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A SAFE analysis of bycatch in the Joseph Bonaparte Gulf fishery for Red-legged Banana Prawns

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Australian Fisheries Management Authority

NPF Industry Pty Ltd

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Producing the finest quality prawns from a sustainable marine ecosystem

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Important disclaimer

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Executive summary

The Joseph Bonaparte Gulf (JBG) is a region within the Northern Prawn Fishery (NPF) management area. The trawl fishery for Red-legged Banana Prawns (*Penaeus indicus*) in the JBG Box produces several hundred tonnes of prawns each year. Like the Tiger Prawn fishery, trawling for Red-legged Banana Prawns incidentally catches many fish species. The sustainability of these species is a concern to fishery managers and the industry. In this report, we conduct the first ecological risk assessment for the observed bycatch species in this fishery. We apply a quantitative method—Sustainability Assessment for Fishing Effect (SAFE)—to 150 fish species and assess the fishing impact in the four years from 2010 to 2013.

The SAFE method adopts the essential concept in a traditional fishery stock assessment: an indicators—reference points system. SAFE focuses on one single indictor — fishing mortality rate. Because of a lack of basic data for non-target species, SAFE derives fishing mortality rate using simple techniques and derives reference points based on life history parameters.

A range of data are sourced and used in this assessment. The list of bycatch species is based on the Bycatch Monitoring database maintained by CSIRO. Three sources provide species distribution information: the National Marine Bioregionalisation database, historical scientific surveys, and the bycatch monitoring program. Fishing effort, measured as total trawling hours, is extracted from AFMA logbooks. Fishing gear configuration, catch efficiency, escapement rate, as well as fish life history parameters, are from previous studies.

Because no one single source can provide distribution information for all species, we use three alternative approaches to derive distribution ranges and the resulting fishing impact. Approach 1 is based on Bioregional maps, Approach 2 on historical surveys, and Approach 3 on Bycatch Monitoring data. An annual instantaneous fishing mortality rate is calculated for each species from spatial overlap between species distribution and area trawled, tuned by catch efficiency and probability of escapement.

Five methods are used to derive sustainability reference points. These methods relate reference points to alternative life history traits, including natural mortality, growth parameters, maximum age, maximum length, and age at maturity. The key reference point is F_{msm}, the instantaneous fishing mortality rate that corresponds to the maximum number of fish in the population that can be killed by fishing in the long term (similar to F_{msy} for target species).

Fishing effort on the Red-legged Banana Prawns was relatively low in the assessment years, ranging from 1,740 to 5,631 trawling hours. On an annual basis, such a low fishing effort covers less than 1% of seabed in the JBG Box.

Among the 150 species, 12 are elasmobranchs and 138 are teleosts. Approach 1 is applied to all elasmobranchs. The spatial overlap between their distribution ranges and fishing effort is less than 2% in any of the four years. The fishing mortality rate is estimated between 0 and 0.018 in the four assessment years. Comparison to the reference point F_{msm} (ranged from 0.066 to 0.250 for these 12 species) reveals no one species at risk of overfishing.

A total of 102 teleost species have spatial information in the Bioregionalisation database so Approach 1 is applied to these species. Among them, fishing in 2010-2013 did not take place within the distribution areas of 10 species. For the remaining 92 species, 0 to 2.2% of their distribution ranges within JBG Box was trawled in 2010-2013. These numbers transfer to a mortality rate between 0 and 0.014, much smaller than the reference point F_{msm} (minimum 0.22 for these species).

Approach 2 is applied to 12 teleost species. Spatial overlap ranges from 0 to 14% for these species in the four assessment years. Consequently, fishing mortality rate is estimated between 0 and 0.11, which is smaller than F_{msm} (minimum 0.40 for these species).

Approach 3 is applied to the remaining 24 teleosts. The spatial overlap fraction ranges from 0 to 25%, with an average about 7%. The higher overlap yields a high fishing mortality, up to 0.2. However, this F is still lower than the smallest F_{msm} of 0.26 for these species.

The overall conclusion from this assessment suggests that fishing intensity at 2010-2013 level has a low impact on fish bycatch and does not affect the long-term sustainability of the bycatch species evaluated.

Key words: Red-legged Banana Prawn, JBG, sustainability, ecological risk assessment, spatial distribution reference points, fishing mortality, North Prawn Fishery, bycatch, elasmobranchs, teleosts

1 Introduction

The fishery for Red-legged Banana Prawns (*Penaeus indicus*) in the Joseph Bonaparte Gulf (JBG) is a sub-fishery in the Northern Prawn Fishery (NPF). The area is defined as west of 129.7^{o}E and south of -12^{o}S, often called the "JBG Box". This fishery started in early 1980s. Since then fishing effort has varied between 700 and 2,600 boat days per year, with catches ranging from 200 to 1,000 t and averaging about 800 t, or about 20% of the yearly banana prawn catch for the whole NPF (Loneragan *et al.*, 2002).

A risk assessment for fishing effects has been completed for the Tiger Prawn sub-fishery in the NPF. However, similar assessment has not been carried out for the JBG Red-legged Banana Prawn sub-fishery.

The Marine Stewardship Council (MSC) accreditation of the fishery requires that an analysis for the Red-legged Banana Prawn fishery be carried out by using the available information (logbook and observer) to demonstrate the status of bycatch species with respect to their biologically sustainable limits.

The FRDC project 2013/47, "Synthesis of existing information, analysis and prioritisation of future monitoring activities to confirm sustainability of the red-legged banana prawn sub-fishery in the Joseph Bonaparte Gulf", recommended that a SAFE analysis should be undertaken for the fishery. This would ensure that the fishery is sustainable and environmentally benign. This project was endorsed by the Northern Prawn Fishery Management Advisory Committee (NORMAC) on 15 September 2014.

In this report, a sustainability assessment for fishing effect (SAFE) is performed for the Red-legged Banana Prawn fishery in JBG. Because of a lack of scientific surveys, the method has been modified from the Tiger Prawn Fishery SAFEs (Zhou and Griffiths, 2008; Zhou *et al.*, 2009b). It also has some variations from the assessments of other Commonwealth fisheries (Zhou *et al.*, 2007, 2011). This report details the assessment methods and results for the JBG fishery.

2 Materials and methods

2.1 Data sources

2.1.1 LIST OF FISH SPECIES CAUGHT IN RED-LEGGED BANANA PRAWN FISHERY

The NPF Bycatch Monitoring (Observer) Program collects a range of biological and fisheries information. We obtained a list of all fish species incidentally caught in the JBG fishery from Bycatch Monitoring Program between 2001 and 2005. Among a total of 150 fish species, there are 12 elasmobranchs and 138 teleost species (Table 2-1). Eight species could not be identified at species level. All these species, except two teleosts (*Nematalosa come* and *Aploactis aspera*), have been observed in the NPF Tiger Prawn Fishery (Brewer *et al.*, 2007).

2.1.2 SPATIAL DISTRIBUTION OF FISH SPECIES

Species distribution information is essential for SAFE analysis. Unfortunately, we were unable to find data for all bycatch species from one single source. We opted to use three alternative data sources and approaches for spatial distribution.

Approach 1: The National Marine Bioregionalisation provides a spatial distribution of the broad scale physical and biological components of Australia's marine jurisdiction (http://www.environment.gov.au/node/18076). The National Marine Bioregionalisation consists of Benthic Regionalisation and Pelagic Regionalisation. The database contains biological and ecological information for thousands of marine species, including their distribution ranges (IMCRA, 1998; Last *et al.*, 2005). We attempted to extract the distribution data for the 150 bycatch species on our list, and found that 114 species, including all the 12 elasmobranchs, have spatial distribution data (Table 2-1). However, the remaining 36 do not have distribution information. Further, amongst these 36 species eight were due to identification issues.

Approach 2: Over 70 scientific voyages have been undertaken in the NPF managed area between 1979 and 2003, mostly by CSIRO and a few by state fisheries agencies. Together, the surveys covered the entire NPF, although not in any one voyage. There were a total of about 6,000 samples taken in the NPF. However, amongst these gear deployments, only about 100 samples took place in the JBG Box (Figure 2-1). Twelve of the remaining 36 species were detected in these samples. Hence, we were able to carry out a SAFE for these 12 species using the spatial distribution from historical scientific surveys. We defined a sampling unit as a 6 by 6 nautical mile grid, which is currently used in NPF logbooks for reporting purposes.

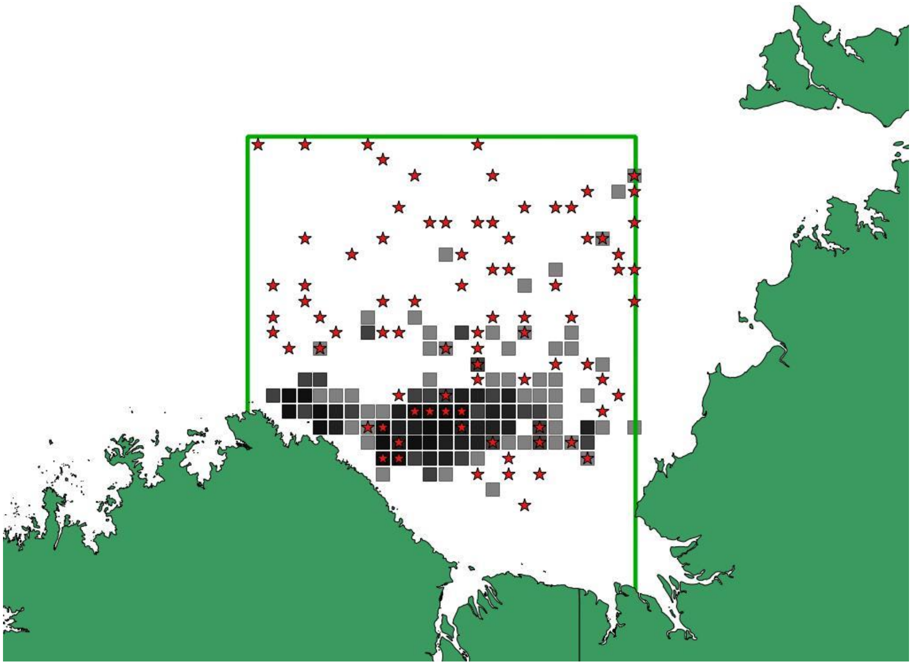

Figure 2-1. Historical scientific surveys (stars) and fishing effort (squares) from 2010 to 2013 in the JBG Box.

Approach 3: The two data sources above provide some information on spatial distribution of 126 species recorded in the monitoring database. For the remaining 24 species (several are not identifiable at species level), we used the actual monitoring data in which these species were recorded (Brewer *et al.*, 2007).

2.1.3 FISHING EFFORT

Fishery logbook data in the JBG prawn fishery from 2010 to 2013 were used to assess the impact of this fishery on fish bycatch species during this 4-year time period. Potentially, fishing effort can be measured in several ways: number of boats and days fishing, total fishing hours, and hours actually trawling. Because fishers might spend a significant time searching for prawn it was recommended that the actual trawling hour is better to use as fishing effort. Although data quality of actual trawling hour might be poor in early years, the records in recent years are considered to be good.

2.1.4 GEAR EFFICIENCY

Gear efficiency is one of the major factors that contribute to the final fishing mortality, because not all individuals on the trawl path can be caught. Two variables are involved in our method: the probability of overran individual entering the fishing gear (i.e., catch rate) and the probability of escaping after the fish have entered the net (i.e., escapement rate). In the previous assessments (Zhou and Griffiths, 2008; Zhou *et al.*, 2009b), these two parameters have been derived for species caught in the NPF Tiger Prawn Fishery. Given that the fishery is prosecuted by the same vessels and gear, we adopt these estimates in this report. Only two species, *Nematalosa come* and *Aploactis aspera*, were not previously recorded. *N. come* belongs to family Clupeidae. We borrowed information from the other three species in the same family, i.e., *Anodontostoma* *chacunda*, *Dussumieria elopsoides*, and *Herklotsichthys lippa*. We assumed a catch rate of 0.33 and an escapement rate of 0 for *A. aspera*, these values being the same as for other similar-sized species.

2.1.5 LIFE HISTORY PARAMETERS

The SAFE method drives reference points from simple life history traits. Necessary data have been compiled for all species (again, except *N. come* and *A. aspera*) in the previous assessment of the Tiger Prawn Fishery. The data were typically obtained from the literature. In cases where life history parameters were not available from literature, information was obtained from the Fishbase database (www.fishbase.org). For *N. come* we again borrowed information from the other three species in the same family. We obtained life history parameters for *A. aspera* from Fishbase.

2.2 Estimating fishery impacts

Our aim is to estimate annual fishing impact from 2010 to 2013. Fishing impact is expressed as instantaneous fishing mortality rate within the JBG Box. For species *i*, fishing mortality in year *y* is derived as:

$$F_{i,y} = \frac{C_{i,y}}{\overline{N}_{i,y}} = \frac{Q_i(1-E_i)(1-S_i)\sum_t L_{t,i}W}{A_i} \qquad (2.1)$$

where C_i is the catch in number of species *i* dead after discarding, $\overline{N}_{y,i}$ is the mean population size over the one year period, Q_i is the gear-efficiency (catch rate), E_i is the escapement rate after the fish entering the trawl, S_i is the discard survival rate, W is the width of trawl wing spread, $L_{t,i}$ is the trawling distance that occurs within the species distribution range, and A_i the occupied area within the fishery jurisdiction. This base equation is similar to the previous studies (Zhou and Fuller, 2011; Zhou *et al.*, 2009a).The trawling length in each tow *t* is calculated from hours-trawled recorded in the logbook and trawling speed. We assume the average width of trawl wing spread is 16.9 m (headrope length of 26 m and a 0.66 spread ratio) and the average towing speed is 3.24 knots (Brewer *et al.*, 2007; Milton *et al.*, 2007).

The same catch rates of each species used in the previous NPF assessment are applied here (Brewer *et al.*, 2007; Zhou and Griffiths, 2008; Zhou *et al.*, 2009b). They are obtained directly from the literature. In cases where data are not available, it is then estimated based on species in the same genus for which catch rates were measured. Furthermore, the same escapement rates used for elasmobranchs in previous assessments (Brewer et al. 2007; Zhou and Griffiths 2008) are applied in this report. Teleosts have low escapement rates so it is assumed $E = 0$ (Brewer *et al*. 2007; Zhou et al. 2009b). The survival rate after returning to the sea, S_i, is assumed to be zero for all species.

The last variable A_i, species distribution area within JBG, is a key input and as stated above we use three approaches to derive this variable.

Approach 1: based on Bioregional maps. The species distribution area is the overlapping between its entire distribution range and the JBG Box boundary.

Approach 2: based on historical scientific surveys. The total distribution area for species *i* is the sum of 6 by 6 NM grids where this species were detected in the surveys.

Approach 3: based on NPF monitoring data. The total distribution area for species *i* is the sum of 6 by 6 NM grids where this species were detected in the monitoring database.

2.3 Sustainability reference points

Two fishing mortality reference points used in the risk assessment of other Commonwealth fisheries (Zhou et al. 2007; Zhou et al. 2009b; Zhou et al. 2010a) are adopted here:

F_{msm} = instantaneous fishing mortality rate that corresponds to the maximum number of fish in the population that can be killed by fishing, yet the population remains sustainable in the long term. The latter is the maximum sustainable fishing mortality (MSM) at B_{msm} (biomass that supports MSM), similar to target species MSY;

F_{crash} = minimum unsustainable instantaneous fishing mortality rate that, in theory, will lead to population extinction in the long term.

These reference points are linked to life history parameters of each species. A meta-analysis reveals that maximum sustainable fishing mortality F_{msy} is a function of natural mortality M (Zhou *et al.*, 2012b). The relationship between the two differs between chondrichthyans and teleosts:

For chondrichthyans: $F_{msy} = 0.41\,M$;

For teleosts: $F_{msy} = 0.87\,M$.

The reference points are derived from the following methods:

i. $F_{msm} = \omega M$, and $F_{crash} = 2\,\omega M$, where M is obtained from literature;

ii. $F_{msm} = \omega M$, and $F_{crash} = 2\,\omega M$, where $\ln(M) = -0.0152 - 0.279\ln(L_\infty) + 0.6543\ln(k) + 0.4634\ln(T)$ (Pauly, 1980; Quinn and Deriso, 1999);

iii. $F_{msm} = \omega M$, and $F_{crash} = 2\,\omega M$, where $\ln(M) = 1.44 - 0.982\ln(t_m)$ (Hoenig, 1983).

iv. $F_{msm} = \omega M$, and $F_{crash} = 2\,\omega M$, where $\log(M) = 0.566 - 0.718\,Log(L_\infty) + 0.02T$ (www.Fishbase.org);

v. $F_{msm} = \omega M$, and $F_{crash} = 2\,\omega M$, where $M = 1.65/t_{mat}$ (Jensen, 1996).

In these equations, k and L_∞ are von Bertalanffy growth parameters, T = average annual water temperature, t_m = maximum reproductive age, and t_{mat} = average age at maturity. If L_∞ is unknown but the maximum length L_{max} is known, we estimate length at infinity as: $\log(L_\infty) = 0.044 + 0.9841\log(L_{max})$ (Froese and Binohlan, 2000). As data availability varies, one or more of the above methods is applied to each species. Considering the uncertainty in the parameters themselves that come from the literature and from applying the methods (as well as potential correlation between these methods), these methods are given equal weight to derive the mean and ranges of F_{msm} and F_{crash}. The value of ω is 0.41 for chondrichthyans and 0.87 for teleosts.

2.4. Risk-based performance measures

Because input parameters for estimating fishing mortality and reference points typically involve large uncertainty, as well as the simplicity of the method, the results also have high uncertainty for many species. The risk categories are as follows:

Low risk (L): $F < F_{msm}$;

Medium risk (M): $F_{msm} \le F < F_{crash}$;

Precautionary medium risk (m): $F \ge \min[F_{msm}]$ or $F + 90\%\mathrm{CI} \ge F_{crash}$;

High risk (H): $F \ge F_{crash}$;

Precautionary high risk (h): $F \ge \min[F_{crash}]$ or $F + 90\%\mathrm{CI} \ge F_{crash}$.

2.5. Uncertainty assessment

Area fished and fishing hours are assumed to contain low uncertainty because the daily fishing locations and time are recorded in compulsory fishery logbooks. However, higher uncertainty may exist in catch rates and the probability of escapement due to TEDs. We evaluate uncertainty around these parameters. Variances of Q and E are calculated from binomial distributions, assuming both capture and escapement from the trawl were binomial processes, using the sample size from field experiments or assumed samples. The combined variance is obtained by a delta method. Finally, the species distribution area is a difficult variable. There aren't enough data from surveys to estimate or validate the distribution areas based on the three alternative approaches. Generally, we believe Approach one, based on Bioregional maps, may overestimate the distribution area and result in an underestimation of fishing mortality rates. On the other hand, Approaches 2 and 3 are likely to be too conservative, underestimating the distribution range and so resulting overestimation of fishing mortality rates.

3 Results

3.1 Fishing effort

Fishing effort can be measure in various ways. Two categories of fishing effort are recorded in the JBG logbook: Hours and Hours-trawled. In addition, the total number of days fished by the fleet can be extracted from the logbook. In many cases, Hours were recorded as 24 h. It was suggested that Hours-trawled was the more appropriate effort because fishers may spend a significant time on searching for prawns in this fishery (P. Robson and M. O'Brien, NPF Industry, personal communication).

The Red-legged Banana Prawn fishery in the NPF has experienced a significant change over the history of the fishery (Figure 3-1). The total trawling hours were very low before 1998, and increased to about 20,000 h in late 1990s and early 2000s. In the assessment years (2010 to 2013), it varied between 1740 and 5631 h. These fishing hours can only cover a very small fraction (about 0.3% to 0.8%) of the total seabed in the JBG Box. However, we note that the data quality recorded as actual trawling hours in the logbook may be poor in the early years.

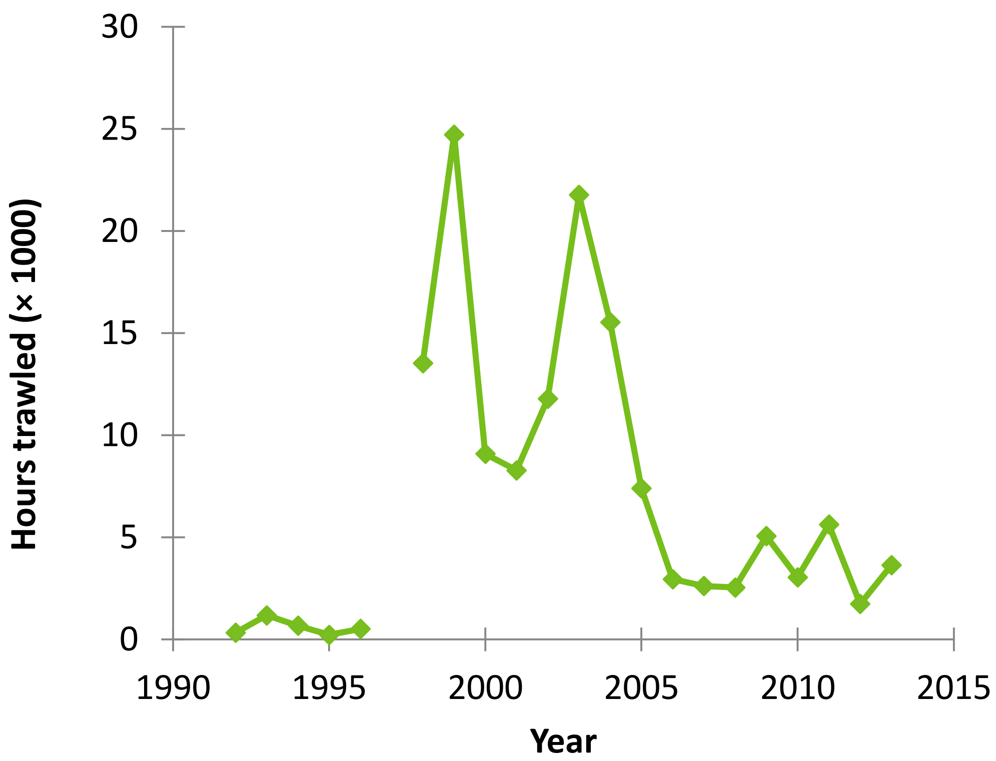

Figure 3-1. Fishing effort measured by actual trawling hours in JBG Redlegged banana fishery.

3.2 Assessment of elasmobranchs bycatch

3.2.1 ELASMOBRANCH SPATIAL OVERLAP BETWEEN DISTRIBUTION AND FISHING

The first indicator of fishing impact is the spatial overlap between species distribution and trawling. Distribution maps of all of the 12 elasmobranch species observed in the bycatch monitoring data were provided by the Bioregionalisation database. Further, all these species had some of their distribution range trawled during 2010-2013. However, their spatial overlap was very low, i.e., between 0 and 1.8%. A value of zero means fishing did not occur within that species' range in that particular year (Figure 3-2).

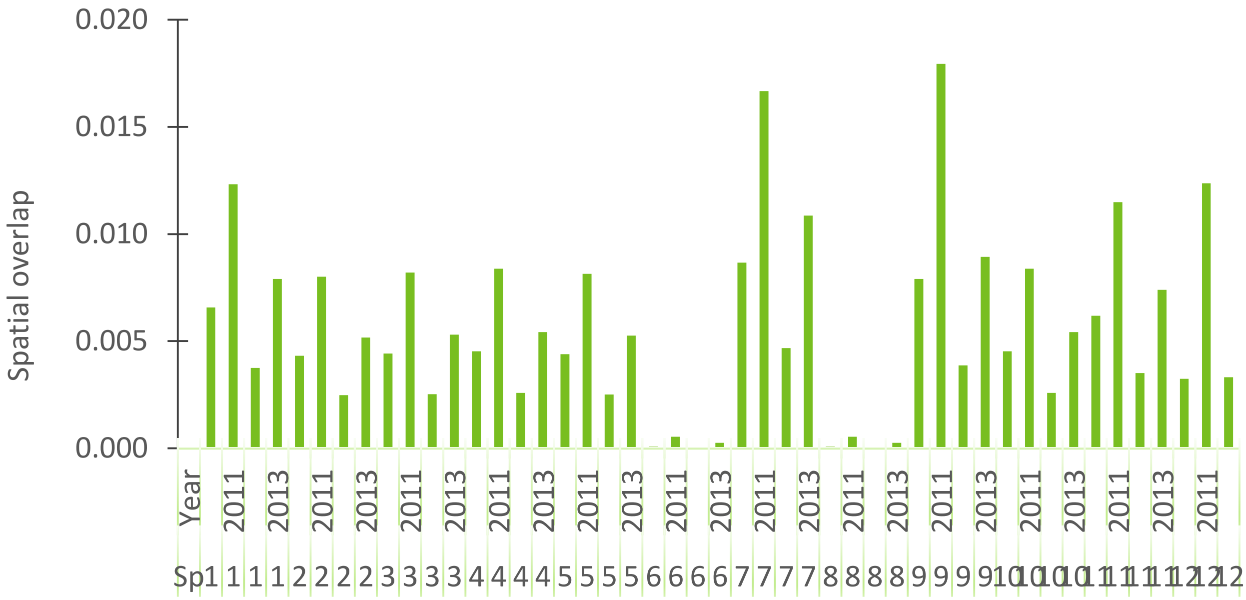

Figure 3-2. Spatial overlap between species distribution range and area trawled for elasmobranchs in JBG. Sp 1 to 12 represents the 12 species recorded in the monitoring data.

3.2.2 SUSTAINABILITY OF ELASMOBRANCHS POTENTIALLY IMPACTED TRAWLING

Because all elasmobranchs have spatial information in the Bioregionalisation database, we used Approach 1 to assess fishing impact. The analysis showed that the point estimates of fishing mortality rate ranged from 0 to 0.018 for these 12 species during 2010-2013, while the point estimates of reference point F_{msm} ranged from 0.066 to 0.250. However, both F and F_{msm} contained high uncertainties. Comparing the two quantities revealed that no one species had an estimated fishing mortality rate greater than their F_{msm} (so certainly not greater than F_{crash}) during the four assessment years, even when the large uncertainty was taken into consideration (Figure 3-3).

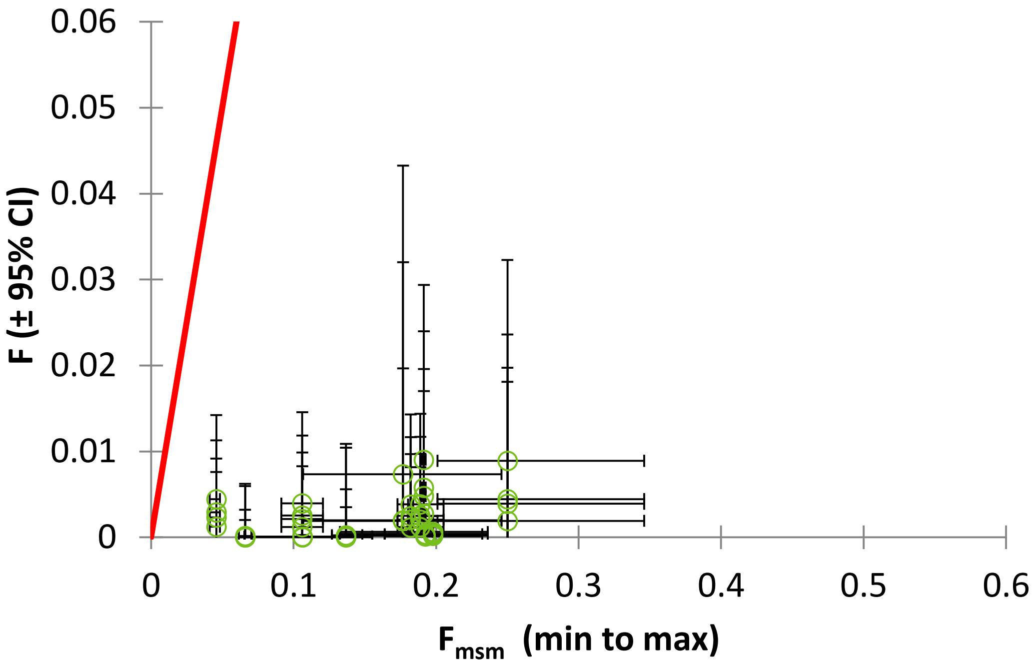

Figure 3-3. Comparison of estimated fishing mortality rate and the sustainability reference point F_{msm} for the 12 elasmobranchs from 2010 to 2013. Each point represents one species in one specific year. The red line is where F equals F_{msm}.

3.3 Assessment of teleost bycatch

3.3.1 TELEOSTS: SPATIAL OVERLAP BETWEEN DISTRIBUTION AND FISHING

Unlike elasmobranchs, not all teleost species have distribution data in the Bioregionalisation database. We used three alternative approaches to assess teleosts.

Approach 1. The majority (92) teleost species were assessed using Approach 1. These species had some of their spatial range fished in at least one year during 2010-2013. In addition to these 92 species, 10 teleosts had distribution information in the Bioregionalisation database but their distribution ranges were outside the fishing zone, i.e., there was no overlap between the distribution space and fishing effort.

Among these 92 species, spatial overlap was smaller than 2% for nearly all species in any one of the four years, excepting just one species, *Leiognathus splendens*, which in one year (2011) had a 2.2% overlap (Figure 3-4). In most cases, the overlap was only about 0.6%

Approach 2. The spatial distributions of the twelve teleost species were based on historical scientific surveys. For all of these 12 species, some of the fished zone during the four years was within their range. The overlap fraction ranged from 0 to 14%, but about 1% of overlap was the most frequent case (Figure 3-5).

Approach 3. The spatial distributions of the 24 teleost species were based on bycatch monitoring records from 2001 to 2005. For all of these 24 species, the fished zone during the four years was within some of their range. The overlap fraction ranged from 0 to 25%, with an average about 7% of overlap (Figure 3-6).

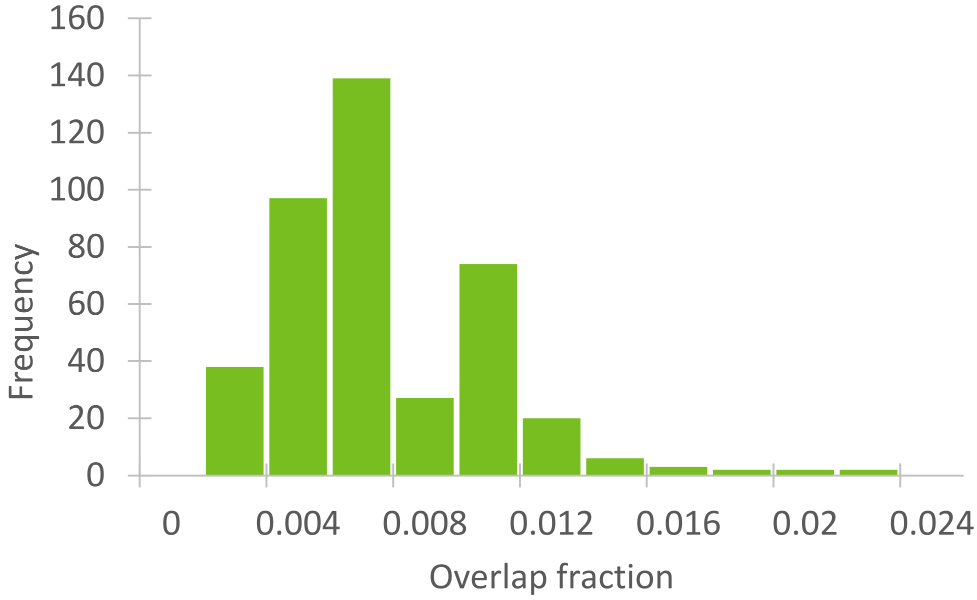

Figure 3-4. Fraction of 92 teleost species distribution ranges trawled by the Red-legged Banana Prawn fishery in 2010-2013. Species distribution is based on Bioregionalisation database (Approach 1).

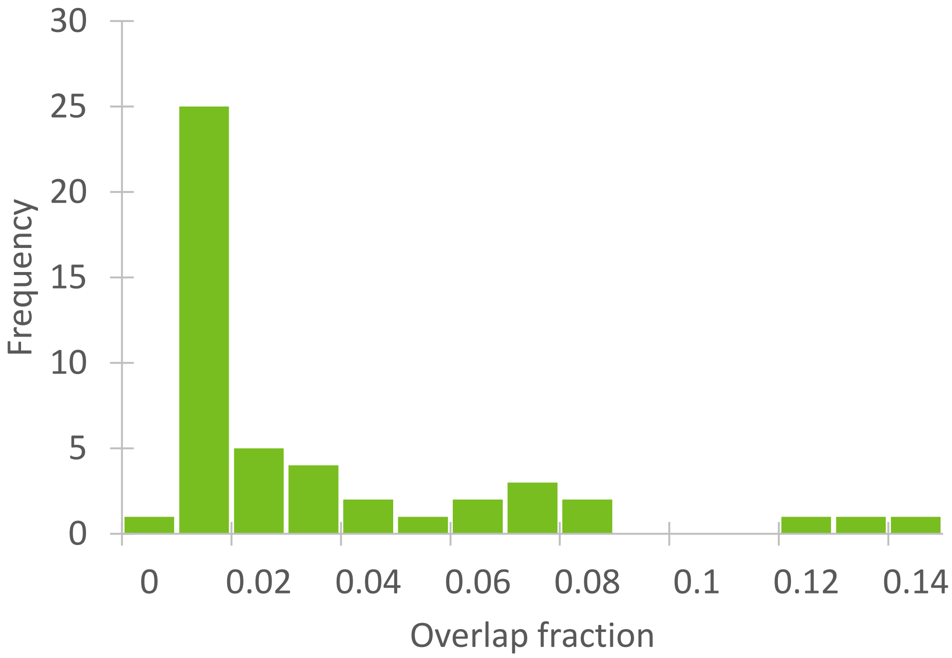

Figure 3-5. Fraction of 12 teleost species distribution ranges trawled by the Red-legged Banana Prawn fishery in 2010-2013. Species distribution is based on historical surveys (Approach 2).

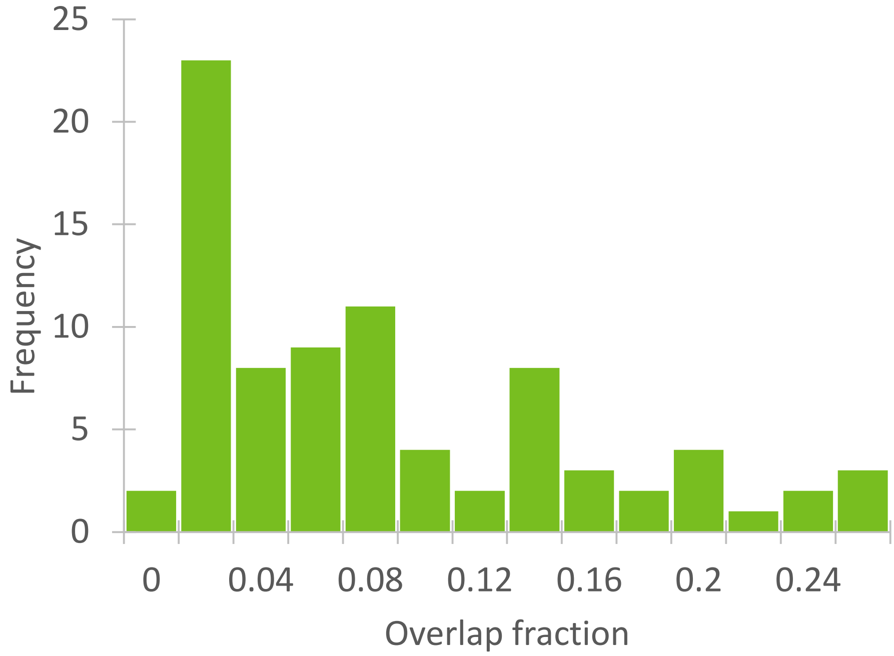

Figure 3-6. Fraction of distribution ranges of 24 teleost species trawled by the Red-legged Banana Prawn fishery in 2010-2013. Species distribution is based on bycatch monitoring data (Approach 3).

3.3.2 SUSTAINABILITY OF TELEOSTS POTENTIALLY IMPACTED BY TRAWLING

Approach 1. Again, this approach was applied to 92 teleost species. Using Equation (2.1) we obtained the point estimates of fishing mortality rates ranging from 0 to 0.014 for these species during 2010-2013. The point estimates of reference point F_{msm} were much larger for most teleosts, with a minimum value of 0.22. Similar to elasmobranchs, both F and F_{msm} contained high uncertainties. Comparing the two quantities suggested that no one species had an estimated fishing mortality rate greater than their F_{msm} (and again certainly not greater than F_{crash}) during the four assessment years, even when the large uncertainty was taken into account (Figure 3-7).

Approach 2. This approach was applied to 12 teleost species where historical scientific surveys provided their distribution information. The point estimates of fishing mortality rates were estimated to be between 0 and 0.11 for these species during 2010-2013. The smallest point estimate of reference point F_{msm} was 0.40. Clearly, all these species had an estimated fishing mortality rate smaller than their F_{msm}, even when the large uncertainty was taken into consideration (Figure 3-8Figure 3-3).

Approach 3. This approach was applied to 24 teleost species where bycatch monitoring records were the last resort for their spatial distribution. The point estimates of fishing mortality rates were much higher than the other species assessed by Approaches 1 and 2, estimated to be between 0 and 0.20 for these species during 2010-2013. The smallest point estimate of reference point F_{msm} was 0.26. All these species had an estimated fishing mortality rate smaller than their F_{msm}, even when the large uncertainty was taken into consideration (Figure 3-9Figure 3-8Figure 3-3).

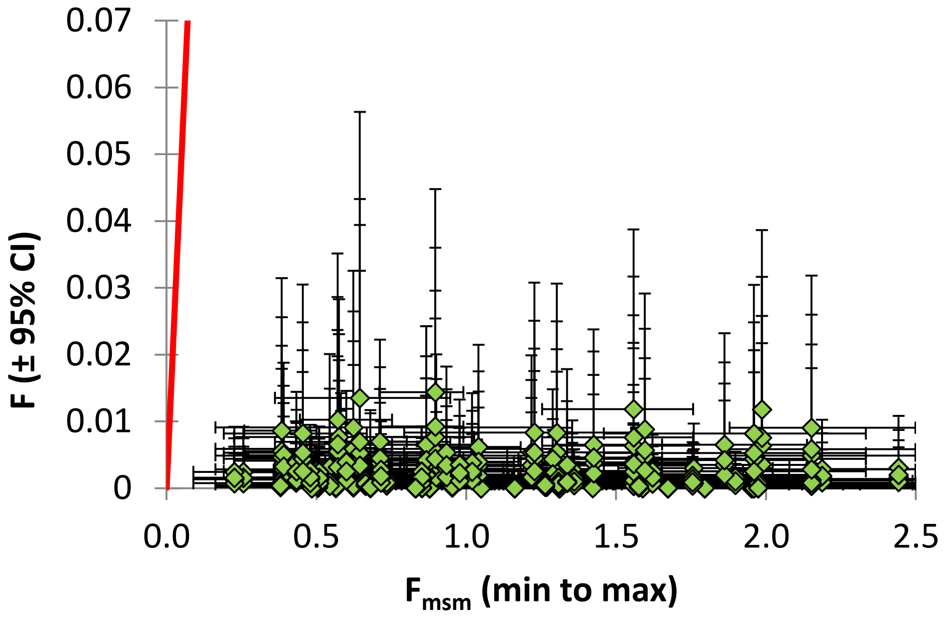

Figure 3-7. Comparison of estimated fishing mortality rate and the sustainability reference point F_{msm} for the 92 teleosts in 2010-2013. The distribution range was based on Bioregionalisation database (i.e., Approach 1). The red line is where F equals F_{msm}.

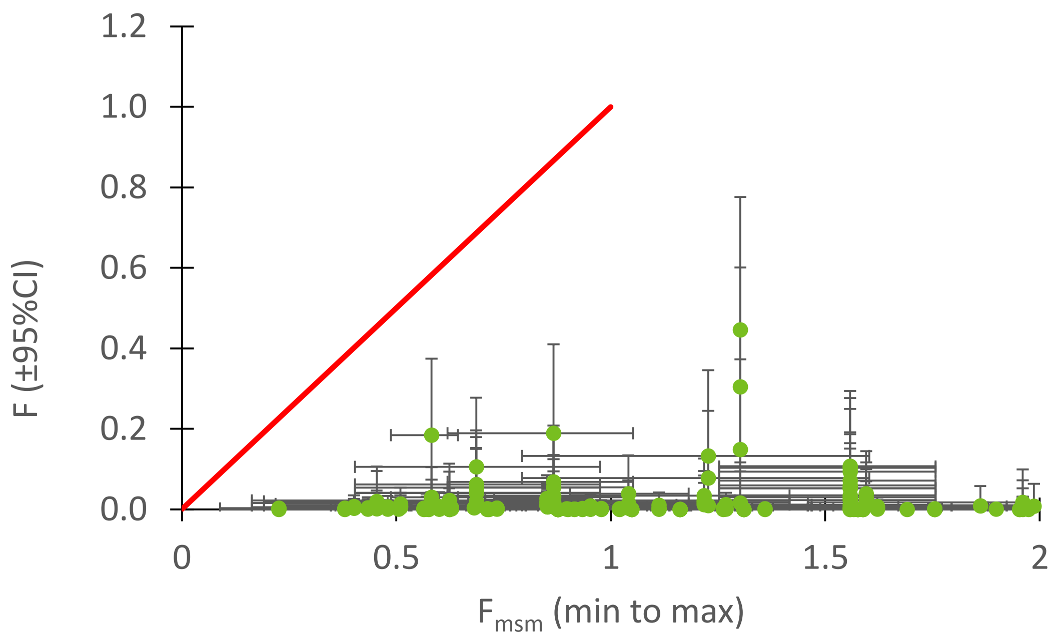

Figure 3-8. Comparison of estimated fishing mortality rate and the sustainability reference point F_{msm} for the 12 teleosts in 2010-2013. The distribution range was based on scientific surveys (i.e., Approach 2). The red line is where F equals F_{msm}.

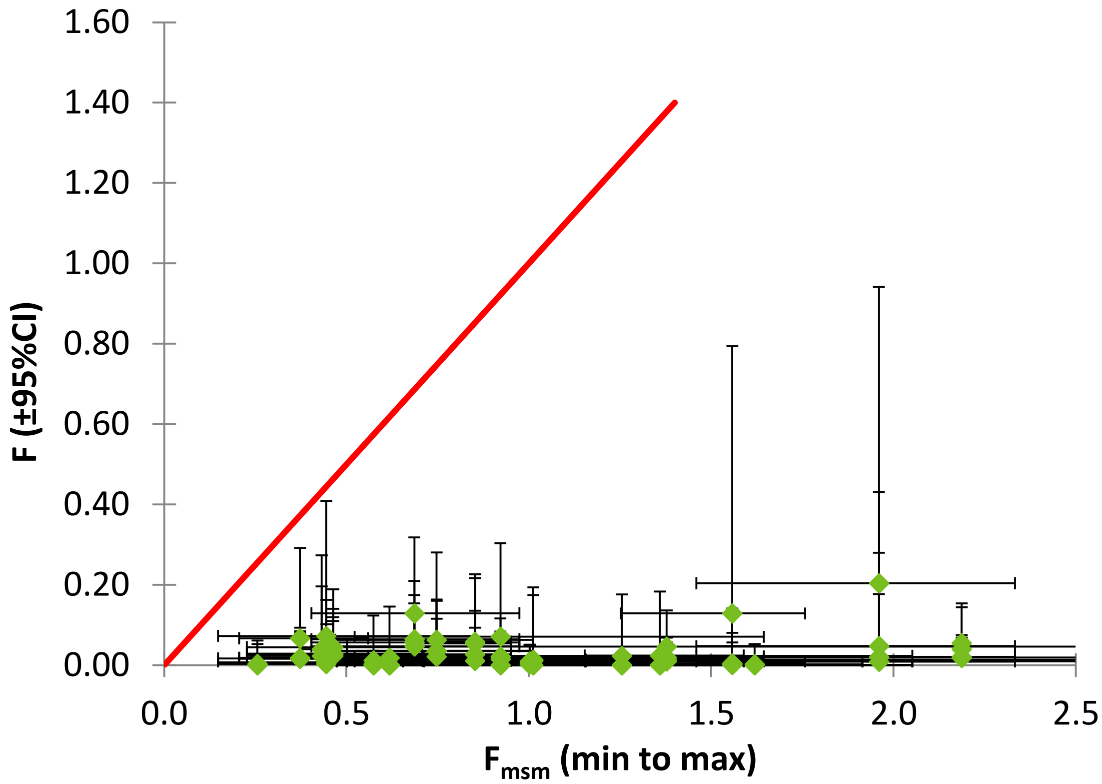

Figure 3-9. Comparison of estimated fishing mortality rate and the sustainability reference point F_{msm} for the 24 teleosts in 2010-2013. The distribution range was based on bycatch monitoring records (i.e., Approach 3). The red line is where F equals F_{msm}.

4 Discussion

This report applies SAFE to the Red-legged Banana Prawn fishery in the JBG Box for 2010 to 2013 fishing seasons. The framework is similar to that previously applied to the NPF (Brewer et al. 2007; Milton et al. 2007; Zhou and Griffiths 2008; Zhou et al. 2009a), SESSF (Zhou *et al.*, 2007, 2011, 2012a), and other fisheries (Zhou and Fuller, 2011; Zhou *et al.*, 2009a). However, there is one major variation: we use three approachs to derive potential fishing mortality rates.

Approach 1 relies on the biological regionalisation database for species distribution range (http://www.marine.csiro.au/marq/edd_search.Browse_Citation?txtSession=1121). This database has been improved and validated since the original Bioregionalisation Project in 1996 (Last *et al.*, 2005). The same distribution information has previously been used in assessment of the SESSF and another seven Commonwealth fisheries (Zhou *et al.*, 2007, 2011, 2012a, Zhou and Fuller, 2011; Zhou *et al.*, 2009a). The distribution data come from various sources, including museums, historical scientific surveys conducted by CSIRO, and records from State agencies (Last *et al.*, 2005). We believe that the quality of the data varies among species, and it is likely that distribution range is overestimated (as the bioregional maps are based on limited observations) for more species than underestimated. If this is true, then the fishing impact will be likely underestimated.

Approach 2 uses data from CSIRO scientific surveys conducted since the 1970s. This dataset is assumed to be more reliable and could be used to map species distributions and their relative density. However, doing so requires sufficient sample sizes with multiple detections over a wide range of space for each species. Examining the database reveals that there were only about 100 shots (samples) using various fishing gears in the JBG Box. Many observed bycatch species have never been detected in these samples. Hence, instead of using statistical models to map distribution and density, we assume that the 6 by 6 nautical miles grids in which a particular species was detected, describes the range of that species. This assumption is more likely to underestimate distribution range because most grids had never been surveyed and the gear might simply miss catching a species even when one or a few shots occurred in that grid. As a result, Approach 2 tends to overestimate fishing impact. On the other hand, the size of the grid used (e.g., 6×6 NM or 1×1 NM) will have an effect on the outcome. A study using extensive survey data may shed light on the most appropriate grid size to use in data-limited situations.

Approach 3 is the last option when there is no external information available beyond the fishery itself. The assumption is similar to Approach 2, that is, only the grids where a particular species was captured by the Red-legged Banana Prawn fishing fleet during 2001-2005 were deemed as that species' distribution range. Because many grids were not fished during these five years and a species might not been caught even when that grid was trawled, this method almost certainly underestimates distribution range for most species, resulting in overestimating fishing mortality rate.

Nevertheless, the three alternative approaches fail to detect any species that is potentially at risk of overfishing. We conclude that the impacts of fishing on the species examined, expressed as instantaneous fishing mortality rates, are less than the maximum rates that would be sustainable. Clearly, a key explanation of these findings is that a low proportion of the species' distribution ranges is being trawled as a result of low fishing effort.

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Table 2-1. List of fish species observed in JBG Red-legged Banana Prawn fishery from 2001 to 2005. Class 1 is elasmobranch and Class 2 is teleost. Approach 1 is based on bioregionalisation maps, Approach 2 on historical surveys, and Approach 3 on bycatch monitoring database.

CAAB code	Class	Scientific name	Common name	Approach
37013008	1	Chiloscyllium punctatum	Grey Carpetshark	1
37018006	1	Rhizoprionodon acutus	Milk Shark	1
37018009	1	Carcharhinus coatesi	Whitecheek Shark	1
37018014	1	Carcharhinus tilstoni	Australian Blacktip Shark	1
37018020	1	Hemigaleus australiensis	Weasel Shark	1
37019003	1	Eusphyra blochii	Winghead Shark	1
37025001	1	Pristis zijsron	Green Sawfish	1
37025002	1	Anoxypristis cuspidata	Narrow Sawfish	1
37035012	1	Neotrygon annotata	Plain Maskray	1
37035020	1	Himantura astra	Blackspotted Whipray	1
37035026	1	Himantura leoparda	Leopard Whipray	1
37037001	1	Gymnura australis	Australian Butterfly Ray	1
37063003	2	Muraenesox bagio	Common Pike Eel	1
37065005	2	Saurenchelys finitimus	Whitsunday Wire Eel	1
37067000	2	Congridae, Colocongridae - undifferentiated	conger & short-tail conger eels	3
37067005	2	Lumiconger arafura	Luminous Conger	1
37067021	2	Uroconger lepturus	Slender Conger	1
37068000	2	Ophichthidae - undifferentiated	snake eels	3
37085008	2	Herklotsichthys lippa	Smallspotted Herring	1
37085009	2	Pellona ditchela	Ditchelee	1
37085010	2	Dussumieria elopsoides	Slender Sardine	1
37085012	2	Ilisha lunula	Longtail Ilisha	1
37085013	2	Sardinella gibbosa	Goldstripe Sardinella	1
37085014	2	Sardinella albella	White Sardinella	1
37085015	2	Anodontostoma chacunda	Gizzard Shad	1
37085016	2	Nematalosa come	Hairback Herring	1
37086003	2	Setipinna paxtoni	Humpback Hairfin Anchovy	2
37086004	2	Thryssa setirostris	Longjaw Thryssa	1
37086005	2	Thryssa hamiltonii	Hamilton's Thryssa	2
37086006	2	Stolephorus indicus	Indian Anchovy	1
37086008	2	Setipinna tenuifilis	Common Hairfin Anchovy	1
37118001	2	Saurida undosquamis	Largescale Saury	1
37118005	2	Saurida argentea	Shortfin Saury	1
37118014	2	Saurida longimanus	Longfin Saury	1
37118901	2	Saurida spp.	lizardfish	3
37119001	2	Harpadon translucens	Glassy Bombay Duck	1
37122079	2	Benthosema pterotum	Opaline Lanternfish	3
37188001	2	Netuma thalassina	Giant Sea Catfish	1
37188013	2	Plicofollis nella	Shieldhead Catfish	3
37192003	2	Euristhmus nudiceps	Nakedhead Catfish	1
37192004	2	Euristhmus lepturus	Longtail Catfish	1
37205003	2	Batrachomoeus trispinosus	Threespine Frogfish	3
37210008	2	Antennarius hispidus	Shaggy Anglerfish	1

CAAB code	Class	Scientific name	Common name	Approach
37210010	2	Tetrabrachium ocellatum	Humpback Anglerfish	1
37212002	2	Halieutaea sp. W4 [of P. Last]	Starry Seabat	1
37225000	2	Bregmacerotidae - undifferentiated	codlets	3
37225002	2	Bregmaceros mcclellandi	Unicorn Codlet	1
37228005	2	Sirembo imberbis	Golden Cusk	1
37287011	2	Apistus carinatus	Longfin Waspfish	1
37287012	2	Pterois russelii	Plaintail Lionfish	1
37287014	2	Cottapistus cottoides	Yellow Waspfish	1
37287015	2	Liocranium pleurostigma	Blackspot Waspfish	1
37287021	2	Minous versicolor	Plumbstriped Stingfish	1
37288016	2	Lepidotrigla russelli	Smooth Gurnard	1
37290005	2	Aploactis aspera	Dusky Velvetfish	3
37296010	2	Inegocia harrisii	Harris' Flathead	3
37296013	2	Elates ransonnettii	Dwarf Flathead	2
37296018	2	Cociella hutchinsi	Brownmargin Flathead	2
37296020	2	Platycephalus westraliae	Yellowtail Flathead	1
37296033	2	Platycephalus indicus	Bartail Flathead	3
37311017	2	Epinephelus sexfasciatus	Sixbar Grouper	1
37311028	2	Synagrops philippinensis	Sharptooth Seabass	1
37314002	2	Pseudogramma polyacanthum	Honeycomb Podge	3
37321002	2	Terapon jarbua	Crescent Grunter	1
37321003	2	Terapon theraps	Largescale Grunter	1
37321006	2	Terapon puta	Spinycheek Grunter	1
37326003	2	Priacanthus tayenus	Purplespotted Bigeye	1
37327012	2	Apogon septemstriatus	Sevenband Cardinalfish	1
37327013	2	Apogon truncatus	Flagfin Cardinalfish	1
37327014	2	Apogon albimaculosus	Creamspotted Cardinalfish	1
37327017	2	Siphamia roseigaster	Pinkbreast Siphonfish	3
37327026	2	Apogon poecilopterus	Pearlyfin Cardinalfish	1
37327158	2	Apogon fasciatus	[a cardinalfish]	2
37330007	2	Sillago lutea	Mud Whiting	1
37336001	2	Echeneis naucrates	Sharksucker	1
37337000	2	Carangidae - undifferentiated	trevallies	3
37337005	2	Carangoides malabaricus	Malabar Trevally	1
37337010	2	Alepes apercna	Smallmouth Scad	1
37337016	2	Caranx bucculentus	Bluespotted Trevally	1
37337023	2	Decapterus russelli	Indian Scad	1
37337028	2	Megalaspis cordyla	Finny Scad	1
37337031	2	Carangoides humerosus	Epaulette Trevally	1
37337036	2	Alepes kleinii	Razorbelly Trevally	1
37337041	2	Ulua aurochs	Silvermouth Trevally	1
37337043	2	Carangoides talamparoides	Whitetongue Trevally	1
37337044	2	Scomberoides tol	Needleskin Queenfish	1
37337072	2	Parastromateus niger	Black Pomfret	1
37340001	2	Mene maculata	Razor Moonfish	3
37341002	2	Photopectoralis bindus	Orangefin Ponyfish	1
37341006	2	Secutor insidiator	Pugnose Ponyfish	1

CAAB code	Class	Scientific name	Common name	Approach
37341010	2	Leiognathus splendens	Blacktip Ponyfish	1
37341012	2	Equulites moretoniensis	Zigzag Ponyfish	1
37341013	2	Nuchequula glenysae	Twoblotch Ponyfish	1
37341014	2	Leiognathus equulus	Common Ponyfish	1
37341015	2	Leiognathus ruconius	deep pugnosed ponyfish	1
37341016	2	Nuchequula gerreoides	Ornate Ponyfish	1
37346007	2	Lutjanus malabaricus	Saddletail Snapper	1
37347014	2	Nemipterus hexodon	Ornate Threadfin Bream	1
37349002	2	Pentaprion longimanus	Longfin Silverbiddy	1
37349003	2	Gerres filamentosus	Threadfin Silverbiddy	1
37349005	2	Gerres subfasciatus	Common Silverbiddy	1
37350002	2	Pomadasys maculatus	Blotched Javelin	1
37350008	2	Pomadasys trifasciatus	Black-ear Javelin	1
37350011	2	Pomadasys kaakan	Barred Javelin	1
37354000	2	Sciaenidae - undifferentiated	jewfishes	3
37354003	2	Protonibea diacanthus	Black Jewfish	1
37354004	2	Johnius laevis	Smooth Jewfish	1
37354006	2	Otolithes ruber	Silver Teraglin	1
37354007	2	Johnius borneensis	River Jewfish	1
37354008	2	Austronibea oedogenys	Yellowtail Jewfish	1
37354012	2	Atrobucca brevis	Orange Jewfish	1
37354022	2	Johnius australis	Little Jewfish	3
37354026	2	Larimichthys pamoides	Southern Yellow Jewfish	3
37355000	2	Mullidae - undifferentiated	goatfishes	3
37355007	2	Upeneus sulphureus	Sunrise Goatfish	1
37355008	2	Upeneus sp. 1 [in Sainsbury et al, 1985]	orange-barred goatfish	1
37362003	2	Zabidius novemaculeatus	Shortfin Batfish	1
37362005	2	Drepane punctata	Sicklefish	2
37364001	2	Rhinoprenes pentanemus	Threadfin Scat	1
37365015	2	Chelmon muelleri	Muller's Coralfish	1
37381023	2	Valamugil perusii	[a mullet]	3
37382001	2	Sphyraena pinguis	Striped Barracuda	1
37383001	2	Polydactylus nigripinnis	Blackfin Threadfin	1
37383002	2	Polydactylus multiradiatus	Australian Threadfin	1
37383004	2	Eleutheronema tetradactylum	Blue Threadfin	1
37386011	2	Chlorurus bleekeri	Bleeker's Parrotfish	1
37401011	2	Champsodon vorax	Greedy Gaper	1
37427011	2	Repomucenus belcheri	Flathead Dragonet	1
37428001	2	Yongeichthys nebulosus	Hairfin Goby	3
37440004	2	Trichiurus lepturus	Largehead Hairtail	1
37441012	2	Rastrelliger kanagurta	Mouth Mackerel	2
37445007	2	Psenopsis humerosa	Blackspot Butterfish	1
37457001	2	Psettodes erumei	Australian Halibut	1
37458001	2	Brachypleura novaezeelandiae	Yellow Largescale Flounder	1
37460009	2	Pseudorhombus arsius	Largetooth Flounder	1
37460022	2	Laeops parviceps	Smallhead Flounder	1

CAAB code	Class	Scientific name	Common name	Approach
37460045	2	Arnoglossus waitei	Waite's Flounder	1
37462007	2	Brachirus muelleri	Tufted Sole	3
37463001	2	Paraplagusia bilineata	Lemon Tongue Sole	3
37463002	2	Paraplagusia longirostris	Pinocchio Tongue Sole	2
37463017	2	Cynoglossus ogilbyi	Ogilby's Tongue Sole	3
37463022	2	Paraplagusia sinerama	Dusky Tongue Sole	1
37464001	2	Trixiphichthys weberi	Blacktip Tripodfish	2
37465024	2	Paramonacanthus filicauda	Threadfin Leatherjacket	2
37466005	2	Rhynchostracion nasus	Shortnose Boxfish	1
37467007	2	Lagocephalus sceleratus	Silver Toadfish	3
37467008	2	Lagocephalus inermis	Smooth Golden Toadfish	1
37467012	2	Lagocephalus lunaris	Rough Golden Toadfish	1
37467017	2	Lagocephalus spadiceus	Brownback Toadfish	2
37469008	2	Cyclichthys hardenbergi	Plain Porcupinefish	2

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