For benthic invertebrates, and some vertebrates they provide information about recruitment that can vary spatially and temporally. How trends in stock dynamics change over time is important for stock assessment and fishery management.

In southern Queensland, Fisheries Queensland conducts a beam trawl survey to determine the abundance of pre-recruit eastern king prawn (*Melicertus plebejus*), blue swimmer crab (*Portunus armatus*) and snapper (*Chrysophrys auratus*). This survey is used to inform both stock assessment and management about the recruitment variability of these three commercially valuable species.

Eastern king prawn is a key target species of the Queensland trawl fishery, and one of the most valuable commercially-fished stocks (Courtney et al. 2014). They are a large penaeid, growing up to 30 cm and may live for more than three years (Ruello, 1975; Courtney et al 2014). They undertake large migrations (<1000 km), cover a wide range of depths (1–250 m) and support shallow (<90 m) and deep (>90 m) water fisheries (Courtney et al. 2014). A fishery-independent survey is important to help understand recruitment timing and factors that influence abundance in key habitats adjacent to the fishing grounds (Courtney et al. 2002).

Blue swimmer crab is widely distributed around the Australian coastline. The species is fished recreationally and commercially in all states except Victoria and Tasmania (Kumar 1997). In Queensland, they are targeted by commercial and recreational fishers in the state's south using pots, and caught as a permitted by-product in commercial demersal trawls. Blue swimmer crabs are short lived and fast growing (Potter et al. 1983; de Lestang et al. 2003). The migratory patterns of blue swimmer crabs are not well known; however, tagging studies undertaken in Moreton Bay suggest a tendency for crabs to move into deeper waters as they increase in size (Sumpton et al. 1994, Sumpton et al. 2003). In addition, many fishers believe that Moreton Bay blue swimmer crabs migrate offshore during winter, reflected in their reduced catch rates, although this could also be due to reduced feeding activity and lower catchability during the winter. Stock structure on the east coast of Australia is uncertain, involving overlapping stocks or a semi-continuous stock (Chaplin et al. 2001).

Snapper is regarded as the premier demersal fish species in southern Queensland. Snapper are broadly distributed and caught in coastal waters from southern Queensland, throughout New South Wales to the south of the continent and north to Shark Bay in Western Australia. Snapper is a popular commercial and recreational (including charter) species with a complex biological structure. Recent genetic analyses have determined a distinct north-east biological stock extending from north of Eden, New South Wales northwards to Proserpine, Queensland (Morgan et al. 2018). Snapper are long-lived and grow slowly, aggregating to spawn in shallow coastal areas (Stewart et al. 2010). The north-

east biological stock are characterised by limited patterns of movement, with the majority of fish exhibiting small home ranges and strong site fidelity (Harasti et al. 2015; Sumpton et al. 2003).

This study aims to develop methodology to standardise pre-recruit abundance indices for eastern king prawn, blue swimmer crab and snapper collected during annual fishery-independent beam trawl surveys.

2 Methods

Fisheries Queensland conducts an annual fishery-independent beam trawl survey to improve understanding of recruitment patterns for eastern king prawns, blue swimmer crabs and juvenile snapper. After a successful pilot study was completed in 2006 using the DAF research vessel Gwendoline May, the survey commenced in 2007 aboard the RV Tom Marshall and has been conducted every year since, except in 2016.

Survey sites are located in key pre-recruit eastern king prawn, blue swimmer crab and snapper habitat between 24° 30' S and 28° S, including Moreton Bay and Hervey Bays (Figure 1). Strata were selected at each of four known nursery areas for eastern king prawn (Moreton Bay, Moreton Island, North and South Stradbroke Islands and Wide Bay), two key nursery areas for blue swimmer crabs (Moreton and Hervey Bays) and the key nursery area for Snapper (Moreton Bay) (Figure 1). Initial eastern king prawn survey strata were defined from historical trawl catch and effort data collected by Courtney et al. (2002), while blue swimmer crab strata design was based on methods developed by Sumpton et al. (2003) and snapper design was taken from Ferrell and Sumpton (1996) and Sumpton and Jackson (2005). The distribution of effort in sites has been refined since the pilot survey in 2006 for logistical and efficiency reasons, but has remained consistent since 2009. Following the completion of the 2008 survey, adjustments to the strata were made due to changes in the zoning of the Moreton Bay Marine Park in March 2009, expansion of the Wide Bay stratum and cessation of the Hervey Bay stratum (Figure 1b). In 2016, the survey was not completed in line with cost savings within the department. In 2017, the survey was reinstated under the *Queensland Sustainable Fisheries Strategy 2017-2027*. The Hervey Bay stratum was also reintroduced to complement data collected from Moreton Bay for blue swimmer crabs (Figure 1b).

The survey currently consists of two legs sampling 400 sites. Leg 1 consists of 13 nights, with four nights in Moreton Bay, two off North and South Stradbroke Islands and Wide Bay, one off Moreton Island and four in Hervey Bay. Leg 2 consists of seven nights, four nights in Moreton Bay, one night off Moreton Island and two nights off North and South Stradbroke Islands. Sites are randomly selected for sampling, with 20 sites selected for each night of the survey. The number of nights (therefore sites) selected for each stratum are proportional to the area of the stratum (Wang and Wang 2012). Further details of sampling details are available (Fisheries Queensland 2016a, 2016b, 2019a, 2019b).

The survey is conducted in November and December each year. The first phase (Leg 1) starts in the first week of November and the second phase (Leg 2) starts in the first week of December. Survey dates are weather dependent. Between 2006 and 2009 trawl surveys were also conducted in Hervey Bay and in March and October for other strata, however, these have been excluded from the analyses. Additionally, records from Hervey Bay in 2017 and 2018 have been excluded until a longer time series is obtained that can be included in future analyses.

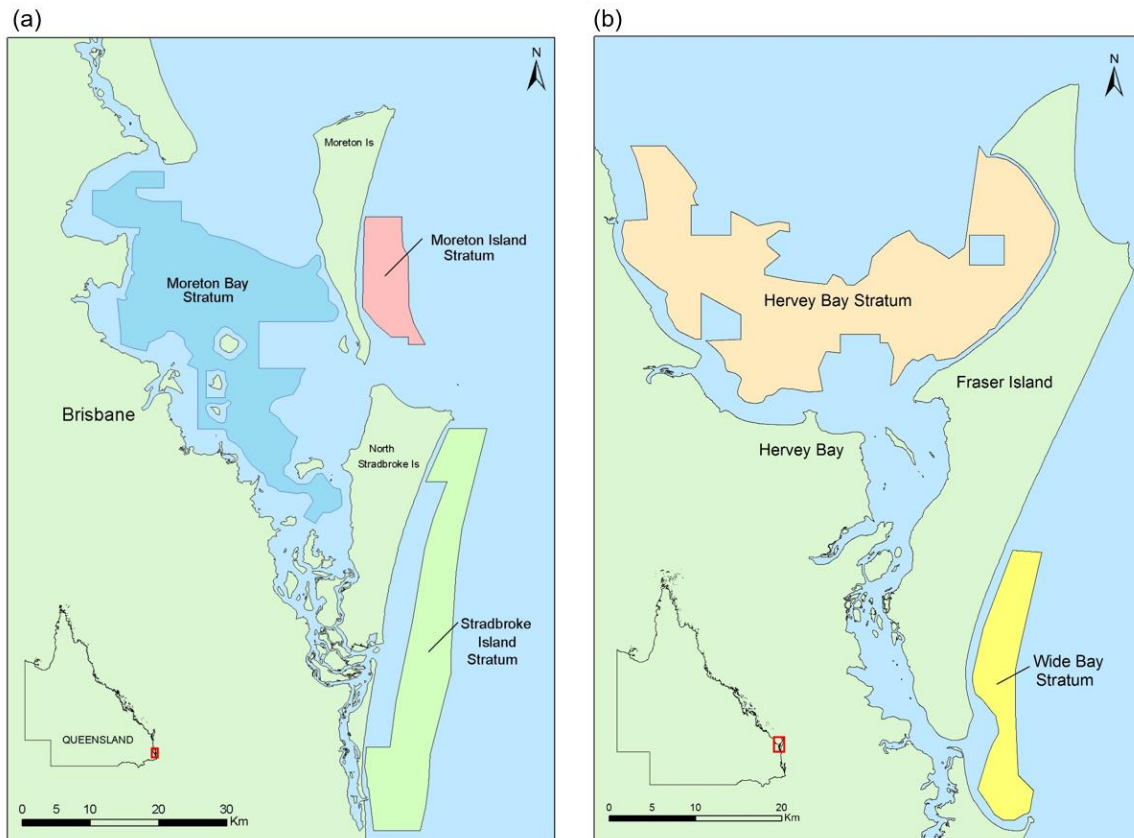


Figure 1: Map of survey strata, including (a) the three southern most strata, and (b) the northern strata, with the recently added Hervey Bay stratum.

2.1 Eastern king prawn

All prawns caught during trawl shots at each site (samples) are identified and the carapace length measured to the nearest 1 mm. If the catch contains over 100 eastern king prawn, a random sample of 100 prawns are measured while the remainder are only counted.

For analyses only prawns between 25 and 35 mm carapace length were included. This size is considered to represent prawns that will recruit to the fishery in the following months (Courtney et al. 2002), and therefore best represents fishery dynamics.

2.2 Blue swimmer crab

Crabs collected within each sample are identified to species. For each blue swimmer crab, carapace width is measured to the nearest 1 mm and sex is recorded. If there are over 50 blue swimmer crabs in a single trawl sample, the first 50 individuals are measured and the remainder counted.

For analysis, only pre-recruit (0+ year old) blue swimmer crab were included. In November pre-recruits were all crabs less than 65 mm, while in December pre-recruits were all crabs less than 85 mm carapace width. Determination of pre-recruit individuals and subsequent size inclusion during analysis were based on a peak spawning period for blue swimmer crabs in Moreton Bay (Sumpton et al. 1994) and growth parameters described by Sumpton et al. (2003).

2.3 Snapper

Snapper collected within each sample are identified to species. Fork length is measured to the nearest 1 mm, however, as the animal is alive sex is not determined.

Only pre-recruit (0+ year old) snapper, with a fork length of less than 150 mm, were included in the analysis. Sumpton (2002) details a consistent (and discrete peak) spawning period for snapper and growth parameters specific to Moreton Bay. Published biological information was used to inform approximate age (in months) and expected length at the time of the survey, this information in conjunction with modes from historical length frequency survey data aided the determination of appropriate lengths for inclusion in analysis of pre-recruit snapper (Sumpton, 2002).

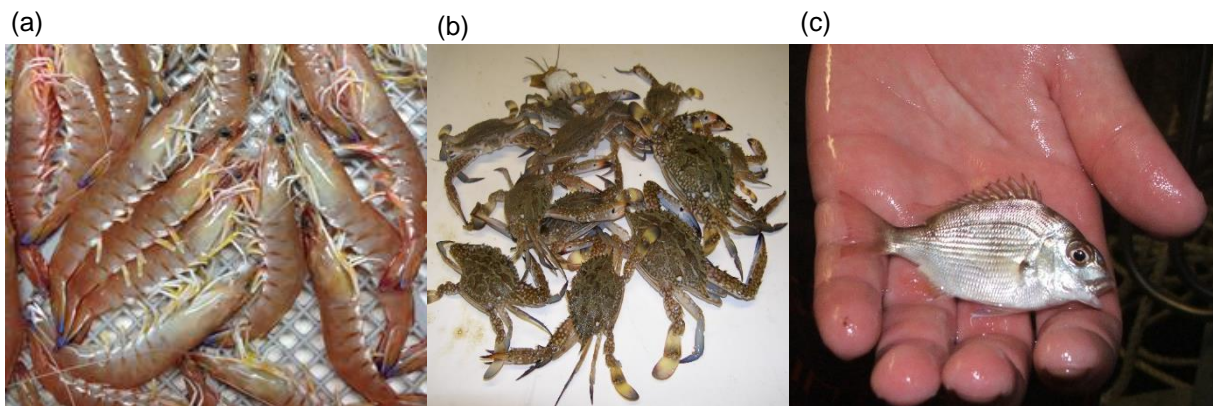


Figure 2: Juvenile (a) eastern king prawn, (b) blue swimmer crab and (c) snapper collected during the survey.

2.4 Analysis

Data were analysed using generalised linear models with a negative binomial distribution (McCullagh and Nelder, 1989). A full subset of models were investigated to determine which variables were influential for each species. These variables included year, month, area, start time group, lunar phase and depth category. Trawled area was used as an offset in each of the models.

Start time group was the start time of each sample grouped into four time blocks, including the three hour blocks following 17:00, 21:00, 00:00 and 03:00. Lunar phase was used as a categorical variable of either full, waxing, waning or new moon split equally between the 29 days of the lunar cycle. Depth was grouped into six categories of 10 m blocks, with each label representing the 10 m up to and including that depth.

The best fitting model was determined from resulting Akaike Information Criteria (AIC). Model results estimated an index of abundance for each of the investigated species. Standardised abundances were obtained from either the predict function for eastern king prawn or the Effects package (Fox and Weisberg 2018, Fox 2003) for blue swimmer crab and snapper. Analyses were conducted using R version 3.6.2 (R Core Team, 2019).

3 Results

3.1 Model terms

For each of the three species, the terms that described the best model differed. For eastern king prawn, the best model included an interaction between year and strata, with additive effects of start time group, lunar phase and depth category. For blue swimmer crab, the best model included additive effects of year, month, start time group, depth category and lunar phase. The best model for snapper included additive effects of year, depth category, start time group and lunar phase.

Table 1: Top model fits for eastern king prawn, blue swimmer crab and snapper, including the model terms, number of parameters (*n*), Akaike Information Criteria (AIC) and delta AIC

Species	Model	<i>n</i>	AIC	δ AIC
Eastern king prawn	Year x Area + Depth + Lunar phase + Start time group	55	20462	0
	Year x Area + Depth + Lunar phase + Start time group + Month	57	20464	2
	Year x Area + Depth + Lunar phase	52	20480	18
	Year x Area + Depth + Start time group	52	20466	4
	Year x Area + Lunar phase + Start time group	50	20546	84
	Year + Area + Depth + Lunar phase + Start time group	24	20609	147
Blue swimmer crab	Year + Month + Start time group + Lunar phase + Depth	22	10746	0
	Year + Month + Start time group + Depth	19	10757	11
	Year + Month + Lunar phase + Depth	19	10774	28
	Year + Start time group + Lunar phase + Depth	20	10855	109
	Year + Month + Start time group + Lunar phase	19	10932	186
Snapper	Year + Depth + Start time group + Lunar phase	19	7148	0
	Year + Depth + Start time group + Lunar phase + Month	22	7149	1
	Year + Depth + Start time group	17	7150	2
	Year + Depth + Lunar phase	17	7153	5
	Year + Start time group + Lunar phase	17	7390	242

3.2 Eastern king prawn

The average number of pre-recruit eastern king prawns in each sample varied between 2007 and 2018. The highest number of pre-recruits was observed in 2008, with a total of 47 pre-recruits per hectare (Figure 3). The next highest years of pre-recruits were in 2009 and 2012. Low years of pre-recruits were observed in 2007, 2010, 2011 and 2014 (Figure 3). In 2014, the year with the fewest pre-recruits sampled, an average of 24 pre-recruits per hectare were observed (Figure 3).

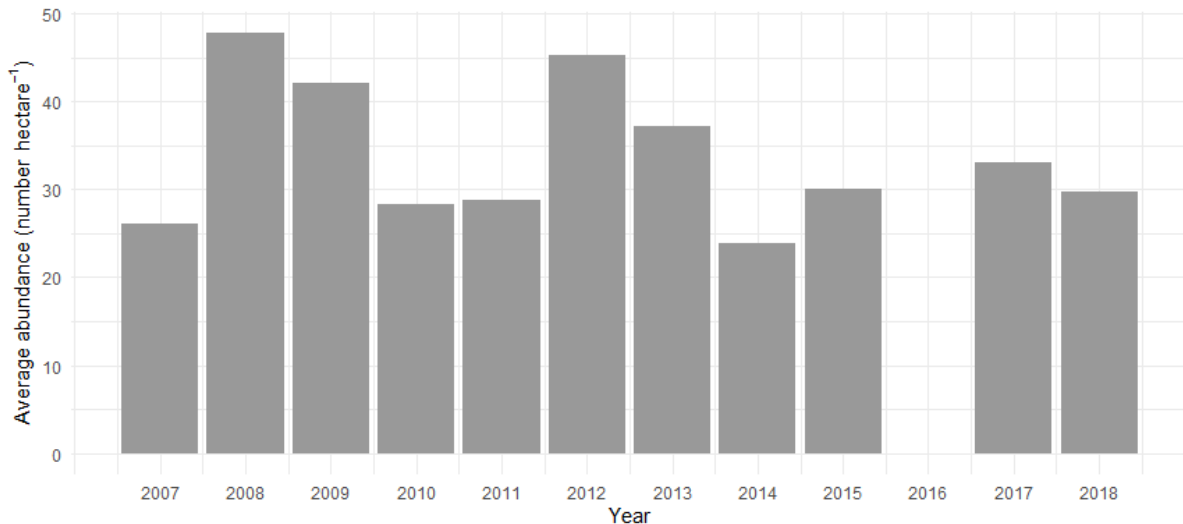


Figure 3: Average number of pre-recruit (25–35 mm) eastern king prawn (*Melicertus plebejus*) per hectare caught in annual fishery-independent beam trawl surveys. Note the survey was not conducted in 2016.

The average number of eastern king prawn pre-recruits recorded varied between the four strata (Figure 4). On average, fewer pre-recruits were observed in the Wide Bay strata compared with Moreton Bay, Moreton Island and Stradbroke Island (Figure 4). In Moreton Bay, the highest number of pre-recruits were observed in 2008 and 2009 (Figure 4). Since 2009, the average number of pre-recruits in each sample has been below 25 per hectare (Figure 4). At Moreton Island, there was a steady increase in the number of pre-recruits from 2007 to a peak in 2012 (Figure 4). The lowest number of pre-recruits was observed in 2014 before another steady increase to the highest number of pre-recruits observed in 2018 (Figure 4). At Stradbroke Island, the number of pre-recruits was generally just below 50 per hectare, however a large peak was observed in 2008, with over 125 pre-recruits per hectare observed (Figure 4). The number of pre-recruits was lowest overall at Wide Bay, with a peak in 2012 only reaching an average of just below 50 pre-recruits (Figure 4).

The best model to standardise the abundance of pre-recruit eastern king prawn included an interaction between year and area, with additive effects of start time group, depth and lunar phase. The annual standardised index has illustrated variability and no overall clear long-term trends in abundance between 2007 and 2018 (Figure 5).

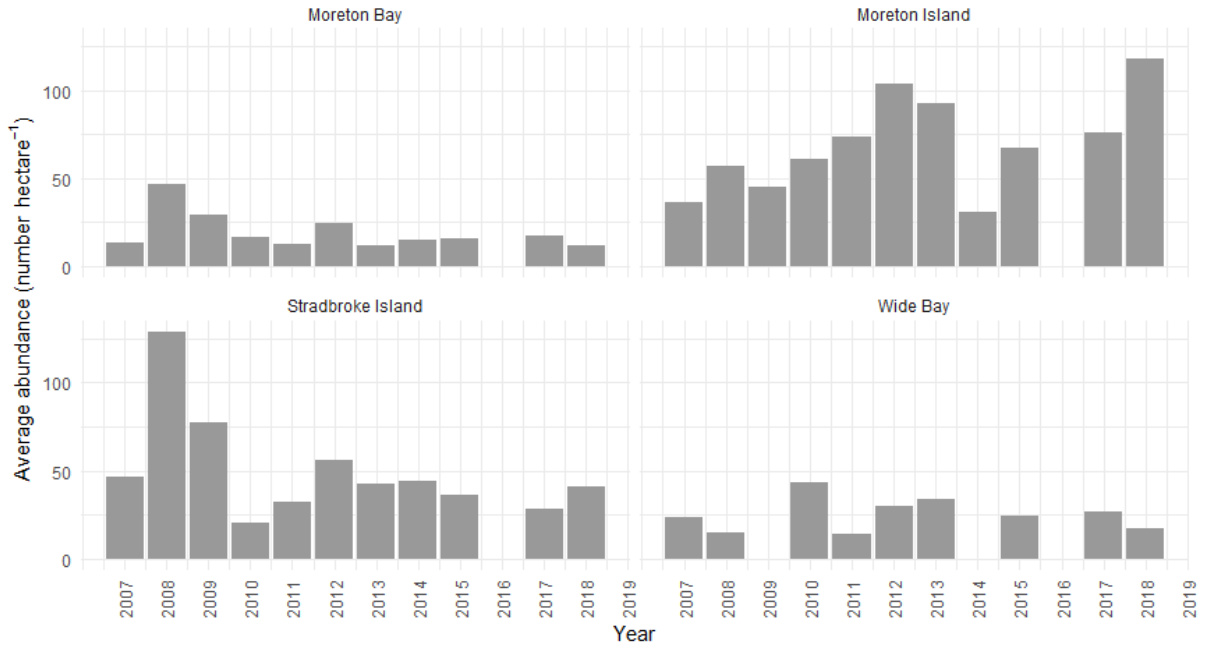


Figure 4: Average number of pre-recruit (25–35 mm) eastern king prawn (*Melicertus plebejus*) per hectare caught in annual fishery-independent beam trawl surveys, in each of the four survey regions. Note the survey was not conducted in 2016.

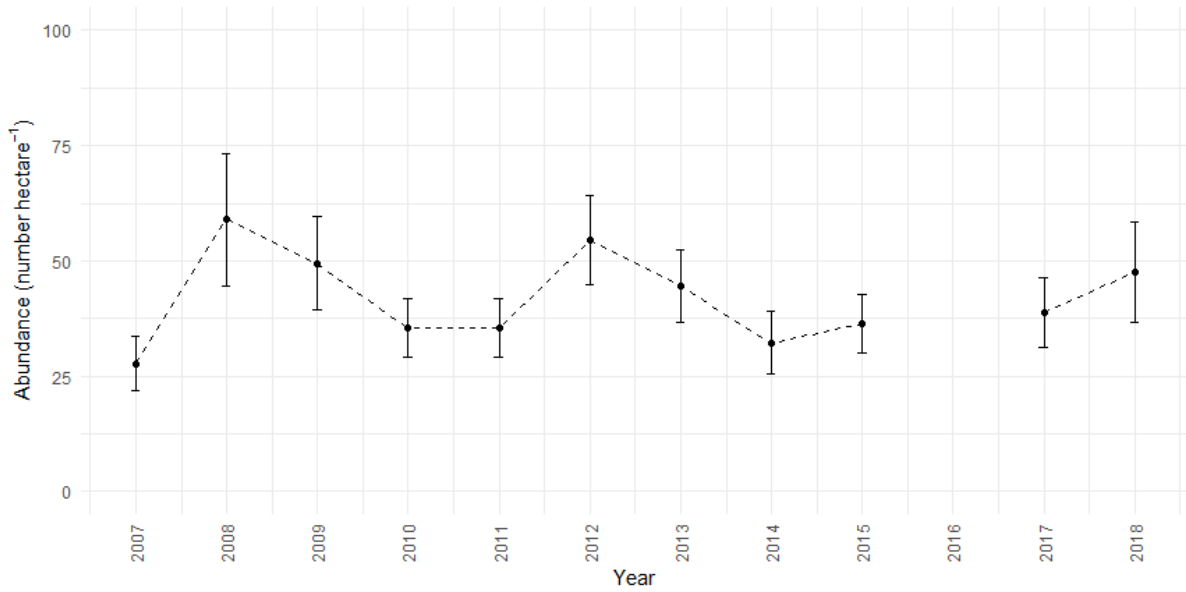


Figure 5: Standardised annual abundance of pre-recruit (25–35 mm) eastern king prawn (*Melicertus plebejus*). Error bars represent 95% confidence intervals. Note the survey was not conducted in 2016.

There was variation in the standardised abundance index between strata (Figure 6). In Moreton Bay, pre-recruit numbers were lower than other strata, with small variation and the peak in abundance was observed in 2008 (Figure 6). At Moreton Island, there was a strong increase in abundance between 2007 and 2013, with large variation associated with these estimates (Figure 6). Abundance decreased in 2014, followed by another increase in abundance, with the highest record observed in 2018 (Figure 6). At Stradbroke Island, the abundance increased from 2007 to 2008, followed by a decline to the lowest estimate in 2010 (Figure 6). Since 2010, the number of recruits ranged between 25 and 60 pre-recruits. At Wide Bay, recruits were consistently lower than Moreton and Stradbroke Islands, with two years of increased abundance in 2009 and 2010 (Figure 6).

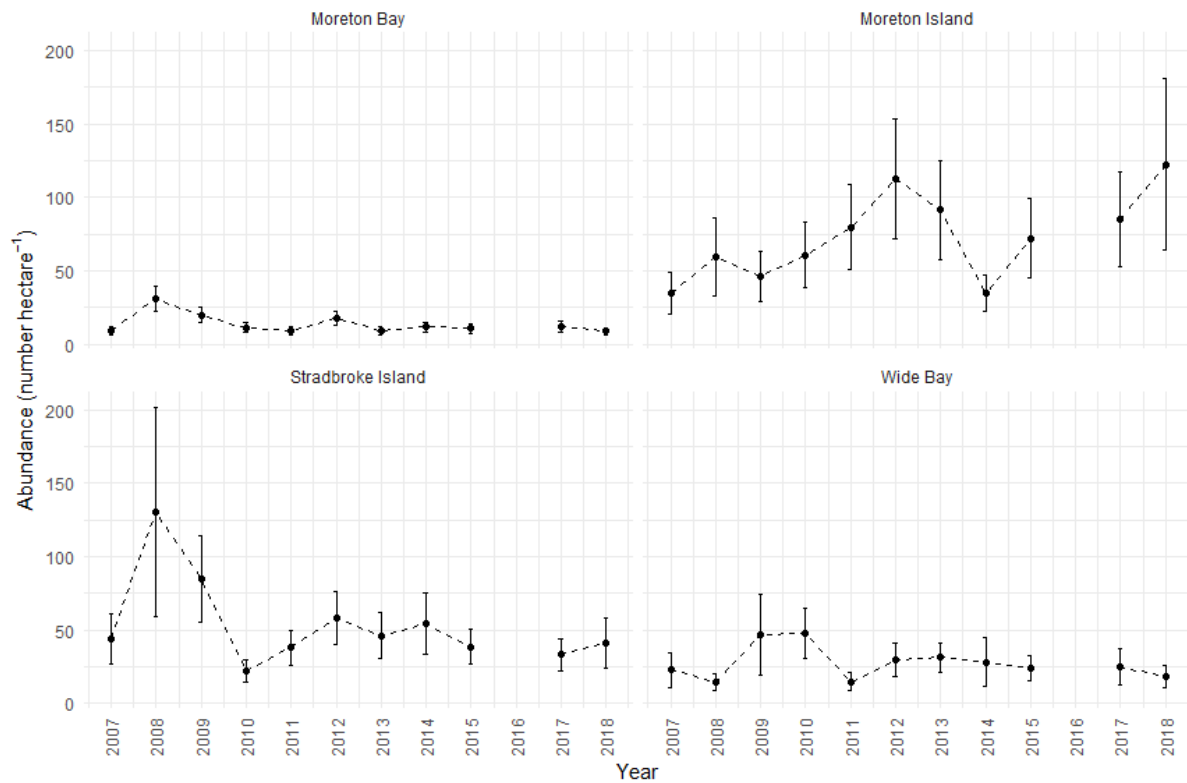


Figure 6: Standardised abundance of pre-recruit (25–35 mm) eastern king prawn (*Melicertus plebejus*) in each of the four sampled strata. Error bars represent 95% confidence intervals. Note the survey was not conducted in 2016.

The results demonstrate that, across all regions and years, higher numbers of pre-recruits were caught when surveys trawls began in the midnight start time group compared to those beginning earlier in the evening or later in the morning (Figure 7). In addition, fewer pre-recruits were observed per hectare on samples conducted during the full moon, compared to those on the new moon, or waxing or waning moon phases (Figure 7). Depth also influenced the number of pre-recruits observed, with fewer pre-recruits observed at depths of 50 m or more, although similar numbers were observed between 20 and 40 m depth, while the highest number of pre-recruits were observed at or below 10 m depth (Figure 7).

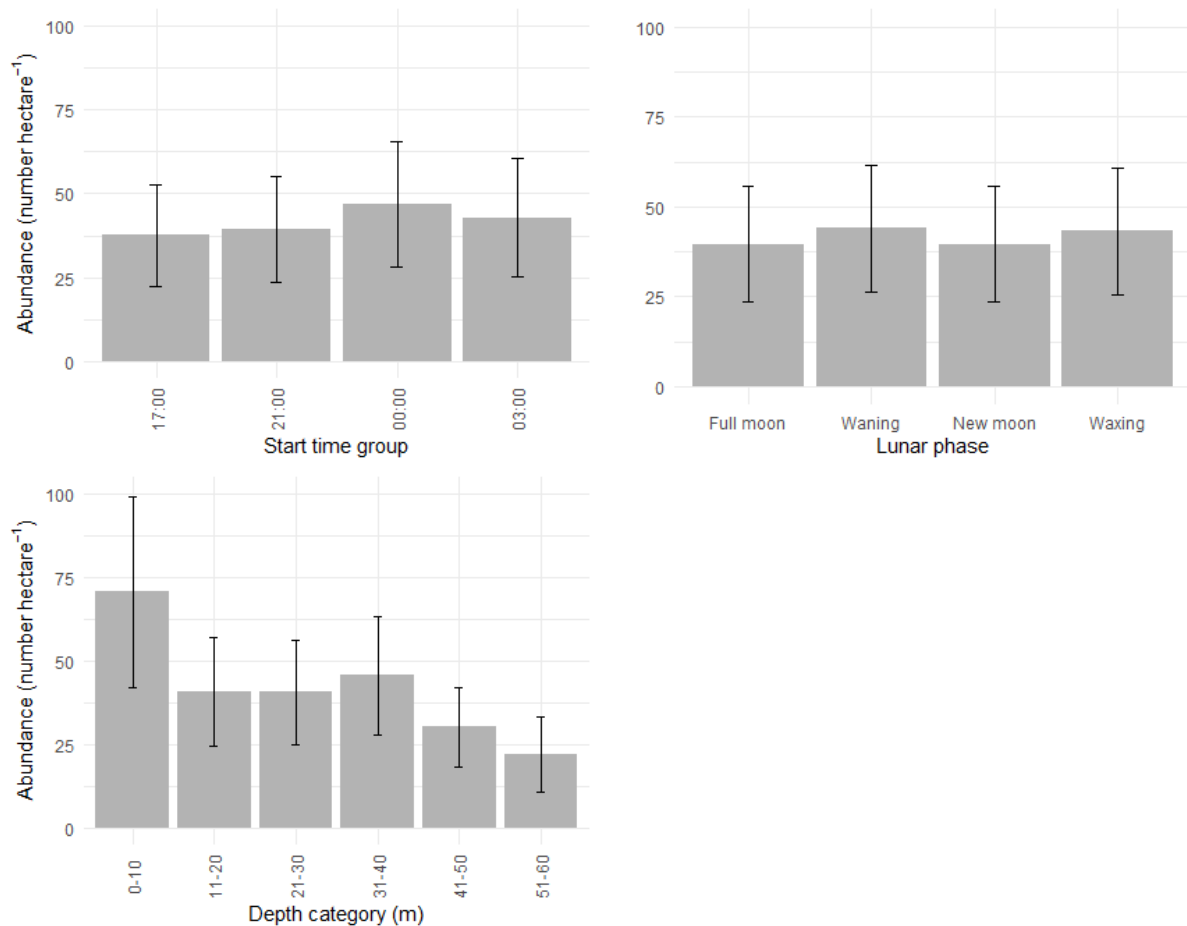


Figure 7: Standardised abundance of pre-recruit (25–35 mm) eastern king prawn (*Melicertus plebejus*) and variation in abundance by trawl start time group, lunar phase and depth of the trawl. Error bars represent 95% confidence intervals.

3.3 Blue swimmer crab

The highest average number of pre-recruit blue swimmer crabs were observed in 2008, with 77 crabs per hectare, and this is considerably higher than all other years of the survey (Figure 6). The second highest year was observed in 2017, with 39 crabs per hectare (Figure 8). The lowest number of pre-recruits was observed in 2010, with 14 crabs per hectare (Figure 8). In all other years, the number of pre-recruit blue swimmer crabs ranged between an average of 20–30 per hectare (Figure 8).

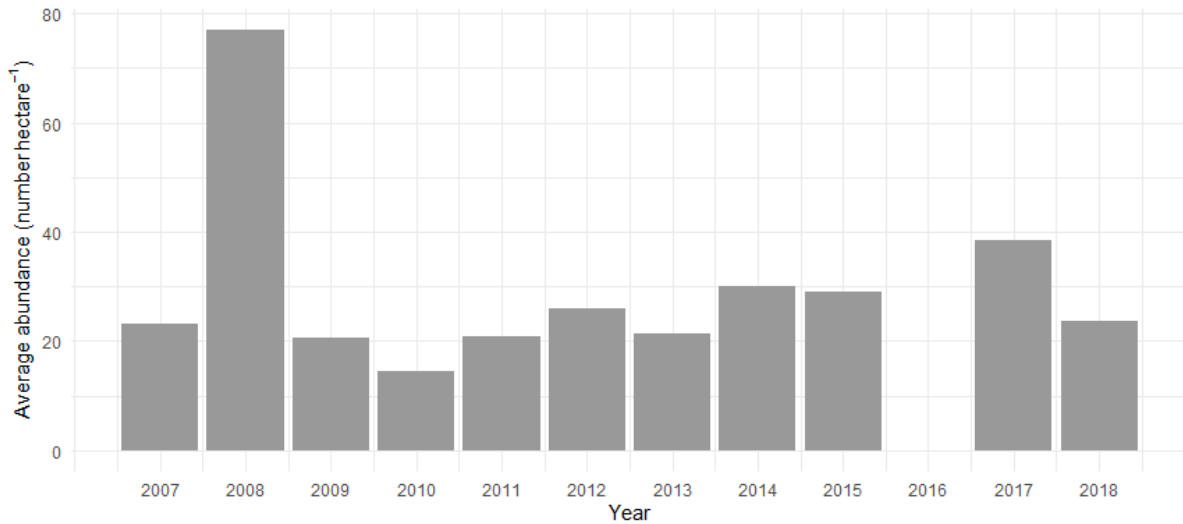


Figure 8: Average number of pre-recruit blue swimmer crabs per hectare caught in annual fishery-independent beam trawl surveys. Note the survey was not conducted in 2016.

The standardised abundance index for pre-recruit blue swimmer crab shows three clear peaks in the number of blue swimmer crabs per hectare, in 2008, 2014 and 2017, of 18, 12 and 13 crabs per hectare respectively (Figure 9). The remainder of the time series has been relatively stable, at between 5 and 8 crabs per hectare (Figure 9).

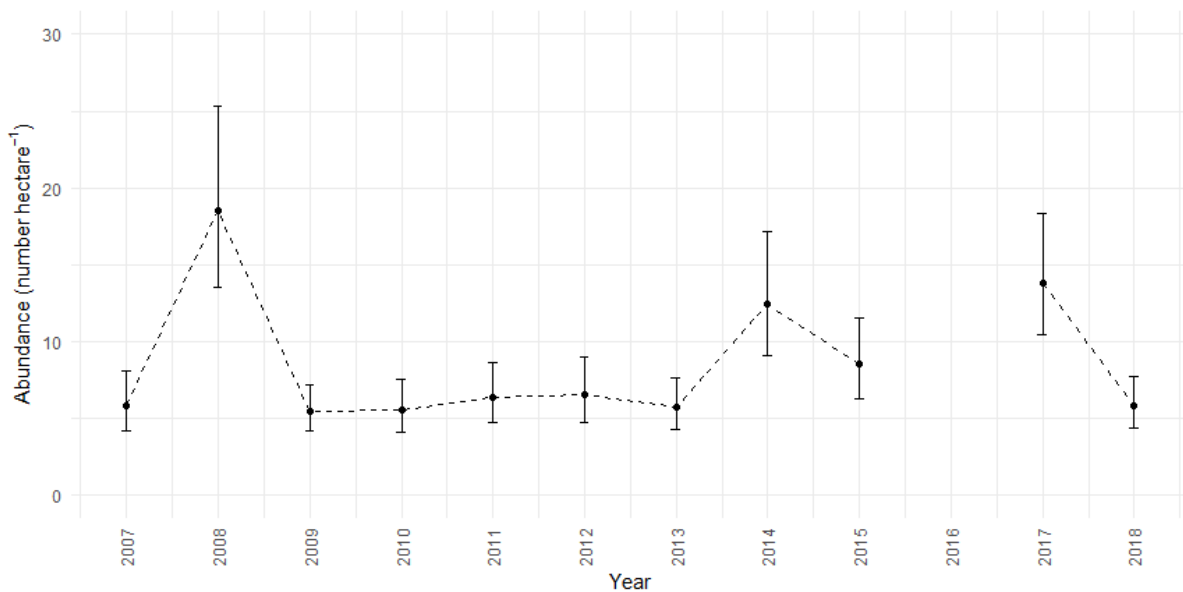


Figure 9: Standardised annual abundance of pre-recruit blue swimmer crabs. Error bars represent 95% confidence intervals. Note the survey was not conducted in 2016.

Variables that influenced the abundance of pre-recruit blue swimmer crabs in the survey, include year, month, lunar phase, start time group and depth category. Overall, more than double the number of crabs were observed in December than in November (Figure 10). Fewer blue swimmer crabs were observed during the waning moon phase, than during the full, new or waxing moon phases (Figure 10). The most pre-recruit blue swimmer crabs were caught when samples were conducted between 5 pm and 9 pm, followed by 9 pm through to midnight and midnight through to 3 am the least number of crabs were observed in samples undertaken after 3 am (Figure 10). Depth also influenced the number of pre-recruits observed, the highest number of pre-recruits were observed at or below 10 m depth, more than double that of the other depth categories (Figure 10).

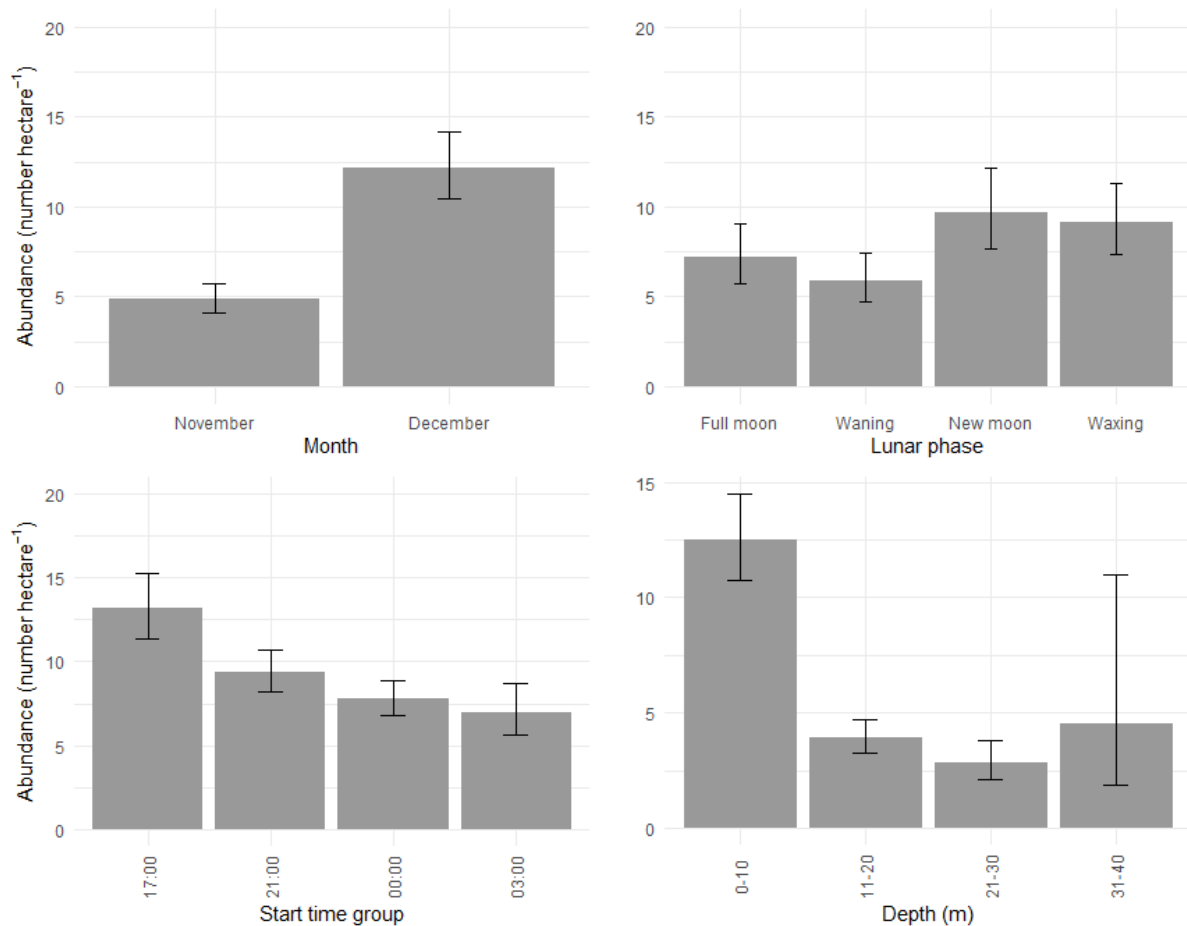


Figure 10: Standardised abundance of pre-recruit blue swimmer crabs and variation in abundance by month, lunar phase, start time of the trawl and depth category. Error bars represent 95% confidence intervals.

3.4 Snapper

The average number of pre-recruit snapper observed each year has been variable, with a peak in numbers observed in 2011 and 2012, with 15 and 11 snapper per hectare recorded respectively (Figure 11). This peak was followed by a sharp decline, with the lowest number of pre-recruits observed in 2014 and 2015, with 2 and 1 snapper per hectare observed respectively (Figure 11). An increase in pre-recruits has been observed in the two most recent surveys (Figure 11).

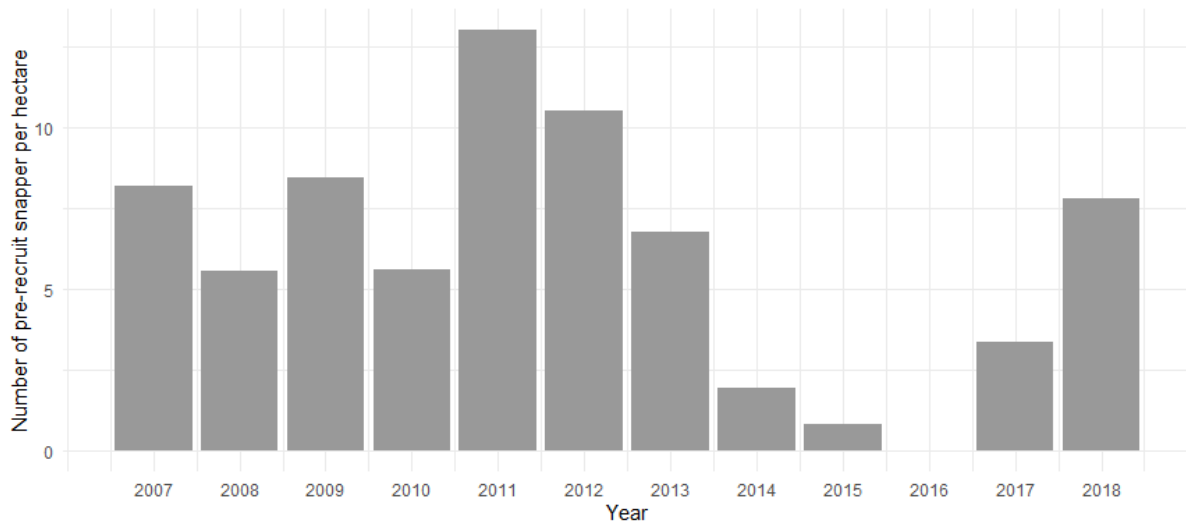


Figure 11: Total number of pre-recruit snapper per hectare caught in annual fishery-independent beam trawl surveys. Note the survey was not conducted in 2016.

The standardised abundance index for pre-recruit snapper peaked in 2011 and 2012, before falling sharply to very low estimates in 2014 and 2015, of 0.9 and 0.4 pre-recruits per hectare respectively (Figure 12). There was also little standard error associated with these low estimates compared to the higher estimates (Figure 12). Since these low abundance estimates, abundance has begun to increase again with the estimate in 2018 nearing the high estimates observed in 2011 and 2012 (Figure 12).

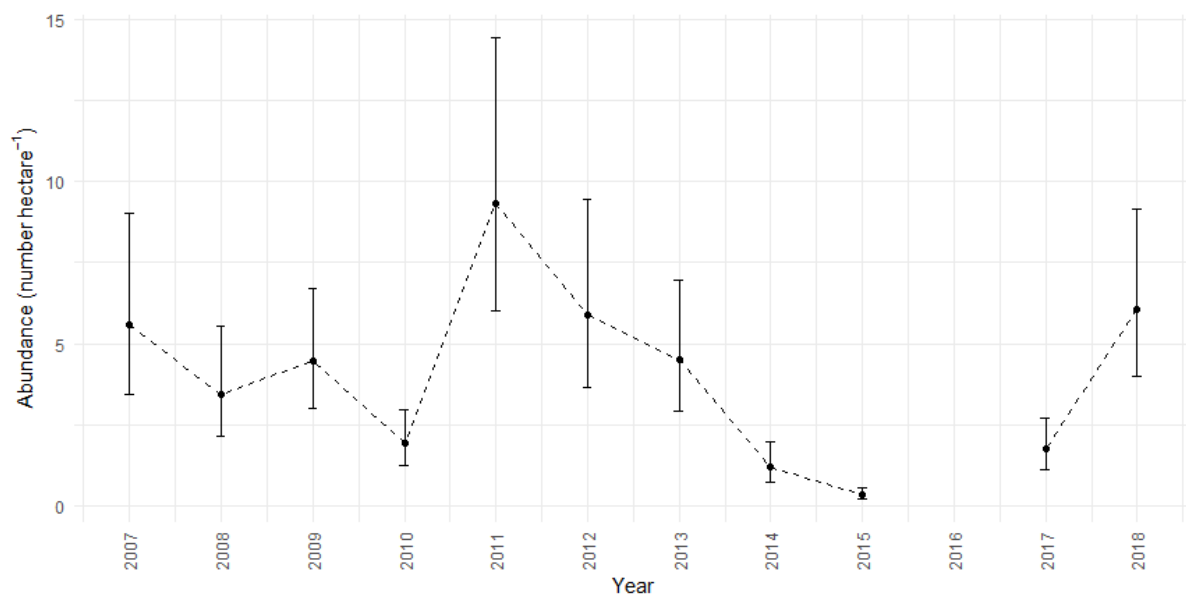


Figure 12: Standardised annual abundance of pre-recruit snapper. Error bars represent 95% confidence intervals. Note the survey was not conducted in 2016.

Several variables influenced the abundance of snapper pre-recruits. The most pre-recruit snapper were observed during the new moon, while fewer were observed during the other three moon phases (Figure 13). Higher numbers were also observed in samples between 5 pm and 9 pm, with the fewest observed during samples conducted after 3 am (Figure 13). Depth was also found to influence the number of pre-recruit snapper observed, with the highest number of individuals found in the 0–10 m depth category and a sharp decline in the numbers of snapper was observed at depths of 11 m or more (Figure 13).

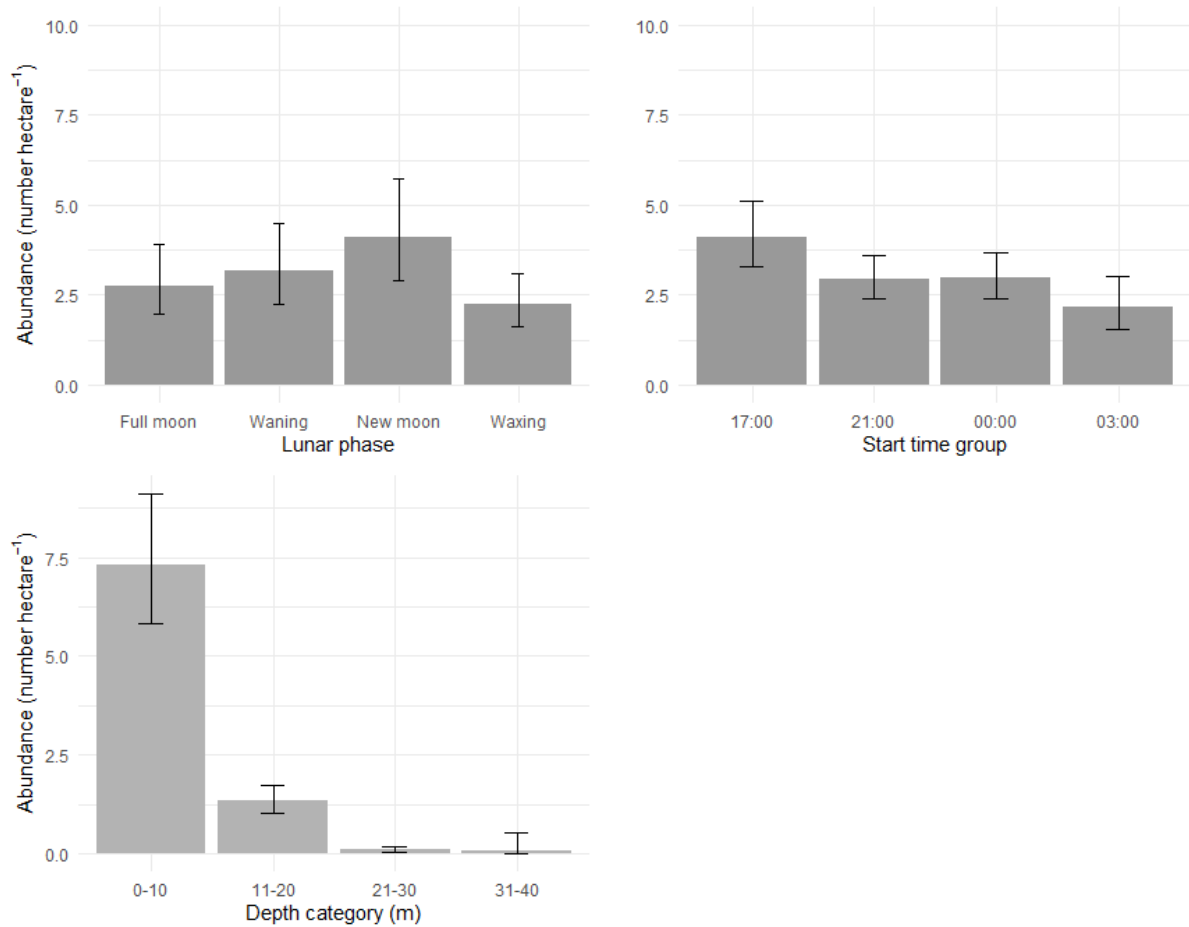


Figure 13: Standardised abundance of pre-recruit snapper and variation in abundance by lunar phase, start time of the trawl and depth category. Error bars represent 95% confidence intervals.

4 Discussion

The fishery-independent beam trawl survey was designed to generate an index of recruit abundance of eastern king prawns, snapper and blue swimmer crab in southern Queensland. The survey has undergone minor design alterations to account for legislation changes (i.e. 2009 Moreton Bay Marine Park rezoning), to improve probability of completing the full survey (i.e. reducing sampling sites at the Wide Bay stratum), and to increase stratum representation across species (i.e. addition of Hervey Bay stratum for blue swimmer crab). However, the areas, timing, gear and vessel used within the survey have remained consistent. The index of abundance has been calculated 11 times between 2007 and 2018, and provides an independent estimate of pre-recruit abundance for this time series. Being independent of the fishery, the abundance index is not biased by fisher or fishery behavior that may be subject to reporting errors as well as economic and social drivers.

Each index of pre-recruit abundance is used as a line of evidence in stock status assessments, Status of Australian Fish Stock (SAFS) assessments and survey data are also used as inputs in periodic quantitative stock assessments. Their robustness and long time series of data from a consistent design mean that the value of the information is of high quality. As Fisheries Queensland develop Harvest Strategies to manage key species, including eastern king prawn, blue swimmer crab and snapper, this time series of information is of increased importance as it can be used to assist in measuring fishery performance and to inform stock assessments to set sustainable catch and effort levels.

Given the way the data are collected there are also opportunities to increase the value of the survey through investigating data uses in addition to generating pre-recruit abundance indices and comparing catch rates. Further investigation of potential data uses should be investigated.

4.1 Eastern king prawn

An independent review of the survey design in 2012 concluded that the survey was the most cost-effective way to sample eastern king prawn effectively compared with alternative designs (Wang and Wang 2012). The study concluded that the timing, location of strata, number of sites sampled per stratum gave the most robust index with the resources Fisheries Queensland had for the survey (Wang & Wang, 2012). Additionally, comparisons of survey catch rates with commercial shallow water eastern king prawn fishery statistics show a strong correlation (Fisheries Queensland, 2012). This supports the continuation of the survey with the current design into the future.

Some observations from the survey include that the abundance of juvenile eastern king prawns are highest at shallow depths; the lunar phase and time of night had an impact upon survey catch rates; and that catch rates differed between the strata within and between years. Post-larval to juvenile stage penaeid prawns seek shallow water habitats in Moreton Bay to use as nursery areas, and the highest abundances were recorded in areas with seagrass communities (Young 1978). This is most likely due to the shallow water and seagrass communities providing protection from predators, suitable water temperature ranges, salinities and current profiles along with access to abundant food resources. As eastern king prawns grow they migrate towards deeper water and generally in a northward direction (Ruello 1975). Additionally, in the 3–4 key recruitment months (October–January) the eastern king prawn population in Moreton Bay reduces by 50% every two weeks through migration and natural mortality (Lucas 1974). Therefore, it makes sense that this study observed

higher catch rates in shallower water as prawns disperse through migration and abundance is reduced due to natural mortality.

Courtney et al. (2002) found that lunar phase did not have a significant effect on juvenile eastern king prawns in Deception Bay (part of Moreton Bay), whereas this study did. Lunar phase has previously been found to significantly affect catch rates in juveniles in shallow nursery areas (e.g. Griffiths 1999) due to a reduction in burying behaviour to escape predators. Prawns are more active and bury less when light intensity is lower (Wassenberg and Hill 1994), which affect catchability and support the findings of this study. Courtney et al. (2002) also found a correlation between time of night and prawn catches, with more prawns being caught at night outside of dawn and dusk times, which is also supported by the results of this study. Although significant, further analysis is required to determine whether start time group and depth are real factors affecting eastern king prawn catch rates and not related to sampling logistics (i.e. the pattern which randomly selected sites within the strata are sampled) or correlations with habitat (i.e. proximity of sites to a coastal bar).

The different abundance between strata and years presented here may be a result of this study sampling a wider range of depths and locations than Courtney et al. (2002) and the different biotic (e.g. food items, seagrass species) and abiotic (e.g. currents, substrate type, salinity, water temperature, distance from nursery areas) characteristics of the locations.

Future data analyses for eastern king prawn could include the development of a stock recruitment relationship, to determine correlations with the deep-water fishery, and also to investigate the impacts of abiotic variables, such as sea temperature on the abundance of juveniles. Increased understanding of these factors would increase our understanding of this stock, improve stock assessment accuracy and therefore ensure sustainable management of the fishery into the future.

4.2 Blue swimmer crab

Fishery-independent monitoring of the juvenile component of the blue swimmer crab fishery was introduced by Fisheries Queensland to help address issues associated with accuracy of historical logbook data and recreational fishing estimates and how this impacts on the reliability of indices of stock abundance. The design of the fishery-independent survey is based on the methods of Sumpton et al. (2003), who used a beam trawl to target juvenile blue swimmer crabs in Moreton Bay during 2000 and 2001. These results and results of the subsequent pilot study suggested that annual surveys to estimate abundance of juvenile blue swimmer crab would be an achievable and cost effective method for monitoring stocks in southern Queensland (Sumpton et al. 2003).

The surveys collecting biological data for blue swimmer crab have remained consistent since 2009. The design of the survey captures the pulse of juveniles resulting from the spring spawning event and is conducted during the optimal period in Moreton Bay, where recruitment is at its peak and there are limited impacts of dispersal, reduced catchability and harvest (Sumpton et al. 2015).

The importance of having an index of relative abundance has also been recognised in South Australia and Western Australia, where the management of blue swimmer crabs is informed by similar independent trawl surveys that have been validated against fishery-dependent abundance indices.

The juvenile blue swimmer crab index of abundance was used in the most recent assessment of the Queensland Blue Swimmer Crab Fishery (Sumpton et al. 2015). The assessment highlighted the need for the fishery-independent trawl surveys to continue, as the assessment relied heavily on the

recruit abundance index (Sumpton et al. 2015). The index will also be incorporated into the upcoming stock assessment of the Queensland Blue Swimmer Crab Fishery.

Previous studies have shown that abundance of juvenile crabs in Moreton Bay is dependent on time of year (Sumpton et al. 2003), while emergence of crabs from the substrate is dependent on time of day (Sumpton and Smith 1990), which is supported by the results presented here. Juvenile blue swimmer crabs are caught in higher abundances immediately after sunset and decline steadily through time until sunrise (more catchable at dusk and at the beginning of night than at and after midnight). These results support findings by Sumpton and Smith (1990), who found that crabs were most active during the same period based on percentage emergence from the substrate. The peak in activity of crabs during this period would make them more susceptible to capture and explain the increased abundance of crabs in samples.

Similarly to eastern king prawn, it would be beneficial to further analyse the effect of depth on blue swimmer crab catch rates. It is important to determine whether depth is an independent factor or whether a correlation between depth and habitat/substrate type is responsible for changes in blue swimmer crab abundance. Further work on blue swimmer crab could also include determination of a stock recruitment relationship, and determining the contribution of juvenile crabs from inshore Moreton Bay to fishing grounds further offshore. A tagging project in combination with this survey could be a potential option to determine the contribution of inshore juveniles to the offshore fishery grounds. Previous tagging studies showed adult blue swimmer crabs remained inside Moreton Bay, however, at that time there was little fishing pressure offshore and the conclusion that the stock is mainly contained within Moreton Bay now comes under question (Potter et al. 1994, Sumpton et al. 2003).

4.3 Snapper

Recruitment surveys have been carried out for snapper in other states of Australia and have proven to be a valuable source of information incorporated into the assessment and management of snapper stocks. In South Australia, Western Australia and Victoria, fishery-independent beam trawl surveys are used to describe patterns of pre-recruit snapper distribution and abundance and determine spatio-temporal variability (Fowler and Jennings 2003, Hamer and Jenkins 2004). In Queensland, previous research has confirmed the presence of pre-recruit snapper in Moreton Bay and the effectiveness of using beam trawls to detect spatial and temporal variation and determine relative abundance of pre-recruit snapper (Ferrell and Sumpton 1996, Sumpton and Jackson 2005).

Fishery-independent monitoring of pre-recruit snapper in Moreton Bay was introduced by Fisheries Queensland to provide a method to estimate and identify trends in pre-recruit snapper abundance independent of the commercial and recreational sectors. It precludes issues associated with relying on historical logbook data and recreational fishing estimates.

Annual fishery-independent beam trawl surveys collecting biological data for snapper have remained consistent since 2009. Survey design is based on other states' recruitment surveys and previous research conducted within Queensland (Fowler and Jennings 2003; Hamer and Jenkins 2004). The survey is conducted approximately one to two months after the completion of spawning events in the local mature snapper population (Sumpton 2002). This timing also coincides with the expected end of the larval settlement period for snapper into nursery areas (Sumpton 2002).

The 2009 east coast snapper stock assessment by Campbell et al. (2009) stated that monitoring was imperative in increasing the accuracy and precision of future assessments. Specifically, the continuation and refinement of the fishery-independent beam trawl survey to collect data designed to assess snapper recruitment, would aid in a better understanding of the status of the snapper stock by reducing assessment uncertainty.

Pre-recruit snapper data was not available for the initial stock assessment of snapper in 2006 as monitoring commenced shortly after this assessment was published, but has been included in all subsequent analysis of the species. Most recently, Wortmann et al. (2018) incorporated fishery-independent snapper pre-recruit catch rates from Moreton Bay as an index of abundance in stock assessment scenarios. Snapper is currently considered to be in a depleted state and it is important to continue monitoring this species to better understand the status of the stock.

The highest catch rates of pre-recruit snapper from this survey were observed at sites equal to or less than 10 m in depth. This is supported by research which has shown that juvenile snapper are more common in the shallower of Moreton Bay (at locations of 10 m and less), with catch rates in the deepest areas an order of magnitude lower than in areas less than 5 m in depth (Sumpton and Jackson 2005, Sumpton 2002). It is important to consider that it is most likely not water depth that directly influences snapper abundance, rather the presence of favourable habitat. For the aforementioned reason, it is important that the significance of the depth factor be further investigated. Additional investigation into the effect of start time group on snapper catch rates should also be conducted to ensure its significance is not related to sampling logistics (i.e. the pattern which randomly selected sites within the strata are sampled).

The snapper stock in Queensland were considered overfished before the survey began in 2007 and the recruitment levels observed, even at higher estimates are likely much lower than would be expected with a healthy stock size (Wortmann et al. 2018). Additionally, limited information is available on annual recruitment to snapper stocks in southern Queensland and the importance and contribution of juveniles from embayments such as Moreton Bay to offshore populations remains poorly understood (Ferrell and Sumpton 1996). Determining a correlation between this fishery-independent abundance index and fishery-dependent ones will be challenging due to the life history strategy of this species and specifically the long time lag between the pre-recruits observed in this survey and individuals recruited to the fishery.

4.4 Conclusions

Overall, the survey and resulting analyses have provided a fishery-independent index of abundance for each of the species investigated. The survey data have been used as a line of evidence to determine stock status of these species in a state and national context, and as recruitment inputs to quantitative stock assessment. Further benefit would arise from linking the abundance indices presented here and other fishery-dependent abundance indices to validate results and increase confidence for stakeholders. Determining these relationships should be of priority for future work in this area. The value of the survey will increase as the time series is extended with consistent methodology.

5 References

- Allen, M., Sumpton, W., O'Neill, M., Courtney, T. and Pine, B. (2006), Stochastic stock reduction analysis for assessment of the pink Snapper (*Pagrus auratus*) fishery in Queensland, Technical Report QI06069, Department of Primary Industries and Fisheries, Brisbane.
- Campbell, A., O'Neill, M., Sumpton, W., Kirkwood, J. and Wesche, S. (2009). Stock assessment of the Queensland snapper fishery (Australia) and management strategies for improving sustainability. Department of Employment, Economic Development and Innovation, Brisbane, Australia.
- Courtney A.J., Cosgrove M.G., Mayer D.G. (2002) Developing indicators of recruitment and effective spawner stock levels in eastern king prawns (*Penaeus plebejus*). Final Report FRDC 97/145, Department of Primary Industries, Queensland
- Courtney AJ, Courtney, A. J., O'Neill, M. F., Braccini, M., Leigh, G.M., Kienzle, M., Pascoe, S., Prosser, A. J., Wang, Y.-G., Lloyd-Jones, L., Campbell, A.B., Ives, M., Montgomery, S.S. and Gorrington, J. (2014) Biological and economic management strategy evaluations of the eastern king prawn fishery. Project Report. FRDC.
- de Lestang, S., Hall, N.G. and Potter, I.C. (2003). Do the age compositions and growth of the crab *Portunus pelagicus* in marine embayments and estuaries differ? Journal of the Marine Biological Association of the United Kingdom, 83: 1– 8.
- Ferrell, D. and Sumpton, W. (1996) Assessment of the fishery for snapper (*Pagrus auratus*) in Queensland and New South Wales. Fisheries Research and Development Corporation, Final Report to FRDC for project no. 93/074, Canberra, Australia.
- Fisheries Queensland (2012) Fishery independent trawl survey review: an assessment of the data 2006-2010. Brisbane, Australia.
- Fisheries Queensland (2016a) Fishery Monitoring Sampling Protocol Section 1: Eastern king prawn. Department of Agriculture and Fisheries. Brisbane, Australia.
- Fisheries Queensland (2016b) Fishery Monitoring Sampling Protocol Section 2: Eastern king prawn. Department of Agriculture and Fisheries. Brisbane, Australia.
- Fisheries Queensland (2019a). Biological Sampling Protocol: Blue Swimmer Crab, Department of Agriculture and Fisheries, Brisbane, Australia.
- Fisheries Queensland (2019b). Biological Sampling Protocol: Pre-recruit Snapper, Department of Agriculture and Fisheries, Brisbane, Australia.
- Fowler, A.J. and Jennings, P.R. (2003). Dynamics in 0+ recruitment and early life history for snapper (*Pagrus auratus*, Sparidae) in South Australia. Marine and Freshwater Research 54, 941–956.
- Griffiths, S.P. (1999). Effects of lunar periodicity on catches of *Penaeus plebejus* (Hess) in an Australian coastal lagoon. Fisheries Research 42, 195–199.
- Haddon, M. (2011). Modelling and Quantitative Methods in Fisheries 2nd Edition. Chapman and Hall, CRC Press.
- Hamer, P.A. and Jenkins, G.P. (2004). High levels of spatial and temporal recruitment variability in the temperate sparid *Pagrus auratus*. Marine and Freshwater Research 55, 663–673.

- Harasti, D., Lee, K., Gallen, C., Hughes, J. and Stewart, J. (2015). Movements, home range and site fidelity of snapper (*Chrysophrys auratus*) within a no-take marine protected area. PLoS One 10(11): e0142454
- Kumar, M. (1997). Proceedings of the First National Workshop on Blue Swimmer Crab *Portunus pelagicus*. SARDI Research Report Series, 16, 129 pp.
- Lowery, W.A. and Geer, P.J. (2000). Juvenile finfish and blue crab stock assessment program bottom trawl survey annual data summary report series. Volume 1999. Virginia Institute of Marine Science Special Scientific Report No. 124. Virginia Institute of Marine Science, Gloucester Point, VA.
- Lucas, C. (1974). Preliminary estimates of stocks of the king prawn, *Penaeus plebejus*, in South-East Queensland. Aust. J. Mar.Freshwater Res. 25, 35–47.
- Maunder M.N., Punt A.E. (2004). Standardizing catch and effort data: a review of recent approaches. Fish. Res. 70(2–3): 141–159
- McCullagh, P. and Nelder, J. A. (1989). Generalized Linear Models (2nd ed.). Chapman and Hall, London.
- Morgan, J., Sumpton, W., Jones, A., Campbell, A., Stewart, J., Hamer, P. and Ovenden, J. (2018). Assessment of genetic structure among Australian east coast populations of Snapper *Chrysophrys auratus* (Sparidae). Marine and Freshwater Research. DOI 10.1071/MF18146.
- Potter, I.C., Chrystal, P. J. and Loneragan. N.R. (1983). The biology of the blue manna crab *Portunus pelagicus* in an Australian estuary. Marine Biology 78:75–85.
- R Core Team (2019). R: A language and environment for statistical computing Version 3.6.2. R Foundation for Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>.
- Ruello, N.V. (1975). Geographical distribution, growth and breeding migration of the eastern Australian king prawn *Penaeus plebejus* Hess Australian Journal of Marine and Freshwater Research 26(3) 343–354
- Sloan, S. R., Smith, A.D.M., Gardner, C., Crosthwaite, K., Triantafillos, L., Jeffries, B. and Kimber, N. (2014) National Guidelines to Develop Fishery Harvest Strategies. FRDC Report – Project 2010/061. Primary Industries and Regions, South Australia, Adelaide, March. CC BY 3.0
- Stewart, J., Rowling, K., Hegarty, A-M. and Nuttall, A. (2010), Size and age at sexual maturity of snapper *Pagrus auratus* in New South Wales 2008/09. Industry and Investment NSW – Fisheries Research Report Series No. 27. 38pp.
- Sumpton, W. (2002). Population Biology and Management of Snapper (*Pagrus auratus*) in Queensland. PhD Thesis. University of Queensland, Brisbane, Australia.
- Sumpton, W., Campbell, M., O'Neill, M., McLennan, M., Campbell, A. and Leigh, G (2015). Assessment of the Blue swimmer crab (*Portunus armatus*) fishery in Queensland. Department of Agriculture and Fisheries.
- Sumpton, W., Gaddes, S., McLennan, M., Campbell, M., Tonks, M., Good, N., Hagedoorn, W., Skilleter, G. (2003). Fisheries biology and assessment of the blue swimmer crab (*Portunus pelagicus*) in Queensland. Final report to FRDC on Project No. 98/117. Department of Primary Industries and Fisheries, Brisbane, Australia.

- Sumpton, W. and Jackson, S. (2005). The effects of incidental trawl capture of juvenile snapper (*Pagrus auratus*) on yield of a sub-tropical line fishery in Australia: An assessment examining habitat preference and early life history characteristics. *Fisheries Research* 71, 335–347.
- Sumpton, W.D., Potter, M.A., and Smith, G.S. (1994). The biology of the commercial sand crab, *Portunus pelagicus* L. in a subtropical Australian embayment. *Asian Fisheries Science* 7: 103-113.
- Wortmann J, O'Neill MF, Sumpton WD, Campbell MJ (2018). Stock assessment of Australian east coast snapper, *Chrysophrys auratus*. Predictions of stock status and reference points for 2016. Department of Agriculture and Fisheries, Brisbane, Australia 128 pp.
- Wang, N., and Wang, Y.-G. (2012). Optimal survey design for the EKP component of LTMP – An assessment of the Fishery-independent trawl survey data. Centre for Applications in Natural Resource Mathematics, University of Queensland 17 pp.
- Wassenberg, T.J., Hill, B.J. (1994). Laboratory study of the effect of light on the emergence behaviour of eight species of commercially important adult penaeid prawns. *Aust. J. Mar. Freshwater Res.* 45, 43–50.
- Ye, Y. and Dennis, D. (2009). How reliable are the abundance indices derived from commercial catch–effort standardization? *Canadian Journal of Fisheries and Aquatic Science.* 66: 1169–1178.