10 Quantifying the performance of bycatch reduction devices (BRDs) on board vessels during their normal fishing activities – an assessment based on “opportunistic” measures of bycatch rates

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10.1 ABSTRACT

This chapter examined the effects of the TEDs and BRDs that fishers were using and was based on “opportunistic” measures of bycatch, prawn and scallop catches obtained by project staff on board vessels during their normal commercial fishing operations (as opposed to previous chapters which evaluated BRD effects from dedicated, controlled, experimental research charters). The conclusions should be interpreted with caution because of the lack of experimental control during such opportunistic sampling. Bycatch rates varied with fishing sector; the scallop fishery had the highest bycatch rate (9.39 S.E. 1.02 kg ha^{-1}) while the deepwater eastern king prawn sector had the lowest (1.30 S.E. 0.19 kg ha^{-1}). When the north Queensland tiger/endeavour prawn and eastern king prawn sectors were pooled, generalised linear modelling indicated that there was no significant reduction in the total mean bycatch rate (i.e., including large fauna or “monsters”) due to TEDs and BRDs. When large fauna were omitted from the analysis, mean bycatch rates (i.e., excluding monsters) declined significantly by 25% when the TEDs and BRDs were used together. No significant effects on marketable prawn catch rates were detected in this analysis. In the shallow water and deepwater eastern king prawn sectors, no significant reduction in total mean bycatch rate (i.e., including monsters) or mean bycatch rate (i.e., excluding monsters) were detected, due to TEDs or BRDs, nor was there any effect on mean marketable prawn catch rate. In the north Queensland tiger/endeavour prawn fishery, a 9% reduction in the catch rate of a) total mean bycatch rate (i.e., including monsters), b) bycatch rate (i.e., excluding monsters) and c) marketable prawns was detected due to the combined effects of TEDs and BRDs. These reductions were statistically significant. In the scallop fishery, a significant reduction in total mean bycatch rate (i.e., includes monsters) of 68% was detected, mainly due to TEDs excluding large bycatch species, predominantly sponges. A significant reduction (11%) in the mean scallop catch rate was also detected, mainly due to the BRDs. In general, the reductions in bycatch rates were low compared to those achieved during the research charters. The results can be used to evaluate bycatch reduction management measures and to plan and prioritise future initiatives.

10.2 INTRODUCTION

The Queensland *Fisheries (East Coast Trawl) Management Plan 1999* provides fishers with a choice of seven BRDs that they can choose from and install in their nets: 1) radial escape section, 2) fisheye, 3) square mesh panel, 4) square mesh codend, 5) bigeye, 6) Popeye fishbox, and 7) V-cut. The last two devices have only recently been approved and it is likely that further devices will be developed and included in the future. Otter trawl fishers are required, by law, to install at least one of these devices with a TED in each net, with the exception of their try-gear net. The previous chapters (Chapters 5 through to 9) quantified the effects of some of these devices with and without TEDs, under controlled experimental conditions in the major Queensland trawl sectors.

While the research charters provided valuable quantitative information on the effectiveness of the BRDs and TEDs, they do not necessarily provide insight on the performance of devices being used by the fleet. Although the charter designs went to considerable length to reflect commercial fishing conditions, (i.e., they deployed commercial vessels, commercial skippers and crews, used commercial trawl gear, were undertaken in the major trawl sectors in grounds that experienced medium to high levels of trawl fishing effort) it would be incorrect to assume that the reductions that were achieved reflected those of the commercial fleet. It was never intended that the charters' results would be representative of the bycatch reductions that were occurring in the fishery, but rather to show the expected or potential reductions in bycatch that could be achieved from certain devices in select sectors. In order to comment on the effectiveness of the devices that are being used by the fleet it was therefore necessary to undertake a second opportunistic sampling program that was focused specifically on quantifying the effects of BRDs and TEDs that the fleet were using. Project staff refer to these as "opportunistic" commercial vessel sampling data, while those of the research charters are referred to as "charter" data. To this end, this chapter quantifies the effects of the BRDs and TEDs being used by the fleet in the major Queensland trawl sectors based on the opportunistic sampling of vessels.

It should be noted that evaluating the performance of BRDs and TEDs at sea on commercial vessels while they are undertaking their normal fishing activities is challenging and in general results in limited robust quantitative data and conclusions. Researchers have very limited control over the experimental design and quality of data while sampling opportunistically. This lack of control greatly reduces our ability to quantitatively assess the bycatch reduction devices. Examples of the lack of control include:

a) inability to ensure all nets being towed on any particular vessel have no significant differences in their catch rates, irrespective of whether they have a BRD or TED installed;
b) side-of-boat or net position effects. For various reasons, the position of the net (i.e., inner port, outer port, inner starboard, outer starboard, stern) may result in it catching more, or less than the other nets, thus affecting interpretation of results;
c) reluctance of the skipper or crew to swap codend treatment types from one side of the vessel to another or from one net position to another, according to a robust statistical design;
d) a reluctance of the skipper or crew to remove the TED (because it may take too long to reinstall) in order for the net to be compared against another identical net with no TED installed;
e) reluctance of the skipper or crew to trawl along a straight line, which is required to ensure the areas swept by all nets being examined are equal; and
f) an inability to obtain a statistically adequate number of measurements.

All of these limitations were overcome by chartering vessels. Although the opportunistic data are not as statistically robust as the research charter data, they nevertheless provide some insight into the performance of the BRDs and TEDs that fishers are using. This chapter therefore presents data, results and conclusions on the effects of the BRDs and TEDs that trawl operators in the major Queensland trawl fishery sectors are using. Specifically, the effects on the catch rates of bycatch, prawns and scallops were quantified. The data, results and conclusions should be interpreted with caution due to the lack of experimental control.

10.3 MATERIALS AND METHODS

10.3.1 Obtaining measures of target species and bycatch catch rates

Fishers were usually approached over the phone and asked if they would allow a researcher on board their vessel for a few nights during normal fishing activities to measure and record the catch rates of bycatch and target species for the purposes of assessing the effectiveness of the TEDs and BRDs they were using.

Fishers who were trawling in the main trawl fishing sectors were approached. The project assumed that a) where there was more trawl fishing effort there was likely to be more bycatch produced, and b) because we were sampling commercial vessels from the main trawling sectors and areas, that the prawn, scallop and bycatch catch rates were representative of the fleet. Information recorded for each net at each trawl location while at sea included:

a) trawl location determined by the vessel’s GPS, including the latitude and longitude where the trawl commenced and finished;
b) mean speed of the trawl, trawl duration and mean depth;
c) head rope length, and other details of the net, including its position (i.e., port, starboard, middle, outer port, etc.);
d) presence or absence of BRD and/or TED;
e) BRD type;
f) weight of the retained target species catch including eastern king prawns, *Penaeus plebejus,* brown tiger prawns *Penaeus esculentus*, blue-legged king prawns, *Penaeus latisulcatus*, endeavour prawns *Metapenaeus endeavouri* and *Metapenaeus ensis*, and saucer scallops *Amusium japonicum ballotti*;
g) large species weighing more than about 5 kg, endangered species or species that were considered to be of high conservation status were identified, weighed to the nearest 1.0 kg, recorded and released before the remaining bycatch was processed. Collectively these species include turtles, sea snakes, large sponges, large sharks and rays, and are referred to as monsters; and
h) the remaining bycatch weight was recorded to the nearest 1.0 kg. A sub-sample of the bycatch was retained and processed in the laboratory to species level. Details of all bycatch species recorded from each sector from the research charters and the opportunistic sampling are provided in Appendices 1, 2, 4 and 5.

The total weight of bycatch from any given net and trawl was estimated as the sum of the monster weight and the remaining bycatch weight. It was necessary to record the bycatch weight in this way because an infrequent catch of a single large animal, such as a shark, ray, turtle or sponge can skew the data and affect the overall predicted means and therefore the conclusions about the effectiveness of the TEDs and BRDs. The marketable catch of prawns and scallops from each net was determined by the crew after each trawl, and then weighed by the researcher. It is important to note that the marketable targeted catch was not defined by researchers. In this way, the weight of the targeted catches more closely reflects those of the industry.

The configuration of the nets towed by vessels in the eastern king prawn and scallop fisheries was typically triple gear (three nets towed from the port, starboard and stern of the vessel), while vessels in the north Queensland tiger/endeavour prawn fishery typically towed quad gear (four nets, with two nets on either side of the vessel) (O'Neill et al., 2005). To assess the effect of the devices the crew were asked to remove the TED and BRD from one net, either port or starboard, to facilitate a paired comparison with a standard net during each trawl (i.e., catch rates from a standard net compared to a net with a TED or BRD, or both). However, fishers were often reluctant to remove one or both devices from a net. When this occurred it prevented any simultaneous paired comparison of treatments from being obtained and compromised the statistical integrity of the sampling program. Measurements from the stern net were not considered because it fishes differently from the port and starboard nets and because no simultaneous paired comparison was possible.

10.3.2 Calculating catch rates

All catch rates were converted to weight (kg or g) per swept area trawled (hectares, ha). The area swept *S* by net *n* during trawl *t* was estimated thus:

$$S_{tn} = \frac{H \times F \times D}{10{,}000}$$

where *H* was the headline length of the net, *F* was the net spread factor from Sterling (2005) and *D* was the distance trawled. Division by 10,000 converts the area from square metres to hectares.

10.3.3 Statistical design and analyses

Generalised linear modelling (GLM) using GenStat (2005) statistical software was used to examine the variation in catch rates of bycatch and target species (i.e., prawns or scallops). Each trawl site location was treated in the model as a blocking term. The model was an accumulated analysis of variance with the following distributions and link functions: a) normal distribution with identity link, and b) gamma distribution with logarithm link function. Catch rates for target species, bycatch (discarded bycatch minus monster weight) and total bycatch (bycatch weight plus monster weight) were the response variables in all models. When a normal distribution was used, the response variable was either log-transformed [$x = ln\ (y)$] or square-root transformed [$x = \surd\ (y)$], depending on the homoscedasticity of the residual output. When a gamma distribution and logarithm link function were used the raw, non-transformed response variable data were used. The best model goodness-of-fit was obtained by examining plots of the standardised residuals and if they were found to be non-normally distributed then the model distribution type or transformation would be changed until normality was attained. Treatment factors and interaction terms were added in a forward step-wise procedure and then dropped from the model if they were found to have no significant effect. The models took the following general form:

$$U = \beta_o + \beta_1(\text{Trawl site}_{1-\text{n}}) + \beta_2(\text{Codend type}_{1-4}) + \varepsilon$$

where *U* was the predicted mean catch rate of bycatch weight, prawn weight or saucer scallop weight, *n* was the number of sites trawled, $\boldsymbol{\beta_o}$ was an estimated scalar parameter, $\boldsymbol{\beta}_1$ and $\boldsymbol{\beta}_2$ were vector parameters that were estimated and ε was the error term. Only estimates of $\boldsymbol{\beta}_2$ are presented as this parameter quantifies the effects of the different codend types. This model differs from the models used for the research charters in that the research charters could control the net position and side-of-boat that the different codend treatments were being tested in. During the opportunistic sampling however, the researchers had no control over these factors, and for these reasons, the model is simpler and does not include terms for net position or side-of-boat effects. For purposes of interpretation and consistency with the statistical methods used in previous chapters, the $\boldsymbol{\beta}_2$ parameter estimates have been proportionally scaled so that they could be compared against a standard codend parameter value of 1.0.

Because there are several different types of BRDs and TEDs that fishers can use, the number of observations that could be obtained for a specific BRD, or a specific BRD and TED combination, was low. Therefore sufficient observations required for a robust analysis of each specific device or combination of BRD and TED were not possible. Codend treatment types were therefore pooled and categorised to four levels:

1) Standard net only (with no BRD or TED)
2) BRD only (this included all recognised BRDs listed in the Management Plan)
3) TED only, and
4) BRD and TED together.

Results were presented as the observed mean catch rate (kg ha^{-1}) from the standard net and the effect of the codend type (i.e., BRD, TED, or BRD and TED together) was displayed as a proportional change in catch rate based on the parameter estimates generated by the model.

10.4 RESULTS

Between April 2000 and April 2002, catch rate information was recorded from 434 individual commercial net trawls (Table 10.4.1). The spatial distribution of the trawl locations is provided in Figure 10.4.1.

Table 10.4.1. Number of individual net trawls for each codend type in each sector. There were so many different TEDs, BRDs, and combinations of the two, used by fishers that four broad categories were identified to represent all possibilities. These were 1) Standard codend (i.e. no BRD or TED), 2) TED only, 3) BRD only, and 4) TED and BRD together.

Codend type	**Tiger/Endeavour prawn**	**Shallow water EKP**	**Deepwater EKP**	**Scallop**
Standard codend	64	27	40	43
BRD only	0	14	36	10
TED only	0	12	3	45
BRD and TED together	64	35	0	41
Total	**128**	**88**	**79**	**139**

Bycatch rates were dependent on sector, with the scallop fishery producing the highest bycatch rates (9.39 S.E. 1.02 kg ha^{-1}), and the deepwater eastern king prawn fishery producing the lowest (1.30 S.E. 0.19 kg ha^{-1}). The mean observed catch rate of prawns from all sectors was 0.93 (S.E. 0.06) kg ha^{-1}, while the mean observed catch rate of scallops was 3.00 (S.E. 0.20) kg ha^{-1}.

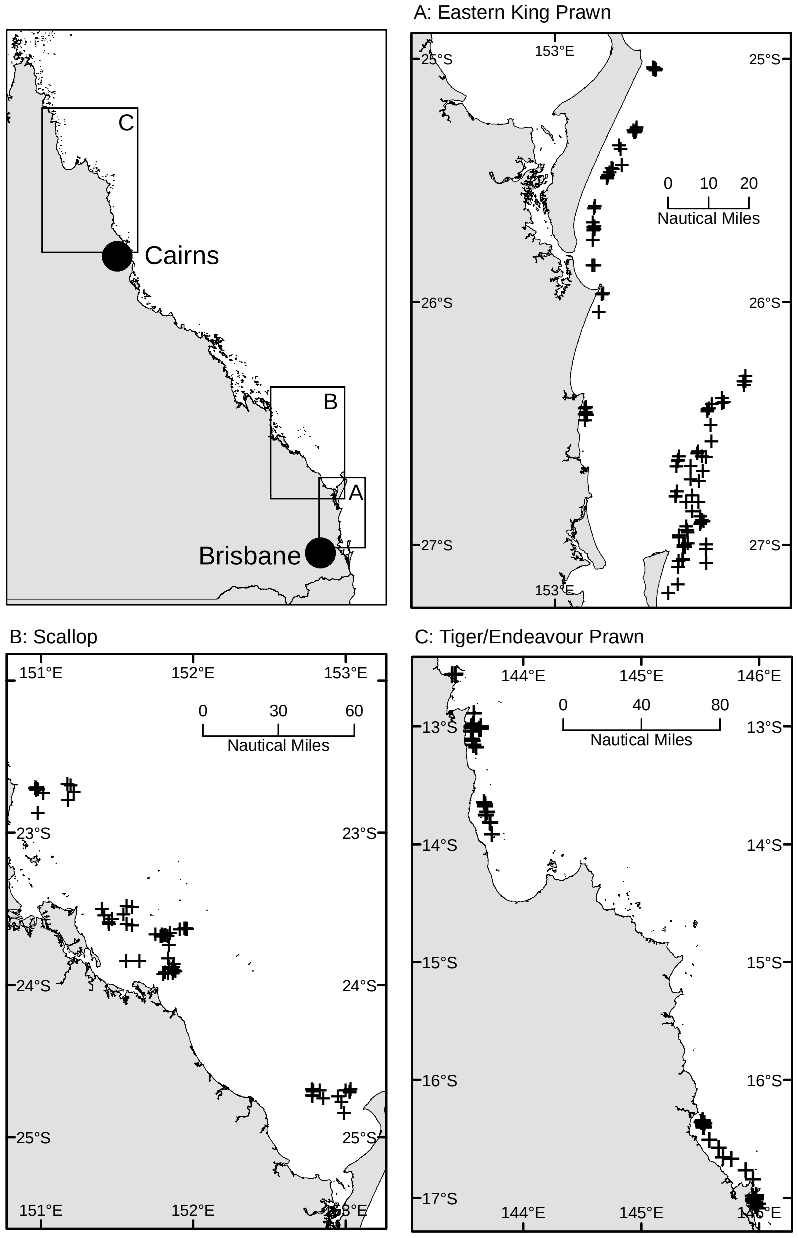

Figure 10.4.1. Locations where measures of target species and bycatch catch rates were obtained during the opportunistic sampling program for the (A) eastern king prawn fishery, (B) the scallop fishery and (C) the tiger/endeavour prawn fishery. These sectors account for about 80% of the trawl fishing effort and catch in Queensland.

10.4.1 Types of bycatch reduction devices that were evaluated

Catch rates of bycatch and target species were measured from a range of codend types. Queensland trawl fishers are required to have a TED and one of seven recognised BRDs installed in their nets. Table 10.4.2 provides a numerical breakdown of the codend types sampled in each sector during the opportunistic sampling program.

Table 10.4.2. Number of measurements obtained from individual net trawls in each sector for each different codend type obtained during the opportunistic sampling program. The numbers include observations where the BRDs were inserted with, and without TEDs.

Codend type	**Tiger/endeavour prawn**	**Shallow water eastern king prawn**	**Deepwater eastern king prawn**	**Scallop**
Bigeye	0	21	15	37
Fisheye	0	15	0	15
Square mesh panel	8	6	24	0
Radial escape section	16	0	0	0
Square mesh codend	0	0	0	0
V-cut	40	7	0	0
None (standard net)	64	27	40	41
TED only	0	12	0	46

10.4.2 Effects of BRDs on prawn catch rates

When all of the prawn sectors (i.e., shallow water eastern king prawn, deepwater eastern king prawn and north Queensland tiger/endeavour prawn) were grouped and generalised linear modelling undertaken on 295 observations, the model parameter estimates indicated no statistically significant reduction in total mean bycatch (i.e., including monsters) rate due to TEDs and BRDs (Table 10.4.3). When large bycatch were omitted from the analyses (i.e., bycatch excluding monsters), a significant reduction of 25% was detected when both the TED and BRD were installed compared to a standard net (β_2 parameter estimate of 0.75, Table 10.4.3). The analyses suggest that the inclusion of infrequently caught large individuals (such as large sharks, rays and sponges) complicates the analysis and may sometimes mask the detection of reductions in bycatch rate. The analyses indicated that TEDs alone, and BRDs alone, had no significant effect on bycatch rates (excluding monsters), but when used together significant reductions were detected. None of the codend types had a significant effect on mean prawn catch rate compared to the standard net.

Table 10.4.3. Mean catch rates of total bycatch, bycatch and marketable prawns from all prawn sectors combined based on 295 individual net tows obtained by opportunistically sampling on board fishing vessels in the eastern king prawn and north Queensland tiger/endeavour prawn sectors. Generalised linear modelling was used to quantify the effects of codend type. Significant differences between treatments ($P < 0.05$) are bolded and identified by different alphabetic characters (A, B, C or D). The parameter estimates have been proportionally scaled so they can be compared to a standard net parameter value of 1. Standard errors in parentheses.

Response variable	**Mean observed catch rate in kg ha^{-1} from standard net**	**Generalised linear model parameter estimates (Proportionally scaled to a standard net parameter value of 1)**			**Distribution type**
		TED only	**BRD only**	**BRD and TED together**	
Total bycatch (includes monsters)	**3.79 (0.33) AB**	**1.40 (0.30) A**	**0.98 (0.09) AB**	**0.92 (0.06) B**	**Gamma**
Bycatch (excludes monsters)	**3.73 (0.32) A**	**1.21 (0.12) A**	**0.84 (0.04) A**	**0.75 (0.02) B**	**Gamma**
Marketable Prawns	0.93 (0.06) A	0.93 (0.01) A	1.00 (0.01) A	0.93 (0.01) A	Normal (square-root transformed)

10.4.3 Shallow water eastern king prawn fishery

Analysis of the 88 individual net catch rate data indicated that the BRDs used in the shallow water eastern king prawn fishery had no significant effect on either total mean bycatch (i.e., including monsters) rate or mean bycatch (i.e., excluding monsters) rate (Table 10.4.4). Mean prawn catch rate was not significantly affected by the BRDs or TEDs used by fishers, nor was it affected when both devices were used together ($\boldsymbol{\beta}_2$ parameter estimate of 0.90, Table 10.4.4).

Table 10.4.4. Mean catch rates of total bycatch, bycatch and target prawn species in the shallow water (< 50 fm) eastern king prawn *Penaeus plebejus* fishery based on 88 individual net tows obtained by opportunistically sampling on board fishing vessels. Generalised linear modelling was used to quantify the effects of codend type. Significant differences between treatments ($P < 0.05$) are bolded and identified by different alphabetic characters (A, B, C or D). The parameter estimates have been proportionally scaled so they can be compared to a standard net parameter value of 1. Standard errors in parentheses.

Response variable	**Mean observed catch rate in kg ha^{-1} standard net**	**Generalised linear model parameter estimates (Proportionally scaled to a standard net parameter value of 1)**			**Distribution type**
		TED only	**BRD only**	**BRD and TED together**	
Total bycatch (includes monsters)	5.48 (1.30) A	1.66 (0.55) A	1.04 (0.28) A	0.91 (0.15) A	Normal (log transformed)
Bycatch (excludes monsters)	5.21 (1.25) A	1.43 (0.06) A	1.10 (0.06) A	0.88 (0.06) A	Normal (square-root transformed)
Marketable Prawns	1.20 (0.13) A	0.78 (0.15) A	1.04 (0.17) A	0.90 (0.09) A	Normal (log transformed)

10.4.4 Deepwater eastern king prawn fishery

The mean catch rate of total bycatch (i.e., including monsters) in the deepwater eastern king prawn fishery was not significantly affected by the BRDs and TEDs that the fishers were using (Table 10.4.5). Mean catch rate of the targeted eastern king prawns was also unaffected by the devices (Table 10.4.5). However, when a BRD was used in conjunction with a TED, the mean catch rate of bycatch (i.e., excluding monsters) was significantly increased ($\boldsymbol{\beta}_2$ parameter estimate of 1.39). No measurements were obtained from this sector for nets that had the TED only.

Table 10.4.5. Mean catch rates of total bycatch, bycatch and target prawn species from the deepwater eastern king prawn fishery *Penaeus plebejus* based on 79 individual net tows obtained by opportunistically sampling on board fishing vessels. Generalised linear modelling was used to quantify the effects of codend type. Significant differences between treatments ($P < 0.05$) are bolded and identified by different alphabetic characters (A, B, C or D). The parameter estimates have been proportionally scaled so they can be compared to a standard net parameter value of 1. Standard errors in parentheses.

Response variable	Mean observed catch rate in kg ha^{-1} from standard net	Generalised linear model parameter estimates (Proportionally scaled to a standard net parameter value of 1)			Distribution type
		TED only	BRD only	BRD and TED together	
Total bycatch (includes monsters)	1.30 (0.19) A	-	1.00 (0.07) A	1.29 (0.03) A	Gamma
Bycatch (excludes monsters)	**1.28 (0.18) A**	**-**	**0.95 (0.05) A**	**1.39 (0.22) B**	**Normal (log transformed)**
Marketable Prawns	0.59 (0.07) A	-	1.03 (0.04) A	1.20 (0.13) A	Normal (log transformed)

10.4.5 North Queensland tiger/endeavour prawn fishery

Analyses of the 128 observations from the north Queensland tiger/endeavour prawn sector indicated that when the TEDs and BRDs were used together, they resulted in a significant reduction (9%) in a) total mean bycatch (i.e., including monsters) rate, b) mean bycatch (i.e., excluding monsters) rate, and c) mean prawn catch rate ($\boldsymbol{\beta}_2$ parameter estimate of 0.91, Table 10.4.6). Note that no measurements were obtained from nets that had BRDs only or TEDs only, and therefore it was not possible to quantify these codend types in this particular sector. The only term that could be quantified was BRDs and TEDs together.

Table 10.4.6. Mean catch rates of total bycatch, bycatch and target prawn species *Penaeus latisulcatus, Penaeus semisulcatus, Metapenaeus endeavouri* and *Metapenaeus ensis* from the north Queensland tiger/endeavour prawn fishery based on 128 individual net tows obtained by opportunistically sampling on board fishing vessels. Generalised linear modelling was used to quantify the effects of codend type. Significant differences between treatments ($P < 0.05$) are bolded and identified by different alphabetic characters (A, B, C or D). The parameter estimates have been proportionally scaled so they can be compared to a standard net parameter value of 1. Standard errors in parentheses.

Response variable	Mean observed catch rate in kg ha^{-1} standard net	Generalised linear model parameter estimates (Proportionally scaled to a standard net parameter value of 1)			Distribution type
		TED only	BRD only	BRD and TED together	
Total Bycatch (includes monsters)	**4.64 (0.26) A**	**-**	**-**	**0.91 (0.02) B**	**Gamma**
Bycatch (excludes monsters)	**4.64 (0.26) A**	**-**	**-**	**0.91 (0.02) B**	**Gamma**
Marketable Prawns	**1.03 (0.08) A**	**-**	**-**	**0.91 (0.03) B**	**Gamma**

10.4.6 Scallop fishery

Analysis of the 139 bycatch measurements obtained in the saucer scallop fishery indicated that a) TEDs, b) BRDs and c) both devices used together all resulted in a significant reduction in mean total bycatch (including monsters) rate (Table 10.4.7). The predicted mean catch rate of total bycatch (i.e., including monsters) was 68% lower in nets with both a TED and BRD ($\boldsymbol{\beta}_2$ parameter estimate of 0.32, Table 10.4.7). Note the same level of reduction was achieved for the TED-only analysis. All codend types caught significantly less total bycatch (i.e., including monsters) compared to the standard net. Of all of the analyses undertaken with the opportunistic data, this was the largest reduction in total mean bycatch (i.e., including monsters) rate of any sector.

When large fauna (i.e., monsters) were excluded from the analyses, the model indicated a 31% reduction in mean bycatch rate in nets with both a TED and BRD ($\boldsymbol{\beta}_2$ parameter estimate of 0.69, Table 10.4.7). The parameter estimates indicated that most of the reductions in bycatch were due to the TED, and that the TED excluded more bycatch in saucer scallop fishery than BRDs. When the TEDs and BRDs were used together, they resulted in a significant (11%) reduction in the mean catch rate of scallops ($\boldsymbol{\beta}_2$ parameter estimate of 0.89, Table 10.4.7). Most of the reduction was due to the BRDs ($\boldsymbol{\beta}_2$ parameter estimate of 0.90, Table 10.4.7), while the TED only had no significant effect on mean scallop catch rate.

Table 10.4.7. Mean catch rates of total bycatch, bycatch and scallops from the Queensland saucer scallop *Amusium japonicum ballotti* fishery based on 139 individual net tows obtained by opportunistically on board fishing vessels. Generalised linear modelling was used to quantify the effects of codend type. Significant differences between treatments ($P < 0.05$) are bolded and identified by different alphabetic characters (A, B, C or D). The parameter estimates have been proportionally scaled so they can be compared to a standard net parameter value of 1. Standard errors in parentheses.

Response variable	**Mean observed catch rate in kg ha^{-1} from Standard net**	**Generalised linear model parameter estimates (Proportionally scaled to a standard net parameter value of 1)**			**Distribution type**
		TED only	**BRD only**	**BRD and TED**	
Total bycatch (including monsters)	**9.39 (1.02) A**	**0.32 (0.03) C**	**0.60 (0.14) B**	**0.32 (0.04) C**	**Normal (log transformed)**
Bycatch (excludes monsters)	**4.46 (0.59) A**	**0.68 (0.05) B**	**0.81 (0.13) AB**	**0.69 (0.06) B**	**Gamma**
Marketable Scallops	**3.00 (0.20) A**	**0.99 (0.01) A**	**0.90 (0.01) AB**	**0.89 (0.01) B**	**Normal (square-root transformed)**

10.5 DISCUSSION

Although maintaining experimental control is challenging when working on board vessels during their normal working operations, the data and analyses provide valuable information on the performance of the BRDs that are being used by the Queensland trawl fleet. The main findings from this chapter are:

1) When the prawn trawl sectors were pooled, no statistically significant reduction in total mean bycatch (i.e., including monsters) rate was detected due to TEDs or BRDs, together or by themselves (Table 10.4.3). When large bycatch species were omitted from the analysis, a statistically significant reduction of 25% in mean bycatch (i.e., excluding monsters) rate was detected when both devices were used together.
2) When the prawn trawl sectors were pooled, no significant effects on mean prawn catch rates were detected for TEDs and BRDs, by themselves or when used together.
3) In the north Queensland tiger/endeavour prawn fishery, mean bycatch rates declined significantly (by 9%, $\boldsymbol{\beta}_2$ parameter estimate of 0.91, Table 10.4.6) when TEDs and BRDs were used together, but a statistically significant equivalent reduction in mean prawn catch rate was also detected.
4) No significant reduction in mean bycatch rate was detected in the shallow water (Table 10.4.4) or deepwater (Table 10.4.5) eastern king prawn sectors, nor was there any significant effect on mean prawn catch rate in these sectors.
5) A 68% reduction in the total mean bycatch (i.e., including monsters) rate was obtained from the saucer scallop fishery when TEDs and BRDs were used together ($\boldsymbol{\beta}_2$ parameter estimate of 0.32, Table 10.4.7). The same reduction was obtained for the TED-only analysis. Significant bycatch reduction due to BRDs is occurring in the scallop fishery, but most is attributed to the TEDs.
6) A statistically significant reduction of 11% in the mean scallop catch rate was detected in nets with both a TED and BRD (Table 10.4.7). This loss of scallops was largely due to the BRDs that fishers were using.

The opportunistic sampling provided detailed information on catch rates directly from the fleet, but it was heavily dependent upon a) when the fishers allowed the researchers on board to obtain measurements and b) where the fishers chose to trawl. For the data and analyses to be of value, we have to assume that the data are representative of the fleet. While such assumptions can be made for the research charters (because the charters were specifically designed to be representative), we had very little control over the opportunistic sampling design. Also, the experimental design and control required for comparing nets with and without BRDs and TEDs was very limited. Fishers in Queensland are required to use a TED and one of seven recognised BRDs. In most cases, the objective for commercial fishers when choosing a suitable device is to minimise the loss of target species and bycatch reduction is of secondary importance.

The mean catch rate of marketable prawns in the eastern king prawn fishery was unaffected by TEDs and BRDs (Table 10.4.4 and Table 10.4.5). The mean bycatch rate was also largely unaffected. In contrast, the devices lowered marketable prawn catch rates in the north Queensland tiger/endeavour prawn fishery (Table 10.4.6). The fact that the reductions for prawns and bycatch occurred at the same rate (i.e., 9%) suggests that the devices being used were inefficient. That is, if efficient BRDs were used, it is reasonable to expect that bycatch reduction would have been higher than prawn loss. The fact that prawn loss and bycatch reduction were similar indicates that the TED and/or BRD were inadvertently allowing the passive loss of both bycatch and target species, rather than providing escape routes for bycatch species only.

The TEDs and BRDs used in the scallop fishery were more effective at reducing mean bycatch rate, with a concurrent small but significant reduction (11%) in mean scallop catch rate. The reduction in mean total bycatch rate was largely due to the TEDs and their interaction with large fauna. Large fauna make up approximately 64% of the bycatch weight in the scallop fishery, of which large sponges (Porifera) comprised 92% (Chapter 7). As such, TEDs were able to exclude the majority of the large fauna, resulting in a significant reduction in total mean bycatch rate. Interestingly, the regular exclusion of this large fauna did not result in a reduced mean scallop catch rate. Scallop loss can occur for two reasons. Firstly, the escape flap on the TEDs will continually open to exclude the large fauna, at which time scallops may also escape. Secondly, if an efficient TED is not used, large fauna may clog the TED, resulting in a build-up of catch and scallops in front of the device. At the completion of a trawl the accumulated catch can then either fall through the TED's escape hole or be forced forward through the mouth of the net. The fact that there was no significant reduction in scallop catch rate due to the TED (Table 10.4.7) suggests that commercial fishers were using relatively efficient devices in the scallop fishery.

10.6 REFERENCES

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11 An overview of the elasmobranch bycatch in the Queensland East Coast Trawl Fishery (Australia) and the effects of bycatch reduction devices

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11.1 ABSTRACT

The Queensland East Coast Trawl Fishery (QECTF) is a complex multi-species and multi-sector fishery operating along Queensland's eastern coastline, with combined annual landings of about 10,000 tonnes. Elasmobranchs represent a relatively small but potentially ecologically significant component of bycatch in this fishery. At least 94 species of elasmobranchs occur in the managed area of the QECTF and half of these were recorded in the fishery's bycatch. Catch rates from the research charters indicated that elasmobranch bycatch was highly variable between sectors. Elasmobranch bycatch was extremely low in the north Queensland tiger/endeavour prawn fishery, low in the deepwater eastern king prawn fishery and moderate in the shallow water eastern king prawn and scallop fishery. The bycatch was dominated by one rhinobatid species (*Aptychotrema rostrata*) and two urolophids (*Trygonoptera testacea* and *Urolophus kapalensis*) in the shallow water eastern king prawn fishery, by one rajid species (*Dipturus polyommata*) and two scyliorhinids (*Asymbolus rubiginosus* and *Galeus boardmani*) in the deepwater eastern king prawn fishery, and by *A. rostrata* and two dasyatid stingrays (*Dasyatis kuhlii* and *D. leylandi*) in the scallop fishery. Significant reductions in the mean catch rate of *A. rostrata* and *A. rubiginosus* due to TEDs and BRDs were detected during two charters. Results from all of the charters were combined to give an overview of elasmobranch bycatch across the fishery. New information on elasmobranch distributions in Queensland waters is also presented.

11.2 INTRODUCTION

It is estimated that approximately half of the annual global catch of chondrichthyans (the cartilaginous fishes: elasmobranchs and holocephalans) is taken as bycatch (Stevens et al., 2000). As a consequence, some species of skates (Rajidae), sawfishes (Pristidae) and deepwater dogfishes (Centrophoridae and Squalidae) have been virtually extirpated from large areas (Stevens et al., 2000). In Australian waters, Graham et al. (2001) reported significant declines in catches of two dogfishes, *Centrophorus harrissoni* and *C. uyato*, together with skates and stingarees (Urolophidae) after 20 years of demersal fish trawling on the continental slope off New South Wales (NSW). Sharks and rays are also a regular component of the bycatch in Australia's Northern Prawn Fishery (Brewer 1999), where Stobutzki et al. (2001) identified 56 species and considered the unsustainability of stingray (Dasyatidae) and sawfish capture of particular concern.

The QECTF is a complex multi-species and multi-sector fishery, operating from Cape York in the north (10º30´ S, 142º30´ E) to the Queensland/NSW border (28º00´ S, 153º30´ E). This fishery is comprised of otter trawlers operating in coastal waters taking prawns (Penaeidae), scallops (*Amusium* spp.) and whiting (*Sillago robusta*); and beam trawlers targeting prawns in estuarine and inshore waters. The combined annual landings of the fishery are close to 10,000 t, with bycatch estimated to exceed 25,000 t (Robins and Courtney, 1999). The bycatch of elasmobranchs is known to vary considerably between fishery sectors. For example, in the Moreton Bay sector, elasmobranchs accounted for 15.4% of the bycatch by weight (Wassenberg and Hill, 1989) while in the banana prawn sector they represented less than 0.25% of the total bycatch (Stobutzki et al., 2001).

Bycatch reduction devices (BRDs) and turtle excluder devices (TEDs) were made mandatory throughout the otter trawl fishery between 2000 and 2002 and a bycatch reduction target of 40% was specified in the fishery's Management Plan [*Fisheries (East Coast Trawl) Management Plan 1999*]. Robins et al. (1999) and Broadhurst (2000) presented overviews of BRDs and TEDs employed in Australian prawn trawl fisheries. Seven BRDs are recognised in the Management Plan including the radial escape section, square mesh panel, fisheye, square mesh codend, bigeye, V-cut and the Popeye fishbox. A number of TED designs can also be used but all TED bar spacings are required to be no more than 12 cm apart. Little research has focused specifically on how BRDs and TEDs influence the capture of elasmobranchs. Robins-Troeger (1994) and Brewer et al. (1998) both highlighted the reduced capture of larger elasmobranchs, particularly batoids, in nets fitted with TEDs. However, while it is expected that the use of TEDs should greatly reduce the capture of larger elasmobranchs, the capture of smaller species and individuals may not be altered (Brewer, 1999).

This chapter describes the elasmobranch catch in various sectors of the QECTF and the effect BRDs and TEDs on their catch rates. While the project used both dedicated research charters and opportunistic sampling of the commercial vessels to sample the bycatch, this chapter presents results largely on the earlier. The species composition of elasmobranch bycatch in these sectors is presented, including new information on occurrence and distribution, and is discussed in the context of conservation and the management of biodiversity.

11.3 MATERIALS AND METHODS

Data on elasmobranchs sampled from the five research charters were analysed, specifically data from the:

1. shallow water eastern king prawn charter (Chapter 5)
2. north Queensland tiger/endeavour prawn charter (Chapter 6)
3. scallop charter (Chapter 7)
4. Hervey Bay whiting bycatch charter (Chapter 8)
5. deepwater eastern king prawn charter (Chapter 9).

In addition, elasmobranch species recorded from opportunistically sampling the bycatch of commercial vessels during their normal trawling activities in the eastern king prawn, tiger/endeavour prawn and scallop fisheries were also presented. Elasmobranch data from a previous FRDC-funded project (Project 96/257, Stobutzki et al., 2001), which includes a description of the bycatch from the Queensland banana prawn fishery, were also incorporated.

11.3.1 Recording catch rates

Details of the bycatch sampling methods can be found in the abovementioned chapters. In brief, all elasmobranchs sampled during the research charters were removed from the bycatch immediately after each trawl and later examined in the laboratory. Individuals were identified, weighed, sexed and measured. Total length (TL) and disc width (DW) were used as standard measurements.

11.3.2 Statistical methods

The effect of the TEDs and BRDs on catch rates of elasmobranchs were analysed using the same generalised linear modelling approaches as described in the previous chapters. Elasmobranch species catch rates were best modelled using a binomial distribution with a logit link function. The RPAIR procedure in GenStat, which performs t-tests for pairwise differences of means from a GLM, was used to test for significant differences in the probability of capture between net types. Due to their relatively low catch rates (i.e., high zero counts) it was not possible to undertake robust statistical tests for all elasmobranch species.

11.4 RESULTS

11.4.1 Elasmobranch bycatch

A total of 48 elasmobranch and one holocephalan species from 21 families were recorded from the bycatch, based on the present study results and those of Stobutzki et al. (2001) (Table 11.4.1). The most speciose families recorded were the whaler sharks (Carcharhinidae) with 12 species and the stingrays (Dasyatidae) with eight species.

The catch rate of elasmobranchs in the tiger/endeavour prawn charter (Chapter 6) was extremely low with only eight individuals from five species captured in the 192 samples. Elasmobranchs were captured in all codend types, however, the largest two individuals, a *Himantura toshi* (505 mm DW) and a *Rhynchobatus australiae* (420 mm DW) were captured in standard nets.

A total of 23 individuals from eight species were captured in the 96 samples during the Hervey Bay charter (Chapter 8). The blue-spotted maskray *Dasyatis kuhlii* (n = 8), and the Australian butterfly ray *Gymnura australis* (n = 5), were the most commonly recorded species. The two largest individuals, *Himantura toshi* with 520 mm and 730 mm DW, were captured in nets without TEDs, however a *G. australis* of 620 mm DW was captured in a net fitted with a TED.

Twelve species of elasmobranchs were recorded from the 120 samples undertaken in the shallow water eastern king prawn charter (Chapter 5) totalling 409 individuals. Elasmobranchs were recorded from 84 of the 120 samples in this sector (Figure 11.4.1). The species composition was dominated by three species, *Aptychotrema rostrata* (Rhinobatidae), *Trygonoptera testacea* (Urolophidae) and *Urolophus kapalensis* (Urolophidae), which together represented 91.9% of the elasmobranch catch by number, and 79.1% by mass (Table 11.4.2). *Aptychotrema rostrata* was recorded from 66 of the 120 trawl measurements (Figure 11.4.1b) and urolophids from 30 of the 120 trawl measurements (Figure 11.4.1c).

Table 11.4.1. Elasmobranch species recorded in the QECTF bycatch based on results from the present study and those Stobutzki et al. (2001). BP, banana prawn; EKP, eastern king prawn; HB, Hervey Bay; SC, scallop; TE, northern tiger/endeavour prawn.

Family	**Species**	**Fishery Sector**
Heterodontidae	*Heterodontus galeatus*	EKP
Parascylliidae	*Parascyllium collare*	EKP
Brachaeluridae	*Heteroscyllium colcloughi*	EKP
Orectolobidae	*Orectolobus maculatus*	EKP
Hemiscylliidae	*Chiloscyllium punctatum*	SC, TE
	Hemiscyllium ocellatum	TE
Scyliorhinidae	*Asymbolus analis*	EKP
	Asymbolus rubiginosus	EKP
	Atelomycterus sp. 1 [Jacobsen & Bennett]	SC
	Galeus boardmani	EKP
Triakidae	*Mustelus* sp. C [White]	EKP
Hemigaleidae	*Hemigaleus australiensis*	HB, SC, TE
Carcharhinidae	*Carcharhinus altimus*	BP
	Carcharhinus brevipinna	BP
	Carcharhinus dussumieri	BP
	Carcharhinus leucas	BP
	Carcharhinus limbatus	BP
	Carcharhinus macloti	BP
	Carcharhinus melanopterus	TE
	Carcharhinus sorrah	BP
	Carcharhinus tilstoni	TE
	Loxodon macrorhinus	SC
	Rhizoprionodon acutus	BP
	Rhizoprionodon taylori	BP
Sphyrnidae	*Eusphyra blochii*	BP
	Sphyrna lewini	BP
Pristidae	*Pristis zijsron*	BP
Rhynchobatidae	*Rhynchobatus australiae*	BP, SC, TE
Rhinobatidae	*Aptychotrema rostrata*	EKP, HB, SC
	Trygonorrhina sp. A [Last & Stevens, 1994]	EKP
Hypnidae	*Hypnos monopterygius*	EKP
Rajidae	*Dipturus australis*	EKP
	Dipturus polyommata	EKP
Urolophidae	*Trygonoptera testacea*	EKP
	Urolophus kapalensis	EKP
	Urolophus sufflavus	EKP
Dasyatidae	*Dasyatis fluviorum*	BP
	Dasyatis kuhlii	EKP, HB, SC, TE
	Dasyatis leylandi	BP, HB, SC, TE
	Dasyatis thetidis	EKP
	Himantura sp. A [Last & Stevens, 1994]	SC, HB
	Himantura toshi	BP, SC, TE
	Himantura uarnak	BP
	Himantura undulata	BP, SC
Gymnuridae	*Gymnura australis*	BP, EKP, HB, SC
Myliobatidae	*Aetomylaeus nichofii*	HB
Rhinopteridae	*Rhinoptera* spp.	BP
Chimaeridae*	*Hydrolagus lemures*	EKP

* Holocephali

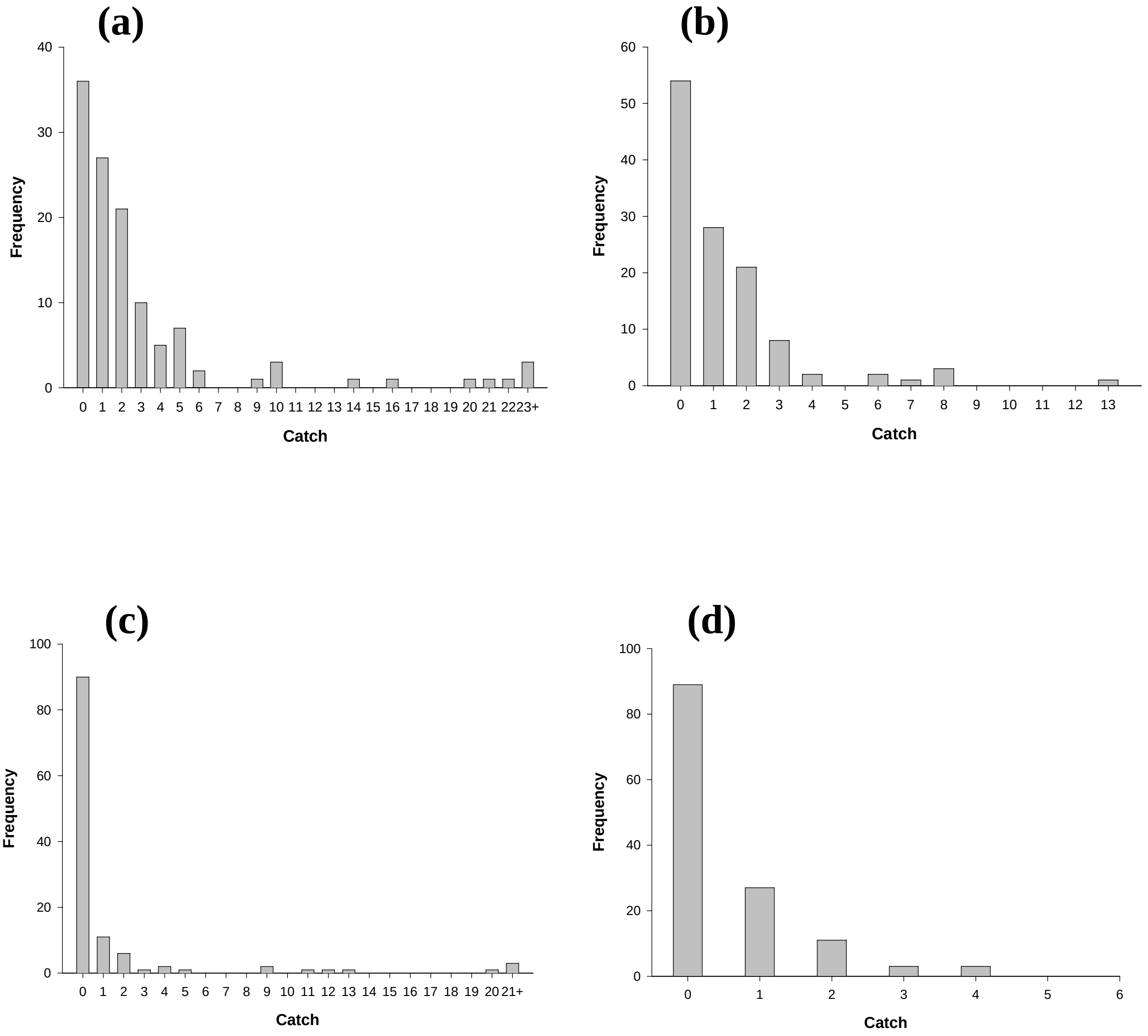

Figure 11.4.1. Catch-frequency distributions of elasmobranchs captured in the eastern king prawn sector. (a) All species, shallow water component; (b) *Aptychotrema rostrata*, shallow water component; (c) Urolophids combined, shallow water component; (d) All species, deep water component.

The generalised linear model predicted probabilities of capturing *A. rostrata* and urolophids in a two-nautical mile trawl in the shallow water eastern king prawn fishery sector are provided in Table 11.4.3. There were no significant effects due to codend treatment type for either *A. rostrata* or the urolophids. The catch of *A. rostrata* from all net types during the survey was dominated by immature individuals in the size range 360–460 mm TL (Figure 11.4.2a). Urolophids (*T. testacea* and *U. kapalensis*) were dominated by individuals in the size range 240–320 mm TL (Figure 11.4.2b).

Table 11.4.2. Elasmobranch bycatch from the shallow water eastern king prawn charter.

Species	**Common name**	**Number**	**% Catch**	**Mass (kg)**	**% Mass**
Aptychotrema rostrata	Eastern shovelnose ray	158	38.63	52.51	40.13
Trygonoptera testacea	Common stingaree	156	38.14	38.93	29.75
Urolophus kapalensis	Kapala stingaree	62	15.16	12.06	9.21
Dasyatis kuhlii	Blue-spotted maskray	12	2.93	7.75	5.92
Heterodontus galeatus	Crested horn shark	4	0.98	8.30	6.34
Hypnos monoterygius	Coffin ray	4	0.98	3.83	2.93
Trygonorrhina sp. A*	Eastern fiddler ray	3	0.73	0.75	0.57
Orectolobus maculatus	Spotted wobbegong	3	0.73	0.72	0.55
Heteroscyllium colcloughi	Bluegray carpetshark	2	0.49	4.55	3.48
Asymbolus analis	Grey spotted catshark	2	0.49	0.74	0.57
Asymblous rubiginosus	Orange-spotted catshark	2	0.49	0.53	0.41
Mustelus sp. C#	--	1	0.24	0.18	0.14
Total:		**409**		**130.85**	

* [Last and Stevens, 1994]; # [White]

Table 11.4.3. Predicted probabilities of capturing the eastern shovelnose ray (*Aptychotrema rostrata*) and urolophids (*Trygonoptera testacea* and *Urolophus kapalensis*) based on 120 trawls undertaken during the shallow water eastern king prawn charter. Standard errors in parenthesis.

Codend treatment type	**Probability of capture** ***Aptychotrema rostrata***	**Urolophids**
Standard	0.56040 (0.0792)	0.2265 (0.0401)
BRD	0.5634 (0.0915)	0.2554 (0.0509)
TED	0.6110 (0.0673)	0.2744 (0.0405)
BRD + TED	0.4825 (0.0567)	0.2456 (0.0451)

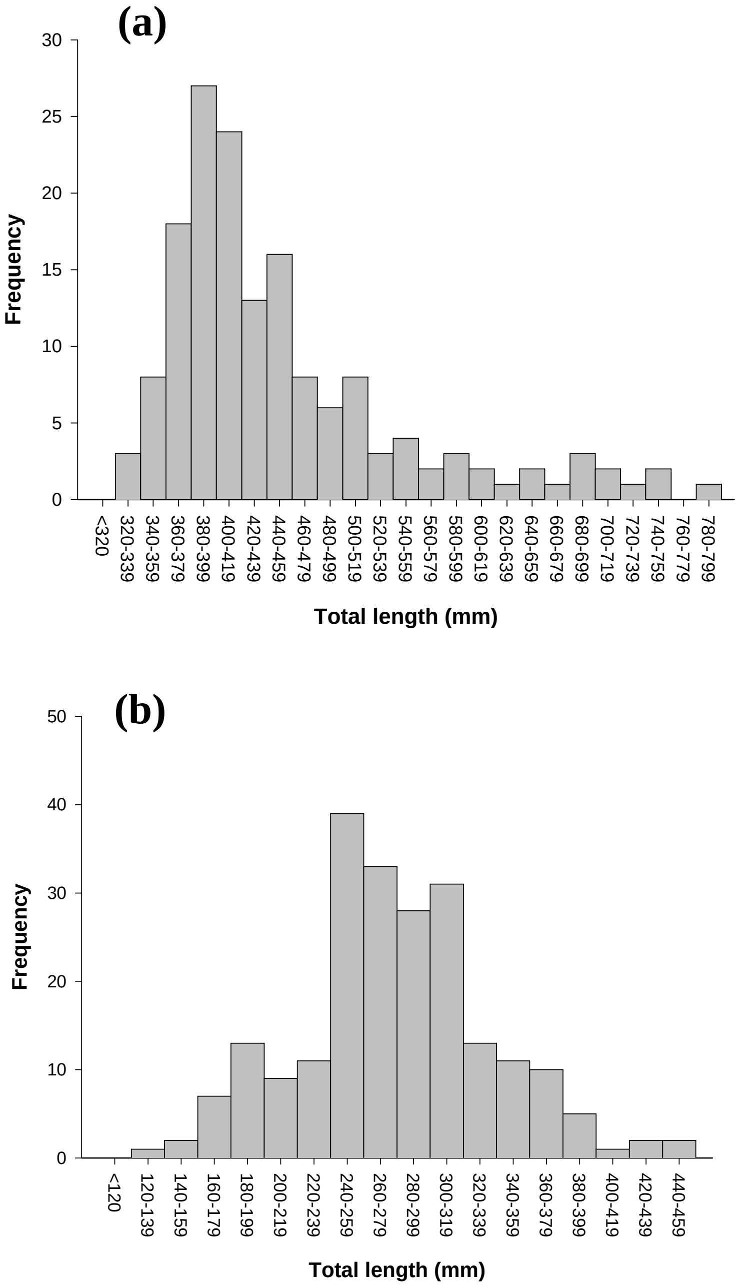

Figure 11.4.2. Size-frequency distributions of elasmobranchs captured during the shallow water eastern king prawn charter. (a) *Aptychotrema rostrata*; (b) Urolophids combined (*Trygonoptera testacea* and *Urolophus kapalensis*).

Nine elasmobranch and one holocephalan species were recorded from the 130 samples undertaken during the deepwater eastern king prawn charter (Chapter 9) totalling 65 individuals. Elasmobranchs were recorded from 41 of the 130 samples (Figure 11.4.1d). The species composition was dominated by *Dipturus polyommata* (Rajidae), *Asymbolus rubiginosus* (Scyliorhinidae) and *Galeus boardmani* (Scyliorhinidae), which together represented 83.5% of the catch by number and

64.6% by mass (Table 11.4.4). Individuals captured were generally small, with only five elasmobranchs weighing ≥ 500 g. Generalised linear modelling revealed a significant difference between codend treatment types for *A. rubiginosus,* but not for *D. polyommata* or *G. boardmani* (Table 11.4.5).

Table 11.4.4. Elasmobranch bycatch from the deepwater eastern king prawn charter.

Species	**Common name**	**Number**	**% Catch**	**Mass (kg)**	**% Mass**
Dipturus polyommata	Argus skate	23	35.83	4.40	21.3
Asymbolus rubiginosus	Orange-spotted catshark	20	30.77	6.20	30.0
Galeus boardmani	Sawtail shark	11	16.92	2.75	13.3
Asymbolus analis	Grey spotted catshark	4	6.15	0.55	2.7
Hypnos monopterygius	Coffin ray	2	3.08	0.35	1.7
Aptychotrema rostrata	Eastern shovelnose ray	1	1.54	1.30	6.3
Dasyatis thetidis	Black stingray	1	1.54	2.50	12.1
Trygonoptera testacea	Common stingaree	1	1.54	0.30	1.5
Urolophus sufflavus	Yellowback stingaree	1	1.54	0.30	1.5
*Hydrolagus lemures**	Blackfin ghostshark	1	1.54	2.00	9.7
Total:		**65**		**20.65**	

* Holocephali

Table 11.4.5. Predicted probabilities of capturing the orange-spotted catshark (*Asymbolus rubiginosus*), the argus skate (*Dipturus polyommata*) and the sawtail shark (*Galeus boardmani*) based on 130 trawls undertaken during the deepwater eastern king prawn charter. Standard errors in parenthesis.

Codend treatment type	**Probability of capture** *Asymbolus rubiginosus*	*Dipturus polyommata*	*Galeus boardmani*
Standard	0.4154 (0.0031)	0.1684 (0.0779)	0.0504 (0.0346)
BRD	0.0154 (0.00002)	0.2361 (0.0539)	0.0748 (0.0289)
TED	0.4154 (0.0022)	0.1378 (0.0310)	0.0623 (0.0432)
BRD + TED	0.0154 (0.0001)	0.2214 (0.0368)	0.0791 (0.0254)

Eleven elasmobranch species were recorded from the 236 trawl measurements undertaken during the scallop charter (Chapter 7) totalling 205 individuals. Elasmobranchs were recorded from 100 of the 236 trawl measurements. The species composition was dominated by *Aptychotrema rostrata* (Rhinobatidae), *Dasyatis kuhlii* and *D. leylandi* (Dasyatidae), which together represented 91.2% of the catch by number and 60.9% by mass (Table 11.4.6.). A single large (1330 mm DW) leopard whipray *Himantura undulata* represented 20.9% of the elasmobranch catch by mass. Generalised linear modelling revealed a significant effect in catch rates due to codend treatment type for the *A. rostrata*, but not for *D. kuhlii* or *D. leylandi* (Table 11.4.7).

Table 11.4.6.. Elasmobranch bycatch from the scallop fishery charter**.**

Species	**Common name**	**Number**	**% Catch**	**Mass (kg)**	**% Mass**
Aptychotrema rostrata	Eastern shovelnose ray	107	52.20	72.47	37.82
Dasyatis kuhlii	Blue-spotted maskray	48	23.41	37.11	19.36
Dasyatis leylandi	Painted maskray	32	15.61	7.20	3.76
Rhynchobatus australiae	White-spotted guitarfish	8	3.90	12.82	6.69
Chiloscyllium punctatum	Grey carpetshark	3	1.46	5.20	2.71
Gymnura australis	Australian butterfly ray	2	0.98	5.49	2.86
Loxodon macrorhinus	Sliteye shark	1	0.49	1.50	0.78
Hemigaleus australiensis	Australian weasel shark	1	0.49	0.47	0.24
Himantura sp. A*	Brown whipray	1	0.49	0.89	0.47
Himantura toshi	Black-spotted whipray	1	0.49	8.50	4.44
Himantura undulata	Leopard whipray	1	0.49	40.00	20.87
Total:		**205**		**191.65**	

* [Last and Stevens, 1994]

Table 11.4.7. Predicted probabilities of capturing the eastern shovelnose ray (*Aptychotrema rostrata*), the blue-spotted maskray (*Dasyatis kuhlii*) and the painted maskray (*Dasyatis leylandi*) based on 236 trawls undertaken during the scallop fishery charter. Standard errors in parenthesis.

Codend treatment type	**Probability of capture**		
	Aptychotrema rostrata	*Dasyatis kuhlii*	*Dasyatis leylandi*
Standard	0.2694 (0.0362)	0.1509 (0.0309)	0.1540 (0.0387)
BRD	0.3582 (0.0322)	0.1363 (0.0318)	0.0851 (0.0356)
TED	0.2136 (0.0308)	0.1506 (0.0313)	0.1067 (0.0337)
BRD + TED	0.1934 (0.0327)	0.1208 (0.0309)	0.1273 (0.0362)

11.4.2 New information on the occurrence of elasmobranchs

Samples collected from research charters provided new information of the occurrence and distribution of several species in Queensland waters. The grey spotted catshark *Asymbolus analis* was recorded for the first time from Queensland, the Sydney skate *Dipturus australis* was confirmed from the state, and significant southern range extensions were documented for the painted maskray *Dasyatis leylandi* and the banded eagle ray *Aetomylaeus nichofii*.

Asymbolus analis was trawled from the shallow and deep water sectors of the eastern king prawn fishery, at depths of 85–159 m. The species is endemic to the east coast of Australia, and was previously thought to be confined to New South Wales and Victorian waters from Port Macquarie south to Lakes Entrance. Records collected in the present study provide the first account of *A. analis* from Queensland waters. *Asymbolus* includes eight species restricted to Australian waters (Last, 1999) and an undescribed species from New Caledonia (Séret, 1994). Further information on the taxonomy and life history of the species in Queensland waters is provided in Kyne et al. (2005).

A specimen of *D. australis* was captured in the deepwater eastern king prawn fishery in 135 m. The individual was deposited in the Queensland Museum and represents the third specimen from Queensland held there. *Dipturus australis* is reported to be ”the most common skate on the continental shelf of central eastern Australia” (Last and Stevens, 1994), being recorded from off Moreton Bay south to Jervis Bay, New South Wales. Last and Stevens (1994: 347) state that “records of this species from prawn trawl catches from southern Queensland require validation”. This specimen, taken by a commercial prawn trawler, confirms that the Queensland trawl fishery interacts with this species. Despite its apparent common occurrence off New South Wales, this species appears to be uncommon in Queensland waters.

Two specimens of *Dasyatis leylandi* were captured during the Hervey Bay charter at a depth of 11 m. These records represent a significant new southern range extension for the species on the east coast of Australia (about 1200 km), having previously been recorded from northern Australia between Monte Bello Islands, Western Australia and Townsville, Queensland, as well as New Guinea (Last and Stevens, 1994). The species appears to be relatively common on the scallop trawling grounds between Hervey Bay and Gladstone.

A specimen of *Aetomylaeus nichofii* was captured during the Hervey Bay charter at a depth of 8 m. Last and Stevens (1994) report that *A. nichofii* has an Indo-West Pacific distribution from southern Japan to Australia and west to India. In Australia it was reported in tropical waters from Bonaparte Archipelago, Western Australia to Cairns, Queensland. The Hervey Bay specimen significantly expands the previously documented southern range of the species on the east coast of Australia (by ~1600 km).

Further information on the above new records as well the biogeography of other Queensland elasmobranchs is provided in Kyne et al. (2005).

11.5 DISCUSSION

At least 94 elasmobranch and two holocephalan species occur in the managed area of the QECTF (Last and Stevens, 1994). Half of these species were recorded in the trawl bycatch, based on data considered herein. Results indicate that elasmobranch bycatch is variable between sectors, with the highest catch rates in the eastern king prawn sector. While TEDs are likely to reduce the capture of large elasmobranchs (Brewer, 1999) preliminary results suggest that neither TEDs nor BRDs are impacting upon the retention of small individuals and species.

Codend type (i.e., Standard codend, BRD, TED, or BRD+TED) did not significantly affect the capture of *A. rostrata* (commonly to 850 mm TL), *T. testacea* (to 450 mm TL) or *U. kapalensis* (to 360 mm TL) – all relatively small species in the shallow water eastern king prawn fishery. Furthermore, codends fitted with TEDs actually had the highest predicted probability of *A. rostrata* capture, and standard codends (no TED or BRD) had the lowest probability of capturing urolophids. However, it needs to be noted that these differences were not significant. The fact that urolophids were often captured in aggregations may have influenced these results.

As female *A. rostrata* are known to mature at 540–660 mm TL and males at 600–680 mm TL (Kyne and Bennett, 2002), the majority of individuals captured during the shallow water eastern king prawn charter were immature. In contrast, both urolophid species (males and females) appear to mature at between 230–270 mm TL (Kyne, unpublished data), indicating that a considerable proportion of mature individuals were captured. The opportunistic sampling also revealed high catches of neonates at certain times of the year, resulting in high levels of trawl-induced juvenile mortality. Furthermore, gravid female *T. testacea* often abort near-term embryos after capture. While *A. rostrata* appears to be a hardy species, usually capable of surviving trawling, urolophids appear to have lower survivability (unpublished information on capture mortality and survivability). Therefore, high rates of mortality at all life stages may have negative impacts on the viability of urolophid populations. Data from the South East Trawl Fishery in New South Wales support this suggestion, where after 20 years of fishing the capture of four urolophid species has suffered a 45–90% reduction depending on area (Graham et al., 2001).

One species of particular concern that has been recorded as bycatch in the QECTF is the bluegray carpetshark *Heteroscyllium colcloughi*. This species is listed as Vulnerable on the IUCN Red List of Threatened Species and occupies a restricted range centred in south-east Queensland, which receives high fishing effort in the eastern king prawn fishery. Prawn trawl bycatch is considered one of the most important threatening processes acting upon this species (Pogonoski et al., 2002). A total of six individuals of this species have been recorded from both charters and opportunistic sampling during the present study, including a female of 670 mm TL captured in a net fitted with a TED (the species is reported to 850 mm TL).

Australia has recently released its draft National Plan of Action for the Conservation and Management of Sharks which highlights the need to reliably assess the bycatch of elasmobranchs in Australian fisheries and undertake research into bycatch reduction techniques. The project is attempting to meet these needs in the QECTF and will provide the first information on elasmobranch bycatch in many sectors of the fishery.

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12 Objective 4. Review the known biology and distribution of all recently approved “permitted fish” species associated with the trawl fishery.

J. A. Haddy

12.1 INTRODUCTION

Recent changes in the management plan of Queensland East Coast Trawl Fishery (QECTF) allow commercial fishers to retain non-target byproduct species. These species include barking crayfish (*Linuparus trigonus*), Balmain bugs (*Ibacus* spp.), three spot crabs (*Portunus sanguinolentus*), mantis shrimps, (Stomatopoda), cuttlefish (*Sepia* spp.), octopus (*Octopus* spp.), pipehorses (*Solegnathus* spp.) and pinkies (*Nemipterus* spp.). Several of these groups consist of numerous species and currently there is no available information on the catch composition and abundance of these species within the fishery. Individual log records of these species have only recently been introduced. These records for 2000 to 2002 are shown in Figure 12.1.1. Despite the obvious economic importance these species contribute to the overall value of the QECTF very little research has been conducted on their biology and or sustainable management.

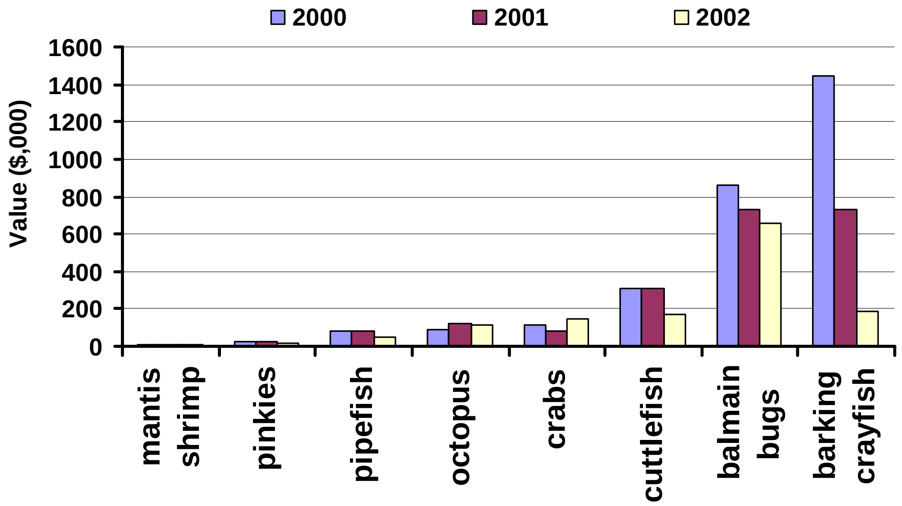

Figure 12.1.1 Approximate value of “permitted species” based on reported logbook landings from 2000 – 2002

The following review outlines the known biology of these recently permitted species. Please note that a report on the Queensland sand crab fishery is currently being compiled and to avoid unnecessary duplication, the biology of sand crabs has not been reviewed here. Readers should therefore refer to the following reviews, Chaplin et al., (2001), Melville-Smith et al., (2001), Potter et al., (2001), Sumpton et al., (2002) for information on sand crabs.

*12.1.1 Barking crayfish (*Linuparus trigonus*)*

Barking crayfish, also known as spear or champagne lobsters, are one of three extant species of the genus *Linuparus* and belong to one of eight genera of the Palinuridae family (spiny lobsters) (Holthuis 1991). They are a deepwater lobster inhabiting waters from 81 to 313 m, and are distributed in the Indo-Pacific region, including Japan, Taiwan, Philippines and eastern and western Australia. There is some evidence that shows that these lobsters may live in burrows as their catch rates have been shown to display diel variability, and fossil records indicate that *Linuparus* species are associated with burrows (Bishop and Williams, 1986). Off Townsville *Linuparus trigonus* occur in sufficient densities to support a commercial fishery. The fishery is confined to a small, well-defined area of the continental slope, about 70 km by 20 km in area. With the development of an export market for barking crayfish several fishers have targeted this deepwater species over recent years. This increase in fishing effort for the species has resulted in a marked increase in landings and during 2000 an estimated 100 tonnes were landed worth approximately $1.4 million dollars (QFS Logbook data). However despite the economic importance of this resource very little is known about the biology of *L. trigonus*.

Planurid lobsters exhibit five major phases within the life cycle: adult, egg, phyllosoma (larval stages), puerulus (postlarval stage) and juvenile (Lipicus and Cobb, 1994). Fertilisation is external whereby the male deposits a spermatophoric mass on the female's sternum. The female rasps the spermatophoric mass prior to spawning to release sperm for fertilising the eggs as they are extruded onto the abdomen and pleopods. The female then carries the egg mass on her abdomen where they develop and hatch as a phyllosoma larvae, which disperse offshore to develop over a long oceanic larval phase prior to settling as post larvae. The first larval stage of *Linuparus* species hatch in a more advanced condition than other planurid lobsters, which indicates that the larval phase has been shortened in these deepwater species (Baisre, 1994), however the duration and total number of the larval phases in *Linuparus* species is currently unknown. Anecdotal evidence indicates that the catch rates of small lobsters increase with depth. This trend indicates that barking crayfish settle in deep water and move to shallower water as they grow (Ward, unpublished data).

There are only two detailed biological studies on *L. trigonus*. Kim (1977) studied gametogenesis and early development of *L. trigonus* from Asian waters. This study demonstrated that these lobsters have an annual reproductive cycle that can be classified into four successive stages: multiplication stage from September to December, growing stage from January to March, maturation division stage from April to May, and mature stage from June to August. Spawning took place from May to August with a peak of activity from late July to early August. Wassenberg and Hill (1989) investigated the diet of *L. trigonus* and demonstrated that these lobsters were predators of slow moving or near sessile benthic invertebrates, with its diet consisting mainly of bivalves, gastropods, ophiuroids, crustaceans, polychaetes and foraminiferans.

The lack of information on this species highlights that more research is needed to ensure that this byproduct fishery is properly developed and sustainable. Research activities should be centred on obtaining an understanding of the reproductive capacity of the Queensland population and growth rates in *L. trigonus*.

12.1.2 Balmain bugs, Ibacus *spp.*

Balmain bugs are marine lobsters of the genus *Ibacus* and belong to the family Scyllaridae. There are eight species of Balmain bugs and five of these species are known to occur in Queensland waters: *I. alticrenatus, I. brevipes, I. brucei, I. chacei* and *I. peronii* (Brown and Holthuis, 1998). The distributions, depth range and maximum sizes of Queensland's *Ibacus* species are shown in Table 12.1.1. Balmain bugs typically inhabit soft bottom substrates such as sand, mud and clay, which allow them to dig into the substrate and cover themselves (Holthuis, 1991). Captive studies on *I. peronii* indicated that both locomotion and feeding are nocturnal activities and that during the day animals remain buried in the substrate (Suthers and Anderson, 1981). Their diet consists of small benthic invertebrates and animal remains (Suthers and Anderson, 1981).

Table 12.1.1. Distributions, depth ranges and maximum sizes of Queensland's *Ibacus* species

Species	Max size CL (mm)	Depth (m)	Distribution
I. alticrenatus	63	82-686	South of the Coral Sea
I. brevipes	45	186-457	North of the Coral Sea
*I. brucei**	72	83-559	South of Central QLD
*I. chacei**	76	22-330	South of Innisfail
I. peronii	86	4-288	South of Moreton Bay

* Indicates the major species harvested in Queensland

As with spiny lobsters, *Ibacus* species carry their eggs on the pleopods underneath the abdomen. Newly deposited eggs of *I. peronii* are bright orange and spherical. During incubation the eggs develop two black eye-spots and as hatching approaches egg colour changes to a brown colour with two enlarged eye-spots (Stewart et al., 1997). Observations by Stewart et al. (1997) on captive berried *I. peronii* indicated the incubation period lasted between three to four months. Female *I. peronii* and *I. chacei* reach sexual maturity at a carapace length of approximately 50 mm and 54 mm respectively. Fecundity estimates of *Ibacus* spp. have only been determined for *I. peronii* and range from 5000 to 37,000 eggs (Stewart et al., 1997). *I. peronii* hatch as an actively swimming pre-phyllosomata that transforms into a phyllosoma within 15 to 20 minutes by unfolding the swimming legs (Stewart et al., 1997). Newly hatched and unfolded phyllosoma larvae are flattened and transparent and range in size from 2.6–3 mm in total length, depending on species (Ritz and Thomas, 1973). The larvae then undergo 7–8 moults prior to metamorphosing into nisto (= puerulus in Palinurids) larvae (Ritz and Thomas, 1973; Takahashi and Saisho, 1978; Atkinson and Boustead, 1982). The nisto larva is a transitory stage between the planktonic phyllosoma and the benthic juveniles. Successful rearing experiments on *Ibacus* spp. indicate that larvae reach the nisto stage within 65–76 days (Takahashi and Saisho, 1978; Mikami and Takashima, 1993) and stay in this stage for a further 21–26 days before moulting into juveniles (Takahashi and Saisho, 1978; Atkinson and Boustead, 1982). These periods indicate that the planktonic phase of *Ibacus* spp. would require at least three months at sea.

Very little biological information is available for Queensland's *Ibacus* species. *I. chacei* and *I. brucei* appear to be the dominant Balmain bugs caught in the QECTF, however some commercial fishers report catching commercial quantities of *I.*

alticrenatus. Data from tag/recapture studies in NSW on *I. peronii* and *I. chacei* indicated that *I. peronii* exhibited a classic nomadic pattern of movement and that *I. chacei* underwent a long northward migration (Stewart and Kennelly, 1998). This movement combined with the fact that reproductively active animals are not found off the New South Wales coast indicates that *I. chacei* migrates to spawn off the Queensland coast, with the larvae being distributed in a southerly direction via the East Australian current.

Ibacus peronii and *I. chacei* are the only species of Balmain bugs in which growth has been studied. Stewart and Kennelly (2000) showed that smaller individuals of both *Ibacus* species displayed a higher moulting frequency and larger moult increments than larger individuals. The von Bertalanffy growth parameters L_∞ and K estimated by Stewart and Kennelly (2000) for *I. chacei* and *I. peronii* are given in Table 12.1.2, the size at age zero was set at 12.2 mm.

Table 12.1.2. von Bertalanffy growth parameter estimates for *I. peronii* and *I. chacei*

Parameter	***Ibacus peronii***		***Ibacus chacei***	
	♂	♀	♂	♀
L_∞	64.8	81.1	72.8	71.9
K	0.504	0.431	0.440	0.730

Kennelly and Stewart (2000) showed that growth was rapid in the first four years but dramatically slowed thereafter indicating that male and female *I. peronii* reached their $L_{\max}$ between 7 and 18 years and 5 and 11 years respectively, whereas *I. chacei* reached their $L_{\max}$ between 4 and 7 years (sexes combined). However, caution should be noted for the population estimates for *I. chacei* in this study, as only 37 animals were used in the analysis and that the maximum observed size was considerably lower than the known maximum size of *I. chacei*.

*12.1.3 Three spot crabs (*Portunus sanguinolentus*)*

The three spot crab, *Portunus sanguinolentus* is distributed throughout the Indo-West Pacific region and typically inhabits sandy oceanic habitats to a depth of 30 metres (Sumpton et al., 1989). These crabs belong to the family Portunidae and are closely related to the sandcrab *Portunus pelagicus*. Portunid crabs form extensive fisheries around the world and a substantial amount is known about their biology. Three spot crabs are primarily predators of slow moving or sessile benthic macro-invertebrates such as bivalves and crabs, however fish remains, algae and other decaying material has also been reported in the diet of this crab (Wu and Shin, 1998, Sukumaran and Neelakantan, 1997a). As a result these crabs are likely to play an important role in consuming the discarded bycatch (Wassenberg and Hill, 1982).

The life cycle of three spot crabs involves five phases: egg, zoea, megalopa, juvenile and adult. Male and female three spot crabs mature between 74 and 90 mm depending on geographical locality (Campbell and Fielder, 1986, Sukumaran and Neelakantan, 1996; Sumpton et al., 1989; Sarada, 1998). Sumpton et al., (1989) reported that the smallest sexually mature male and female three spot crabs had carapace widths of 83 and 74 mm respectively (Sumpton et al., 1989). Similarly, Campbell and Fielder

(1986) demonstrated that female three spot crabs reached their first maturity instar moult at carapace widths of 75-115 mm. Continuous year-round spawning has been reported in Hawaiian and Indian populations of three spot crabs (Ryan 1967; Sarada, 1998), however in southern Queensland, Campbell and Fielder (1986) reported that no ovigerous females were caught from May to July indicating that although three spots were capable of year-round spawning they were limited by water temperature. A similar trend has also been reported in Indian populations of three spot crabs during the monsoon season with the authors suggesting that low in-shore salinity levels may be responsible for reduced reproductive activity (Sukumaran and Neelakantan, 1998). The peak breeding season of three spot crabs in Queensland, in which over 50% of females are ovigerous, extends from October to February (Campbell and Fielder, 1986). Three spot crabs have a size-dependent fecundity ranging from 44,000 to 1.2 million eggs (Sukumaran and Neelakantan, 1997b). Sukumaran and Neelakantan (1997b) investigated the reproductive potential of the Indian population off the Karnataka coast and indicated that crabs ranging in carapace width between 100 and 120 mm contributed over 50% of the total egg production of the population.

The population dynamics of three spot crabs have been studied extensively in Indian waters (Sukumaran and Neelakantan, 1996; Sukumaran and Neelakantan, 1997; Sarada, 1998). Three spot crabs grow rapidly in their first year with a mean monthly growth rate of 10.3 and 8.8 mm and attaining carapace widths of 124.1 and 112.5 mm in males and females respectively after one year (Sukumaran and Neelakantan, 1997). In contrast Sarada (1998) indicated a faster growth rate with female three spot crabs reaching 131.5, 155.5 and 160.5 mm, and males reaching 136.8, 164.8 and 171.1 mm in their first, second and third years, respectively. Estimates of the von Bertalanffy growth parameters L_∞ (CW), K (annual) and t_0 (annual) for male and females three spot crabs by Sarada (1998) were 172.9 mm, 1.4939 and –0.0482 in males, and 161.8 mm, 1.574 and –0.0635 in females. The respective values published by Sukumaran and Neelakantan (1997) were 195 mm, 0.99, –0.0132 for males, and 188 mm, 0.82 and –0.0975 for females.

12.1.4 Mantis shrimps (Stomatopoda)

Mantis shrimps are marine crustaceans that belong to the order Stomatopoda. Historically the Australian stomatopod fauna has received very little attention with most reports detailing taxonomic and distributional details of a few species. However, Ahyong (2001) recently reviewed the Australian stomatopod fauna in which 72 species are newly reported to Australia. Currently the Australian stomatopod fauna consists of 146 species in 63 genera many of these species are widely distributed (i.e., Indo-West Pacific). Within Queensland waters there are 99 species of mantis shrimps that range in size from 19 mm to 335 mm. Furthermore, 22 of these species are endemic to Australia.

Mantis shrimps are highly specialised predators of crustaceans (mainly prawns and other mantis shrimps), and small fish (Ruppert and Barnes, 1994, Sreelatha and John, 1996). The second pair of thoracic appendages are enlarged for raptorial feeding with the inner edge of the dactyl possessing numerous long spines or shaped like the blade of a knife. Prey is captured by “spearing” or “smashing”, depending on whether the dactyl is extended or folded during the strike (Caldwell and Dingle, 1976). Mantis shrimps inhabit rock or coral crevices or in burrows excavated in the sea floor and rigorously defend their territories. They either hunt at the entrance of their burrows, crawl on the bottom or swim through the water column in search of prey. When prey is detected the raptorial claw extends with such force and speed (within four milliseconds) that captive animals have been known to break the glass of their aquariums (Jones and Morgan, 1994; Ruppert and Barnes, 1994).

Mantis shrimps are exploited in several parts of the world with the most extensive fisheries being for *Squilla mantis* in the Mediterranean, *Oratosquilla oratoria* in Japan and *Oratosquilla nepa* in India (James and Thirumilu, 1993; Ahyong, 2001). Within these markets they are used as a dependable source of raw material for fishmeal, poultry feeds, and fertilisers and are also eaten as the meat is reported to posses medicinal value (James and Thirumilu, 1993). Within Queensland, Moreton Bay appears to be where the majority of mantis shrimps are harvested. There are currently 20 species known to inhabit Moreton Bay, however some species are too small to be caught and/or inhabit un-trawlable habitats. Dell and Sumpton (1999) identified eight species of mantis shrimps within the bycatch from prawn trawling in Moreton Bay, these included *Anchisquilla fasciata, Belosquila laevis, Clorida granti, Eurosquilla woodmasoni, Harpiosquilla harpax, Odontodactylus cultrifer, Oratosquillina interrupta*, and *Oratosquillina stephensoni*. The species of mantis shrimps that grow over 100 mm (animals smaller than this are too small to market) in Queensland waters are detailed in Table 12.1.3.

The life cycle of the mantis shrimp involves four major phases: egg, larvae, juvenile and adult. Some mantis shrimp pair for life, sharing the same burrow or retreat (Rupert and Barnes, 1994). Many populations of mantis shrimps breed for extended periods often with peaks in frequency in tropical waters. For example, *Oratosquilla nepa* spawn over 10 months with peaks in February to April and September to October off the Mangalore coast (Reddy and Shanbhogue, 1994). Similarly, *Harpiosquilla melanoura* spawns over nine months from November through to June off the south-east coast of India (Lyla et al., 1999). Captive breeding studies have highlighted that mantis shrimps are capable of multiple broods. For example, *Gonodactylus bredini* can spawn up to five clutches within one year. Furthermore, Hamano and Matsuura (1984) demonstrated that a second spawning occurred 40 days after the first spawning.

Mantis shrimps usually spawn, brood and hatch their eggs within their burrows. The eggs of mantis shrimps are agglutinated to form a globular mass in which the female usually cares for and shapes during incubation (Hamano and Matsuura 1984; Morgan and Goy, 1987). The incubation period is temperature dependent and becomes shorter at higher temperatures (i.e. 8 days at 27^{o}C and 23 days at 19^{o}C in *Oratosquilla oratoria*, Hamano and Matsuura, 1987). Similarly, Morgan and Goy (1987) reported that the incubation period of *Gonodactylus bredini* required 14–15 days at 28^{o}C. Once hatched the larvae remain in the burrows and pass through one to three pelagic stages, which contain yolk and do not feed, before leaving the burrow and entering the plankton as feeding pelagic larvae. The duration and number of larval stages differs with species but ranges from eight stages over 35–50 days in *Gonodactylus bredini* (Morgan and Goy, 1987), eleven stages over 36–59 days in *Oratosquilla oratoria* (Hamano and Matsuura, 1987), and three stages over 60–70 days in *Heterosquilla tricarinata* (Greenwood and Williams, 1984). The duration of larval development is also temperature dependent (Hamano and Matsuura, 1987).

Table 12.1.3. List of the maximum size, depth range and distribution of Queensland mantis shrimp species that attain sizes greater than or equal to 100 mm in total length

Species	**TL (mm)**	**Depth (m)**	**Distribution within Queensland**
Anchisquilla fasciata *	100	7-55	Moreton Bay north
Anchisquilloides mcneilli	110	14-308	Coral Sea (17 deg) south
Bathysquilla crassispinosa	297	170-420	Coral Sea (23 deg) north
Bathysquilla microps	221	728-1006	Coral Sea (17 deg south)
Belosquilla laevis *	127	0-40	Mackay south
Carinosquilla australiensis	123	20-30	Princess Charlotte Bay to Keeper Reef
Carinosquilla redacta	150	20-45	Princess Charlotte Bay to Gulf of Carpentaria
Carinosquilla thailandensis	152	11-51	Shelburne Bay to Gulf of Carpentaria
Clorida bombayensis	100	0-47	Gulf of Carpentaria
Clorida wassenbergi	105	21-30	The Gulf of Carpentaria and Arafura Sea
Cloridina moluccensis	108	26-90	Gulf of Carpentaria
Cloridopsis terrareginensis	103	0-25	Carins north
Dictyosquilla tuberculata	124	5-57	Townsville to Gulf of Carpentaria
Erugosquilla grahami	177	?-66	Gulf of Carpentaria
Erugosquilla woodmasoni *	153	0-55	All QLD
Faughnia serenei	143	73-310	Coral Sea (17-22 deg)
Gonodactylus chiragra	102	Subtidal	Rockhampton to Torres Strait
Gonodactylus platysoma	110	Subtidal	Southern border to Torres Strait
Harpiosquilla annandalei	137	15-206	Gulf of Carpentaria
Harpiosquilla harpax *	262	0-93	All QLD
Harpiosquilla melanoura	168	60-80	All QLD
Harpiosquilla stephensoni	315	0-46	Yeppoon north
Kempina Mikado	182	30-804	All QLD
Lysiosquilla colemani	170	36-280	Calounda South
Lysiosquilla suthersi	195	55	Cairns (1 only)
Lysiosquilla tredecimdentata	276	Subtidal	Townsville South
Lysiosquillina maculate	335	Subtidal	All QLD
Lysiosquillina sulcata	153	6	One Tree Island (1 only)
Lysiosquilloides siamensis	180	?	Gulf of Carpentaria
Miyakea nepa	166	2-25	Hinchinbrook Island to Gulf of Carpentaria
Odontodactylus cultrifer *	125	7-51	All QLD
Odontodactylus japonicus	175	30-82	Southern border to Heron Island
Odontodactylus scyllarus	171	0-30	All QLD
Oratosquillina gravieri	123	2-59	Moreton Bay north
Oratosquillina inornata	112	Subtidal	Carins to Gulf of Carpentaria
Oratosquillina interrupta *	160	0-25	All QLD
Oratosquillina quinquedentata	155	0-51	Mackay to Gulf of Carpentaria
Oratosquillina stephensoni *	157	6-43	Moreton Bay north
Quollastria capricornae	110	71-212	All QLD
Quollastria gonypetes	104	13-73	All QLD
Quollastria kapala	110	131-411	Mooloolaba south

* indicates species, which are known to be harvested in Moreton Bay

Once the larva has metamorphosed into a juvenile it enters a growth phase. There are only a few studies that report on the population dynamics of mantis shrimps. Dell and Sumpton (1999) showed that the most abundant species of mantis shrimp in Moreton Bay, *Oratosquillina stephensoni*, exhibited bi-modal length-frequency distributions, suggesting the presence of two age cohorts and that this species exhibited fast growth (L_∞ = 163mm, K = 1.52 year^{-1}) and a high instantaneous mortality rate (3.8–4.7 year^{-1}) with an estimated life span of 2.5 years.

*12.1.5 Cuttlefish (*Sepia *spp.)*

There are at least 31 species of cuttlefish (*Sepia* spp.) in Australian waters and 17 of these are known to inhabit Queensland's east coast (Reid, 2000; Lu, 1998). Some of these species are small and do not contribute to commercial catches while other species such as *Sepia apana* can grow up to over 50 cm in mantle length and weigh over 5 kg. The taxonomy and biology of the cuttlefish are not well understood and have received scant attention. The known distributions, depth ranges and maximum sizes of Queensland *Sepia* species are listed in Table 12.1.4.

Table 12.1.4. Distributions, depth ranges and maximum sizes of Queensland cuttlefish species

Species	**Max Size DML (mm)**	**Depth (m)**	**Distribution**
S. apama	520	1-100	Southern Australia: South of Moreton Bay (27^{o}25'S, 153^{o}20'E)
S. bidhaia	47	200-304	Eastern Australia : 17^{o}20'S, 146^{o}41'E to 22^{o}07'S, 153$_{o}$19'E
S. braggi	80	30-146	Southern Australia: South of the Gold Coast (26^{o}30'S, 153^{o}44'E)
S. cultrata	93	132-803	Southern Australia: South of the Gold Coast (26^{o}35'S, 153^{o}45'E)
S. elliptica	173	16-142	Indo-West Pacific: North of the Capricorn Group (23^{o}30'S, 152^{o}00'E)
S. latimanus	138	?	Indo-West Pacific: North of the Capricorn Group (23^{o}00'S, 152^{o}00'E)
S. limata	42	43-146	South East Australia: South of the Gold Coast (26^{o}36'S, 153^{o}35'E)
S. mestus	67	0-146	Eastern Australia: South of Lizard Island (14^{o}40'S, 145^{o}28'E)
S. mira	55	?	Eastern Australia : South of Lizard Island (14^{o}40'S, 145^{o}28'E)
S. opipara	116	83-184	Northern Australia: North of the Gold Coast (36^{o}57'S, 151^{o}45'E)
S. papuensis	99	17-155	Indo-West Pacific: All of Qld
S. pharaonis	247	25-102	Northern Australia: North of the Capricorn Group (23^{o}32'S, 151^{o}44'E)
S. plangon	88	1-83	Eastern Australia : All of Qld
S. rex	113	55-400	Southern Australia: South of the Gold Coast (22^{o}35'S, 153^{o}46'E)
S. rosella	141	27-183	South East Australia: South of the Gold Coast (27^{o}42'S, 153^{o}32'E)
S. smithi	133	33-138	Northern Australia: North of Moreton Bay (27^{o}25'S, 153o20'E)
S. whitleyana	174	23-160	Eastern Australia : All of Qld

Cuttlefish are primarily demersal ranging from shallow waters to the upper continental slope (about 600 m). Many cuttlefish species bury themselves in the sediment with only their eyes exposed. In this way they can hide from predators and ambush prey such as fish, prawns and crabs. Cuttlefish exhibit fast growth rates and typically live for 1 to 2 years. The eggs are usually large, up to the size of a ping-pong ball for *Sepia latimanus*, which places eggs individually into spaces in staghorn corals (Norman and Reid, 2000). Other *Sepia* species attach their eggs in clusters to various substrates with egg clusters of some species being removed by trawling (Boletzky, 1983; Moltschaniwskyj and Jackson, 2000). Eggs hatch as juveniles and commence feeding immediately with reproductive activity increasing in the later 1/2 to 2/3 of the life cycle (Boletzky 1983; Gabr et al., 1998). Males typically mature at much smaller sizes than females however specific information on the majority of Queensland species is currently lacking. Generally adults usually die after spawning and spawn only once, however some species of *Sepia* spawn smaller clutches of eggs over a spawning period until the ovary is empty (Boletzky, 1983; Gabr et al., 1998). Of the species encountered in Queensland only two have been studied in detail, *Sepia pharonis* and *Sepia elliptica* (Silas et al., 1985; Gabr et al., 1998; Gabr et al., 1999; Martinez and Moltschaniskyj, 1999; Martinez et al., 2000).

Sepia pharonis

Gabr et al. (1998) studied the maturation, fecundity and seasonality of reproduction of *S. pharonis* in the Suez Canal. Their study highlighted that *S. pharonis* reached sexual maturity at 61 and 122 mm mantle length (ML) for males and females, respectively, with animals migrating to breeding grounds and spawning from March to June. In contrast, Silas et al. (1985) estimated size at first maturity at 119 and 120 mm ML (male and female, respectively) with spawning occurring from October to August off the Indian coast at Madras. Maturation of both sexes of *S. pharonis* over a large size range points to considerable individual variation in size at maturity. *S. pharonis* has a maximum fecundity of 517–1525 ova for females 110–240 mm ML. Gabr et al. (1998) reported that egg clusters of *S. pharonis* were laid on hard substrates and frequently found from April to August in sheltered areas ranging from 0.5 to 5.0 m deep. In contrast with many other cephalopods *S. pharonis* appears to display a multiple spawning pattern in which it is plausible that females lay eggs in different bouts over a sizeable portion of their life cycle. The absence of dead and spent females and the highly variable ova sizes in mature animals provides additional information for the potential of continued egg production in *S. pharonis*. Furthermore, it appears that both males and females continue to feed as maturity is reached, which provides energy for oocyte production without metabolising reserves from other tissues (Gabr et al., 1999). Growth studies on *S. pharonis* show that the growth rate is different between sexes (Silas et al., 1985 Table 12.1.5)

Table 12.1.5. Age and growth increments of *S. pharonis and S. elliptica*

Age (months)	***S. pharonis*** **Male (mm)**	**Female (mm)**	***S. elliptica*** **Sexes combined (mm)**
6	109.4	119.9	60.9
12	186.1	197.8	95.9
18	239.7	248.3	120.3
24	277.3	281.2	137.8
30	303.6	302.5	148.4
36	322	316.3	

Sepia elliptica
Silas et al. (1985) reported that *S. elliptica* reach sexual maturity between 75 and 115 mm and that spawning animals were caught between October and December, however the presence of mature animals over a prolonged period in their study suggested that breeding activity extended over a long period in a year. Although the spawning season of *S. elliptica* is yet to be determined in Queensland waters, Moltschaniwskyj and Jackson (2000) obtained egg clusters of *S. elliptica* from trawling in July for captive juvenile growth studies. Furthermore, Martinez and Moltschaniwskyj (1999) collected adults from February to November and the eggs laid by these captive broodstock were used for juvenile growth studies. This indicates that *S. elliptica* has a prolonged spawning season in Northern Queensland. Kasim (1993) reported on the population dynamic of *Sepia elliptica* and that the von Bertalanffy growth parameters, L_{∞}, K and t_0 to be 174 mm, 0.0887 and –0.7478 respectively.

12.1.6 Octopus (Octopus *spp.)*

The taxonomy of benthic octopuses (family Octopododa) is very poor with several Queensland species being undescribed or poorly described (Norman, 1998). As a consequence very little is known about Queensland's octopuses with almost all published information detailing taxonomic descriptions and biogeographic data. A taxonomic key of some of the better known octopus occurring in the central and western Pacific has been compiled by Norman (1998).

Although species-specific information on the biology, distribution and importance to fisheries in currently lacking for the majority of Queensland's octopus fauna, there are several general characteristics of the biology and ecology of octopus. Octopuses belonging to the Octopodidae family are bottom-dwelling species inhabiting intertidal areas through to 5 km deep. They inhabit a wide range of habitats ranging from soft substrates to coral reefs and generally are more active at night foraging for crabs, shellfish and fish. All octopuses have short life cycles (typically 1–2 years) in which growth is relatively fast (Wells and Wells, 1977; Joll, 1983; Van Heukelum, 1983). Females produce a single egg mass, lay their eggs in crevices or lairs, protect and clean the eggs during incubation and die when the eggs have hatched (Wells and Wells 1977; Norman and Reid, 2000). Fertilisation takes place within the oviduct or ovary in which the male inserts a specialised arm holding the spermatophores into the mantle of the female (Wells and Wells 1977). Octopus produce either small numbers of large eggs, in which the young hatch as benthic juveniles, or large numbers of small eggs in which the young hatch as pelagic larvae.

Many of the Queensland octopus species do not inhabit trawlable habitats and do not contribute to the QECTF. Information from recent research surveys, Norman and Reid (2000) and Norman (1998), indicate that the most likely species to be caught in commercial quantities by trawling on the east coast of Queensland are *Octopus australis, Octopus dierythraeus*, *Octopus exannulatus*, *Octopus graptus, Octopus marginatus* and the eye-cross octopus (*Octopus* cf *kagoshimensis*). Details of these octopus distributions and known biological details are given in Table 12.1.6.

Table 12.1.6. Distributions, depth ranges and known biological information of commercially important octopuses from Queensland waters

SPECIES	Distribution in Qld	Depth (m)	Maximum Size TL and weight		Egg length	Largest known fecundity
O. australis[1]	South of 25 ^{o}S	3-134	282 mm	**?** g	12mm	Unknown
O. dierythraeus[2]	North of 21^{o}S	0-78	810 mm	1500 g	14 mm*	350
O. exannulatus[3]	North of 27^{o}S	0-84	200 mm	75 g	3.9mm	5000
O. graptus[2]	North of 19^{o}S	11-36	1300 mm	4200 g	28 mm	680
O. marginatus[4]	North of 27^{o}S	1-190m	300 mm	400 g	3 mm	100,000
O. cf *kagoshimensis*[5]	South of 23 ^{o}S	1-115	335 mm	200 g	3.8 mm	60,000

[1] Stranks and Norman 1992; [2] Norman 1992a; [3] Norman 1992b; **4** Norman 1998*; [5] Norman unpublished data. * measurement from a sub-mature animal.

*12.1.7 Pipehorses (*Solegnathus *spp.)*

Pipehorses are unusual fish belonging to the family Syngnathidae, which also includes the pipefish, seadragons and seahorses. Over-exploitation of some *Syngnathids* species has resulted in the family being red listed as vulnerable under the International Union for Conservation. Currently there are two species of pipehorses that are retained by commercial fishers, *Solegnathus hardwickii* and *Solegnathus dunckeri*. Both species are endemic to Australia and are among the largest species of syngnathids in the world. As a result they are highly valuable in the Asian medicine market and can obtain prices varying from \$130 to \$1300 kg^{-1}. Currently Queensland exports between 800–1000 kg of dried pipehorses per year (Connolly et al., 2001). Anecdotal evidence from fishers indicates that each pipehorse averages \$10 per fish, therefore, as 7067 pipehorses were recorded in logbook data in 2000 the approximate value of the fishery is \$70,000.

Despite their large size and economic importance very little is known about the biology and ecology of *Solegnathus* species. *S. hardwickii* is distributed from Cairns (16°55’ S) to south of the Tweed River (28°10’ S) whereas *S. dunkeri* is distributed from Fraser Island south to Booti Booti (36°16’ S) (Pogonoski et al., 2001). Current information on the habitat and depth distribution is limited as observations are based solely from trawl captures. Connolly et al., (2001) reported that pipehorses were only caught at depths greater than 25 m and appeared to be more abundant with proximity to reefs in areas having some three-dimensional structure such as sponges and gorgonian corals. A closely related species from southern Australia, *S. spinossimus*, has been recorded from 300-400 m with divers observing them living around sea whips (Edgar, 1997). The extent of movement by *S. hardwickii* and *S. dunckeri* is unknown, but they are likely to be sedentary as they lack a caudal fin and have prehensile tails.

Syngnathids are unusual fish in that the male incubates the eggs. Male *Solegnathus* species have their eggs embedded in a spongy brood patch on the ventral surface of the tail. Other species of large syngnathids from Australian waters that use this mode of reproduction include the seadragons *Phyllopteryx taeniolatus* and *Phycodurus eques* (Mackay, 1998). Pregnant males of *S. hardwickii* have been found from July through to October (QFS, 2001). In contrast, Connolly et al. (2001) reports that pipehorses breed year round with a peak in reproductive activity from mid-winter to spring based on the observation of the presence of egg scars. However, it must be noted that the duration and persistence of egg scars on *Solegnathus* species is currently unknown. The minimum size at maturity for male *S. hardwickii* is 322 mm and the size at which 50% of pipehorses are mature is 420 mm (Connolly et al., 2001). Although the brood duration is not known for pipehorses, the seadragons *Phyllopteryx taeniolatus* and *Phycodurus eques,* which display a similar reproductive strategy, incubate their eggs for 4–5 weeks and eggs hatch over 10 days (Groves, 1998). This strategy is believed to distribute the young over a wider area, offering the young less competition from siblings. Brood size in *S. hardwickii* ranges from 19–207 with eggs measuring 5 mm in diameter. At hatching juveniles measure 34 mm in total length and for the first nine months they grow at 1.2 mm per day, however this growth rate slows down to 0.3–0.5 mm per day once pipehorses are approaching adult sizes. Current estimates of longevity in *S. hardwickii* indicate that pipehorses live for 3–5 years and reach a maximum size of 515 mm.

*12.1.8 Pinkies (*Nemipterus *spp.)*

Fishes belonging to the Nemipteridae family are marine perciformes that occur in the tropical–subtropical Indo-West Pacific region and inhabit mud and sand bottoms to a depth of 410 m, although most species occur in much shallower waters. They belong to the superfamily Sparoidea, a monophyletic group that also include members of the families Sparidae (porgies), Lethrinidae (emperor fishes and large eye breams), Centracanthidae (Picarels) and Lutjanidae (snappers) (Russell, 1990). The genus *Nemipterus* is one of five genera belonging to the Nemipteridae family. *Nemipterus* fishes are typically pink with yellow, red and/or blue markings with a slender to ovate body shape. There are currently seven species of *Nemipterus* that are distributed along Queensland’s east coast. However, the catch composition and biology of these species caught by trawlers in Australian waters are poorly understood. *N. aurifilum* (yellowlip butterfly bream) and *N. theodorei* (Theodore’s butterfly bream) inhabit depths ranging from 24–220 m and 19–410 m, respectively, and are endemic to the east coast of Australia. *N. furcusus* (rosy threadfin bream), *N. hexodon* (yellow banded butterfly bream) and *N. peronii* (notched threadfin bream) have wider distributions being also found throughout South-East Asia and inhabit depths down to 110 m, 80 m and 100 m, respectively (Russell, 1990). Two other species *N. marginatus* (no local common name, to 70 m) and *N. nematopus* (yellow-tipped threadfin bream, to 102 m) have been caught on the eastern tip of Cape York.

Several studies have investigated the reproductive biology of a variety of *Nemipterus* species and indicate that fish mature and spawn after one year (Eggleston, 1972; Sainsbury and Whitelaw 1984; Acharya, 1990; Samuel, 1990; Vivekanandan, 1991). The maturity stage of the testes is difficult to assess by eye as its appearance changes little throughout the year and are relatively small in mature fish (i.e. 1/7 of the body cavity length, Eggleston, 1972). Ovarian development is easily divided into various stages of development through macroscopic examination. In young fish the ovary develops from a small thread to a short solid cylinder and in contrast to the testis lies beneath the peritoneum. During vitellogenesis the ovary grows to approximately 1/3 to 1/2 of the body cavity length with opaque oocytes clearly visible to the naked eye. In fully mature fish the ovary is blotched with clusters of hydrated eggs and vitellogenic eggs of a range of sizes. As no wholly ripe gonads have been found and vitellogenic eggs are present over a prolonged period in *Nemipterus* species, they are most likely to be fractional spawners releasing eggs at several spawnings throughout the breeding season (Eggleston, 1972). This mode of reproduction is the dominant mode displayed by tropical and warm temperate marine fishes (Pankhurst, 1998), and within the closely related Sparidae family daily broadcast spawning at dusk is common (Haddy and Pankhurst, 1998; Scott et al., 1993). However, the spawning behaviour and periodicity and timing of spawning in *Nemipterus* species is currently unknown. The fecundity of Nemipterids is directly related to the size of the fish (Eggleston, 1972; Murty, 1984; Mohan and Velayudhan, 1986; Raje, 1996). Fecundity estimates range from 5344 to 64,369 eggs in *N. mesoprion* (Raje, 1996); 23,049 to 139,160 eggs in *N. japonicus* (Murty, 1984), and 86,184 to 497,230 eggs in *N. delagoae* (Mohan and Velayudhan, 1986). The eggs of *N. virgatus* are small (0.7–0.8 mm), colourless, buoyant and spherical and hatch in 24 hours as yolk sac larvae measuring 1.7 mm in length (Aoyama and Sotogaki, 1955; Renzhai and Suifen, 1980).

Nemipterid fishes are entirely carnivorous fishes that feed by sight during the day. Their main prey items are crustaceans (60–75%), but they also consume small fish, (8–30%), polychaetes (3–6%) and cephalopods (0.4–5%) (Eggleston 1972; Sainsbury and Whitelaw, 1984; Salini et al., 1994). Many *Nemipterus* species show size-related differences in sex ratio, with large specimens being mainly males. This size-related skew in sex ratios appears to be due to faster growth rates in males as growth slows at the onset of sexual maturity in females (Eggleston, 1972; Russell, 1990; Samuel, 1990), however, there is evidence of protogynous hermaphroditism in *N. furcosus* (Young and Martin, 1985). Other species of *Nemipterus* appear to be non-functional rudimentary hermaphrodites in which males have functional testies, but retain rudimentary ovarian tissue throughout their life (Young and Martin, 1985; Lau and Sadovy, 2001).

The von Bertalanffy growth parameters have been estimated for several species of *Nemipterus*, however, most of these studies have concentrated on populations from Asian waters (India to Hong Kong) where substantial fisheries exist for these species. The mean population parameter estimates generated for *N. furcosus*, *N. hexodon N. marginatus* and *N. peronii* in these studies are summarised in Table 12.1.7. Values of K and L_∞ reported for *Nemipterus* by Pauly (1980) range from 0.27–0.98 and 19.5–31.5, respectively. *N. furcosus* and *N. peronii* are the only species in which the von Bertalanffy growth parameters have been determined in Australian waters. Sainsbury and Whitelaw (1984) collected otoliths from *N. furcosus* captured at the North-West Shelf (WA) and estimated L_∞, K, t_o and M to be 41.9 cm, 0.25, 0.74 years and 1.85 respectively, however these findings were outside the previously known ranges of the genus indicated by Pauly (1980). Morales-Nin (1989) used several methods to estimate the growth parameters of *N. furcosus* from the North-West Shelf and reported values of L_∞ and K ranging from 26.7–28.4 cm and 0.42–0.71, respectively.

Table 12.1.7. Population parameter estimates for Queensland Nemipterid species. Note: Parameter estimates were derived from Fishbase 99 using the references cited below.

Species	L_∞	***K***	t_0	***M* at 25°C**	**Life span** (yrs)	t_m (yrs)	L_m (TL)
N. aurifilum[1]	18.5 (SL)	?	?	?	?	?	?
N. furcosus[2]	26.7 (TL)	0.45	-0.38	0.94	6.3	1.7	16.0
N. hexodon[3]	25.5 (TL)	0.48	-0.36	1.00	5.9	1.5	15.3
N. marginatus[4]	19.5 (TL)	0.63	-0.29	1.2	4.5	1.2	12.0
N. nematopus[1]	18.5 (SL)	?	?	?	?	?	?
N. peronii[5]	28.5 (TL)	0.44	-0.38	0.91	6.4	1.7	16.9
N. theodorei[1]	20.0 (SL)	?	?	?	?	?	?

[1] Russell 1990; [2] Morales-Nin 1989; [3] Tandog-Edralin, et al. 1988;. Dwiponggo, et al. 1986; Pauly 1980; [4] Weber & Jothy 1977; [5] Ingles & Pauly 1984; Weber & Jothy 1977;. Wu & Yeh 1986.

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