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# Sustainability assessment of fish species potentially impacted in the Northern Prawn Fishery: 2007-2009

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# Summary

As requested by Australia Fisheries Management Authority, a sustainability assessment for fishing effect (SAFE) is updated for the tiger prawn sub-fishery in the Northern Prawn Fishery (NPF). The SAFE method was initially developed for the NPF in 2005 and applied to bycatch of elasmobranchs, teleosts, and sea snakes. This method is again used in this assessment. The following data used previously are also applied in this report: scientific survey (for mapping species distribution), catch rate, escapement rate, and life history parameters. However, the method has been improved by incorporating several changes and modifications in this updated assessment based on more recent research. These changes include: using the most recent (2007-2009) fishery distribution and effort data, adopting a new method for estimating fishing mortality based on actual fishing effort, adopting a new relationship between sustainability reference points and life-history parameters, including uncertainty in both estimated fishing mortality and reference points.

This assessment includes 51 elasmobranchs and 428 teleosts. The results show that fishing effort in 2007-2009 is at the lowest level since early 1980s. About 31% of elasmobranchs abundance and 32% of teleosts abundance are estimated to be within fished areas.

The annual fishing mortality ranges from 0 to 0.2 for elasmobranchs, with a mean of 0.03 $yr^{-1}$. Five species have estimated $F_{2007\text{-}2009}$ (instantaneous fishing mortality during 2007-2009) greater than their mean maximum sustainable fishing mortality $F_{msm}$. There is no species with $F_{2007\text{-}2009}$ greater than their mean unsustainable fishing mortality $F_{crash}$. However, if uncertainty is considered, these same 5 species have upper $F_{2007\text{-}2009}$ (i.e., $F_{2007\text{-}2009}$ + 90%CI) greater than $F_{crash}$, or $F_{2007\text{-}2009}$ greater than lower $F_{crash}$ (i.e., minimum $F_{crash}$). Close examination of these species based on additional biological and fishery information indicates that the fishing mortality may have been overestimated for these species, and no elasmobranchs may be at true risk of un-sustainability from tiger prawn trawls when one investigates life history patterns and the incidence of their capture. However, continuous monitoring and further assessment are needed for this group of species because of their vulnerability and because of the inclusion of only one single tiger prawn fishery in this assessment without taking other fishing sectors into account.

For teleosts, the annual fishing mortality is estimated to range from 0 to 0.36, with a mean $F_{2007\text{-}2009}$ of 0.03. No species has mean $F_{2007\text{-}2009}$ greater than its mean $F_{msm}$. Further, no species is found to have $F_{2007\text{-}2009}$ greater than its $F_{crash}$ even when uncertainty is taken into consideration (i.e., no species with $F_{2007\text{-}2009}$ + 90%CI > $F_{crash}$ or $F_{2007\text{-}2009}$ > minimum $F_{crash}$).

Keywords: sustainability, ecological, risk, assessment, reference points, fishing mortality, prawn, North Prawn Fishery, bycatch, elasmobranchs, teleosts

# 1. Introduction

A quantitative ecological risk assessment for fishing effects was conducted for the Northern Prawn Fishery in 2007 (Brewer et al. 2007). The NPF's Export Exemption recommends that such assessment need to be re-assessed at least within three years, which is due in 2010. Since then the fishery has experienced some changes in the fleet structure, fishing pattern, and fishing effort. In 2010 AFMA requested that the assessment be updated using more recent fishery data. The requested research was to be a rapid assessment using existing techniques and information, with results expected to be delivered within 6 months.  Some consideration has been given to applying a consistency of terms between this assessment and those used in the ERA Level 2 and Harvest Strategy Framework to ensure greater end user understanding and comparison of results.

In this report, a sustainability assessment for fishing effect (SAFE) is performed for the tiger prawn fishery in the NPF. The method is essentially the same as the one used in the previous assessments (Brewer et al. 2007; Zhou and Griffiths 2008; Zhou et al. 2009a). However, there are some changes and modifications in this updated assessment based on more recent research (Zhou et al. 2007, 2009b, 2010a). This report details the assessment results for these fisheries.

# 2. Methods

Similar method used in the previous assessments is applied in this report and briefly explained here, particularly to describe any modification.

## 2.1. Data sources

Over 70 scientific voyages have been undertaken in the Northern Prawn Fishery (NPF) managed area between 1979 and 2003, mostly by CSIRO Marine and Atmospheric Research and a few by state fisheries agencies. Together, the surveys covered the entire NPF, although not in any one voyage. These data were used to assess fish spatial distribution. Because of a lack of data on bycatch, some species cannot be estimated by conventional techniques. We opted to pool the data from all scientific surveys to maximize the sample sizes and geographical coverage, and used detection-nondetection information that was collected to estimate bycatch species' distribution and abundance in the region.

To model the abundance of bycatch species using detection-nondetection data, we defined a sampling unit as a 6 by 6 nautical mile grid, which is currently used in NPF logbooks for reporting purposes. There are a total of 6,963 grids in the NPF-managed area. The composition of bycatch species varies spatially within the NPF (Blaber et al. 1990; Stobutzki et al. 2001; Tonks et al. 2008), as well as with sampling effort. Therefore, we stratified the NPF-managed area into five bioregions based on established bioregions for fishes (IMCRA, 1998) and expert opinion (Fig. 1). During the surveys, a total of 5,835 samples were taken in 924 grids, using trawl gear of various types. Some grids were repeatedly surveyed over a number of years. The sampling rate in bioregion 4 was higher than in the other bioregions because it had a higher fishing effort and consequently was surveyed more often to investigate fishery-related problems.

Fishery logbook data in the tiger prawn fishery from 2007 to 2009 were used to assess the impact of this fishery on fish bycatch species during this 3-year time period.

Fish life history information was obtained from the literature. In cases where life history parameters were not available from literature, we obtained them fishbase database.

### 2.2. Estimating fishery impacts

First, the "fished area" is defined as grids where the total fishing effort recorded in logbooks is greater or equal to 3 boat-days over the 3 years between 2007 and 2009, i.e., one boat-day/year. Three days of fishing effort is equivalent to about 6% of sea floor within the grid being systematically swept by prawn trawls in 3 years, assuming trawling occurs for 12.3 hours per day (Rawlinson 2003) at a speed of 3.24 knots (Bishop 2003) with a headrope length of 14 fathoms and a 0.66 spread ratio (Bishop and Sterling 1999). This criterion may overestimate fishing impact, as trawls are unlikely to sweep the entire "fished area". Further, because trawl tracks often overlap, the actual impact is expected to be less than 6% (Stobutzki and Pitcher 1999). We treat grids where the fishing effort is less than 3 boat-days as “unfished area”.

Incidental fishing mortality rate is estimated from the relative abundance of each species within fished areas relative to the entire NPF management area, the observed catch rate (the probability that a fish is caught when the trawl passed over it), and the escapement rate from the trawl after the fish has entered the net. We use two methods to estimate the fishing mortality rate.

**2.2.1. Method 1**

In the first method, which was used in the previous assessments, the total annual instantaneous fishing mortality rate for species *i*, $F_i$ is calculated using the following equation (similar to Zhou and Griffiths 2008 and Zhou et al. 2009):

$$F_i = \frac{\sum_{R=1}^{5} N_{i,R,\,fished}}{\sum_{R=1}^{5}\left(N_{i,R,\,fished} + N_{i,R,unfished}\right)} q_i (1 - E_i) \qquad (1)$$

where $N_{i,R,fished}$ and $N_{i,R,unfished}$ are the estimated mean abundance of the species in bioregion $R$ and fished or unfished area, $q_i$ is the catch rate, and $E_i$ is the escapement rate. This formula implies that we simplified the fishing process to assume trawling uniformly sweeps an entire fished area once a year. Because the fishing grounds may shift from year to year, and our minimum unit of fishing effort (one boat-day) only covers a small proportion of a grid, this method tends to overestimate the fishing mortality rate.

**2.2.2. Method 2**

The second method is similar to that applied to sea snake bycatch in the NPF (Milton et al. 2007). In this method, we use actual fishing effort to derive an estimate of the fishing mortality rate:

$$F_i = \frac{\sum_{R=1}^{5} \frac{N_{i,R,\,fished}}{A_{R,\,fished}} a h_R q_i (1 - E_i)}{\sum_{R=1}^{5} \left(N_{i,R,\,fished} + N_{i,R,unfished}\right)} \qquad (2)$$

where $A_{R,fished}$ is size of the fished area in bioregion $R$, $a$ is the mean swept area per hour by prawn trawl, $h_R$ is the average annual fishing hours in region $R$. In the above equations, $N_{i,R,fished}$, $N_{i,R,uffished}$, $a$, $q_i$, and $E_i$ are all treated as random variables, while $A_{R,fished}$ and $h_R$ are considered constants since they are based on logbook record. Trawling speed is estimated as 3.38 kts (SD = 0.202, n = 407) (Bishop 2003). With a headrope length of 26 m and a 0.66 spread ratio, swept area by one vessel is estimated to be 52.83 $m^2.s^{-1} \pm 0.21$, or 0.19 $km^2.h^{-1} \pm 0.002$ (Bishop & Sterling 1999).

The key component of Eqs. 1 and 2 is the relative abundance of a species exposed to trawling, $N_{i.R,fished}/(N_{i,R,fished} + N_{i,R,uffished})$. The relative abundance is estimated by using simple detection—nondetection records in scientific surveys in the NPF management area. The statistical model is the same described in the previous studies (Zhou and Griffiths 2007, 2008; Zhou et al. 2009a).

Equations 1 and 2 indicate that there are 10 strata in the NPF area: five bioregions each further divided into fished and unfished areas. It is then assumed that individuals of each fish species are randomly distributed within each of the ten strata.

The same catch rates of each species used in the previous assessment are applied here. They are obtained directly from experimental trawl data (Pitcher et al. 2002). In cases where data are not available, it is then estimated by one of three methods: (a) based on related species in the same genus for which catch rates were measured, since closely related species are likely to have similar vulnerability to capture, (b) based on values estimated by Blaber et al. (1990) for the same species; or (c) based on values of Blaber et al. (1990) for species having similar vertical distribution, size, and locomotory behaviour.

Furthermore, the same escapement rates based on Brewer et al. (2004, 2006) used for elasmobranchs in the previous assessment (Brewer et al. 2007; Zhou and Griffiths 2008) are applied in this report. Teleosts have low escapement rate so it is assumed $E = 0$ (Brewer et al. 2007; Zhou et al. 2009a).

### 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 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. unpublished data). The relationship between the two differs between chondrichthyans and teleosts:

For chondrichthyans: $F_{msy} = 0.45\ M$;

For teleosts: $F_{msy} = 0.91\ M$.

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. $F_{msm} = \omega M$, $F_{lim} = 1.5\ \omega M$, and $F_{crash} = 2\ \omega M$, where $M = 1.65/t_{mat}$ (Jensen 1996).

In these equations, $k$ and $L_\infty$ are von Bertalanffy growth parameters, $T$ = average annual water temperature, $t_m$ = maximum reproductive age, and $t_{mat}$ = average age at maturity. If $L_\infty$ 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 $\omega$ is 0.45 for chondrichthyans and 0.91 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%CI $\ge F_{crash}$;
High risk (H): $F \ge F_{crash}$;
Precautionary high risk (h): $F \ge \min[F_{crash}]$ or $F$ + 90%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 the relative abundance estimates from scientific surveys, catch rates, and the probability of escapement due to TEDs. We evaluate uncertainty around these parameters. Approximate standard errors (SE) around the abundance are derived from the square roots of the diagonal elements of the covariance matrix of the parameter estimates. Variances of $q$ and $E$ are calculated from binomial distributions, assuming both capture and escapement from trawl were binomial processes, using the sample size from field experiments or assumed samples. The combined variance is obtained by a delta method.

## 3. Results

### 3.1. Fishing effort

The tiger prawn fishery in the NPF has experienced a significant change over the history of the fishery (Figure 1). Fishing effort increased from an average of about 6 thousand boat-days in the early 1970s to an average of over 32 thousand boat-days in the early 1980s. It gradually declined since then and has reached an average of less than five thousand boat-days in the last three years (2007-2009).

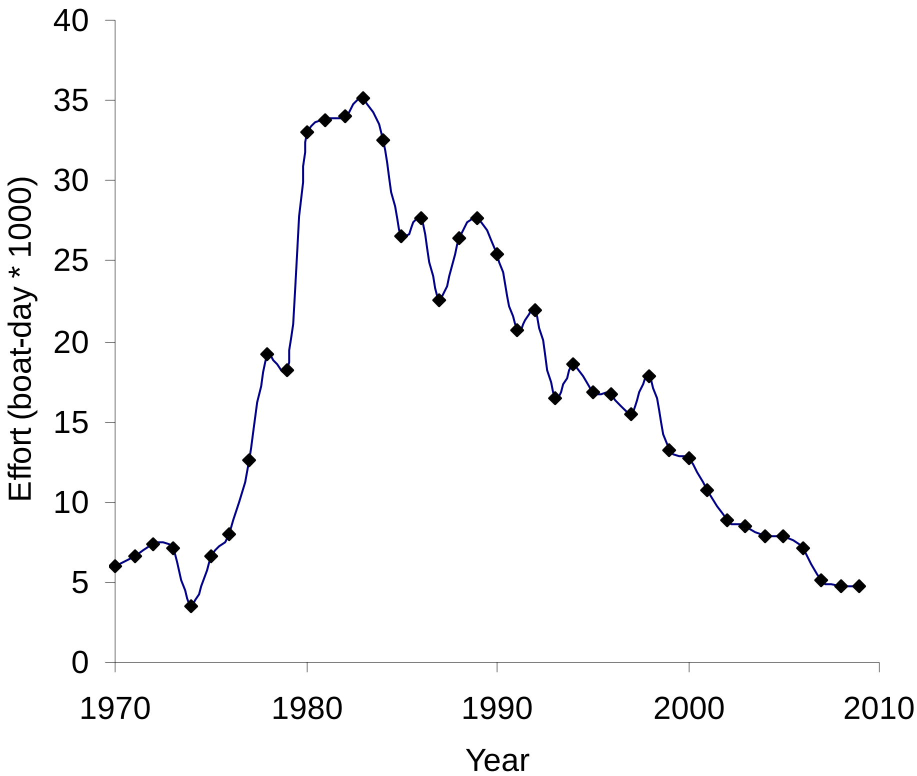


Figure 1. Change of tiger prawn fishing effort in the NPF between 1970 and 2009.

## 3.2. Assessment of elasmobranchs bycatch

### 3.2.1. Relative proportion of population in fished area

Fifty one species of elasmobranchs that potentially encounter tiger prawn trawls in the NPF were assessed. We first estimate the proportion of each species' population within the 2007-2009 fished area based on detection-nondetection data from surveys. The proportion of the population in fished areas ranged from 0 to 100% with a mean of 31% (SD 0.27) for the 51 species. One species (*Pristis microdon*) is detected only in unfished area and two species (*Carcharhinus leucas*, *Carcharhinus albimarginatus*) are detected only in fished area (Figure 2).

### 3.2.2. Sustainability of elasmobranchs potentially impacted by tiger prawn trawling

Method 1, which assumes the entire fished area is swept by the prawn trawl once a year, results in 18 species with $F_{2007\text{-}2009} > F_{msm}$ (Figure 3) and 7 species with $F_{2007\text{-}2009} > F_{crahs}$. As mentioned in the Method section, this method tends to overestimate fishing impact. Therefore, we focus on the results from Method 2.

In contrast to Method 1, Method 2 that uses actual fishing effort results in lower fishing mortality. The annual fishing mortality during 2007-2009 ranged from 0 to 0.2 for the 51 elasmobranchs, and the mean $F_{2007\text{-}2009}$ was 0.03 (SE 0.049) (Figure 4). Compared to reference point $F_{msm}$, 5 species have $F_{2007\text{-}2009} > F_{msm}$ (*Carcharhinus albimarginatus*, *Carcharhinus leucas*, *Galeocerdo cuvier*, *Orectolobus ornatus*, and *Sphyrna mokarranare*) (Figure 4). However, if uncertainty is taken into consideration, 9 species have upper $F_{2007\text{-}2009}$ (i.e., $F_{2007\text{-}2009}$ + 90%CI) greater than $F_{msm}$ or $F_{2007\text{-}2009}$ greater than lower $F_{msm}$ (i.e., minimum $F_{msm}$): *Carcharhinus albimarginatus*, *Carcharhinus fitzroyensis*, *Carcharhinus leucas*, *Chiloscyllium punctatum*, *Dasyatis thetidis*, *Galeocerdo cuvier*, *Orectolobus ornatus*, *Sphyrna mokarran*, and *Urogymnus asperrimus* (Figure 5).

For the unsustainable fishing mortality reference point, there is no species with $F_{2007\text{-}2009} > F_{crash}$. However, if uncertainty is considered, 5 species have upper $F_{2007\text{-}2009}$ greater than $F_{crash}$ or $F_{2007\text{-}2009}$ greater than lower $F_{crash}$ (Figure 6). They are the same species whose $F_{2007\text{-}2009} > F_{msm}$ (i.e., *Carcharhinus albimarginatus*, *Carcharhinus leucas*, *Galeocerdo cuvier*, *Orectolobus ornatus*, and *Sphyrna mokarran*).

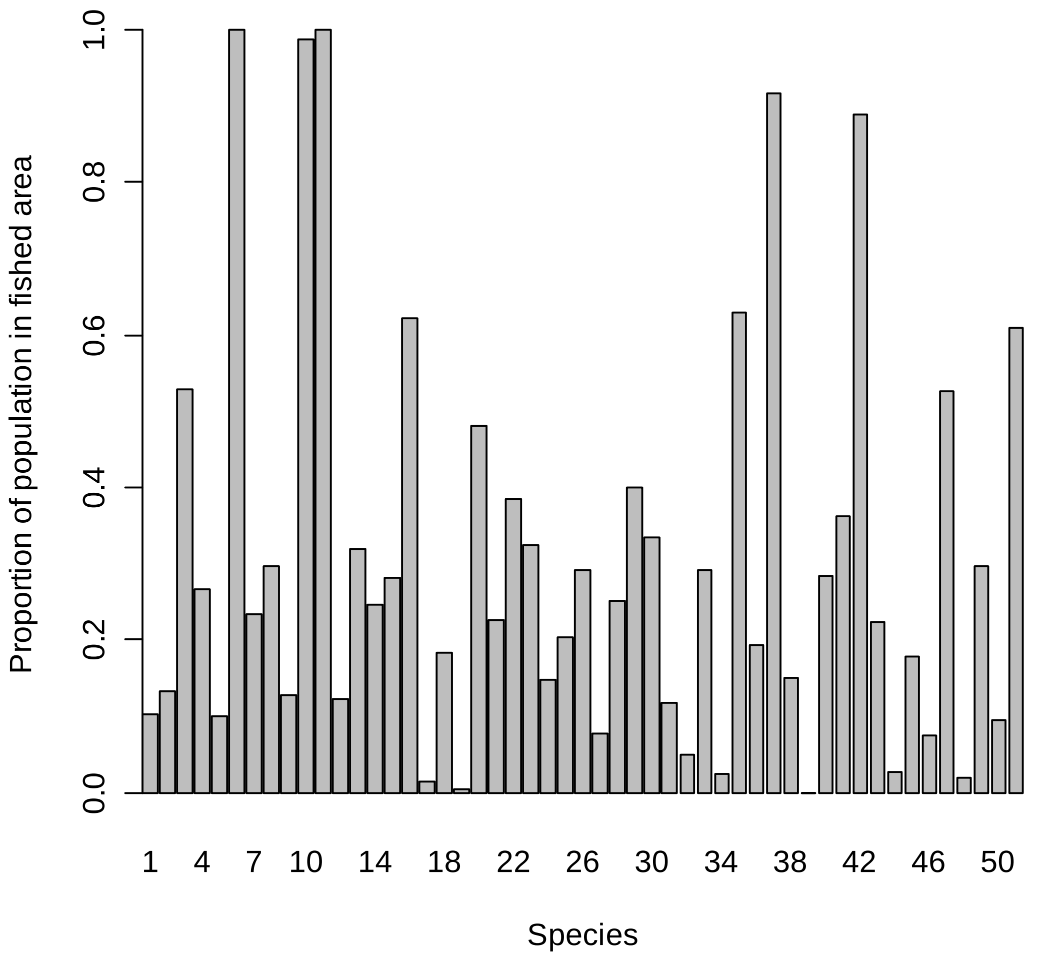


Figure 2. Relative abundance in fished area in 2007-2009. The species are ordered alphabetically by their scientific names for easy identification in the figure and the codes are: 1. *Aetobatus narinari*; 2. *Aetomylaeus nichofii*; 3. *Aetomylaeus vespertilio*; 4. *Anoxypristis cuspidate*; 5. *Atelomycterus fasciatus*; 6. *Carcharhinus albimarginatus*; 7. *Carcharhinus amboinensis*; 8. *Carcharhinus brevipinna*; 9. *Carcharhinus dussumieri*; 10. *Carcharhinus fitzroyensis*; 11. *Carcharhinus leucas*; 12. *Carcharhinus limbatus*; 13. *Carcharhinus macloti*; 14. *Carcharhinus sorrah*; 15. *Carcharhinus tilstoni*; 16. *Chiloscyllium punctatum*; 17. *Dasyatis annotate*; 18. *Dasyatis brevicaudata*; 19. *Dasyatis kuhlii*; 20. *Dasyatis leylandi*; 21. *Dasyatis thetidis*; 21. *Eusphyra blochii*; 23. *Galeocerdo cuvier*; 24. *Gymnura australis*; 25. *Hemigaleus microstoma*; 26. *Hemipristis elongate*; 27. *Himantura fai*; 28. *Himantura granulate*; 29. *Himantura jenkinsii*; 30. *Himantura* sp. A; 31. *Himantura toshi*; 32. *Himantura uarnak*; 33. *Himantura undulate*; 34. *Narcine westraliensis*; 35. *Nebrius ferrugineus*; 36. *Negaprion acutidens*; 37. *Orectolobus ornatus*; 38. *Pastinachus sephen*; 39. *Pristis microdon*; 40. *Pristis zijsron*; 41. *Rhina ancylostoma*; 42. *Rhinobatos typus*; 43. *Rhizoprionodon acutus*; 44. *Rhizoprionodon taylori*; 45. *Rhynchobatus djiddensis*; 46. *Sphyrna lewini*; 47. *Sphyrna mokarran*; 48. *Squatina* sp. A; 49. *Stegastoma fasciatum*; 50. *Taeniura meyeni*; 51. *Urogymnus asperrimus*.

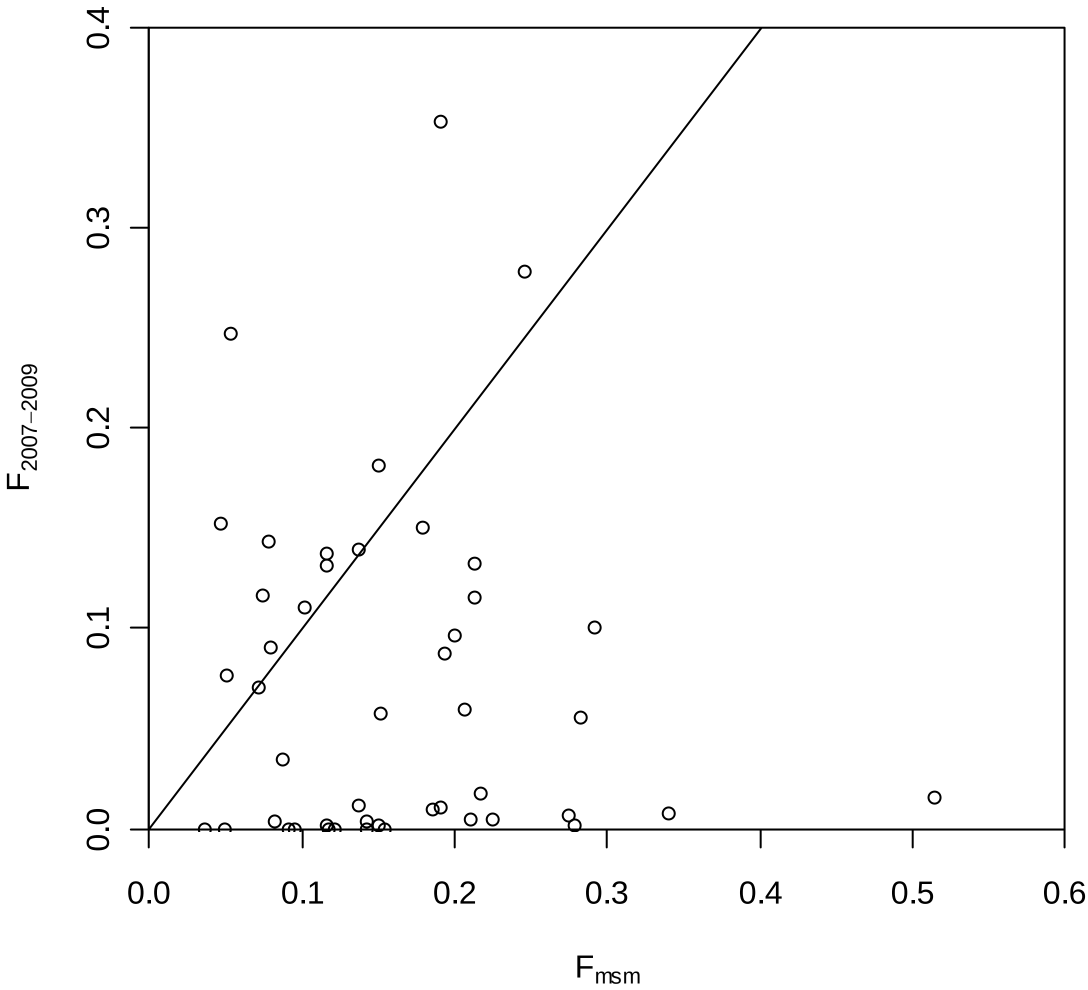


Figure 3. Comparison of estimated fishing mortality in 2007-2009 from M**ethod 1** and the reference fishing mortality corresponding to the maximum sustainable mortality for **elasmobranchs** caught in the NPF tiger prawn fishery. This method of estimating fishing mortality assumes the entire fished area is swept once a year. The diagonal line is where $F_{2007\text{-}2009} = F_{msm}$.

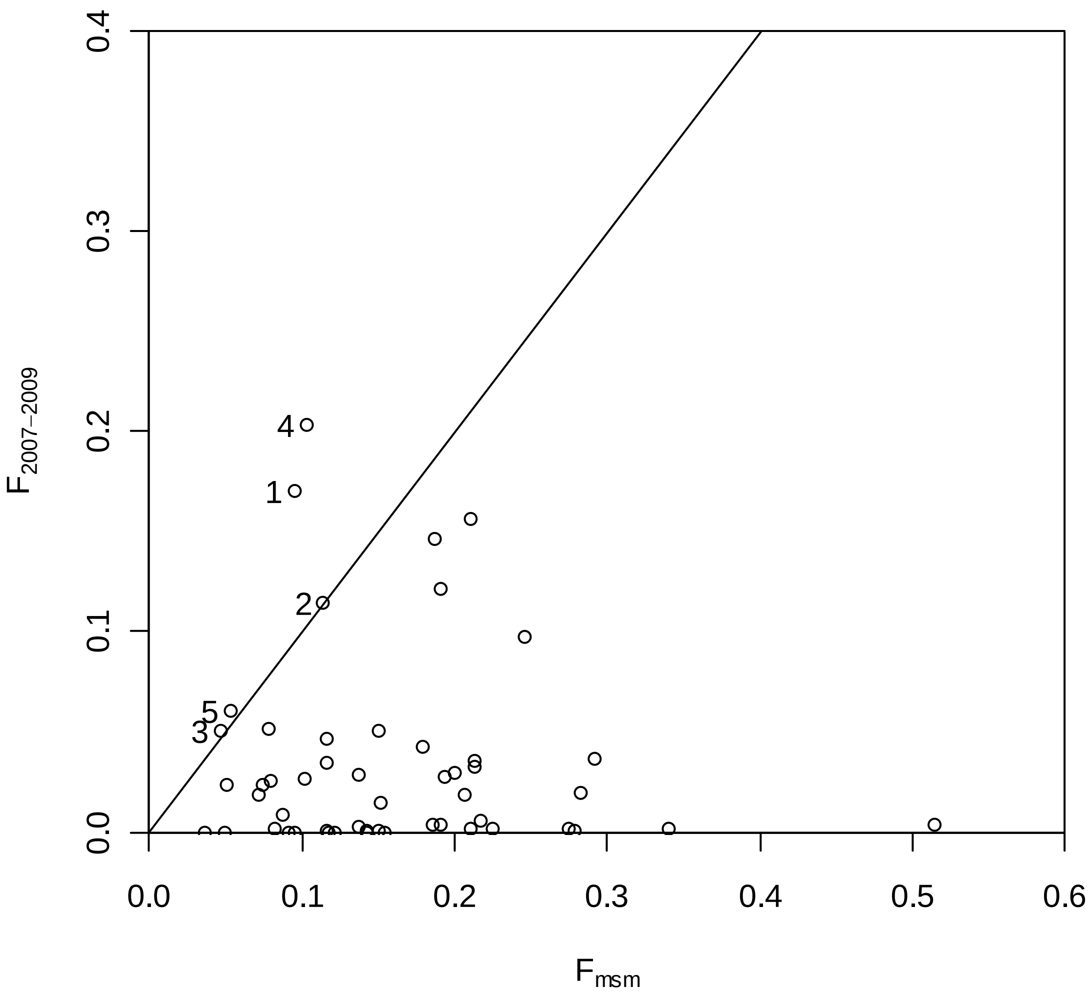


Figure 4. Comparison of estimated fishing mortality in 2007-2009 from M**ethod 2** and the reference fishing mortality corresponding to the maximum sustainable mortality for **elasmobranchs** caught in the NPF tiger prawn fishery. This method of estimating fishing mortality uses actual fishing effort. The diagonal line is where $F_{2007\text{-}2009} = F_{msm}$. The species whose estimated fishing mortality is above the diagonal line are: 1. *Carcharhinus albimarginatus*; 2. *Carcharhinus leucas*; 3. *Galeocerdo cuvier*; 4. *Orectolobus ornatus*; 5. *Sphyrna mokarran*.

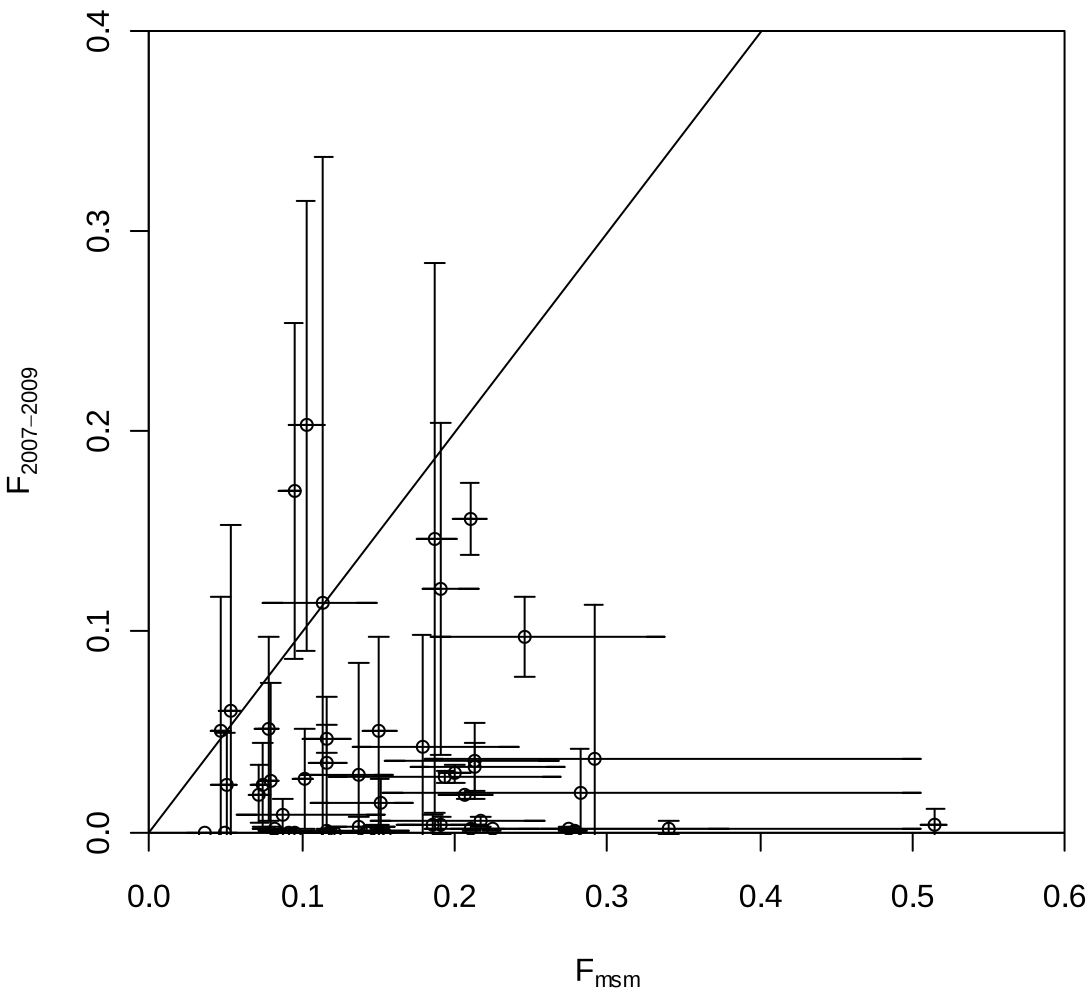


Figure 5. Comparison of estimated fishing mortality in 2007-2009 from M**ethod 2** and the reference fishing mortality corresponding to the maximum sustainable mortality for **elasmobranchs** caught in the NPF tiger prawn fishery. This method of estimating fishing mortality uses actual fishing effort. The diagonal line is where $F_{2007\text{-}2009} = F_{msm}$, and the error bars represent 90% CI for $F_{2007\text{-}2009}$ and minimum and maximum $F_{msm}$.

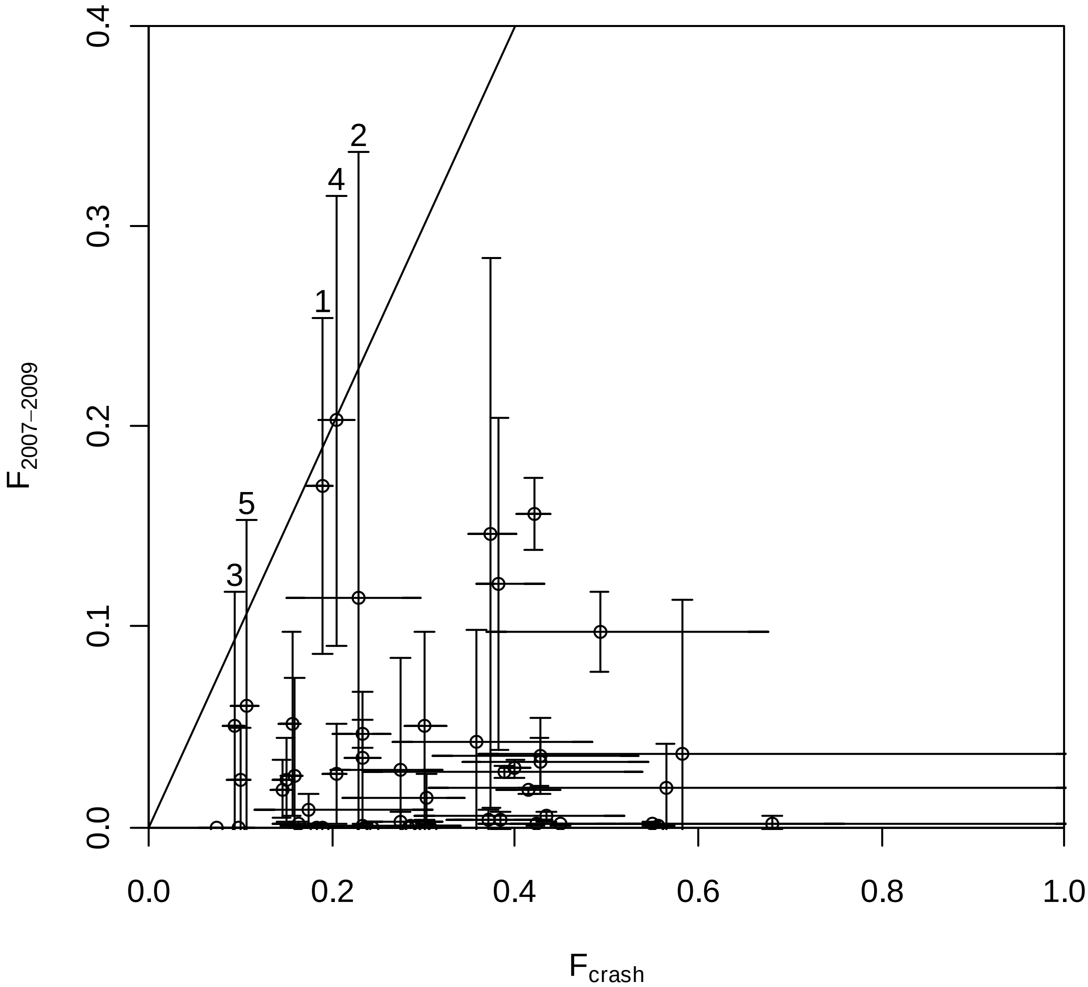


Figure 6. Comparison of estimated fishing mortality in 2007-2009 from M**ethod 2** and the reference fishing mortality corresponding to the unsustainable mortality for **elasmobranchs** caught in the NPF tiger prawn fishery. This method of estimating fishing mortality uses actual fishing effort. The diagonal line is where $F_{2007\text{-}2009} = F_{crash}$, and the error bars represent 90% CI for $F_{2007\text{-}2009}$ and minimum and maximum $F_{crash}$. Five species have their estimated upper $F_{2007\text{-}2009}$ greater than $F_{crash}$: 1. *Carcharhinus albimarginatus*; 2. *Carcharhinus leucas*; 3. *Galeocerdo cuvier*; 4. *Orectolobus ornatus*; 5. *Sphyrna mokarran*.

### 3.3. Assessment of teleost bycatch

#### 3.3.1. Relative proportion of population in fished area

We initially included 478 species of the teleosts potentially encountering with the tiger prawn trawls. Among these, 50 species have not been caught in surveys so we assess the remaining 428 species in this report. The proportion of the population in fished areas ranged from 0 to 100% with a mean of 32% (SD 0.21) for these 478 teleosts (Figure 7). Eighteen species (4%) are detected only in fished area while 39 (9%) species are detected only in unfished area.

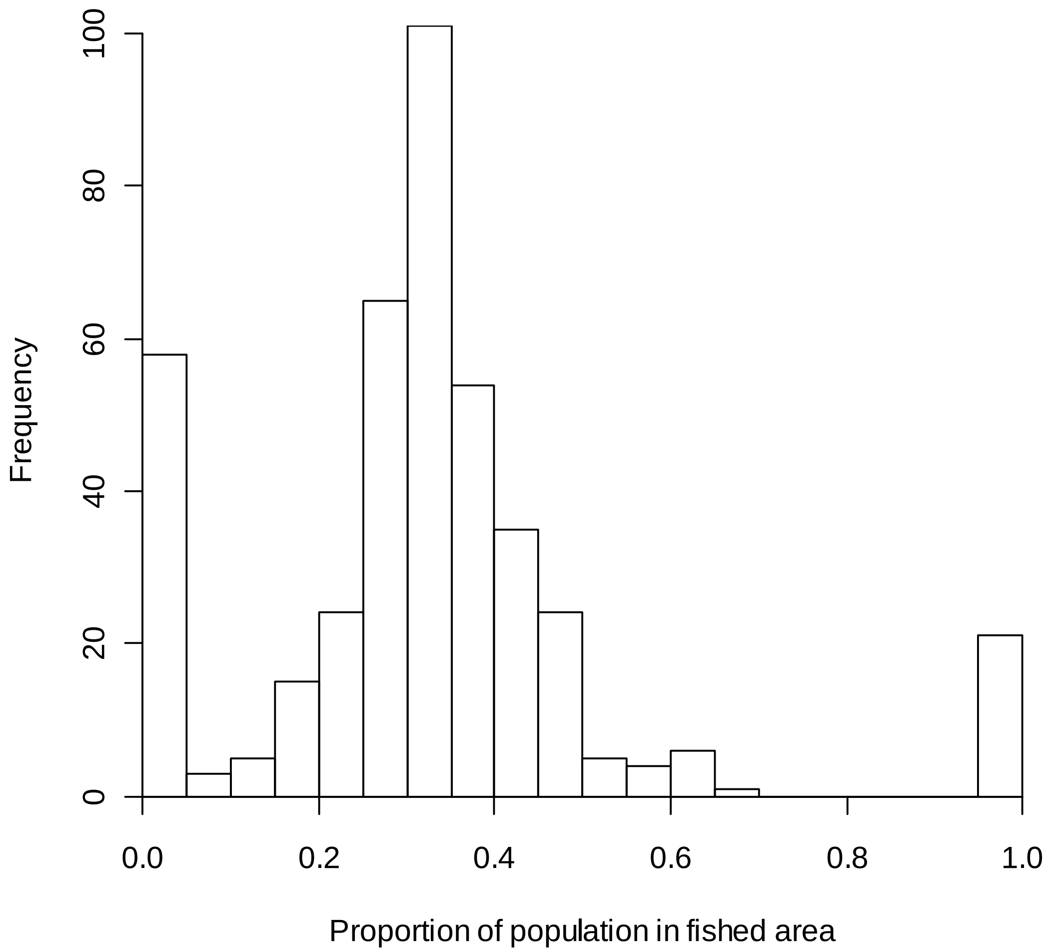


Figure 7. Frequency distribution of the estimated proportion of **teleosts** populations (abundance) in fished area in 2007-2009.

### 3.3.2. Sustainability of teleosts potentially impacted by tiger prawn trawling

Method 1, which assumes the entire fished area is swept by the prawn trawl once a year, results in 6 species whose $F_{2007\text{-}2009} > F_{msm}$ (Figure 8) and no species with $F_{2007\text{-}2009} > F_{crahs}$. As for the elasmobranchs, we focus on the results from Method 2 because Method 1 tends to overestimate fishing impact.

Method 2 results in annual fishing mortality from 0 to 0.36, with a mean $F_{2007\text{-}2009}$ of 0.03 (SE 0.042) (Figure 9). No species has $F_{2007\text{-}2009} > F_{msm}$. However, if uncertainty is taken into consideration, 6 species have upper $F_{2007\text{-}2009}$ (i.e., $F_{2007\text{-}2009}$ + 90%CI) greater than $F_{msm}$ or $F_{2007\text{-}2009}$ greater than lower $F_{msm}$ (i.e., minimum $F_{msm}$) (*Ariosoma anago*, *Conger cinereus*, *Epinephelus malabaricus*, *Lepidotrigla* sp., *Leptojulis cyanopleura*, and *Sphyraena qenie* (Figure 10).

For the unsustainable fishing mortality reference point, there is no species with $F_{2007\text{-}2009} > F_{crash}$ even when uncertainty is taken into consideration.

# 4. Discussion

## 4.1. Improvements of assessment method

In this report, SAFE for the NPF is updated using fishery data from 2007-2009. The basic method is similar to that previously applied to the elasmobranchs and teleosts (Brewer et al. 2007; Milton et al. 2007; Zhou and Griffiths 2008; Zhou et al. 2009a). Data used for previous risk assessments for the NPF include: survey data from 1979 to 2003, life-history parameters, catch rate, and escapement rate. However, this update has several improvements over the previous assessment.

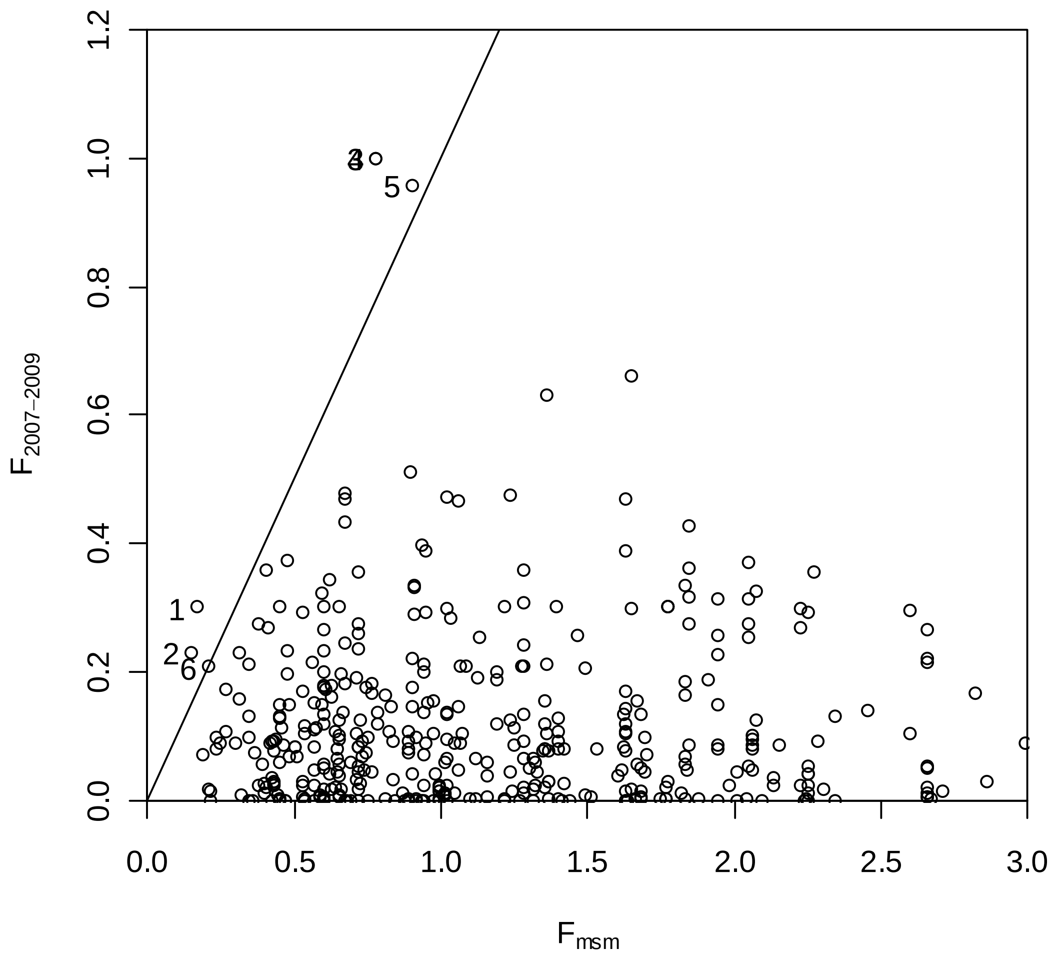


Figure 8. Comparison of estimated fishing mortality in 2007-2009 from M**ethod 1** and the reference fishing mortality corresponding to the maximum sustainable mortality for **teleosts** caught in the NPF tiger prawn fishery. This method of estimating fishing mortality assumes the entire fished area is swept once a year. The diagonal line is where $F_{2007\text{-}2009} = F_{msm}$. The six species about the diagonal line are: 1. *Ariosoma anago*; 2. *Epinephelus malabaricus*; 3. *Lepidotrigla argus*; 4. *Lepidotrigla* sp. 2 (species 3 and 4 have same values); 5. *Leptojulis cyanopleura*;  6. *Sphyraena qenie*.

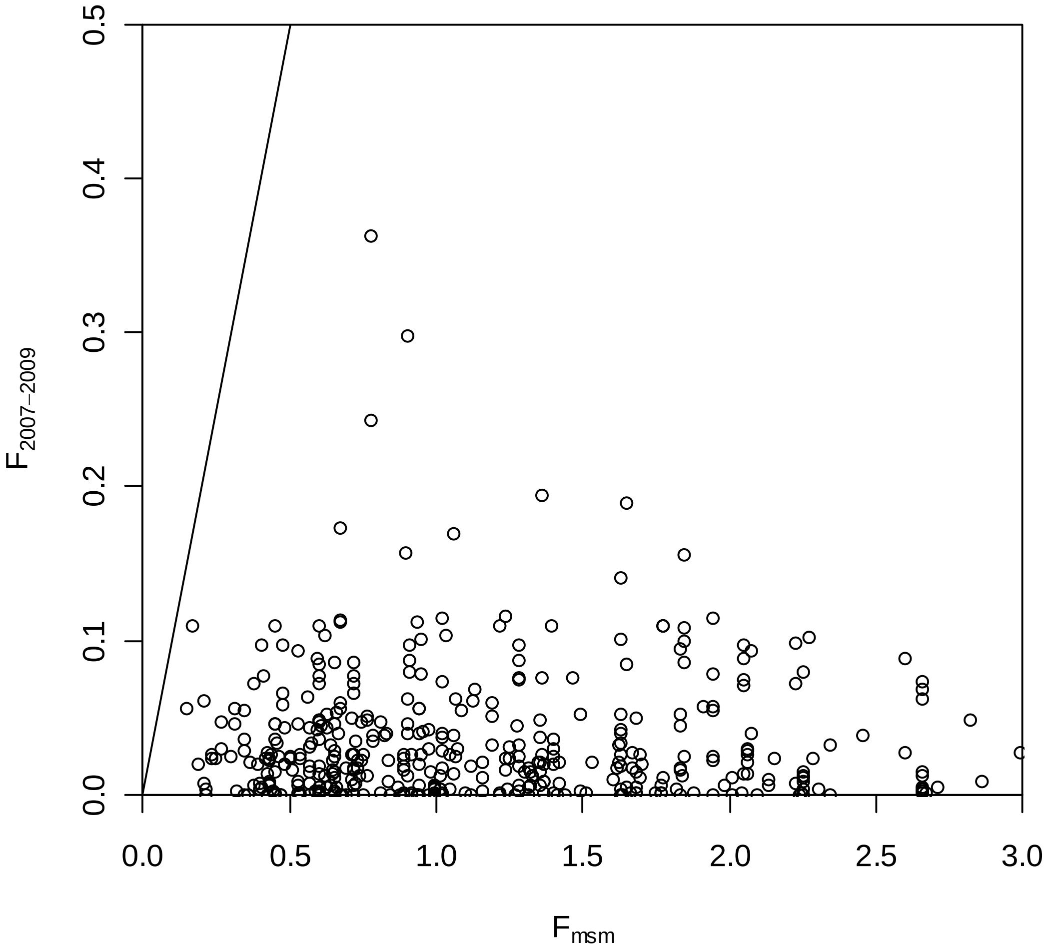


Figure 9. Comparison of estimated fishing mortality in 2007-2009 from M**ethod 2** and the reference fishing mortality corresponding to the unsustainable mortality for **teleosts** caught in the NPF tiger prawn fishery. This method of estimating fishing mortality uses actual fishing effort. The diagonal line is where $F_{2007\text{-}2009} = F_{msm}$.

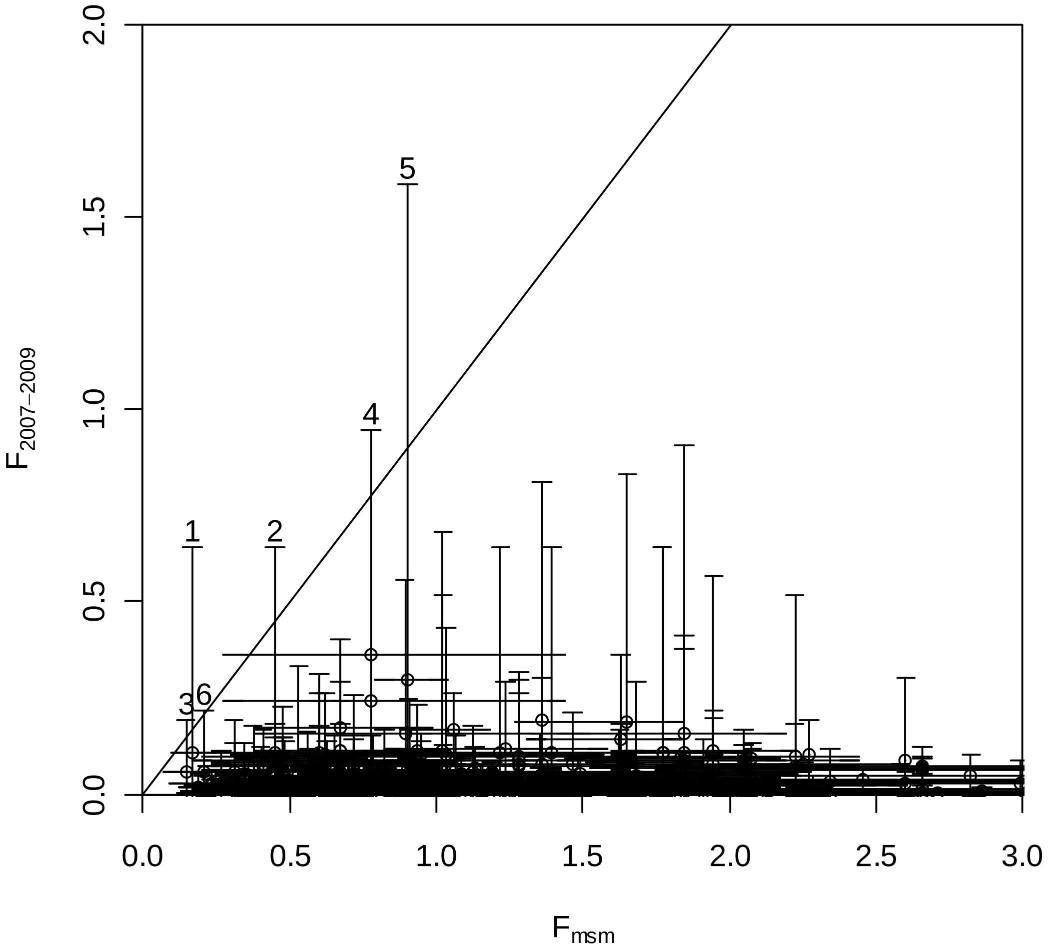


Figure 10. Comparison of estimated fishing mortality in 2007-2009 from M**ethod 2** and the reference fishing mortality corresponding to the unsustainable mortality for **teleosts** caught in the NPF tiger prawn fishery. This method of estimating fishing mortality uses actual fishing effort. The diagonal line is where $F_{2007\text{-}2009} = F_{msm}$ and the error bars represent 90% CI for $F_{2007\text{-}2009}$ and minimum and maximum $F_{msm}$. The six species whose estimated upper fishing mortality is great than $F_{msm}$ are: 1. *Ariosoma anago*; 2. *Conger cinereus*; 3. *Epinephelus malabaricus*; 4. *Lepidotrigla* sp.; 5. *Leptojulis cyanopleura*; and 6. *Sphyraena qenie*.

One of such improvements is the inclusion of two quantitative methods for estimating fishing mortality. The first method assumes the entire fished area is swept by tiger prawn trawls once a year, which is the same method used in the previous NPF assessment. The second method uses actual fishing effort recorded as number of fishing hours. Although this method is deemed more realistic, using the recorded fishing hours may still have overestimated the fishing impact because fishing time includes searching, gear deploying and retrieving, as well as actual trawling time, thus creating a slightly conservative estimate.

When estimating sustainability reference points, we use new information from a recent meta-analysis to link sustainable fishing mortality to life history parameters. The meta-analysis is based on quantitative analysis of target species worldwide that have sufficient time series data. Evidences show that the conventional "rule of thumb" approach, $F_{msy} = M$, is not conservative, particularly for elasmobranchs. The new relationship adopted in this report is more conservative for management of data poor species. In addition, we attempt to estimate uncertainty of reference points by using multiple methods, recognizing that the quality of the input data (life history parameters) will affect the mean and range of the estimated reference points.

### 4.2. Elasmobranchs at potential risk from fishing impact

The results indicate that five elasmobranchs have estimated fishing mortality in 2007-2009 greater than their maximum sustainable fishing mortality $F_{msm}$. These same species also have their estimated upper fishing mortality greater than their unsustainable fishing mortality $F_{crash}$. We closely examine these species as follows.

*Carcharhinus albimarginatus*: it is noted that this species is a widely distributed pelagic species and is rarely caught in prawn trawls; the fishing impact on this species is likely to be overestimated (Brewer et al. 2007). It is widely distributed outside of NPF and has extensive distribution across tropical Indo-Pacific coastal waters (Fry et al 2009). This species is highly unlikely to be at risk from NPF activity, including using quite conservative criteria.

*Carcharhinus leucas*: this species was only caught once in a survey by Florida Flyer trawl in fished area in bioregion 5. This has resulted in an estimated 100% of the population being affected by tiger prawn fishery. It is very likely that the fishing mortality is overestimated within high uncertainty (Figure 6) and that the species should not be listed as ‘at risk’ from NPF activity.

*Galeocerdo cuvier*: the estimated fishing mortality in 2007-2009 is 0.05 with high uncertainty (SE = 0.04). However, the estimated natural mortality is also low ($M$ = 0.10), resulting an $F_{msm}$ smaller than 0.05. This tiger shark is widely distributed outside the NPF. Its large size (maximum size 750 cm) allows them to be easily excluded by TED. Therefore, the risk of unsustainably impacted by prawn fishery should be low.

*Orectolobus ornatus*: this species was also previously assessed as at risk (Brewer et al. 2007). However, it is widely distributed across eastern Australian coast and is typically reef associated. Experts agreed it was not ‘at risk’ from NPF activity as its main habitat and areas of distribution were outside the NPF high effort areas (Fry et al. 2009).

*Sphyrna mokarran*: the estimated fishing mortality is 0.06 with high uncertainty (SE = 0.06) while the natural mortality is 0.12. Hence, $F_{2007\text{-}2009}$ is barely higher than $F_{msm}$. The great hammerhead is a highly migratory species with wide distribution in temperate and tropic seas. It will be readily excluded by TED because of its large size (610 cm maximum length) and should not be deemed to be ‘at risk’ from NPF activity.

As a summary, these five species should not be deemed to be ‘at risk’ of overfishing by NPF tiger prawn trawling and close monitoring it not necessary. However, because this report only assesses tiger prawn fishery, further analysis may be needed to include all fisheries that have potentially impact on elasmobranchs.

Two additional species of elasmobranchs, *Taeniura meyeni* and *Urogymnus asperrimusare*, were considered at potential risk from previous assessment (Brewer et al. 2007; Zhou and Griffiths 2008) and are currently on the list of fishery monitoring program (D. Brewer, CSIRO Brisbane, personal communication). In this updated assessment with new data, *Taeniura meyeni* has a small $F_{2007\text{-}2009}$, mainly due to its low occurrence in fished area. The estimated fishing mortality is smaller than its $F_{msm}$, even when uncertainty is taken into account. For *Urogymnus asperrimusare*, although its mean $F_{2007\text{-}2009}$ is smaller than its $F_{msm}$, its $F_{2007\text{-}2009}$ + 90%CI is slightly larger than its $F_{msm}$. Continuous monitoring is recommended.

**4.3. Teleosts at potential risk from fishing impact**

This assessment did not find any teleosts that have estimated fishing mortality greater than its maximum sustainable fishing mortality ($F_{msm}$). There is also no species with $F_{2007\text{-}2009} > F_{crash}$ even when uncertainty is taken into consideration. There are six species whose upper fishing mortality is greater than their $F_{msm}$. One of the reasons is that the estimated $F$ has high uncertainty.

Two teleost species were previously assessed as at potential risk of overfishing: Dendrochirus brachypterus and Scorpaenopsis venosa, the latter was based on one detection from a scientific survey in fished area (Brewer et al. 2007). In this updated report, neither has estimated fishing mortality greater than $F_{msm}$, even when uncertainty is taken into consideration. It was concluded that these species were at risk from trawling by the NPF and they should be removed from the list of species being monitored (Fry et al. 2009).

**4.4. Bycatch in prawn fisheries and their role in ecosystem balance**

Tropical prawn trawl fisheries have been found to generate more bycatch and discards per unit of catch than any other fishery type (Alverson et al. 1994). This assessment again reveals that elasmobranchs are a group of fish vulnerable to fishing. Management should focus on this group to ensure they are sustainable to cumulative fishing mortality from multiple sectors.

However, the majority of discards in the NPF are teleosts with small body sizes and short life spans (Stobutzki et al. 2001). This analysis shows it is unlikely that current fishing intensity in the NPF tiger prawn fishery alone will cause risk to the sustainability of these teleosts. Evidence of negative impact on the ecosystem and fishery by these bycatch is needed to support further reduction of bycatch (Zhou 2008; Zhou et al. 2010b).

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