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Monitoring interactions with bycatch species using crew-member observer data collected in the Northern Prawn Fishery: 2017 - 2019

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Acknowledgments

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This Sustainability Assessment Project, and its predecessors; 'Assessing the sustainability of the NPF bycatch from annual monitoring data: 2008', ‘Ensuring ongoing sustainable interactions bycatch species in the Northern Prawn Fishery; 2011 – 2013’, ‘Monitoring interactions with bycatch species using crew-member observer data collected in the Northern Prawn Fishery: 2013 – 2014’ and ‘Monitoring interactions with bycatch species using crew-member observer data collected in the Northern Prawn Fishery: 2014 – 2016’ was funded by the Australian Fisheries Management Authority. The NPF Industry Pty Ltd funded the crew-member observer program and annual crew-member observer training workshops.

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1 Non-technical summary

2017/0835 Monitoring interactions with bycatch species using crew-member observer data collected in the Northern Prawn Fishery: 2017 – 2019

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OUTCOMES

- The effectiveness of the Northern Prawn Fishery crew-member observer program varies from species to species. It is also highly dependent on the participation of crew-member observers and the quality of the data collected. Changes in catch rates for the relatively abundant species targeted by the program could be detected from the current data sets collected, especially from 2011 to 2019. Some species are so rare that longer time series (or greater observer effort) are required, and a continuation of the program may provide a robust data series. For others, their rarity and difficulty recognising them among the catch during commercial fishing operations has led to the likely impossibility of detecting real changes in catch rates from the observer-sourced monitoring procedure. To overcome the non-detection of rare, cryptic species would involve large numbers of samples collected on board in conjunction with the detailed sorting of these samples in the laboratory to provide reliable data on their catch rates and trends over time. Alternative approaches for dealing with these species such as survival studies or trawl gear modifications could be considered.

- Trends in catch rates for 14 of the 40 'Threatened, Endangered and Protected' and 'at risk' bycatch species are statistically measureable and assessable by the observer-sourced monitoring and assessment program in the 17 years of data collected to date. The current program has led to an increase in number of species assessed for catch rate trend analysis; three species in 2009, 11 species in 2015, 11 species (one species removed and one new species added) in 2018 and 14 species in this assessment. It appears to be a cost-effective way to assess the sustainability of these species. In time, as more long-term data is accumulated, other less abundant, but conspicuous species should be represented by a data series that enables them to be included in this list.

- For the 14 species that were assessed, no statistically detectable declines in catch rates through time were observed. Most of the ten sea snake species assessed showed relatively stable catch rates from 2010 to 2016 with a slight decline from 2017 to 2019. However recent catch levels remain higher than those prior to 2010, despite the small decline after 2017. The Narrow Sawfish (*Anoxypristis cuspidata*) showed a stable catch rate trend from 2010 to 2019. Both the Straightstick Pipefish (*Trachyrhamphus longirostris*) and Brown-striped Mantis Shrimp (*Dictyosquilla tuberculata*) showed steady increases in catch rates over the last ten years with a marked decline in catch rates in 2014, 2016 and 2017.

- The Northern Prawn Fishery needs to use alternative strategies for ensuring the sustainability of those rare and inconspicuous species targeted by this program that will never be effectively assessed using the current methods.

- There has been a significant improvement in the accuracy and reliability of data collected in the crew-member observer program since 2011. This has been evident in the participation rates of crew-member observers and data collection procedures such as being able to record catches to species via comprehensive photographic records. The crew-member observers have performed their data collection tasks effectively as outlined in the 'Crew-member Observer Manual' and provided scientifically valid catch data on ‘Threatened, Endangered and Protected’ and 'at risk' bycatch species.

- The crew-member observer data was validated using the Australian Fisheries Management Authority scientific observer and Northern Prawn Fishery prawn population monitoring data by comparing modelled catch rates over time. While species catch rates varied between data sets for some species, the trends over time were statistically similar demonstrating that the crew-member observer data was of sufficient quality to be used in scientific catch trend analysis.

- Continued monitoring by the Northern Prawn Fishery of all ‘Threatened, Endangered and Protected’ species is required (turtles, sea snakes, syngnathids and most sawfishes). We recommend monitoring to continue for all sawfish species as they are highly vulnerable to impacts of fishing even though catch rate trends for the most common species, the Narrow Sawfish (*Anoxypristis cuspidata*) were stable over the period of 2010 to 2019.

- The one ‘at risk’ elasmobranch species, *Urogymnus asperrimus*, has only been observed and recorded in the crew-member observer program seven times in a try net since 2006. This species is likely to be effectively removed from trawl nets with Turtle Excluder Devices and is widely distributed outside of the Northern Prawn Fishery high effort areas. We conclude that this species is unlikely to be at risk from the fishery and should be removed from the list of species being monitored.

- The two ‘at risk’ teleost species, *Lepidotrigla spinosa* and *Lepidotrigla* sp A, have not been observed and recorded in the crew-member observer program. However, they are unlikely to be effectively sampled by this program as there is very little distribution data and suitable descriptive information available to assist in species identification onboard vessels. For these reasons, it is recommended that they continue to be monitored by the Northern Prawn Fishery prawn population monitoring surveys until there is more available information collected.

- The two ‘at risk’ mantis shrimp species, *Dictyosquilla tuberculata* and *Harpiosquilla stephensoni*, have widespread distributions across the NPF. *Dictyosquilla tuberculata* has shown steady increases in crew-member observer catches since 2010 and is unlikely to be adversely impacted by current trawling patterns. It is recommended that *Dictyosquilla tuberculata* is unlikely to be at risk from this fishery and should be removed from the list of species being monitored. *Harpiosquilla stephensoni* had similar increased catches from 2009 to 2012. Following a marked drop in catches in 2013, catches increased again from 2014 to 2016. However, there has been a progressive decline in the catch rate trend over the last three years (2017 to 2019). It is recommended that *Harpiosquilla stephensoni* be monitored until further distribution and catch data is available to undertake a robust catch rate trend analysis.

- The crew-member observer program derived knowledge is valuable to the fishery to demonstrate their obligation to ecological sustainability of trawl bycatch species. The crew-member observer program continually improves data quality, increases the number of species quantitatively modelled and strongly contributes to the attainment of Marine Stewardship Council Certification for the fishery. However, improved rigour of data quality and quantity remain a key objective for this project. Given the suite of rigorous data for 14 bycatch species and the likely provision of comprehensive data series for other species, ongoing monitoring and assessment is recommended.

OBJECTIVE 1: Attend the 2018, 2019 and 2020 annual crew-member observer workshops and collaborate with NPFI representatives to deliver an annual training program for crew-member observers in identifying and recording all TEP and 'at risk' species interactions during the 2015 – 17 prawn seasons

From 2003 to 2008, Commonwealth Scientific and Industrial Research Organisation (CSIRO) scientists have participated in organizing and delivering annual training workshops, in conjunction with staff from the Australian Fisheries Management Authority (AFMA) and the NPF Industry Pty Ltd (NPFI). This included preparing field manuals and datasheets, sampling kits and information packs for each crew-member observer. A number of CSIRO scientists attended these courses to aid facilitation and to deliver talks to the crew members on current catch data collected and biological information on Threatened, Endangered and Protected' species and 'at risk' bycatch species that are being recorded by the crew-member observers.

As of 2009, the organising and running of the crew-member training workshop was handed over to NPFI via the co-management arrangement with AFMA. Each year since then, a two-day workshop has been held during late July in north Queensland. CSIRO scientists participate in these workshops, presenting training information focused on past data collected on the TEP and 'at risk' bycatch species and biological information; species identifications and general life-history information for these species. The CSIRO project staff were also involved in gathering observer feedback for the ongoing evaluation of the bycatch data collection methods.

The crew-member observer workshops were held in Cairns on the 23rd and 24th July 2018 and on the 22nd July 2019. There were around 12 crew-member observers attending each of the workshops. This represented a fleet coverage of around 20% in boat days. Two AFMA scientific observers attended the 2018 and 2019 crew-member observer workshops. Due to travel restrictions in 2020, the crew member observer workshop was run remotely with crew members being trained through video conferencing and phone calls.

OBJECTIVE 2: Process and summarize all crew-member observer and AFMA scientific observer catch and image data on TEPs and 'at risk' species collected in 2017, 2018 and 2019 banana and tiger prawn seasons

Since the last Bycatch Sustainability Assessment in 2018, catch data on 'Threatened, Endangered and Protected' (TEP) and 'at risk' bycatch species has continued to be collected from a number of sources. Catch data recorded by the Northern Prawn Fishery (NPF) crew-member observer program between 2017 and 2019 was obtained from the NPFI Pty Ltd. Catches of all TEP and 'at risk' bycatch species have also been recorded during the annual NPF prawn population monitoring surveys from 2017 to 2019 (as part of '*An integrated monitoring program for the Northern Prawn fishery 2015-2018 R2015/0810*' and '*An integrated monitoring program for the Northern Prawn fishery 2018-2021 R2017/0819*' Projects). In addition, AFMA's NPF scientific observer program has provided additional catch data on TEP and 'at risk' bycatch species from 2017 to 2019.

The additional data collected from these sources to date was combined with the existing data sets and used in the current Bycatch Sustainability Assessment. A detailed description of the data sets used is provided below:

1. Crew-member observer program (2003 – 2019); long-term bycatch monitoring program in the NPF where trained crew members collect fishery-dependent catch data on 'Threatened, Endangered and Protected' species and 'at risk' elasmobranch, teleost and invertebrate bycatch species.

2. AFMA scientific observer program (2005 – 2019); fishery-dependent data collection by AFMA scientific observers onboard NPF commercial vessels during the tiger and banana prawn seasons for catch data on Threatened, Endangered and Protected' species and 'at risk' elasmobranch, teleost and invertebrate bycatch species.

3. NPF prawn population monitoring survey (2002 – 2019); bi-annual fishery-independent monitoring surveys carried out in the NPF by CSIRO to collect prawn stock catch data, including catch data on 'Threatened, Endangered and Protected' species and 'at risk' elasmobranch, teleost and invertebrate bycatch species.

4. CSIRO scientific research and observer surveys (1976 – 2005); fishery-independent research trawl surveys and CSIRO scientific observers onboard NPF commercial vessels collecting catch data on 'Threatened, Endangered and Protected' species and 'at risk' elasmobranch, teleost and invertebrate bycatch species.

These data have undergone processing and quality control including image processing of all photographs taken of TEP and 'at risk' bycatch species by crew-member observers and AFMA scientific observers. Each photograph was viewed for species identification and then matched with the catch records recorded by the observers. Each animal was also measured for total length using 'Image J' software and sexed where possible.

Catch records for the crew-member observer and AFMA scientific observer data sets were matched with NPF logbook data to obtain trawl information; trawl date and time, trawl duration, trawl location, trawl depth and trawl gears used. From this information, catches per unit effort (numbers per km^2) for TEP and 'at risk' bycatch species were calculated for catch trend analysis.

OBJECTIVE 3: Undertake a catch trend analysis of NPF crew-member observer and AFMA scientific observer data collected up to the 2019 banana and tiger prawn seasons, including an evaluation of the performance of the NPF crew-member observer and AFMA scientific observer programs over the last three years

For the 2021 Bycatch Sustainability Assessment, the raw catch rates of the crew-member observer, AFMA scientific observer and NPF prawn population monitoring data sets were analysed separately. Comparisons of catch rate trends between these three data sets were made to check for consistency and validation of the crew-member observer data. Since the AFMA scientific observer and NPF prawn population monitoring data were collected on a similar spatial and temporal scale as the crew-member observer data was collected, initially they were used to validate the crew-member observer data.

Total catch numbers recorded for some species differed slightly between the crew-member observer and NPF prawn population monitoring data sets, however their trends in catch rates over time ('Years') showed similar patterns between the data sets. The AFMA scientific observer data set showed quite large discrepancies in total catch numbers when compared to the crew-member observer data set in some 'Regions' but not others.

As the data sets vary spatially (including depth) and temporally in both catch and effort, it is important to compare the trends after correcting for these differences through a statistical modelling process. Generalised Additive Models (GAMs) were used to estimate the trend in catch rates through time for the crew-member observer program, AFMA scientific observer program and NPF prawn population monitoring surveys and where sample numbers were large enough for the models to fit (Wood, 2017). The catch was modelled using a GAM with a zero-inflated Poisson distribution (ziP) using the mgcv package in R. Initially only the crew-member observer data was modelled. The AFMA scientific observer and NPF prawn population monitoring data sets were then combined and statistically compared with the crew-member observer data for catch rate trend analysis for the TEP and 'at risk' bycatch species where sufficient catch data was available. For the rarest species, GAM analysis procedures were not suitable. For these species, unmodelled catch rate data was plotted on a spatial and temporal scale to describe general trends in catches.

A large amount of catch per unit effort data from previous CSIRO scientific research and observer surveys from 1976 to 2005 was sourced and included in this assessment for species distribution mapping. These early CSIRO data sets were included to (i) potentially provide a longer-term view of catches and (ii) to compensate for the overall low numbers of catch data records for most of these TEP and ‘at risk’ species in the NPF. All catch data was standardised to numbers of individuals caught per swept area (km^2).

In the previous 2018 assessment, the bycatch monitoring programs collected sufficient data to assess 11 species (eight sea snakes, one sawfish, one syngnathid and one mantis shrimp species) for catch trends. There were sufficient data available in this current assessment to undertake quantitative catch rate trend analysis for one marine turtle species (*Natator depressus*), ten sea snake species (*Acalyptophis peronii*, *Aipysurus duboisii*, *Aipysurus mosaicus*, *Aipysurus laevis*, *Astrotia stokesii*, *Disteira major*, *Hydrophis elegans*, *Hydrophis ornatus*, *Hydrophis pacificus* and *Lapemis curtis*), one syngnathid (*Trachyrhamphus longirostris*), one sawfish species (*Anoxypristis cuspidata*), and one invertebrate species (*Dictyosquilla tuberculata*). None of these species showed clear declines in catches from 2003 to 2019 during either the crew-member observer program or the combined AFMA scientific observer program and NPF prawn population monitoring surveys. For some of these species, catches had appeared to steadily increase over the data collection period. About half of the 14 species showed increases in catch rates from around 2009 – 2010 to 2016, followed by a slight decline over the last three years to 2019. The Narrow Sawfish; *Anoxypristis cuspidata*, showed a relatively stable catch rate trend over the last ten years. However, no species showed consistent declining catch rate trends over the period of data collection and catch rates for many species were highly variable within years.

The remaining 26 TEP and ‘at risk’ bycatch species were not able to be assessed by the GAM method due to the scarcity of catch records in the time series data. For these species, the most suitable method of assessing their susceptibility to trawling in the NPF was to plot standardized (for effort only) catches on a spatial and temporal scale to look for trends in their catch rates. There was high variability in catch rates across Regions and Years for most of these species. Most of these species appeared to show no consistent downward trend in their catch rates from 2002 to 2019 that would indicate an unsustainable impact from trawling. The Stephenson’s Mantis Shrimp appeared to show a slight decline over the last three years however catch rates did not drop lower than levels seen in the previous years. The only other noticeable declines in catch over the last several years were in the unidentified-taxa groups from the crew-member observer program and indicates an improvement in crew-member observer data collection and species identification.

For the rarest or cryptic TEP and 'at risk' bycatch species, numbers of catch records were very low and catch rate trends could not be assessed. Future interactions with these species will need continued monitoring by the crew-member observer program, AFMA scientific observer program and during the NPF prawn population monitoring surveys, especially if the current commercial fishing intensity and effort distribution changes.

Species of marine turtles, sea snakes, syngnathids and sawfishes are listed through the EPBC Act 1999; recording interactions with fishing activities in the NPF is a legislative requirement. Therefore, continued monitoring by fishery-dependent and fishery-independent programs is necessary. Additionally, as an outcome of this project, we strongly recommend monitoring to continue for all sawfish species as they are highly vulnerable to impacts of fishing. For the most common species, the Narrow Sawfish (*Anoxypristis cuspidata*), modelled catch data showed a stable catch rate trend over the last ten years from the crew-member observer program.

The ‘at risk’ elasmobranch species; *Urogymnus asperrimus*, has only been recorded seven times during the crew-member observer program from 2003 to 2019 and has not been found by the AFMA scientific observer program or the NPF prawn population monitoring surveys. As these are large animals and all seven catch records were try-net captures, they would likely be excluded by TEDs and available evidence suggests that they are widespread across the Indo-Pacific region. We conclude that it is unlikely that this species is at risk from trawling by the NPF and that *Urogymnus asperrimus* should be removed from the list of species being monitored.

An additional two teleost species; *Lepidotrigla spinosa* and *Lepidotrigla* sp A, were identified as potentially 'at risk' and included in the priority monitoring list in 2011. Neither of these species have been found to date during either of the three monitoring programs and there is very limited distribution data and suitable descriptive information to assist in species identification onboard vessels. It is recommended that the two teleost species continue to be monitored by the fishery-independent NPF prawn population monitoring surveys until there is more available information collected.

The two ‘at risk’ mantis shrimp species; *Dictyosquilla tuberculata* and *Harpiosquilla stephensoni*, have been regularly recorded across most of the NPF during the crew-member observer program, AFMA scientific observer program and NPF prawn population monitoring surveys from 2009 to 2019. *Dictyosquilla tuberculata* has shown consistent marked increases in crew-member observer catches from 2009 indicating that this species is quite common within the NPF and its distribution is likely to be more widespread than the catch records previously showed. It is recommended that *Dictyosquilla tuberculata* is unlikely to be at risk from this fishery and should be removed from the list of species being monitored.

While similar steady increases in crew-member observer catches were seen for *Harpiosquilla stephensoni* from 2009 to 2016, catch rates began to decline from 2017 to 2019 for both the crew-member observer program and AFMA scientific observer program. The reason for this decline is unclear and therefore it is recommended that *Harpiosquilla stephensoni* continue to be monitored, at least for the next three years, until further distribution and catch data is available to undertake a robust catch rate trend analysis.

OBJECTIVE 4: To deliver an updated triennial bycatch sustainability assessment report for the TEP and ‘at risk’ bycatch species impacted by the NPF

The objective of the crew-member observer program is to provide accurate and reliable data on TEP and 'at risk' bycatch species for catch rate trend analysis. An assessment of the success of the crew-member observer program was made during this project. It was carried out by comparisons of the number of species that could be assessed for catch rate trends and the similarities between the trends for the crew-member observer data, compared to trends for the combined AFMA scientific observer and NPF prawn population monitoring data sets.

The crew-member observer program over the last nine years (2011 – 2019) has been successful in collecting robust and reliable catch data on the TEP and ‘at risk’ bycatch species and has led to an increase in number of species assessed for catch rate trend analysis; three species in 2009, 11 species in 2015, 11 species (one new species) in 2018 and 14 species in this assessment. For comparison, there was sufficient data available from the combined AFMA scientific observer and NPF prawn population monitoring data to assess catch rate trends for six of these 14 species. The six species included five sea snake species (*Astrotia stokesii*, *Disteira major*, *Hydrophis elegans*, *Hydrophis ornatus* and *Lapemis curtis*) and a syngnathid (*Trachyrhamphus longirostris*). Although the modelled catch rates for these six species were not always identical when compared to the catch rates from the crew-member observer data, the modelled catches over time showed similar trends. This trend was more evident over the last ten years of the programs; 2011 to 2019. It indicates that the crew-member observers performed their data collection tasks effectively as outlined in the 'Crew-member Observer Manual'. They provided accurate and reliable data on at least six of the TEP and 'at risk' bycatch species which was verified by the combined AFMA scientific observer and NPF prawn population monitoring data and could be used in scientific analysis of changes in catch rate trends.

KEYWORDS: AFMA scientific observer, at risk, bycatch, crew-member observer, elasmobranch, invertebrate, marine turtle, Northern Prawn Fishery, sawfish, scientific observer, sea snake, sustainability, syngnathid, teleost, Threatened, Endangered and Protected.

2 Project background and need

A critical part of demonstrating ecological sustainability in the NPF is measuring and reducing its trawling impacts on the marine environment. As a result, the NPF has developed and adopted the Bycatch Strategy (https://www.afma.gov.au/sites/default/files/uploads/2014/02/NPF-Bycatch-Strategy-2015-18-FINAL-VERSION.pdf) and strongly supported the development and funding of several scientific research projects aimed at reducing and assessing impacts on bycatch species.

In 2001, as part of the *Ecological Sustainability of Bycatch and Biodiversity in Prawn Trawl Fisheries* Project (P/N FRDC 96/257), Stobutzki et al. (2000) developed a qualitative approach to examine the likely impact of trawling on vertebrate bycatch species of the NPF. They used a two-axis matrix with scored criteria to determine a species' position within the matrix: (i) the susceptibility of a species to capture and mortality due to prawn trawling and (ii) the capacity of a species to recover once the population is depleted.

Following on from this study, Griffiths et al. (2006c) undertook an Ecological Risk Assessment for Effects of Fishing (ERAEF V9.2) on bycatch of the NPF. This study highlighted a number of vertebrate and invertebrate bycatch species that were determined to be most 'at risk' from trawling in the NPF. In 2007, the bycatch monitoring project; *Design, trial and implementation of an integrated, long-term bycatch monitoring program road tested in the Northern Prawn Fishery* (P/N FRDC 2002/035) developed a cost-effective way of assessing sustainability of bycatch in the NPF. This included development and implementation of a risk assessment method to identify elasmobranch and teleost bycatch species that are or may be at risk to trawling (Brewer et al. 2007). This method has been further developed into an ecological Sustainability Assessment for Fishing Effects (SAFE) approach to quantitatively assess the impacts of trawling on all bycatch species. This work highlighted several bycatch species potentially 'at risk' from prawn trawling in the NPF (Zhou and Griffiths 2008; Zhou et al. 2009a).

The bycatch monitoring project: *Design, trial and implementation of an integrated, long-term bycatch monitoring program road tested in the Northern Prawn Fishery* (P/N FRDC 2002/035), also trialed methods for establishing a long-term bycatch monitoring program. As part of that project, in 2003 crew-member observers voluntarily collected species-specific bycatch data on an annual basis. In April 2008, the NPF commenced a long-term bycatch sustainability program with AFMA taking responsibility for ensuring the long-term sustainability of all bycatch species impacted by the fishery and consequently, for organizing and running an on-going bycatch data collection program; the crew-member observer program. The crew-member observer data collection process is now funded directly by the NPFI with participating crew members being employed to carry out their crew-member observer duties. The AFMA funds a separate component project dedicated to the data analysis and reporting of the Bycatch Sustainability Assessment.

There have been three NPF Bycatch Sustainability Assessments undertaken to date, initially in 2009, then in 2015 and again in 2018. These assessments analysed all available catch and biological data on TEP and 'at risk' bycatch species sourced from the crew-member observer program, AFMA scientific observer program, NPF prawn population monitoring surveys and CSIRO scientific research and observer surveys that were available up until the end of 2016. In those studies, there was sufficient data available to undertake the catch rate trend analysis for eight sea snake species (*Aipysurus mosaicus*, *Aipysurus laevis*, *Astrotia stokesii*, *Disteira major*, *Hydrophis elegans*, *Hydrophis ornatus, Hydrophis pacificus* and *Lapemis curtis*), one syngnathid (*Trachyrhamphus longirostris*), one sawfish species (*Anoxypristis cuspidata*), and one invertebrate species (*Dictyosquilla tuberculata*). None of these species showed clear declines in catches from 2003 to 2016 from either the crew-member observer program or the combined AFMA scientific observer program and NPF prawn population monitoring surveys.

Most of these TEP and ‘at risk’ bycatch species were not able to be assessed using the catch rate trend analysis method due to the scarcity of catch records in the time series data. For these species, standardised catches were plotted on a spatial and temporal scale to look for trends in their catch abundance. None of the TEP and ‘at risk’ bycatch species appeared to show any consistent downward trend in their catch rates from 2003 to 2016 that would indicate an unsustainable impact from trawling. However, the rarer or cryptic TEP and ‘at risk’ bycatch species required continued monitoring by the crew-member observer and AFMA scientific observer programs and during the NPF prawn population monitoring surveys, especially if the commercial fishing intensity and effort distribution changes over time.

The use of this long-term catch data is critical for monitoring the abundances of these species and re-assessing their risk to trawling with the changes in effort and spatial intensity of the fishing fleet. It is essential that this data collection continue through the AFMA scientific observer and crew-member observer programs; and that the data is assessed in order to determine whether these species are being impacted in a manner that allows sustainable or viable populations into the long term. AFMA has requested that CSIRO use these and other historical data to continue to provide triennial assessments of the sustainability for all impacted bycatch species. This project delivers the fourth Bycatch Sustainability Assessment within these long-term monitoring programs.

3 Objectives

OBJECTIVE 1: Attend the 2018, 2019 and 2020 annual crew-member observer workshops and collaborate with NPFI representatives to deliver an annual training program for crew-member observers in identifying and recording all TEP and 'at risk' species interactions during the 2015 – 17 prawn seasons

CSIRO researchers will participate in the annual NPF crew-member observer training workshops in 2018, 2019 and 2020 to help educate NPF crew-member observers in the appropriate methods for identifying and measuring TEP and 'at risk' bycatch species and recording data correctly.

OBJECTIVE 2: Process and summarize all crew-member observer and AFMA scientific observer catch and image data on TEPs and 'at risk' species collected in 2017, 2018 and 2019 banana and tiger prawn seasons

CSIRO researchers will also process all digital data records of TEP and 'at risk' bycatch species submitted by NPF crew-member observers and AFMA scientific observers throughout the 2017 – 2019 banana and tiger prawn seasons to confirm species identifications and length measurements. This will include the entry of all biological data into a central database, and matching/merging NPF commercial logbook data with NPF crew-member observer and AFMA data in a central database to derive spatial and shot-based information not collected by NPF crew-member observers and AFMA observers.

OBJECTIVE 3: Undertake a catch trends analysis of NPF crew-member observer and AFMA scientific observer data collected up to the 2019 banana and tiger prawn seasons, including an evaluation of the performance of the NPF crew-member observer and AFMA scientific observer programs over the last three years

CSIRO researchers will undertake a triennial sustainability analysis in 2020 for the NPF using data collated through objectives 1 and 2 above, involving re-running catch trend analysis to update the 2018 sustainability report ('Monitoring interactions with bycatch species using crew-member observer data collected in the Northern Prawn Fishery: 2014-16' - R2015/0812). The assessment will use time-series data from the crew-member observer program, AFMA scientific observer program and NPF prawn population monitoring surveys to analyse (using data modelling techniques) and monitor catch trend changes over time for each TEP and 'at risk' bycatch species. Recommendations will then be given in the report on the likely susceptibility of these species to trawling in the NPF and future monitoring priorities. The next sustainability analysis will be due in 2023.

OBJECTIVE 4: To deliver an updated triennial bycatch sustainability assessment report for the TEP and 'at risk' bycatch species impacted by the NPF

CSIRO researchers will deliver a scientific report documenting the scientific results of the bycatch sustainability assessment and provide recommendations to AFMA for priority bycatch species and future monitoring. This data set and report may be used to assess and demonstrate ecological sustainability of the TEP and 'at risk' bycatch species; one of the NPF's Ecological Risk Assessment and Management obligations for commonwealth fisheries.

4 General introduction

The incidental take of bycatch species has become an important issue in trawl fisheries worldwide over the last decade (Eayrs 2007). In Australia's NPF, this has led to considerable resources being expended on designing, implementing and monitoring new gear technologies; e.g. Turtle Excluder Devices (TEDs) and Bycatch Reduction Devices (BRDs), to reduce the catch of Threatened, Endangered and Protected (TEP) and other large bycatch species (Brewer et al. 2004; Brewer et al. 2006; Brewer et al. 2007; Milton et al. 2008). These species include marine turtles, sea snakes, sawfishes, sharks and rays. In 2000, AFMA introduced mandatory usage of these TEDs and BRDs in trawl nets for all vessels fishing in the NPF.

Recently, there has been increased focus directed towards ecosystem-based fishery management as a result of greater environmental concern for marine habitats. This has included assessing the long-term sustainability of all species caught in commercial fisheries, especially tropical trawl fisheries where large numbers of bycatch species are caught. These bycatch species, and the impacts of trawling on their populations, are generally poorly understood because of the limited amount of data that is available. However, demonstrating that populations of bycatch species are sustainable under the impacts of trawl fishing requires species-specific and quantitative approaches; in particular, quantitative risk or stock assessments, or long-term monitoring programs (Brewer et al. 2007).

In 2006, Griffiths et al. (2006c) assessed the ecological impacts of the NPF on bycatch species by using the Ecological Risk Assessment for Effect of Fishing model (ERAEF V9.2) jointly developed by CSIRO and AFMA. This approach provided a hierarchical framework for a comprehensive assessment of the ecological risks to elasmobranch, teleost and invertebrate species arising from fishing, with impacts assessed against five ecological components: target species; byproduct and bycatch; threatened, endangered and protected species; habitats; and ecological communities (Griffiths et al. 2006c). A new quantitative approach to the ecological Sustainability Assessment for Fishing Effects (SAFE) was then developed for the diverse and data-poor bycatch species of elasmobranchs (Brewer et al. 2007; Zhou and Griffiths 2008) and teleosts (Brewer et al. 2007; Zhou et al. 2009a) in the NPF. This method estimated fishing impacts and compared the impact to sustainability reference points based on basic life-history parameters (Zhou and Griffiths 2008).

The SAFE approach was run in 2011 and identified a number of bycatch species that may be 'at risk' to trawling in the NPF (Table 1). Each of these 'at risk' bycatch species were then further assessed by expert scientists to evaluate all available data and provide justification on retaining or removing a species from the 'at risk' list. This SAFE approach is repeated periodically as more data for each species becomes available. The SAFE approach was run again in 2018 and the results are currently being finalized. These 'at risk' species will be monitored in future through the crew-member observer program, AFMA scientific observer program and NPF prawn population monitoring surveys.

This is the fourth Bycatch Sustainability Assessment undertaken for the NPF and aims to use data collected between 2017 to 2019 from crew-member observer, AFMA scientific observer, NPF prawn population monitoring surveys and CSIRO scientific research and observer surveys to update the previous assessment of TEP and 'at risk' bycatch species. This up-to-date data set will increase the robustness of the analysis with a greater number of catch records, more precise catch rate estimates over time, and increase the number of species for which individual catch rate trend analysis can be performed on. In addition, we provide advice on future assessment strategies and alternative strategies for assessing sustainability where this is necessary.

5 Methods

5.1 Data sources and data collection

All available catch and biological data on TEP species and 'at risk' bycatch species were sourced from within CSIRO and from AFMA and NPFI. This data was standardised and collated into a central database. This includes; (i) fishery-dependent data collected as part of the crew-member observer program, (ii) fishery-dependent data collected by AFMA scientific observers onboard commercial vessels, (iii) fishery-independent data collected from the NPF prawn population monitoring surveys and (iv) data collected from previous CSIRO scientific research and observer surveys onboard commercial vessels, from the early 1990's to 2019. The early CSIRO scientific research and observer data was included due to the overall low numbers of catch data records for these TEP and 'at risk' species in the NPF.

As the data have come from a number of sources, it consequently required a degree of preparation in order for the assessments and analyses to continue. To this end, we standardised each data set for trawl effort producing numbers of animals per km^2 swept area for each of the TEP and 'at risk' bycatch species. In each of the data sets, there was a proportion of catch records where individuals were only recorded to group level and not to species level; turtles, sea snakes, syngnathids and sawfishes. These records were treated as unidentified individuals of that group for the analysis. As a consequence, the species-specific catch rates calculated may be lower since some individuals of that species (the ones not identified to species) would have been included at the group level.

5.1.1 Nominated species for assessment

Threatened, Endangered and Protected Species

As legislated by the *Environmental Protection and Biodiversity Conservation Act 1999*, all Threatened, Endangered and Protected (TEP) species interactions are required to be recorded by fishers in the NPF. The TEP groups recorded in the NPF are one species of dolphin, five species of marine turtles, at least 14 species of sea snakes, at least 11 species of syngnathids (pipefish/seahorses) and the four species of sawfishes (Table 1). These species are included in this Bycatch Sustainability Assessment.

Catches of these species have been recorded during the crew-member observer program (2003 – 2019), AFMA scientific observer program (2005 – 2019) and NPF prawn population monitoring surveys (2002 – 2019). These TEP species have also been recorded during most of the previous CSIRO scientific research and observer surveys in the NPF from 1976 to 2005.

Sawfishes

All sawfishes are listed under the EPBC Act 1999 as vulnerable and/or migratory species. They are recognised as being highly susceptible to any activity that impacts their populations, with populations already being severely impacted by fishing. Furthermore, it is likely to take many years, if not decades, for sawfish populations to recover from significant declines. These species are listed under the International Union for Conservation or Nature (IUCN) as Critically Endangered (*Pristis pristis* and *Pristis zijsron*) or Endangered (*Pristis clavata* and *Anoxypristis cuspidata*) (Dulvy et al. 2016). Importantly, northern Australia is a remnant stronghold for the worldwide sawfish population.

Catches of sawfish species have been recorded during the NPF prawn population monitoring surveys since 2002, crew-member observer program since 2003 and the AFMA scientific observer program since 2005. Catches of sawfishes have also been recorded during most of the previous CSIRO scientific research and observer surveys in the NPF from 1990 to 2005.

'At risk' bycatch species

This group consists of elasmobranch (not including sawfishes), teleost and invertebrate bycatch species and were assessed as potentially 'at risk' from semi-quantitative 'Ecological Risk Assessment for Effects of Fishing' (Griffiths et al. 2006c) and quantitative 'Sustainability Assessment for Fishing Effects' (Zhou and Griffiths 2008; Zhou et al. 2009a, Zhou 2011) approaches.

During the time series of data collection, there were some changes to the nominated 'at risk' bycatch species for monitoring. From the results of the ERAEF and SAFE approaches in 2006 and 2007, the 'at risk' species comprised three elasmobranch species: *Orectolobus ornatus*, *Taeniura meyeni* and *Urogymnus asperrimus*, and two teleost species: *Dendrochirus brachypterus* and *Scorpaenopsis venosa* (see Appendix A). Any interactions with these species were recorded from 2006 onwards for the elasmobranchs and 2007 onwards for the teleosts by the crew-member observers and during the NPF prawn population monitoring surveys.

In 2009, the NPF Bycatch Subcommittee working group held a meeting at CSIRO where a further two elasmobranch (*Carcharhinus albimarginatus* and *Squatina albipunctata*), seven teleost (*Parascolopsis tosensis*, *Hemiramphus robustus*, *Lutjanus rufolineatus*, *Onigocia spinosa*, *Benthosema pterotum*, *Scomberoides comersonnianus* and *Sphyraena jello*), three cephalopod (*Euprymna hoylei*, *Metasepia pfefferi* and *Photololigo* sp. 3 / 4) and three crustacean (*Solenocera australiana*, *Dictyosquilla tuberculata* and *Harpiosquilla stephensoni*) species were nominated as 'at risk' species (see Appendix A). These species were highlighted as 'at risk' from a re-run of the ERAEF V9.2 and SAFE approaches in 2009 (refer Griffiths et al. 2006c; Zhou and Griffiths 2008; Zhou et al. 2009a).

The updated 'at risk' bycatch species list was then distributed to key biological researchers to provide expert opinion on the species in each of their research fields. The researchers provided detailed distribution and biological information and assessed the appropriateness of these species to be in the 'at risk' list (see Appendix A for details). This process removed from the list three elasmobranch species (*Orectolobus ornatus*, *Carcharhinus albimarginatus* and *Squatina albipunctata*), seven teleost species (*Parascolopsis tosensis*, *Hemiramphus robustus*, *Lutjanus rufolineatus*, *Onigocia spinosa*, *Benthosema pterotum*, *Scomberoides comersonnianus* and *Sphyraena jello*) and three cephalopod species (*Euprymna hoylei*, *Metasepia pfefferi* and *Photololigo* sp. 3 / 4) (see Appendix A).

In 2010, an updated SAFE assessment using more recent fishery data was requested by AFMA due to the fishery experiencing significant changes in fleet structure, fishing patterns and fishery effort distribution. This assessment included 51 elasmobranch and 428 teleost species. There were five species of elasmobranchs (*Carcharhinus albimarginatus*, *Carcharhinus leucas*, *Galeocerdo cuvier*, *Orectolobus ornatus*, and *Sphyrna mokarran*) where estimated fishing mortality was greater than their maximum sustainable mortality (Zhou 2011). However due to their wide distribution, likelihood of being excluded through the TED and rarity in prawn trawls, these species were not regarded as 'at risk' to trawling in the NPF (Zhou 2011). The updated assessment also showed one of the previously nominated species; *Taeniura meyeni*, has estimated fishing mortality smaller than its maximum sustainable mortality and its distribution mostly outside the current fishing area. Therefore, this species was also removed from the 'at risk' list in 2011. The other previously nominated elasmobranch, *Urogymnus asperrimus*, had its upper 90% CI limit of mean estimated fishing mortality slightly larger than the maximum sustainable mortality, therefore further monitoring was recommended (Zhou 2011).

For the teleosts, none of the 428 species were determined to be 'at risk' to trawling with estimated fishing mortalities lower than maximum sustainable mortalities (Zhou 2011). Although six species (*Ariosoma anago*, *Conger cinereus*, *Epinephelus malabaricus*, *Lepidotrigla* sp., *Leptojulis* *cyanopleura*, and *Sphyraena qenie*) did show upper 90% CI limit of estimated fishing mortality greater than the maximum sustainable mortality, this was due to high uncertainty in data. The two previously nominated teleosts; *Dendrochirus brachypterus* and *Scorpaenopsis venosa*, had estimated fishing mortality lower than their maximum sustainable mortality in this updated assessment so they were removed from the 'at risk' list (Zhou 2011). Furthermore, eight teleost species were assessed as having a 'Precautionary Medium Risk' score: *Pterygotrigla hemisticta*, *Lepidotrigla* sp C, *Lepidotrigla spiloptera*, *Lepidotrigla kishinoyi*, *Lepidotrigla* sp 2, *Lepidotrigla spinosa*, *Lepidotrigla argus*, *Lepidotrigla* sp A. These species were then assessed by key biological researchers using the expert opinion method and only two of these species (*Lepidotrigla spinosa* and *Lepidotrigla* sp A) were regarded as 'at risk' to trawling and subsequently included in the list for future monitoring. However due to their rarity, difficulty in identification and lack of suitable descriptive information for easy identification onboard vessels, these two *Lepidotrigla* species were only monitored during the NPF prawn population monitoring surveys and not during the crew-member observer or AFMA scientific observer programs (see Appendix A).

In 2012, the Marine Stewardship Council (MSC) certification process for the NPF highlighted that one of the three current 'at risk' invertebrate species; *Solenocera australiana*, has a widespread distribution across northern Australia, including in offshore areas, where no NPF trawling is likely to occur (Fry et al. 2009). Although this prawn species is consistently caught in the NPF, it was concluded that populations are not adversely susceptible to impacts from NPF trawling and removed from the 'at risk' priority list (MRAG 2012).

The current list of TEP and bycatch species identified to be 'at risk' is given in Table 1.

Table 1: List of Threatened, Endangered and Protected (TEP) and 'at risk' bycatch species from the NPF region which were identified in the ERAEF (2006) and SAFE (2008; 2009; 2011) approaches. List includes both currently and previously monitored TEP and bycatch species from the start of the crew-member observer program onwards.

Group	Family	CAAB	Species	Common Name	Source	Period	Status
Dolphin	Delphinidae	41116000	Delphinidae spp	Dolphin	TEP	2003-2016	Current
Marine Turtle	Cheloniidae	39020001	*Caretta caretta*	Loggerhead Turtle	TEP	2003-2016	Current
	Cheloniidae	39020002	*Chelonia mydas*	Green Turtle	TEP	2003-2016	Current
	Cheloniidae	39020003	*Eretmochelys imbricata*	Hawksbill Turtle	TEP	2003-2016	Current
	Cheloniidae	39020004	*Lepidochelys olivacea*	Olive Ridley Turtle	TEP	2003-2016	Current
	Cheloniidae	39020005	*Natator depressus*	Flatback Turtle	TEP	2003-2016	Current
Sea Snake	Hydrophiidae	39125001	*Acalyptophis peronii*	Horned Sea Snake	TEP	2003-2016	Current
	Hydrophiidae	39125003	*Aipysurus duboisii*	Dubois Sea Snake	TEP	2003-2016	Current
	Hydrophiidae	39125004	*Aipysurus mosaicus*	Stagger-banded Sea Snake	TEP	2003-2016	Current
	Hydrophiidae	39125007	*Aipysurus laevis*	Olive Sea Snake	TEP	2003-2016	Current
	Hydrophiidae	39125009	*Astrotia stokesii*	Stokes Sea Snake	TEP	2003-2016	Current
	Hydrophiidae	39125010	*Disteira kingii*	Spectacled Sea Snake	TEP	2003-2016	Current
	Hydrophiidae	39125011	*Disteira major*	Olive-headed Sea Snake	TEP	2003-2016	Current
	Hydrophiidae	39125013	*Enhydrina schistosa*	Beaked Sea Snake	TEP	2003-2016	Current
	Hydrophiidae	39125021	*Hydrophis elegans*	Elegant Sea Snake	TEP	2003-2016	Current
	Hydrophiidae	39125025	*Hydrophis mcdowelli*	Small-headed Sea Snake	TEP	2003-2016	Current
	Hydrophiidae	39125028	*Hydrophis ornatus*	Ornate Sea Snake	TEP	2003-2016	Current
	Hydrophiidae	39125029	*Hydrophis pacificus*	Large-headed Sea Snake	TEP	2003-2016	Current
	Hydrophiidae	39125031	*Lapemis curtis*	Spine-bellied Sea Snake	TEP	2003-2016	Current
	Hydrophiidae	39125033	*Pelamis platurus*	Yellow-bellied Sea Snake	TEP	2003-2016	Current
Syngnathid	Syngnathidae	37282005	*Hippocampus histrix*	Thorny Seahorse	TEP	2006-2016	Current
	Syngnathidae	37282006	*Trachyrhamphus bicoarctata*	Double-ended Pipefish	TEP	2006-2016	Current
	Syngnathidae	37282007	*Haliichthys taeniophorus*	Ribboned Pipefish	TEP	2006-2016	Current
	Syngnathidae	37282030	*Halicampus grayi*	Grays Pipefish	TEP	2006-2016	Current
	Syngnathidae	37282042	*Choeroichthys brachysoma*	Pacific Short-bodied Pipefish	TEP	2006-2016	Current

	Syngnathidae	37282064	*Filicampus tigris*	Tiger Pipefish	TEP	2006-2016	Current
	Syngnathidae	37282080	*Hippocampus zebra*	Zebra Seahorse	TEP	2006-2016	Current
	Syngnathidae	37282101	*Trachyrhamphus longirostris*	Straightstick Pipefish	TEP	2006-2016	Current
	Syngnathidae	37282110	*Hippocampus queenslandicus*	Queensland Seahorse	TEP	2006-2016	Current
	Syngnathidae	37282998	*Trachyrhamphus* sp A	Pipefish	TEP	2006-2016	Current
	Syngnathidae	37282999	*Trachyrhamphus* Short-tailed sp	Pipefish	TEP	2006-2016	Current
Sawfish	Pristidae	37025001	*Pristis zijsron*	Green Sawfish	TEP	2003-2016	Current
	Pristidae	37025002	*Anoxypristis cuspidata*	Narrow Sawfish	TEP	2003-2016	Current
	Pristidae	37025003	*Pristis pristis*	Largetooth (Freshwater) Sawfish	TEP	2003-2016	Current
	Pristidae	37025004	*Pristis clavata*	Dwarf Sawfish	TEP	2003-2016	Current
Elasmobranch	Orectolobidae	37013001	*Orectolobus ornatus*	Banded Wobbegong	SAFE	2006-2009	Removed
	Dasyatidae	37035017	*Taeniura meyeni*	Blotched Fantail Ray	SAFE	2006-2011	Removed
	Dasyatidae	37035027	*Urogymnus asperrimus*	Porcupine Ray	SAFE	2006-2016	Current
Teleost	Pteroidae	37287010	*Dendrochirus brachypterus*	Dwarf Lionfish	SAFE	2007-2011	Removed
	Scorpaenidae	37287086	*Scorpaenopsis venosa*	Raggy Scorpionfish	SAFE	2007-2011	Removed
	Triglidae	37288028	*Lepidotrigla spinosa*	Shortfin Gurnard	SAFE	2011-2016	Current
	Triglidae	37288506	*Lepidotrigla* sp A	Gurnard	SAFE	2011-2016	Current
Invertebrate	Squillidae	28051030	*Dictyosquilla tuberculata*	Mantis Shrimp	SAFE	2009-2016	Current
	Squillidae	28051039	*Harpiosquilla stephensoni*	Mantis Shrimp	SAFE	2009-2016	Current
	Solenoceridae	28714011	*Solenocera australiana*	Coral Prawn	SAFE	2009-2013	Removed

5.1.2 Crew-member observer program; 2003 – 2019

The crew-member observer program began in 2003 as part of the long-term bycatch monitoring project (FRDC Project No. 2002/035) (see Brewer et al. 2007). Each year crew members from a selection of NPF vessels volunteered to participate in annual training workshops. In the workshops run from 2003 to 2006, crew members were trained in the collection of reliable and accurate data for TEP species (turtles and sea snakes), sawfishes and other large elasmobranchs (Table 2). This included collecting and recording vessel and trawl information, species catch statistics and photographing these species for later identification by CSIRO staff. For the 2007 and 2008 training workshops, crew members were not required to record catches of all large elasmobranchs, instead, were trained in the identification and recording of three 'at risk' elasmobranch and two 'at risk' teleost bycatch species, as well as all TEP species. In the 2009 training workshop, crew members were also required to record data on three 'at risk' invertebrate species (see Table 1). From 2010 to 2019, the 'at risk' bycatch species monitored by crew-member observers was determined by re-running of the SAFE approach in 2009 and 2011 (see Table 1).

At the annual workshops, each crew-member observer was supplied with a sampling kit and digital cameras for recording catch data and taking photographs of the TEP species and 'at risk' bycatch species caught in trawls during the banana and tiger prawn seasons. For each trawl, the crew-member observer would inspect the total catch in all nets, search for the selected species and record on the datasheets provided if any TEP or 'at risk' bycatch species were caught. They would also take a photograph of the animal, including a scaled label with vessel name, date and shot number, and then release the animal back to the water.

Completed data sheets and digital camera memory cards were returned to the NPFI Projects Officer. The catch data was then entered into a MS Excel database. This data was sent to CSIRO Oceans and Atmosphere, Dutton Park for further analysis. For each digital image of a TEP or 'at risk' species, identification was carried out by CSIRO scientific staff and total length of the animal was measured using the 10 cm scale bar on the scaled label and the pixel measurement software program, 'Image J'.

The catch data recorded by crew-member observers was matched with the NPF commercial logbook data to obtain trawl information; trawl duration, speed and depth, latitude and longitude of trawl and trawl gear specifications. The trawl sites from the crew-member observer program for the years 2003 to 2019 are shown in Figure 1.

5.1.3 AFMA scientific observers; 2005 – 2019

Catch data on TEP species, sawfish and 'at risk' bycatch species collected by AFMA scientific observers from 2005 to 2019 in the NPF were requested and sourced from the NPF Database Section at AFMA, Canberra (Table 2). Similar to the procedures used by NPF crew-member observers, the AFMA scientific observers collected and recorded the numbers of these species caught in each trawl and took photographs for species identification purposes and measurements of total length of animals.

The trawl sites from AFMA scientific observers onboard commercial vessels for the years 2005 to 2019 are shown in Figure 2.

5.1.4 NPF prawn population monitoring surveys; 2002 – 2019

Catch data on TEP and 'at risk' bycatch species were also obtained from research trawling between 2002 and 2016 in the Gulf of Carpentaria as part of the NPF prawn population monitoring surveys (Projects: MIRF R01/1144 [2002]; FRDC 2002/101 [2002]; FRDC 2003/075 [2003-04]; FRDC

2004/099 [2004-05]; AFMA R05/0599 [2005-06]; AFMA R05/1024 [2006-08]; AFMA R08/0827 [2008-10]; AFMA R2009/0863 [2009-10]; AFMA R2011/0811 [2011-2015]; AFMA R2015/0810 [2015-2018]; AFMA R2017/0819 [2018-2021]) (Table 2).

Data collection and recording was similar to the procedures used by the crew-member observers where each trawl was inspected for TEP and ‘at risk’ bycatch species. Catch numbers were recorded for each trawl and photographs taken of the selected species for verification of species identification and measurement of total length of animal back at the CSIRO Oceans and Atmosphere Laboratory, Dutton Park.

The trawl sites from the NPF prawn population monitoring surveys for the years 2002 to 2019 are shown in Figure 3.

5.1.5 CSIRO scientific research and observer surveys; 1976 – 2005

An extensive data search was also carried out on all databases held by CSIRO. This search included all scientific trawl surveys and scientific observer fieldwork undertaken by CSIRO staff in the NPF region from 1976 to 2005 (Table 2). The objectives of these surveys varied between projects, but all involved a stratified random trawl survey design. As some of these surveys were conducted using trawl nets without TEDs installed (especially pre-2000), this data was also recorded for each trawl. Catches of all TEP and some ‘at risk’ bycatch species caught during these surveys were recorded to species, counted and weighed. However, not all of these surveys recorded catches of all of the ‘at risk’ species of bycatch. This data was included in the database for species distribution purposes and were not used in the catch rate trend analyses.

The trawl sites from CSIRO scientific research and observer surveys for the years 1976 to 2005 are shown in Figure 4.

5.1.6 Museum Records; 1877 – 2006

All available museum records for sea snakes were sourced from the Australian, Queensland, Northern Territory and Western Australian Museums. These records, dating back to 1877 only serve as presence data for species distribution purposes and were not used in the catch rate trend analyses.

Table 2: Summary of data set name, collection method, date range, fishing season, number of vessels, number of prawn trawls and the TEP and 'at risk' bycatch groups recorded in each of the data sets. (TL: turtles; SF: sawfishes; SS: sea snakes; SY: syngnathids; EL: elasmobranchs; TT: teleosts; IN: invertebrates; CP: Coral Prawn; ALL: all current groups included).

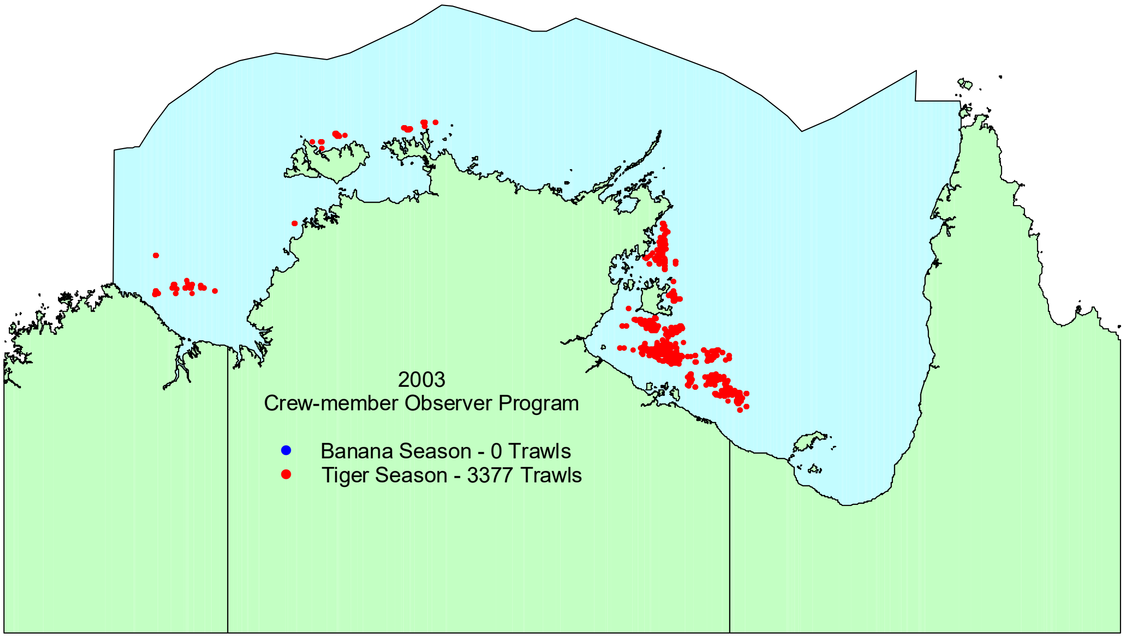
Data Set	Data Collection	Date Range	Season	No. Vessels	No. Trawls	Groups Recorded
Crew-member Observer Program						
CMO_2003_1	CMO	Sep – Dec 03	Tiger	13	3377	TL/SF/SS
CMO_2004_1	CMO	Apr – May 04	Banana	4	310	TL/SF/SS
CMO_2004_2	CMO	Sep – Nov 04	Tiger	12	2610	TL/SF/SS
CMO_2005_1	CMO	Aug – Nov 05	Tiger	6	1317	TL/SF/SS
CMO_2006_1	CMO	Aug – Nov 06	Tiger	3	911	TL/SF/SS/SY/EL
CMO_2007_1	CMO	Jul – Nov 07	Tiger	6	1302	ALL (excl IN)
CMO_2008_1	CMO	Aug – Oct 08	Tiger	5	451	ALL (excl IN)
CMO_2009_1	CMO	Jul – Dec 09	Tiger	7	1370	ALL
CMO_2010_1	CMO	Aug – Nov 10	Tiger	5	1317	ALL
CMO_2011_1	CMO	Apr – Jun 11	Banana	1	66	ALL
CMO_2011_2	CMO	Aug – Nov 11	Tiger	11	2752	ALL
CMO_2012_1	CMO	Mar – Jun 12	Banana	4	640	ALL
CMO_2012_2	CMO	Aug – Nov 12	Tiger	11	2929	ALL
CMO_2013_1	CMO	Apr – Jun 13	Banana	1	126	ALL
CMO_2013_2	CMO	Aug – Nov 13	Tiger	11	3492	ALL
CMO_2014_1	CMO	Apr – Jun 14	Banana	1	187	ALL
CMO_2014_2	CMO	Aug – Nov 14	Tiger	9	2972	ALL
CMO_2015_1	CMO	Apr – Jun 15	Banana	3	529	ALL
CMO_2015_2	CMO	Aug – Dec 15	Tiger	8	3041	ALL
CMO_2016_1	CMO	Apr – Jun 16	Banana	2	185	ALL
CMO_2016_2	CMO	Aug – Nov 16	Tiger	10	2665	ALL
CMO_2017_1	CMO	Apr – Jun 17	Banana	3	480	ALL
CMO_2017_2	CMO	Aug – Nov 17	Tiger	11	3402	ALL
CMO_2018_1	CMO	Apr – Jun 18	Banana	2	282	ALL
CMO_2018_2	CMO	Aug – Nov 18	Tiger	12	3923	ALL
CMO_2019_1	CMO	Apr – May 19	Banana	2	291	ALL
CMO_2019_2	CMO	Aug – Nov 19	Tiger	10	3141	ALL

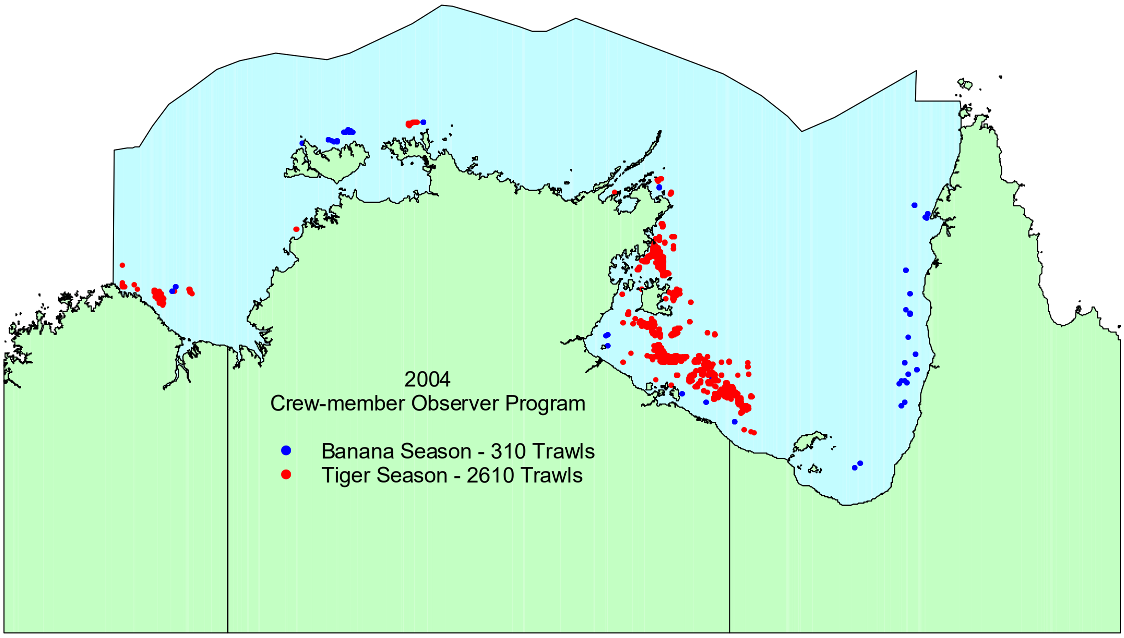
AFMA Scientific Observer						
AFMA Observer 2005_1	AFMA Scientific	Sep – Nov 05	Tiger	3	140	TL/SF/SS
AFMA Observer 2007_1	AFMA Scientific	Apr – Jun 07	Banana	3	98	TL/SF/SS/SY
AFMA Observer 2007_2	AFMA Scientific	Jul – Dec 07	Tiger	9	433	TL/SF/SS/SY
AFMA Observer 2008_1	AFMA Scientific	Apr – Jun 08	Banana	5	243	TL/SF/SS/SY
AFMA Observer 2008_2	AFMA Scientific	Aug – Nov 08	Tiger	5	328	TL/SF/SS/SY
AFMA Observer 2009_1	AFMA Scientific	Apr – May 09	Banana	2	65	TL/SF/SS/SY
AFMA Observer 2009_2	AFMA Scientific	Jul – Oct 09	Tiger	3	290	TL/SF/SS/SY
AFMA Observer 2010_1	AFMA Scientific	May – Jun 10	Banana	4	148	TL/SF/SS/SY
AFMA Observer 2010_2	AFMA Scientific	Aug – Sep 10	Tiger	7	319	ALL
AFMA Observer 2011_1	AFMA Scientific	Apr – Jun 11	Banana	4	127	ALL
AFMA Observer 2011_2	AFMA Scientific	Sep – Nov 11	Tiger	4	307	ALL
AFMA Observer 2012_1	AFMA Scientific	Apr – May 12	Banana	3	146	ALL
AFMA Observer 2012_2	AFMA Scientific	Aug – Oct 12	Tiger	6	249	ALL
AFMA Observer 2013_1	AFMA Scientific	Apr – Jun 13	Banana	4	245	ALL
AFMA Observer 2013_2	AFMA Scientific	Jul – Sep 13	Tiger	6	330	ALL
AFMA Observer 2014_1	AFMA Scientific	Apr – Jun 14	Banana	3	120	ALL
AFMA Observer 2014_2	AFMA Scientific	Aug – Nov 14	Tiger	6	317	ALL
AFMA Observer 2015_1	AFMA Scientific	Apr – Jun 15	Banana	4	117	ALL
AFMA Observer 2015_2	AFMA Scientific	Aug – Nov 15	Tiger	7	216	ALL
AFMA Observer 2016_1	AFMA Scientific	Apr – Jun 16	Banana	5	141	ALL
AFMA Observer 2016_2	AFMA Scientific	Aug – Nov 16	Tiger	7	369	ALL
AFMA Observer 2017_1	AFMA Scientific	Apr – Jun 17	Banana	3	113	ALL
AFMA Observer 2017_2	AFMA Scientific	Aug – Nov 17	Tiger	7	440	ALL
AFMA Observer 2018_1	AFMA Scientific	Apr – Jun 18	Banana	4	162	ALL
AFMA Observer 2018_2	AFMA Scientific	Aug – Dec 18	Tiger	5	291	ALL
AFMA Observer 2019_1	AFMA Scientific	Apr – Jun 19	Banana	9	456	ALL
AFMA Observer 2019_2	AFMA Scientific	Aug – Nov 19	Tiger	8	452	ALL
NPF Prawn Population Monitoring Surveys						
NPF_2002_01	CSIRO Scientific	Aug 02	Tiger	2	169	TL/SF/SS/SY
NPF_2003_01	CSIRO Scientific	Jan – Feb 03	Banana	2	357	TL/SF/SS/SY
NPF_2003_02	CSIRO Scientific	Mar 03	Banana	1	158	TL/SF/SS/SY
NPF_2003_03	CSIRO Scientific	Jul – Aug 03	Tiger	2	298	TL/SF/SS/SY
NPF_2003_04	CSIRO Scientific	Sep – Oct 03	Tiger	1	30	TL/SF/SS/SY

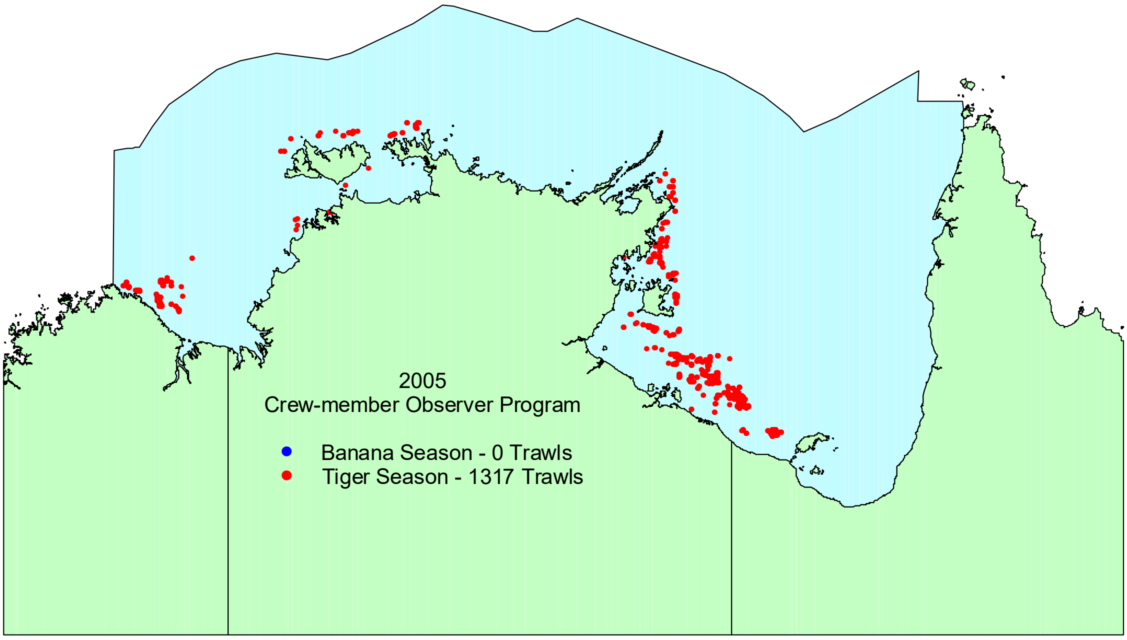
NPF_2004_01	CSIRO Scientific	Jan 04	Banana	3	291	TL/SF/SS/SY
NPF_2004_02	CSIRO Scientific	Feb – Mar 04	Banana	1	168	TL/SF/SS/SY
NPF_2004_03	CSIRO Scientific	Jul – Aug 04	Tiger	3	316	TL/SF/SS/SY
NPF_2004_04	CSIRO Scientific	Oct 04	Tiger	1	40	TL/SF/SS/SY
NPF_2005_01	CSIRO Scientific	Feb 05	Banana	2	304	TL/SF/SS/SY
NPF_2005_02	CSIRO Scientific	Jul 05	Tiger	1	212	TL/SF/SS/SY
NPF_2006_01	CSIRO Scientific	Jan – Feb 06	Banana	2	301	TL/SF/SS/SY
NPF_2006_02	CSIRO Scientific	Jun – Jul 06	Tiger	1	210	TL/SF/SS/SY
NPF_2007_01	CSIRO Scientific	Feb 07	Banana	2	309	TL/SF/SS/SY
NPF_2007_02	CSIRO Scientific	Jun – Jul 07	Tiger	1	208	ALL (excl IN)
NPF_2008_01	CSIRO Scientific	Jan – Feb 08	Banana	2	300	ALL (excl IN)
NPF_2008_02	CSIRO Scientific	Jul 08	Tiger	1	209	ALL (excl IN)
NPF_2009_01	CSIRO Scientific	Feb – Mar 09	Banana	2	304	ALL (excl IN)
NPF_2009_02	CSIRO Scientific	Jun – Jul 09	Tiger	1	210	ALL
NPF_2010_01	CSIRO Scientific	Feb 10	Banana	2	303	ALL
NPF_2011_01	CSIRO Scientific	Jan – Feb 11	Banana	2	306	ALL
NPF_2011_02	CSIRO Scientific	Jun – Jul 11	Tiger	1	210	ALL
NPF_2012_01	CSIRO Scientific	Feb 12	Banana	2	308	ALL
NPF_2012_02	CSIRO Scientific	Jun – Jul 12	Tiger	1	193	ALL
NPF_2013_01	CSIRO Scientific	Feb 13	Banana	2	306	ALL
NPF_2013_02	CSIRO Scientific	Jun – Jul 13	Tiger	1	213	ALL
NPF_2014_01	CSIRO Scientific	Jan – Feb 14	Banana	2	301	ALL
NPF_2014_02	CSIRO Scientific	Jun – Jul 14	Tiger	1	214	ALL
NPF_2015_01	CSIRO Scientific	Feb 15	Banana	2	305	ALL
NPF_2016_01	CSIRO Scientific	Feb 16	Banana	2	305	ALL
NPF_2016_02	CSIRO Scientific	Jul 16	Tiger	1	214	ALL
NPF_2017_01	CSIRO Scientific	Jan – Feb 17	Banana	2	307	ALL
NPF_2018_01	CSIRO Scientific	Feb 18	Banana	2	309	ALL
NPF_2018_02	CSIRO Scientific	Jun – Jul 18	Tiger	1	213	ALL
NPF_2019_01	CSIRO Scientific	Feb – Mar 19	Banana	2	308	ALL
CSIRO Scientific Research and Observer Data Sets						
SE Gulf Tropical Prawn	CSIRO Scientific	Apr 76 – Mar 79	–	–	3907	SS
Tropical Fish Ecology	CSIRO Scientific	Nov – Dec 90; Nov – Dec 91; Jan – Feb 93	–	–	518	ALL
Effects of Trawling	CSIRO Scientific	Aug – Nov 93; Mar – Nov 94; Feb – Mar 95; Oct – Nov 95; Feb – Mar 05	–	–	1049	ALL

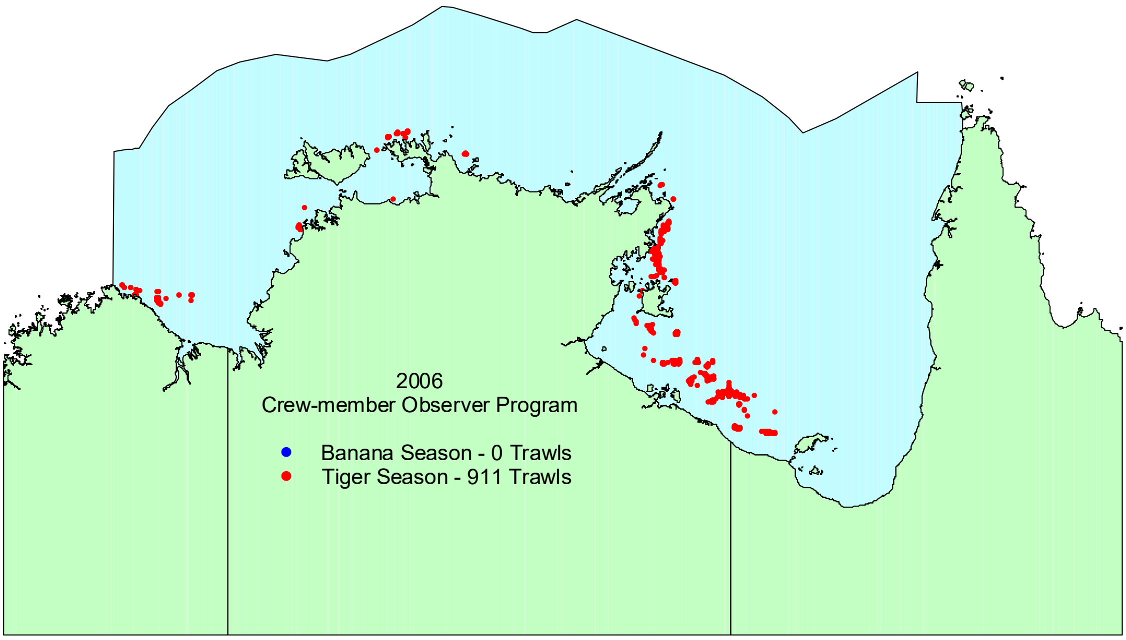
Tropical Prawn Ecology	CSIRO Scientific	Jun 95	–	–	39	ALL
TED and BRD Design	CSIRO Scientific	Sep 96; May – Jun 97; Sep – Oct 97; Jun 98	–	–	225	ALL
TED and BRD Design	CMO	Aug – Oct 96; Aug – Oct 97; Mar 98	–	–	483	TL/SF/SS
Bycatch Sustainability	CSIRO Scientific	Feb – Mar 97; Oct – Nov 97; Sep – Oct 98	–	–	1144	ALL
Juvenile *Lutjanus* Survey	CSIRO Scientific	May 00; May 01; Jun 02	–	–	118	ALL
Total Bycatch Assessment	CSIRO Scientific	Aug – Nov 01	–	–	1636	TL/SF/SS
Bycatch Monitoring	CSIRO Scientific	Sep 03; Apr 04; Apr 05	–	–	148	TL/SF/SS
Bureau of Rural Science	BRS Scientific	Nov 90; Sep 96; Feb–Oct 97; Aug – Nov 98; Apr – Nov 99; Apr – Nov 00; Apr – Oct	–	–	7254	TL/SF/SS

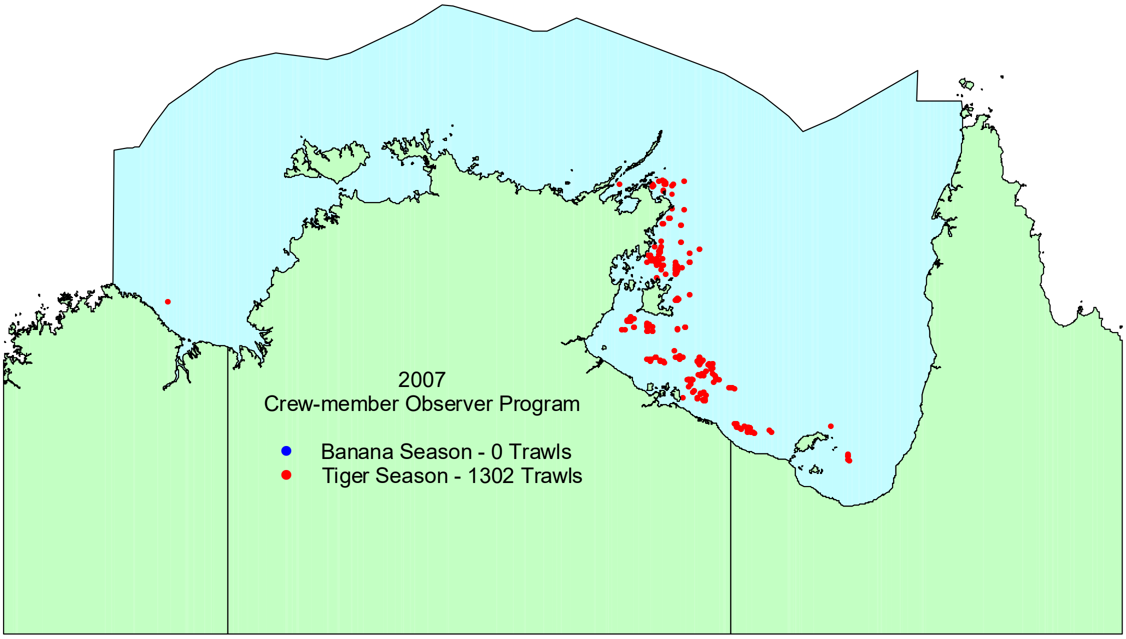
Figure 1: Yearly map series of the trawl sites recorded for the crew-member observer program from 2003 to 2019 in the NPF.

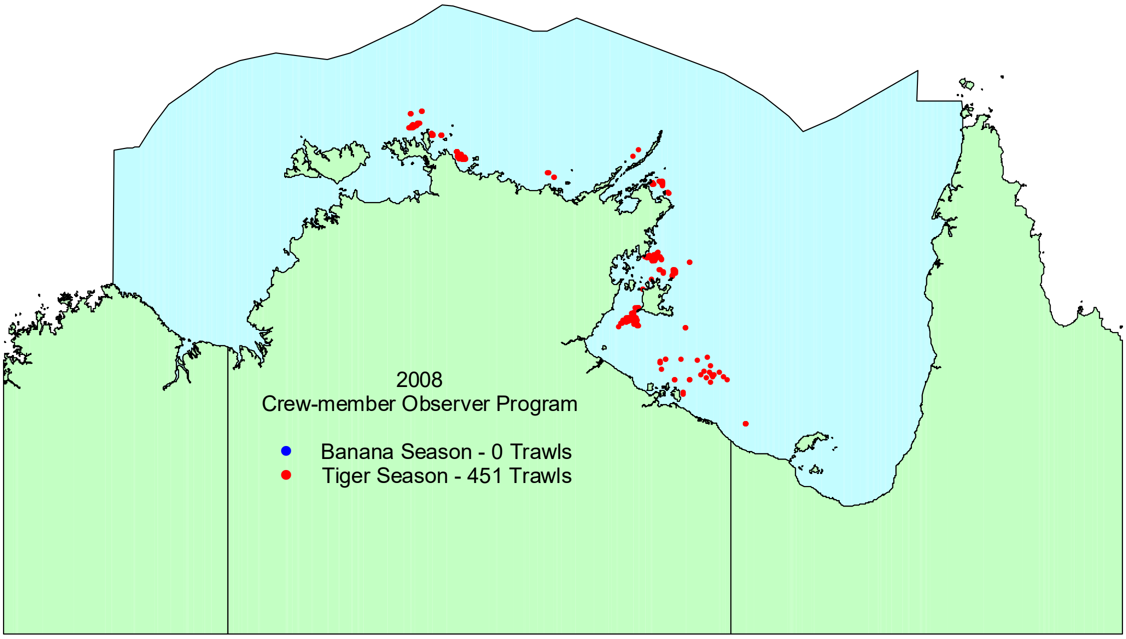


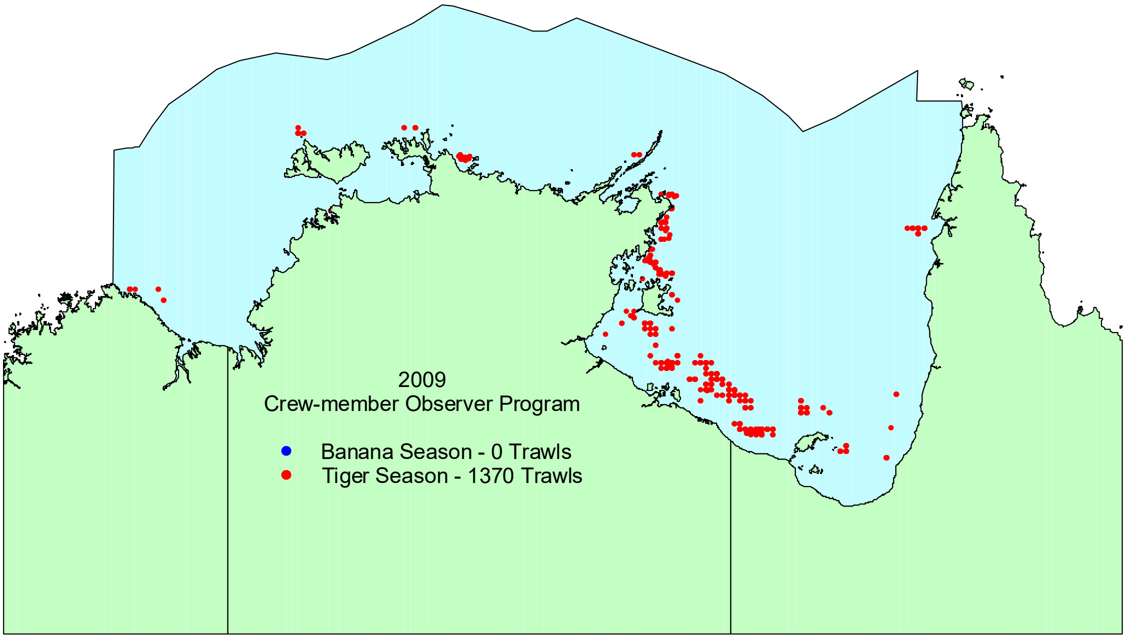


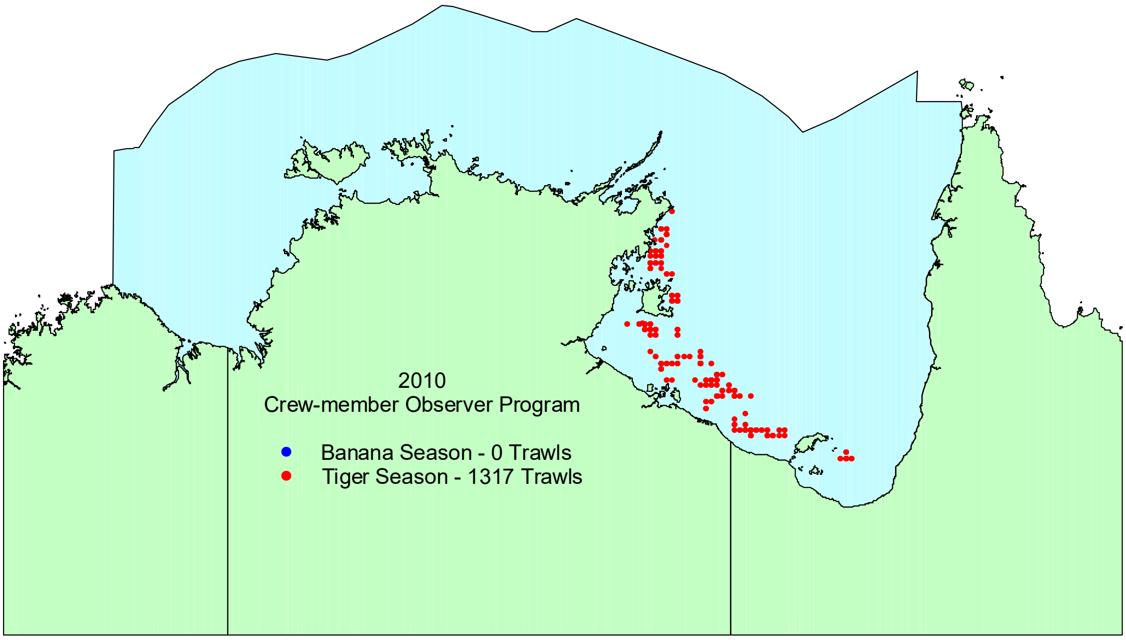

2005
Crew-member Observer Program
Banana Season - 0 Trawls
Tiger Season - 1317 Trawls

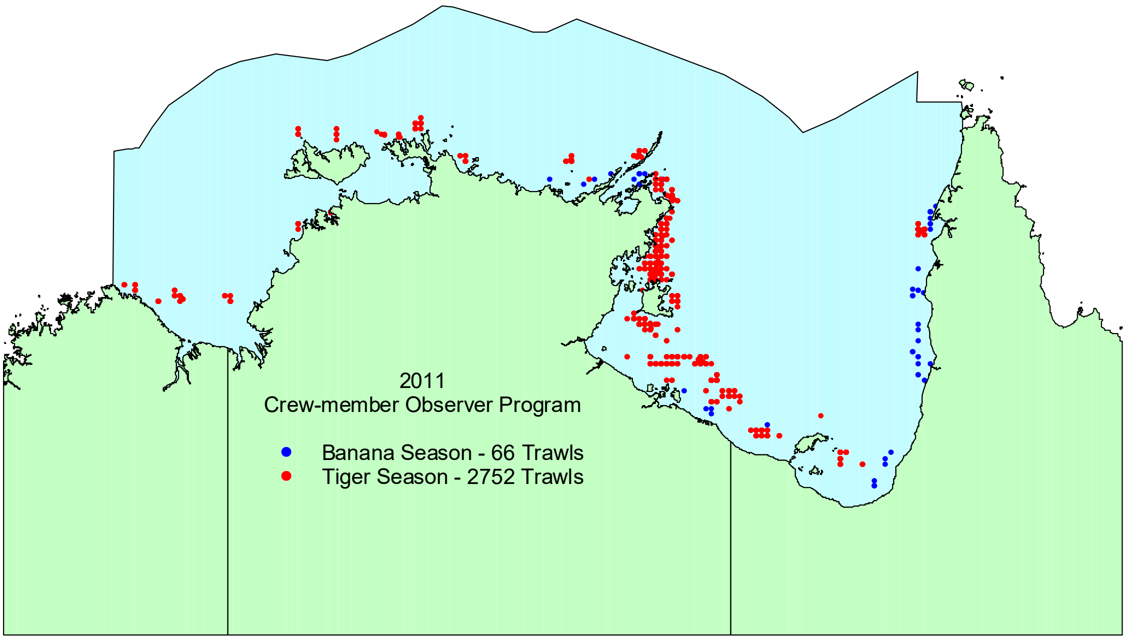

2006
Crew-member Observer Program
Banana Season - 0 Trawls
Tiger Season - 911 Trawls

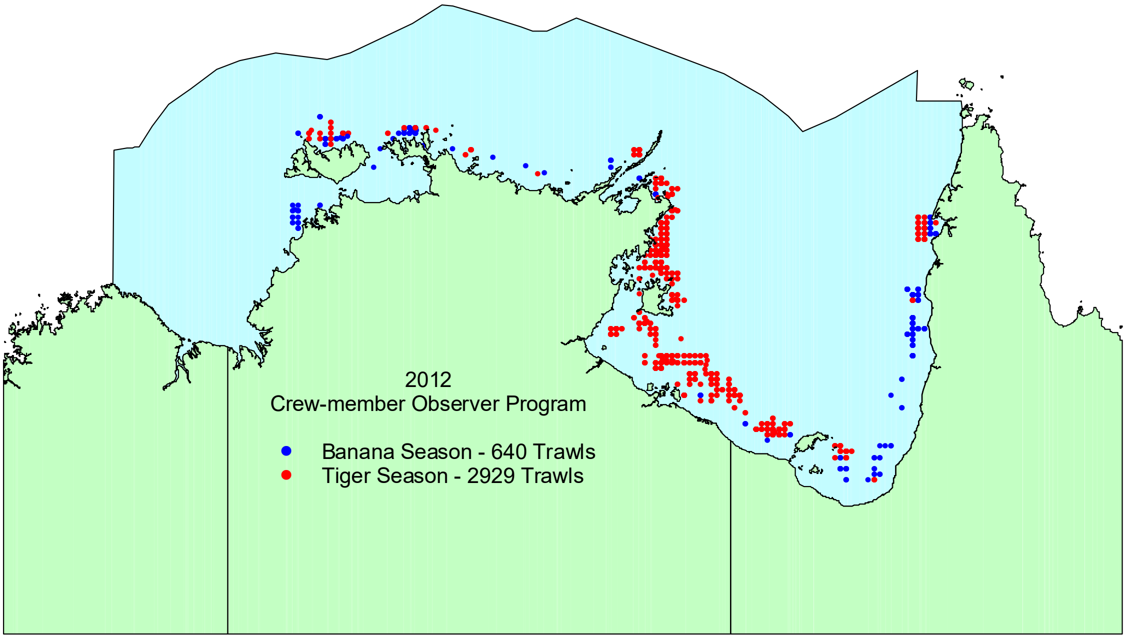

2007
Crew-member Observer Program
Banana Season - 0 Trawls
Tiger Season - 1302 Trawls

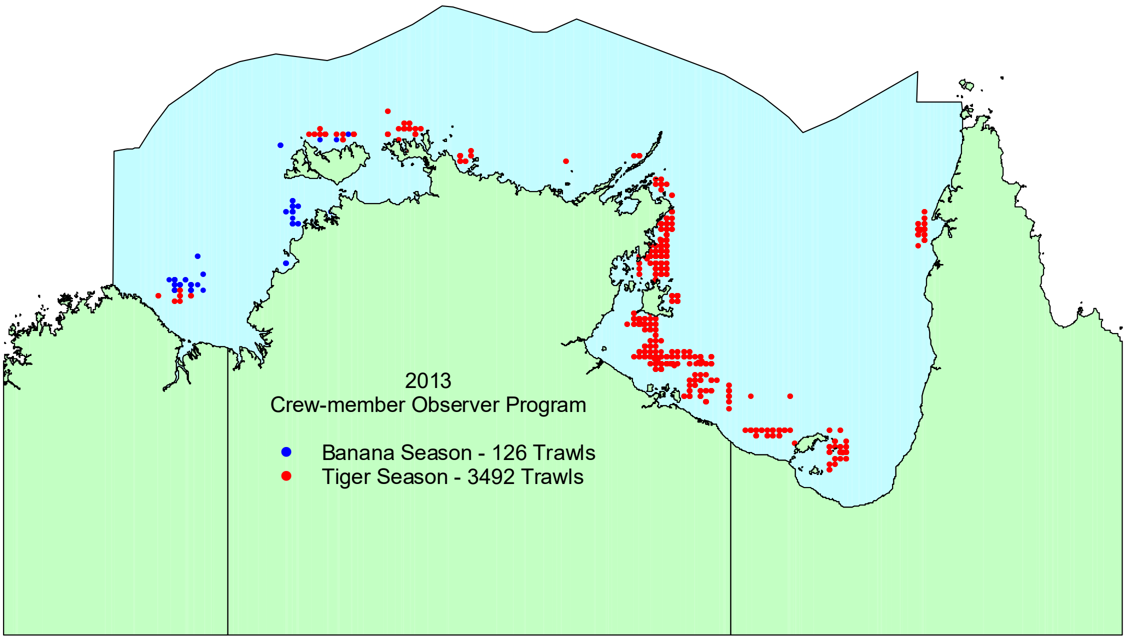

2008
Crew-member Observer Program
Banana Season - 0 Trawls
Tiger Season - 451 Trawls

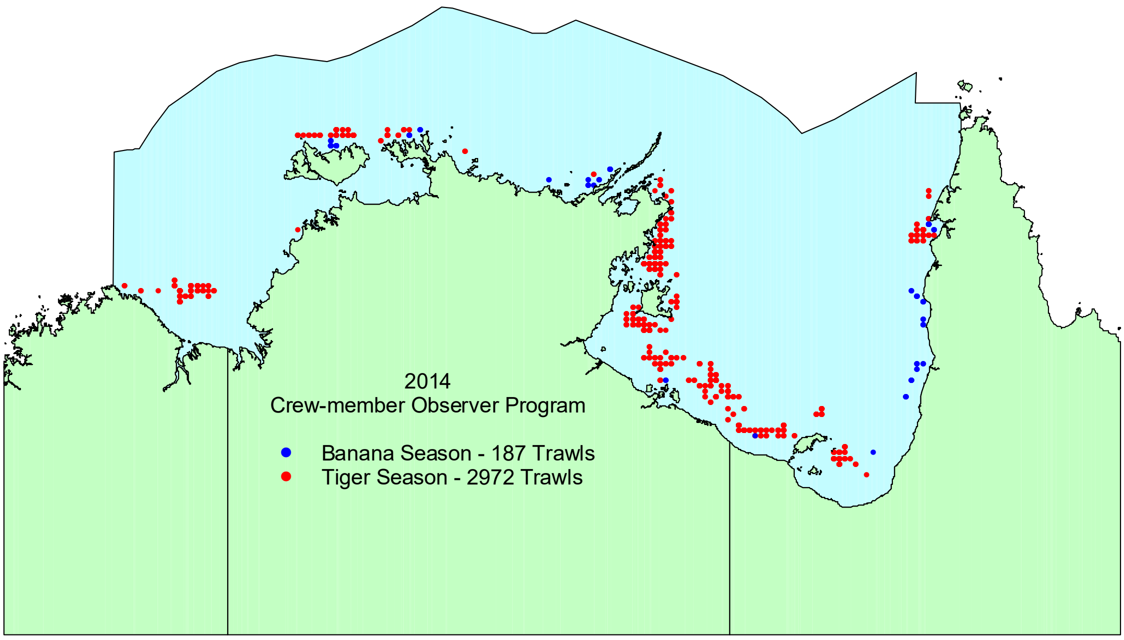

2009
Crew-member Observer Program
Banana Season - 0 Trawls
Tiger Season - 1370 Trawls

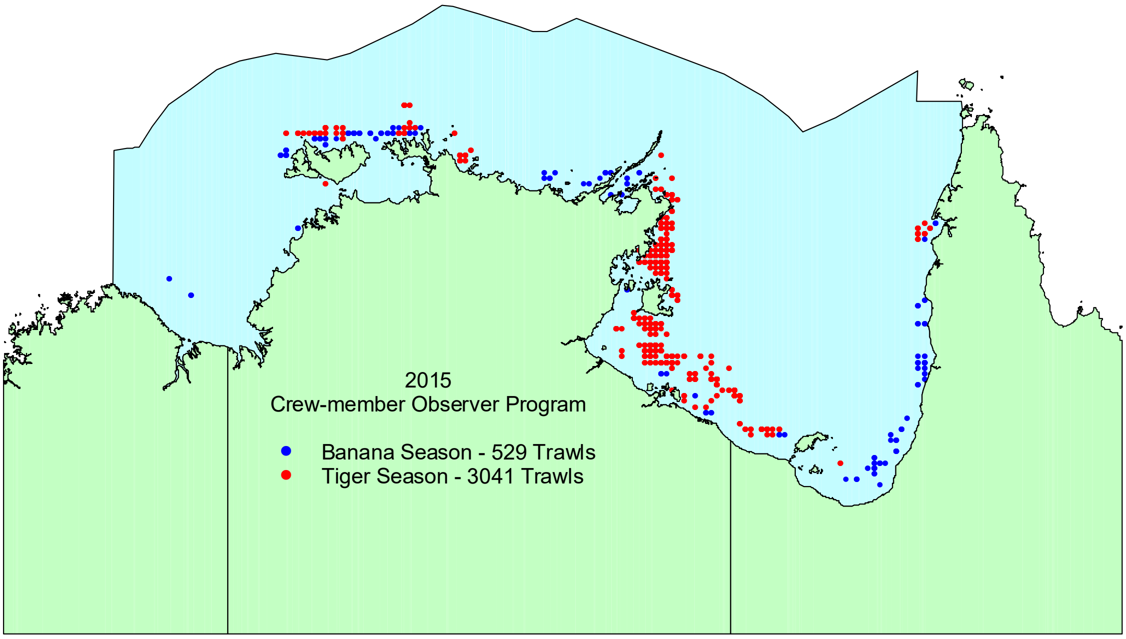

2010
Crew-member Observer Program
Banana Season - 0 Trawls
Tiger Season - 1317 Trawls

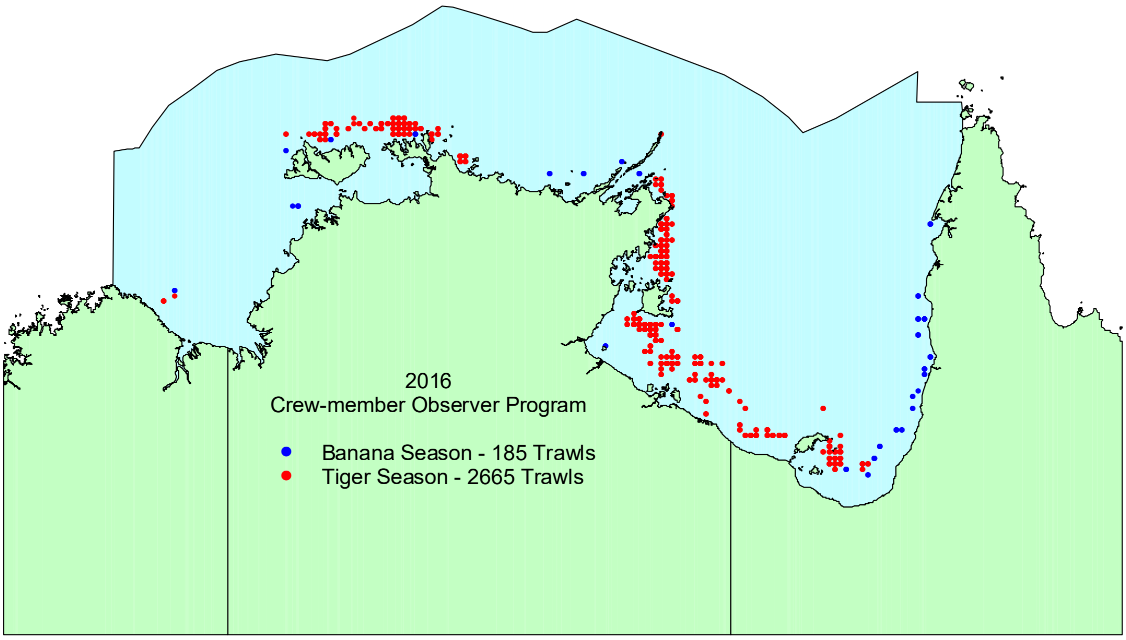

2011
Crew-member Observer Program
Banana Season - 66 Trawls
Tiger Season - 2752 Trawls

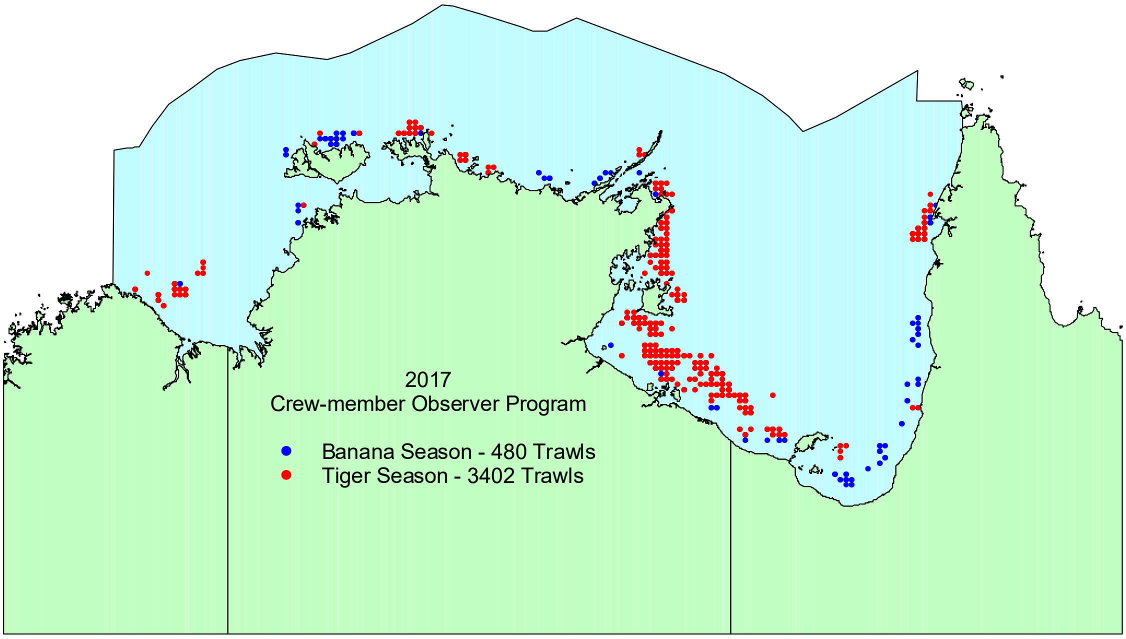

2012
Crew-member Observer Program
Banana Season - 640 Trawls
Tiger Season - 2929 Trawls

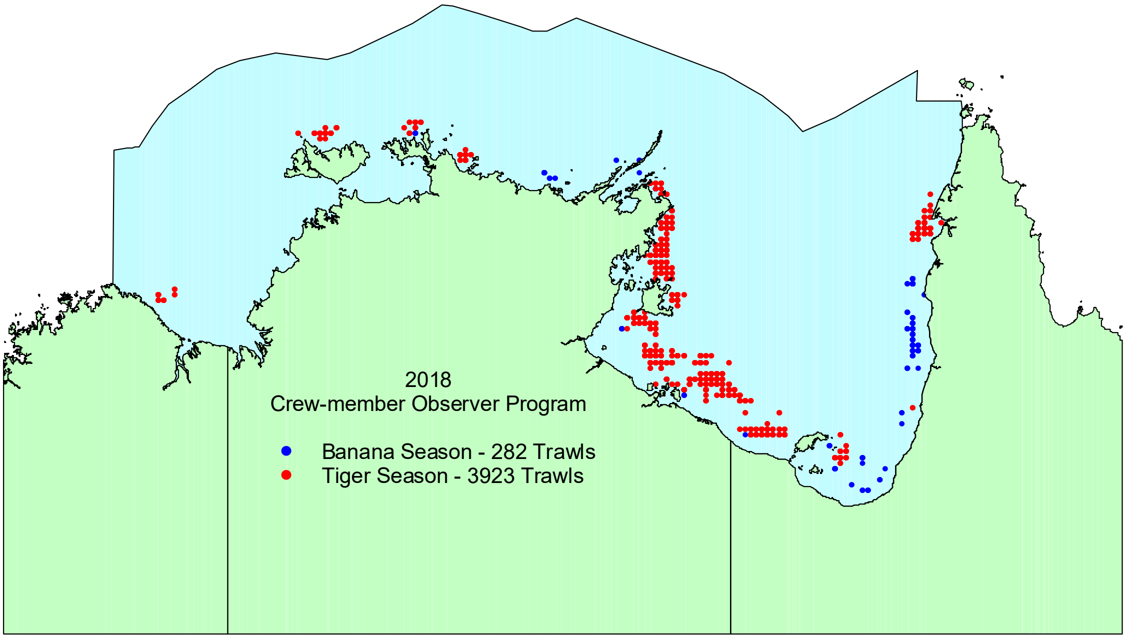

2013
Crew-member Observer Program
Banana Season - 126 Trawls
Tiger Season - 3492 Trawls


2014
Crew-member Observer Program
Banana Season - 187 Trawls
Tiger Season - 2972 Trawls


2015
Crew-member Observer Program
Banana Season - 529 Trawls
Tiger Season - 3041 Trawls


2016
Crew-member Observer Program
Banana Season - 185 Trawls
Tiger Season - 2665 Trawls


2017
Crew-member Observer Program
Banana Season - 480 Trawls
Tiger Season - 3402 Trawls


2018
Crew-member Observer Program
Banana Season - 282 Trawls
Tiger Season - 3923 Trawls

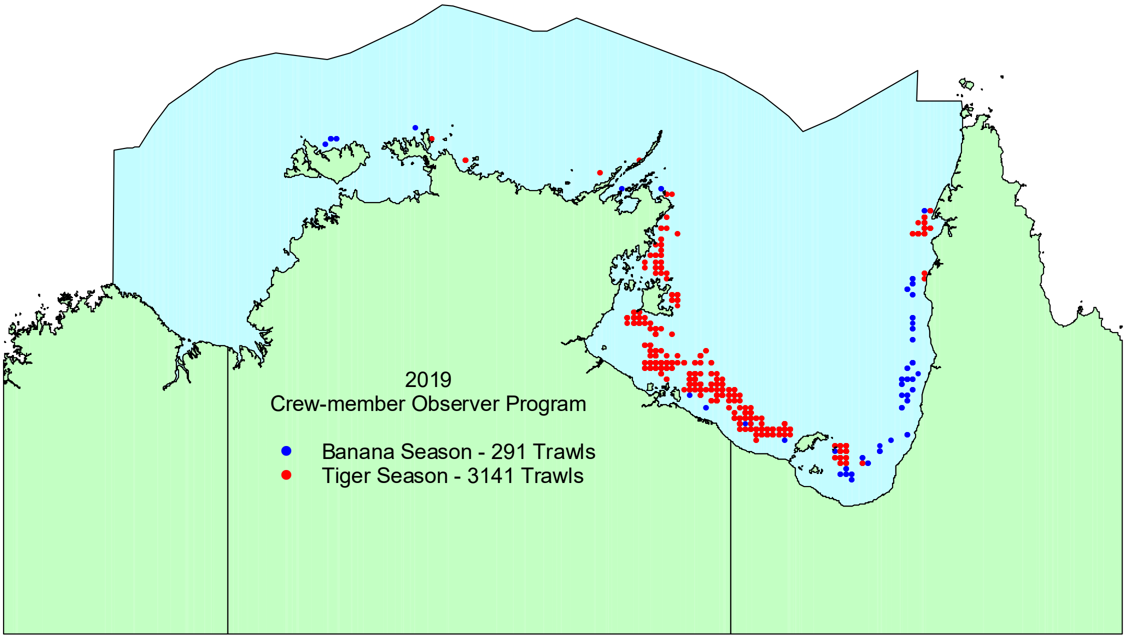
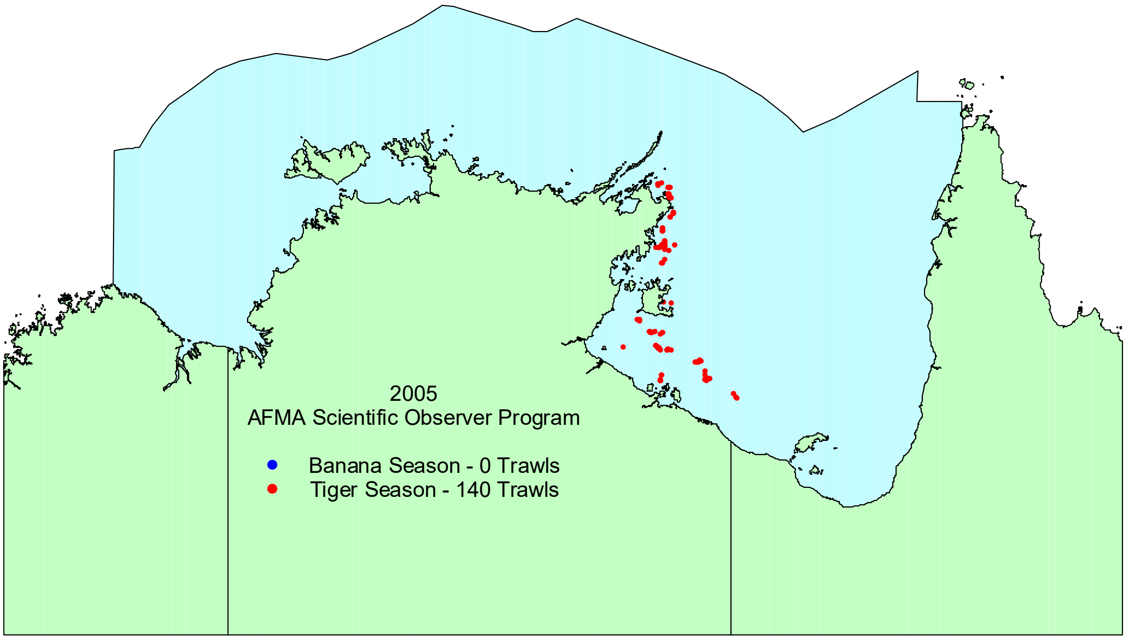
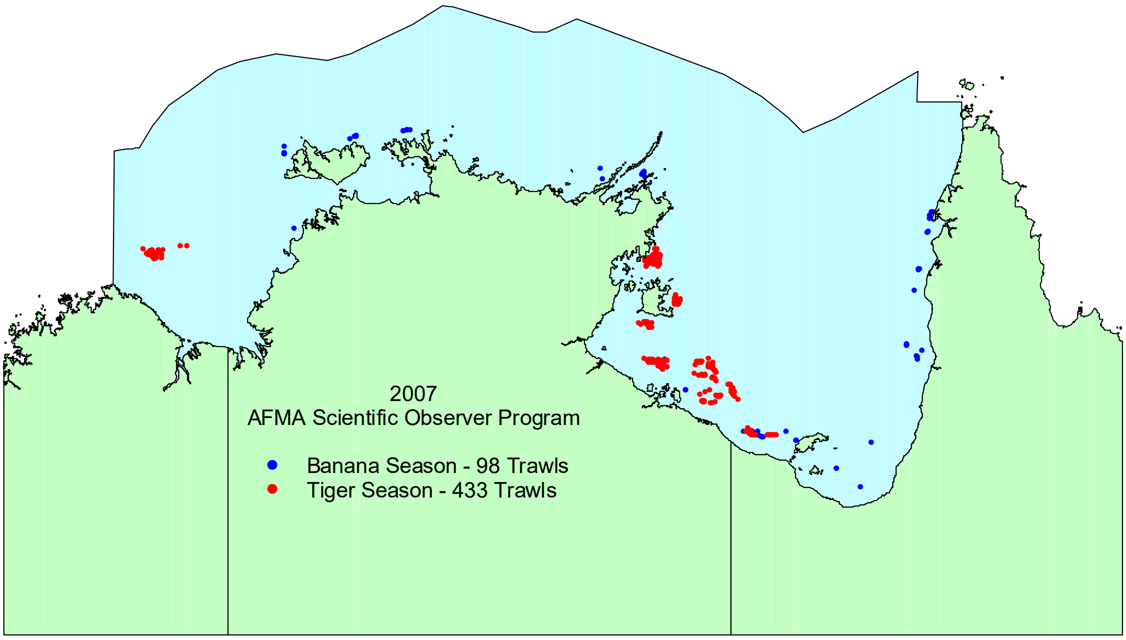
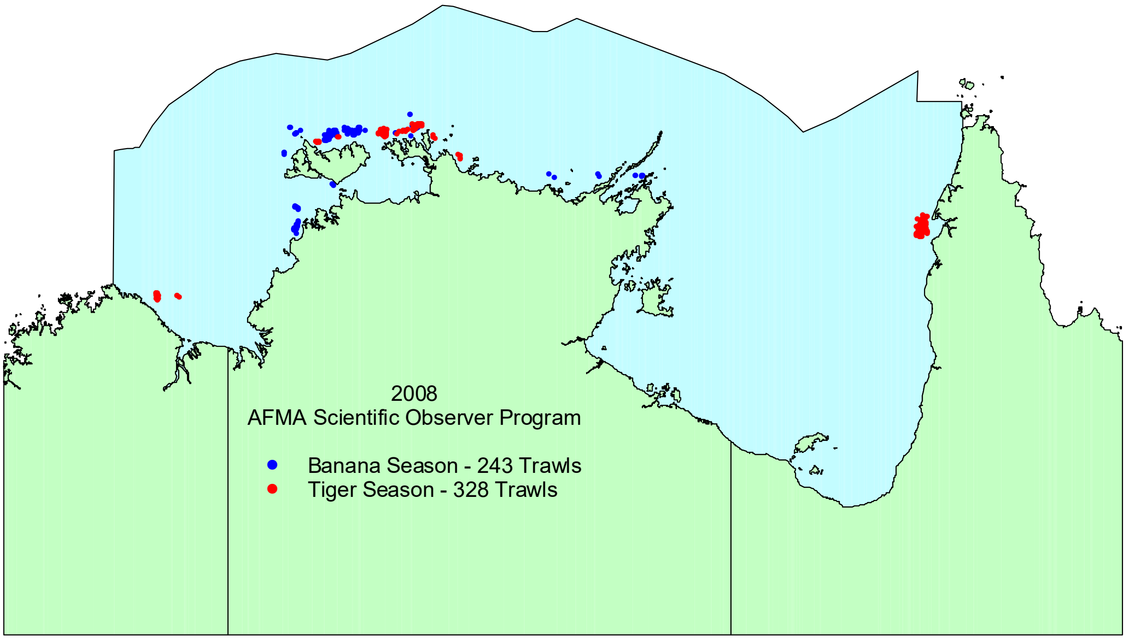
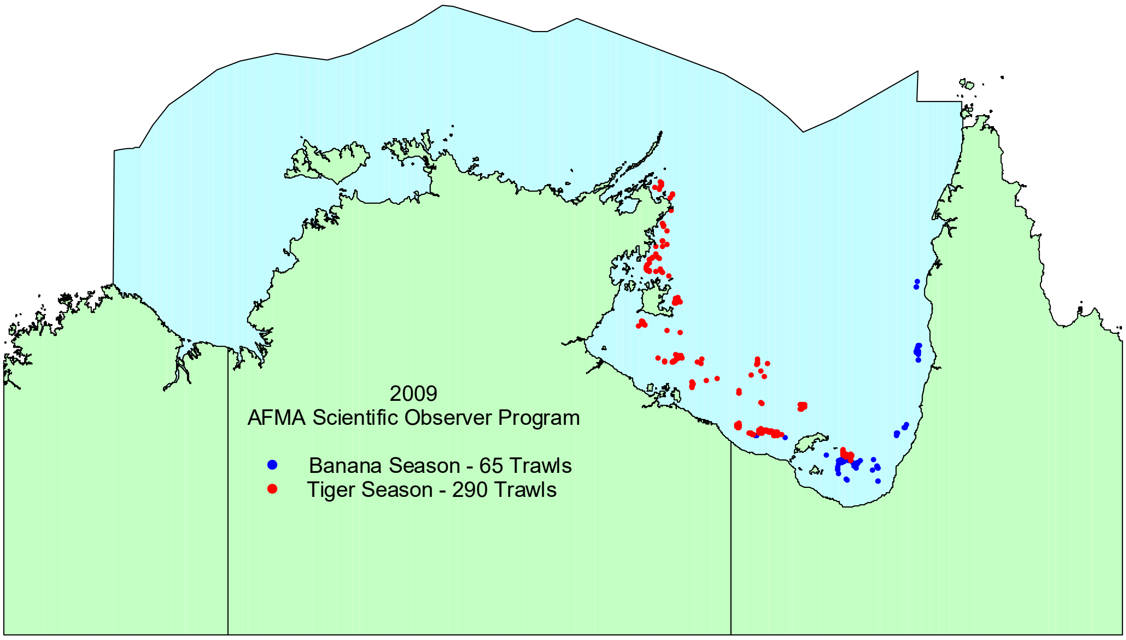

2019
Crew-member Observer Program
Banana Season - 291 Trawls
Tiger Season - 3141 Trawls

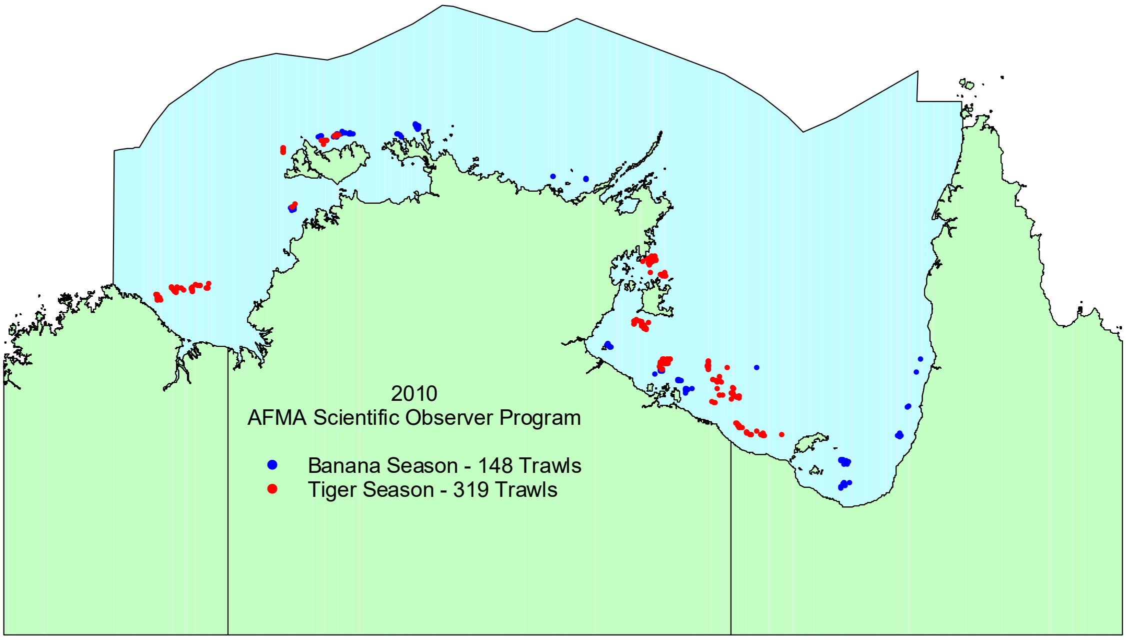
Figure 2: Yearly map series of the trawl sites recorded by AFMA scientific observers onboard commercial vessels from 2005 to 2019 in the NPF.

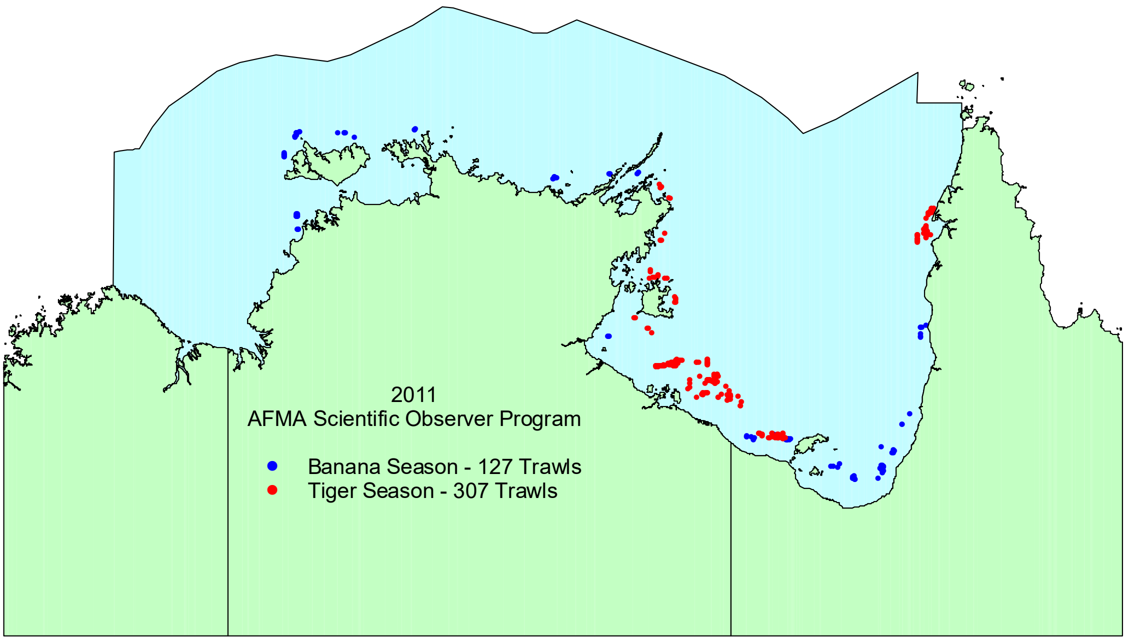


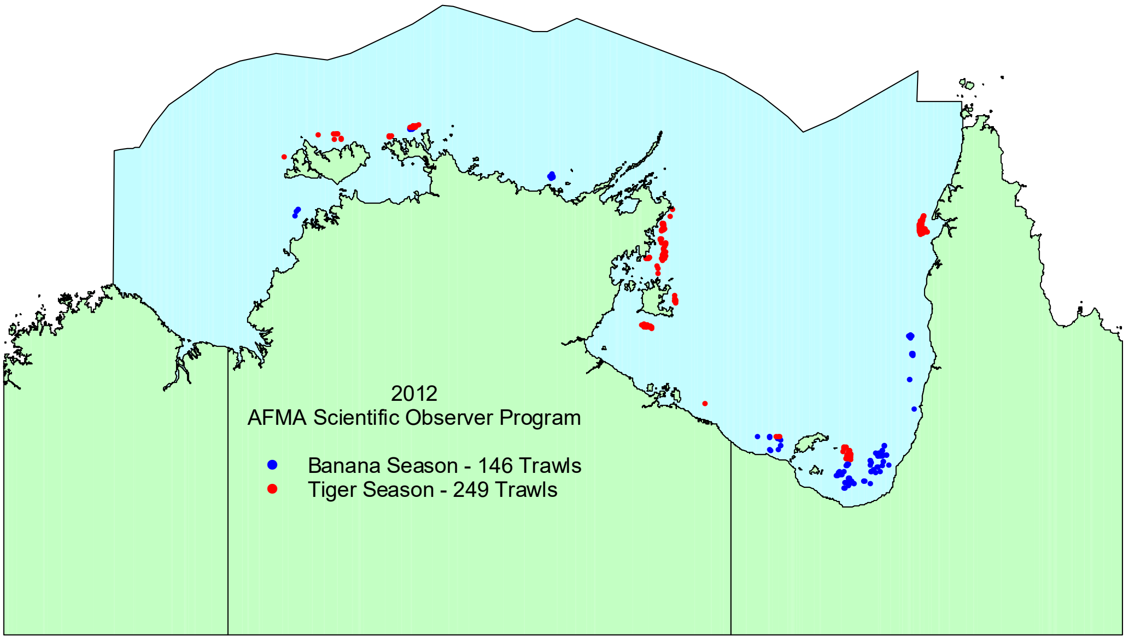


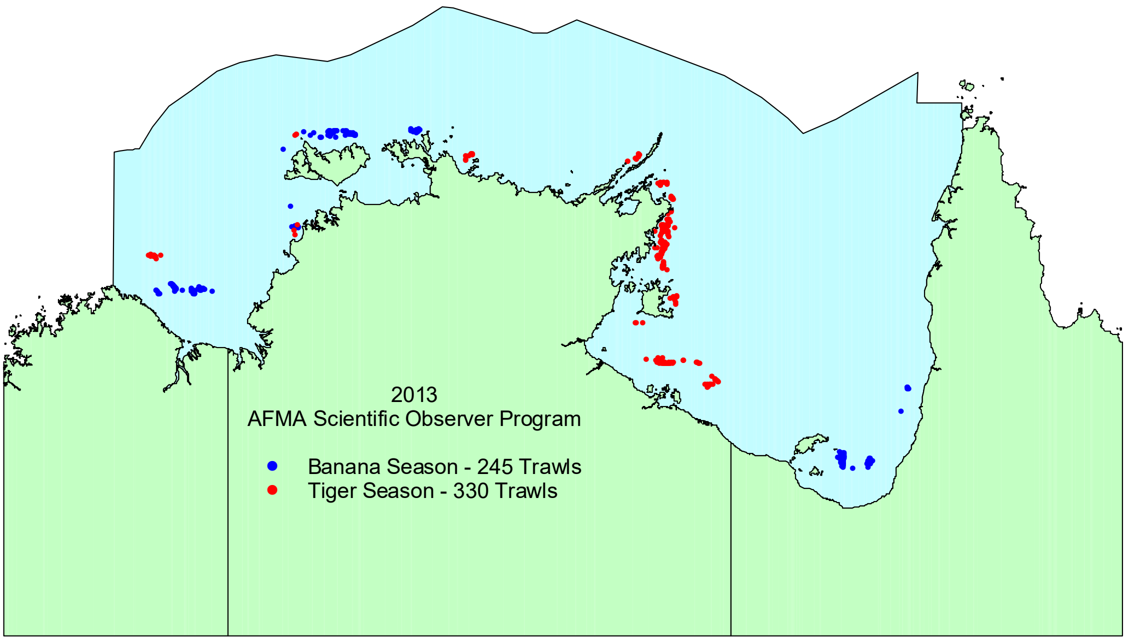

2008
AFMA Scientific Observer Program
Banana Season - 243 Trawls
Tiger Season - 328 Trawls

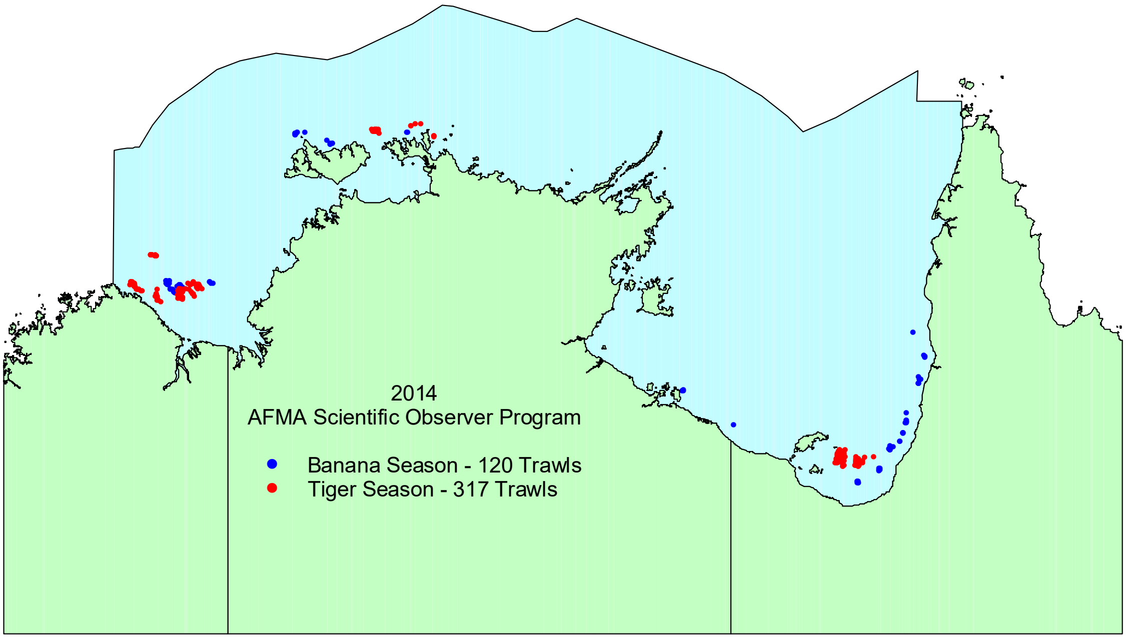

2009
AFMA Scientific Observer Program
Banana Season - 65 Trawls
Tiger Season - 290 Trawls

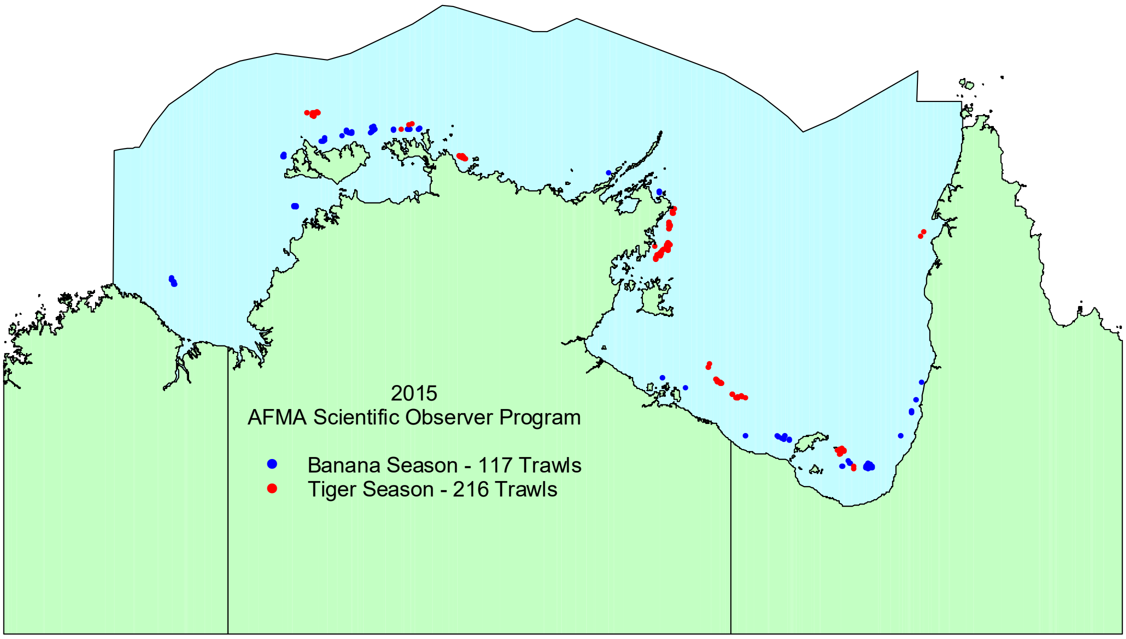

2010
AFMA Scientific Observer Program
Banana Season - 148 Trawls
Tiger Season - 319 Trawls

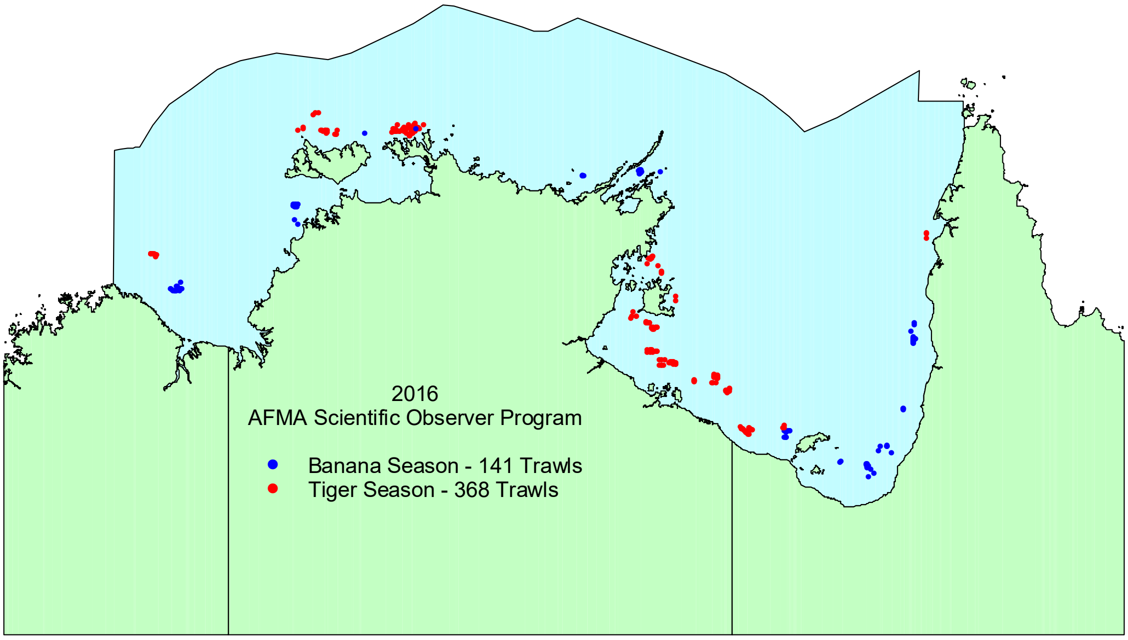

2011
AFMA Scientific Observer Program
Banana Season - 127 Trawls
Tiger Season - 307 Trawls

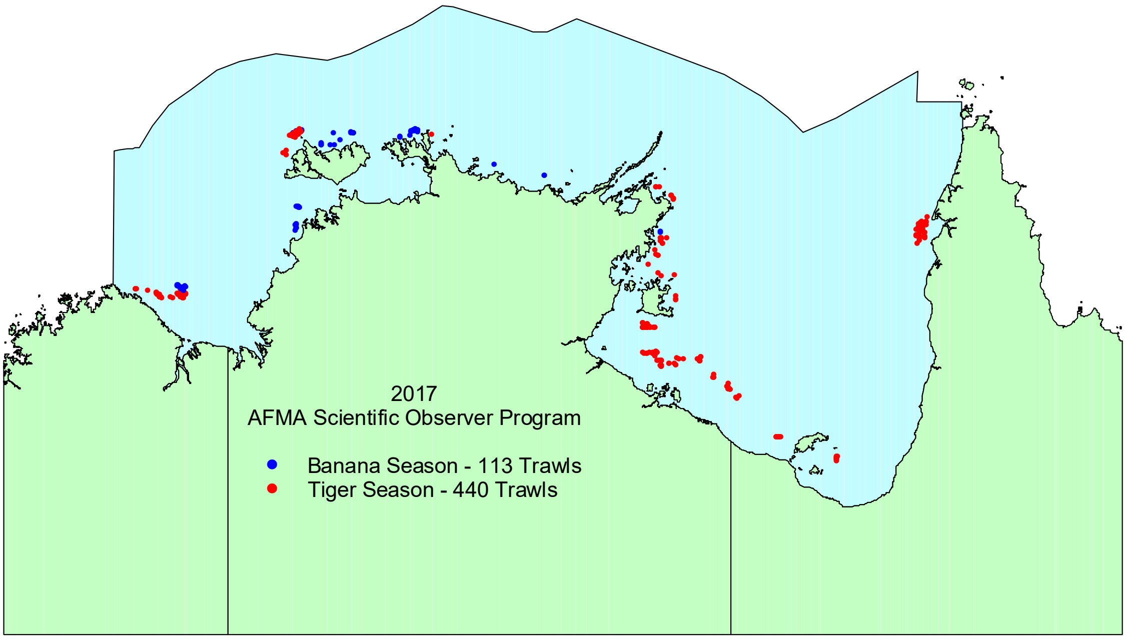

2012
AFMA Scientific Observer Program
Banana Season - 146 Trawls
Tiger Season - 249 Trawls

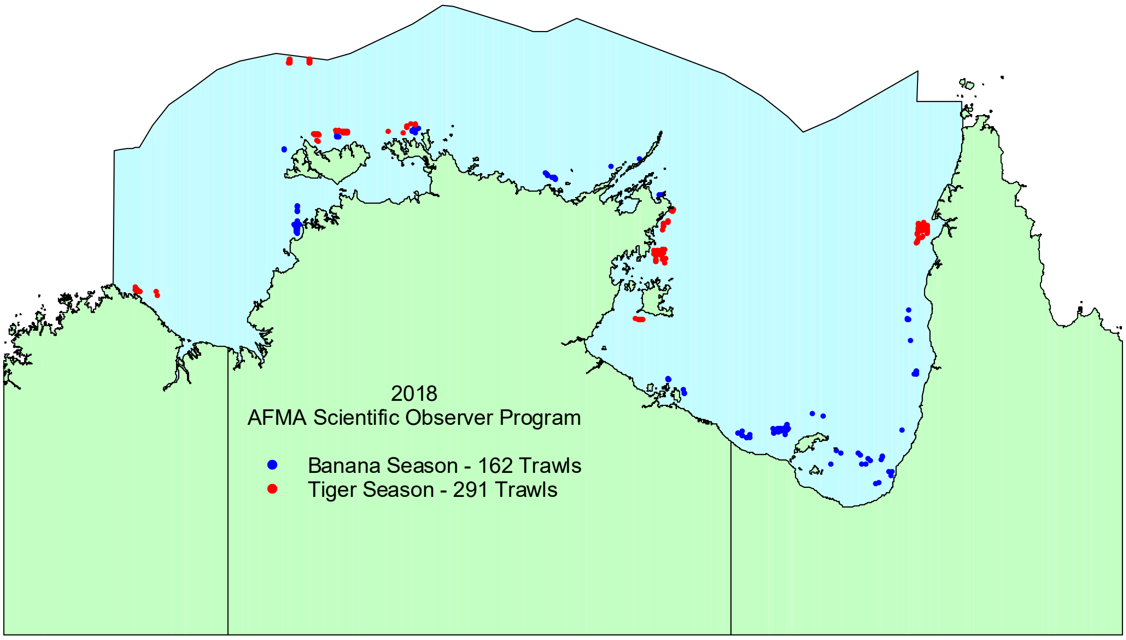

2013
AFMA Scientific Observer Program
Banana Season - 245 Trawls
Tiger Season - 330 Trawls


2014
AFMA Scientific Observer Program
Banana Season - 120 Trawls
Tiger Season - 317 Trawls


2015
AFMA Scientific Observer Program
Banana Season - 117 Trawls
Tiger Season - 216 Trawls


2016
AFMA Scientific Observer Program
Banana Season - 141 Trawls
Tiger Season - 368 Trawls


2017
AFMA Scientific Observer Program
Banana Season - 113 Trawls
Tiger Season - 440 Trawls


2018
AFMA Scientific Observer Program
Banana Season - 162 Trawls
Tiger Season - 291 Trawls

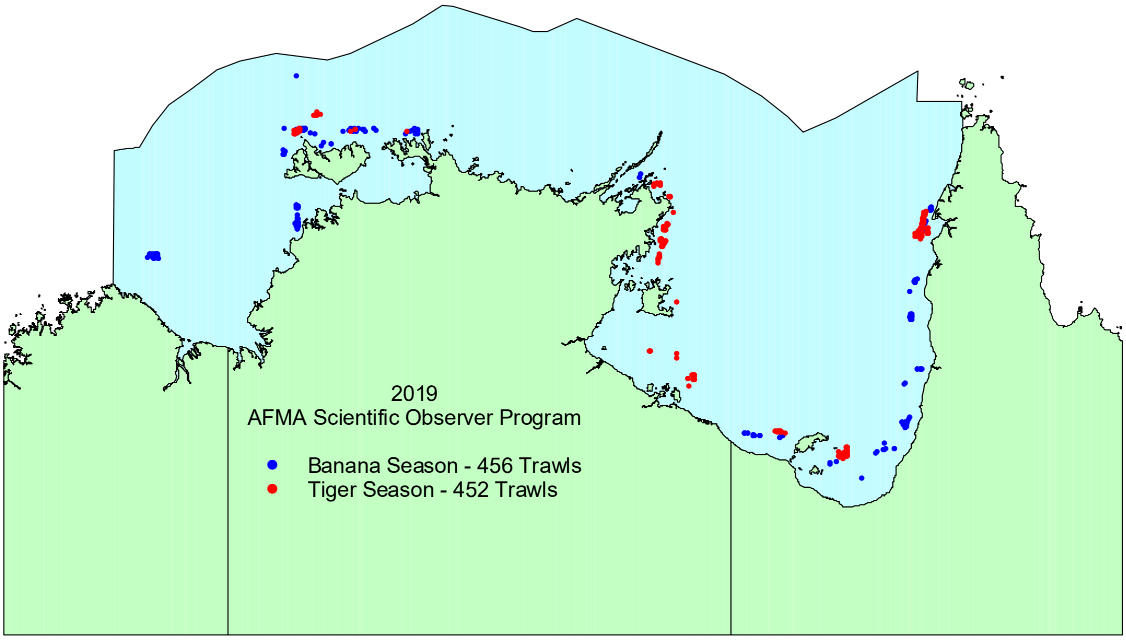
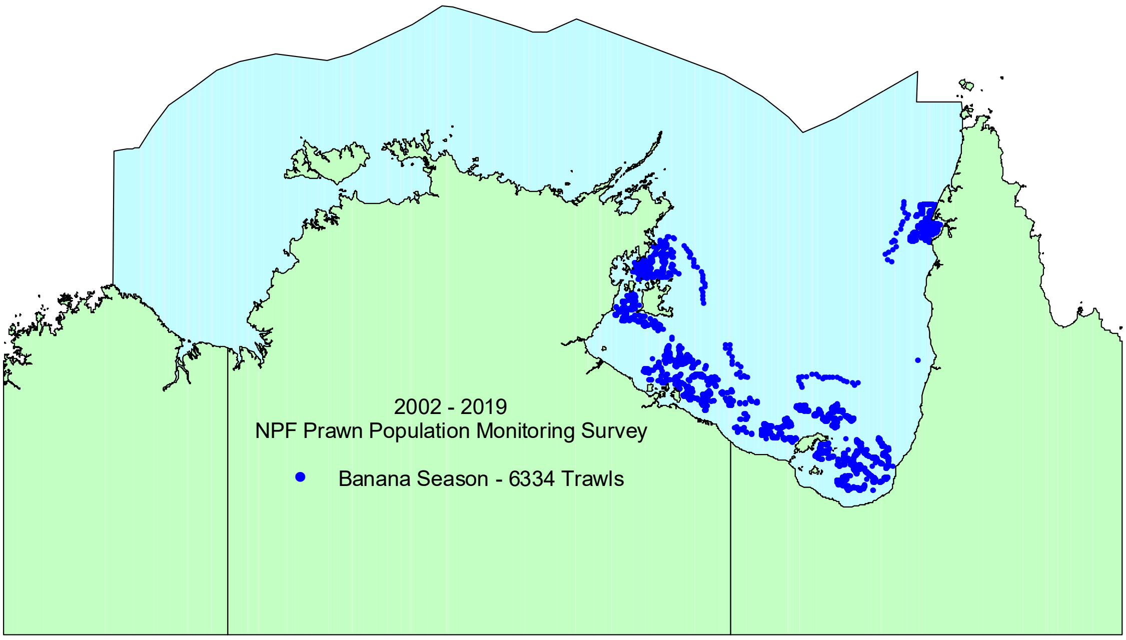

2019
AFMA Scientific Observer Program
Banana Season - 456 Trawls
Tiger Season - 452 Trawls

Figure 3: Map of the trawl sites completed during the NPF prawn population monitoring surveys from 2002 to 2019 in the NPF.



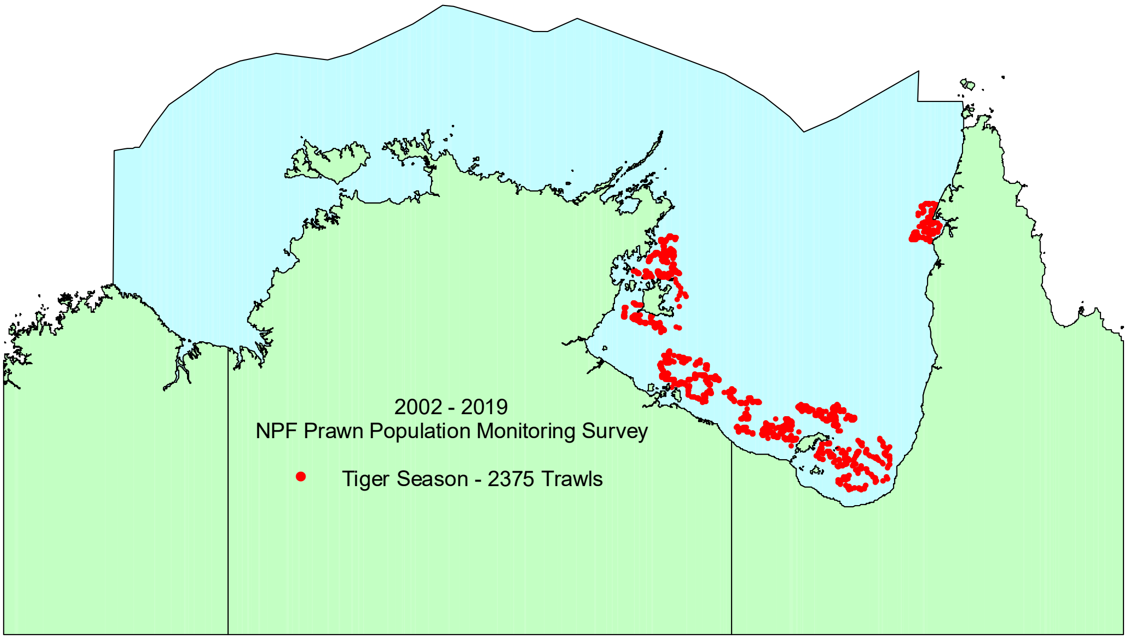
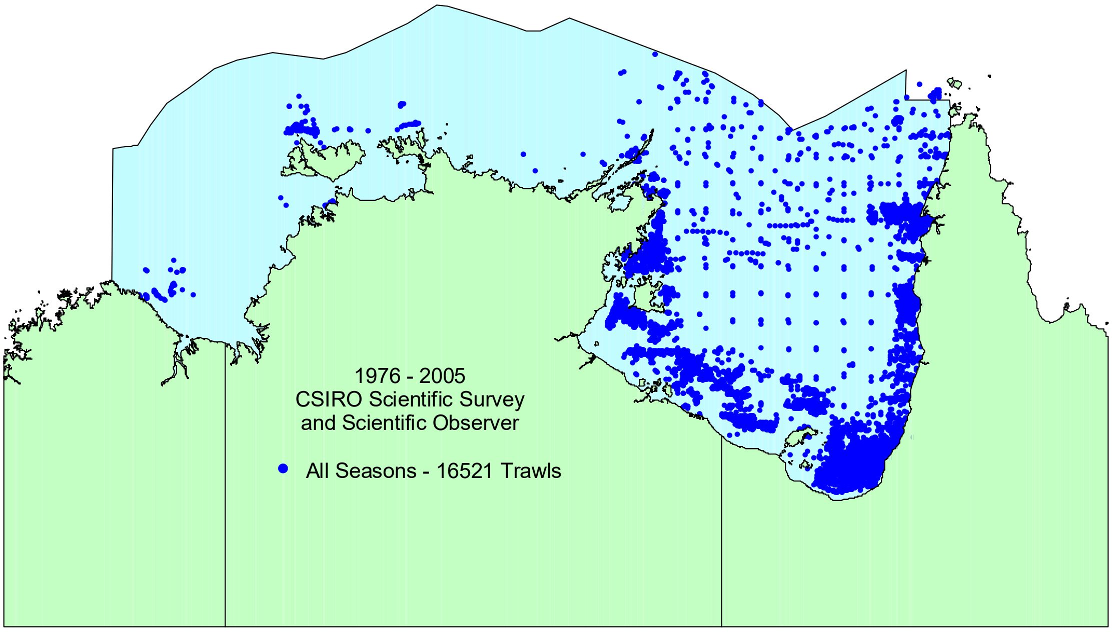


Figure 4: Map of all trawl sites completed during CSIRO scientific research and observer surveys from 1976 to 2005 in the NPF.



5.2 Data analysis approach

5.2.1 Background

During the first project 'Assessing the sustainability of the NPF bycatch from annual monitoring data: 2008' project (R2008/826), catch per unit effort data on each of the TEP and 'at risk' bycatch species was presented at two internal workshops (23rd October 2008 and 20th May 2009) at CSIRO Marine and Atmospheric Research, Cleveland. These workshops were designed to examine the available data and decide on the best analytical approach to use in the Bycatch Sustainability Assessment for each species (Appendix B; C).

The first workshop was designed to present the data that were available and have discussions regarding possible approaches to data analysis. Following this workshop, CSIRO Statistical Modelling staff were supplied with a copy of the data set and then given time to consider alternate approaches before the second workshop. This second workshop was planned to present and discuss possible data analysis approaches which were dependent on the amount and length of time series of data available for each of the 'at risk' and TEP groups. The most appropriate statistical analyses were agreed upon for the Bycatch Sustainability Assessment. However, it was also agreed that the rarer TEP and 'at risk' bycatch species, did not have sufficient data to apply standard analytical methods. The purpose of the analytical approach was to determine the trends in catch rates of TEP and 'at risk' bycatch species in the NPF.

As there were compatibility issues with the data – differing collection methods, fishing gears used and differing spatial and temporal scales – initial analysis was required to determine the potential use of each source of data, rather than immediately pooling the data. There were issues with the accuracy and reliability of data collected in the crew-member observer program for a number of years up until 2008. Although comparison between the three individual data sets did not reveal any major discrepancies between the overall catch rates of species aggregated to the family level, on a species level, there were large discrepancies in catch rates recorded between the crew-member observer program, AFMA scientific observer program and the NPF prawn population monitoring surveys. The crew-member participation was low resulting in inadequate catch records for many of the TEP and 'at risk' bycatch species and many of these records were not accompanied by photographs for later identification purposes so a much greater occurrence of records of unidentified individuals were assigned to the family groups. This means that calculations of absolute estimates of bycatch at the species level based on all data sets combined would be an underestimate.

As a consequence, in the first 2009 Bycatch Sustainability Assessment, the crew-member observer data set was not combined with the AFMA scientific observer and NPF prawn population monitoring survey data sets for catch rate trend analysis. In the 2009 assessment, it was also recommended that greater effort be required in recording catches to species via photographic records and greater crew-member participants to boost the spatial and temporal coverage of the program to allow sustainability assessments for more species in future assessments (see Fry et al. 2009).

In the following 2015 Bycatch Sustainability Assessment, the three data sets; crew-member observer, AFMA scientific observer and NPF prawn population monitoring data sets, were again initially assessed separately to determine their potential for use in the catch rate trend analysis. With the continual developments and improvements of the crew-member observer program over the years, this data set was shown to be comparable to the AFMA scientific observer and NPF prawn population monitoring data and therefore used for catch trend analysis.

For the 2018 Bycatch Sustainability Assessment, the three data sets were assessed for use in a pooled data set for catch trend analysis. There are 10 statistical 'Regions' for banana prawns in the NPF (see Dichmont et al. 2001; Figure 5). For each data set, latitude and longitude were used to assign ‘Region’ to trawl records to identify any patterns in the distribution of the TEP and ‘at risk’ bycatch species. Mean catch rate per trawl was calculated for each of the species for each ‘Region’ to determine whether the species were caught across the entire NPF or some species were solely caught in particular 'Regions'. The analyses performed on each data set are described below.

5.2.2 Crew-member observer program

This data set has been collected 'in season' from 2003 to 2019 by fishery crew members and may be unbalanced or inconsistent with respect to its spatial effort coverage (Table 2). The variables available in the data include operation number, vessel, date of trawl, latitude, longitude, depth and various gear attributes. Swept area (km^2 trawled) was derived and used throughout the analysis as a measure of effort. The crew-member observer program has had a broad effort coverage across all of the 10 ‘Regions’ of the NPF (Table 3;Table 4). About 99% of the trawls were recorded using a prawn trawl net with the remaining trawls using a try net. Approximately 1.5% of the records were missing a measurement for depth and for these records, an estimate of depth was assigned using mean depth per 6 nautical mile grids of the NPF.

For those species with sufficient data, generalized additive models (GAMs) were used to analyse the trend in catch rates through time (Wood 2017). The TEP and ‘at risk’ bycatch species data is zero-inflated; meaning that a large proportion of the trawls did not catch any of these species. The data contained more instances of zero counts than would be predicted using a standard Poisson log-linear model, which would usually be applied to count data such as these (Welsh et al. 1996). To cater for the excess zero’s the catch was modelled using a GAM with a zero-inflated Poisson distribution (ziP) using the mgcv package in R. The models contained an offset term to represent ‘Effort’, and the estimated parameters included in the final model were ‘Year’, ‘Region’ and a spline term for ‘Depth’. The ‘Year’ trend for each species was obtained by setting ‘Depth’ to the mean depth recorded (24m) and ‘Region’ to 6 (the ‘Region’ containing the most samples). Although it would have been valuable to include a ‘Month’ variable to determine any seasonal effects, this was not possible due to the limited amount of data available.

This model fitting process is different to previous reports where a separate two-stage (delta) model fitting process was used. The change has been implemented due to improved model fitting capability in R, providing a more robust model fitting approach. The overall effect on the historical trends of the bycatch species, as a result of this change in methodology, was tested and is minimal. However, it has allowed more species and years (for some species) to be added to the modelled trends.

The confidence interval around the index was calculated by taking +/- 1.96 x the estimated standard error of each estimated ‘Year’ trend term. The bootstrapping approach used to generate the uncertainty estimates in the past was not necessary as the new modelling approach is able to directly estimate the standard errors of the trend terms, largely simplifying the estimation procedure.

5.2.3 AFMA scientific observer program

This data set has also been collected 'in season' from 2005 to 2019 by AFMA scientific observers onboard NPF commercial vessels while operating during the season (Table 2). The aim of the AFMA scientific observer program is to obtain a representative coverage across the NPF both spatially and temporally. However, it may be unbalanced or inconsistent with respect to its spatial and temporal coverage. The variables available in the data include operation number, vessel, date of trawl, trawl start and end time, trawl latitude and longitude, depth and various gear attributes. Swept area (km^2 trawled) was derived and used throughout the analysis as a measure of effort.

The effort distribution for the AFMA scientific observer program between 2005 and 2019 was similar to the crew-member observer program with trawls within all ‘Regions’ with greatest effort in ‘Regions’

1, 2, 4, 6 – 8 and 10 (Table 3;Table 4). However, trawl effort per year is much lower than the crew-member observer program. This data set was used to validate the crew-member observer data set with respect to catch rates and species identifications.

As with the crew-member observer data, the same species were modelled (using the zero-inflated Poisson GAM approach outlined previously) and comparisons made with the crew-member observer analysis, to check for consistency and validation of data quality of the crew-member observer collection. As only a small percentage of TEP and ‘at risk’ bycatch species had sufficient data to model the AFMA scientific observer data, more basic summary statistics were also compared across the two data sets to gauge consistency. These statistics included the proportion of trawls where the species was not found and the maximum count of the species in each trawl. In addition, the nominal catch rates by ‘Region’ and by ‘Year’ for 2005 to 2019 were calculated and compared.

5.2.4 NPF prawn population monitoring surveys

This fishery-independent data set was consistently collected using the same methods and in the same areas and times each year (2002 – 2019) (Table 2). It is the most robust and reliable data set in terms of fishing gear consistency, data collection methods, temporal and spatial influences that may otherwise impact on the catch rates of species. Although, as with the AFMA scientific observer data set, trawl effort per year is much lower than the crew-member observer program. The variables available in the NPF prawn population monitoring data include operation number, vessel, trawl date, trawl latitude and longitude, trawl depth and vessel speed. Swept area (km^2 trawled) was derived and used throughout the analysis as a measure of effort.

The NPF prawn population monitoring data set covers a subset of the 10 ‘Regions’ and was therefore matched to the crew-member observer data set spatially at the banana prawn stock region level i.e. ‘Regions’ 4, 5, 6, 7, 8 and 10, as closely as possible to the same spatial coverage (Table 3;Table 4). Statistical stock ‘Regions’ 1 to 3 and ‘Region’ 9 were not included in the tabulation as four or less trawl records were present for these 'Regions' across the 18 years of data collection. This data set was then used to validate the crew-member observer data set with respect to catch rates and species identifications. It should be noted that this data is collected 'out of fishing season', but it is not anticipated that this should have a large effect on the species under consideration.

Catch rates were modelled (using the zero-inflated Poisson GAM approach outlined previously) and comparisons made for the same species modelled using the crew-member observer data analysis, to check for consistency and validation of data quality of the crew-member observer data. As only a percentage of TEP and ‘at risk’ bycatch species had sufficient data to model the NPF prawn population monitoring data, more basic summary statistics were also compared across the two data sets to gauge consistency. These statistics included the proportion of trawls where the species was not found and the maximum count of the species in each trawl. In addition, the nominal catch rates by ‘Region’ and by ‘Year’ for ‘Regions’ 4, 5, 6, 7, 8 and 10 for 2003 to 2019 were calculated and compared.

5.2.5 CSIRO scientific research and observer surveys

As most of this data was collected ‘out of season’ and generally not spatially comparable with the current NPF commercial fishery effort distribution, this data set was not used in modelling trends in catch rates for the TEP and ‘at risk’ bycatch species. Furthermore, the majority of the data was collected before the crew-member observer, AFMA scientific observer and NPF prawn population monitoring programs began (pre-2002). This data set was only used in species distribution mapping and raw catch rate descriptions in Section 6 (Table 2).

Table 3: Summary of total trawl number for each data source across the 10 stock 'Regions' of the NPF between 1976 and 2019.

Trawls	**Year**	**Region 1**	**Region 2**	**Region 3**	**Region 4**	**Region 5**	**Region 6**	**Region 7**	**Region 8**	**Region 9**	**Region 10**	***Total Trawls***
Crew-member Observer	2003	258	95	0	534	485	1485	461	59	0	0	3377
	2004	102	155	22	723	299	959	552	10	66	32	2920
	2005	210	106	48	161	53	365	374	0	0	0	1317
	2006	129	48	9	199	34	182	309	1	0	0	911
	2007	4	0	62	386	113	524	187	26	0	0	1302
	2008	0	241	35	75	53	35	12	0	0	0	451
	2009	27	62	14	150	68	482	321	177	6	63	1370
	2010	0	0	0	317	172	379	362	87	0	0	1317
	2011	159	172	327	906	307	455	198	85	33	176	2818
	2012	26	213	226	1087	307	585	411	136	258	310	3559
	2013	141	227	67	1475	299	789	201	206	0	213	3618
	2014	314	271	51	721	356	322	376	291	60	397	3159
	2015	19	577	148	1207	371	733	248	84	76	107	3570
	2016	21	686	75	692	416	364	206	327	55	8	2850
	2017	192	384	126	601	626	857	583	84	47	382	3882
	2018	42	248	92	1112	415	863	612	143	150	528	4205
	2019	0	38	22	204	243	1173	1002	322	133	295	3432
	Total	***1644***	***3523***	***1324***	***10550***	***4617***	***10552***	***6415***	***2038***	***884***	***2511***	***44058***
AFMA Scientific Observer	2005	0	0	21	53	20	43	3	0	0	0	140
	2007	75	19	7	153	39	106	108	4	11	9	531
	2008	78	304	10	0	0	0	0	0	0	179	571
	2009	0	0	9	66	15	46	122	78	19	0	355
	2010	72	98	5	43	44	103	65	33	4	0	467
	2011	17	30	19	19	9	149	84	37	8	62	434
	2012	5	41	9	75	22	1	16	137	16	73	395
	2013	140	83	27	152	3	80	0	83	7	0	575
	2014	173	60	0	0	0	3	1	183	17	0	437
	2015	17	112	4	95	0	24	28	45	6	2	333
	2016	125	114	22	13	30	104	52	22	25	3	510
	2017	76	271	12	22	37	59	20	8	0	48	553

	2018	63	159	21	59	12	7	38	20	13	61	453
	2019	110	456	19	56	0	39	36	73	34	85	908
	Total	***951***	***1747***	***185***	***806***	***231***	***764***	***573***	***723***	***160***	***522***	***6662***
NPF Prawn Monitoring	2002	0	0	0	37	19	37	37	39	0	0	169
	2003	0	0	0	102	50	116	97	332	4	142	843
	2004	0	0	0	89	51	109	88	315	0	163	815
	2005	0	0	0	82	52	109	73	160	0	40	516
	2006	0	0	0	82	49	111	72	156	0	41	511
	2007	0	0	0	81	51	110	73	161	0	41	517
	2008	0	0	0	80	52	110	70	156	0	41	509
	2009	0	0	0	81	51	110	71	160	0	41	514
	2010	0	0	0	41	30	57	29	105	0	41	303
	2011	0	0	0	82	50	110	72	161	0	41	516
	2012	0	0	0	64	53	106	77	160	0	41	501
	2013	0	0	0	81	51	112	73	161	0	41	519
	2014	0	0	0	81	51	108	73	161	0	41	515
	2015	0	0	0	42	29	57	30	106	0	41	305
	2016	0	0	0	82	50	111	73	162	0	41	519
	2017	0	0	0	41	30	57	29	109	0	41	307
	2018	0	0	0	81	51	111	73	163	2	41	522
	2019	0	0	0	41	31	57	30	108	0	41	308
	Total	***0***	***0***	***0***	***1270***	***801***	***1698***	***1140***	***2875***	***6***	***919***	***8709***
CSIRO Scientific Survey	1976	0	0	0	0	0	0	0	66	93	107	266
	1977	0	0	0	0	0	0	0	693	271	249	1213
	1978	0	0	0	0	0	0	0	1040	264	252	1556
	1979	0	0	0	0	0	0	0	872	0	0	872
	1990	0	0	42	49	4	14	11	19	36	61	236
	1991	0	0	48	20	0	0	0	0	0	56	124
	1993	0	0	21	14	0	0	0	0	0	429	464
	1994	0	0	0	0	0	0	0	0	0	24	24
	1995	0	0	0	37	4	24	20	48	8	511	652
	1996	7	3	1	98	4	62	23	16	0	20	234
	1997	0	95	0	136	187	101	88	269	0	147	1023
	1998	93	205	339	911	753	954	824	244	6	152	4481

1999	41	5	95	275	236	675	449	168	11	6	1961
2000	33	0	24	339	76	320	128	60	17	4	1001
2001	0	0	97	670	249	458	265	123	20	47	1929
2002	0	0	26	20	0	0	0	0	0	0	46
2003	27	0	0	0	0	0	0	0	0	0	27
2004	0	4	5	0	0	5	4	35	17	0	70
2005	0	7	1	92	0	37	56	123	25	1	342
Total	***201***	***319***	***699***	***2661***	***1513***	***2650***	***1868***	***3776***	***768***	***2066***	***16521***

Table 4: Summary of the total swept area (km^2) trawled for each of the data sources across the 10 banana prawn regions of the NPF between 1976 and 2019.

Data Source	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Region 9	Region 10	Total (km^2)
Crew-member Observer	1016.9	2609.5	953.1	8332.7	3671.8	8023.3	4647.8	1439.5	230.8	1981.8	32907.3
AFMA Scientific Observer	476.7	798.4	100.6	661.3	183.5	629.4	357.4	347.1	30.7	398.7	3983.6
NPF Prawn Monitoring	0.0	0.0	0.0	111.8	70.3	149.4	100.8	255.4	0.3	78.4	766.6
CSIRO Scientific Survey	85.7	155.4	376.3	1408.6	765	1574.9	1041.4	534.8	75.6	257.1	6274.8

5.2.6 Combined analysis

The crew-member observer program was designed and implemented to collect data on the TEP and 'at risk' bycatch species interacted with in the NPF. This necessitates the collection of a large volume of species-specific catch data on a range of species that are usually rare in trawls. An important part of the program is to demonstrate the data being collected are of high quality that can be used for scientific catch analysis. The AFMA scientific observer program and NPF prawn population monitoring surveys were used as benchmark data sets to compare to the crew-member observer data for species-specific catch rates over the years 2003 to 2019.

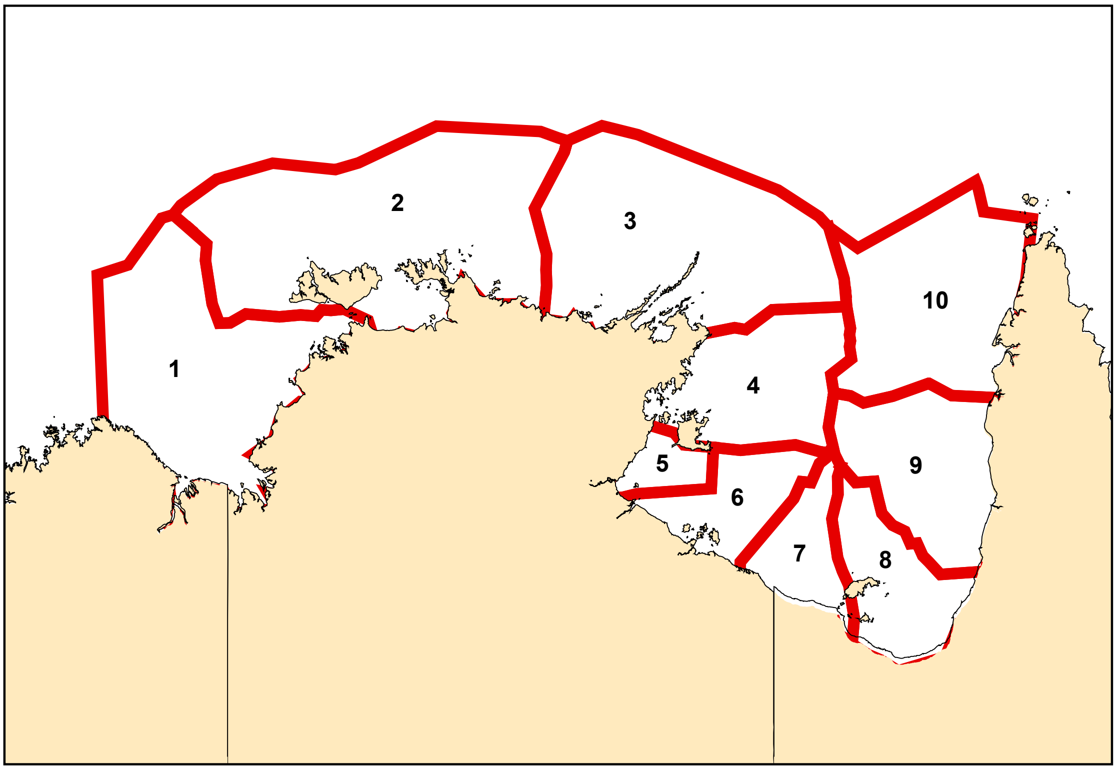
Initially the crew-member observer, AFMA scientific observer and NPF prawn population monitoring data sets were modelled separately for catch rate trend analysis to determine the number of TEP and 'at risk' species with sufficient data to fit the specified model. The AFMA scientific observer and NPF prawn population monitoring data sets were then combined and modelled for catch rate trends to determine the species that fit the same model type (different parameter estimates). Model results determine the similarities of the catch data sets and give an indication of the accuracy of the crew-member observer data set.

Comparisons of catches between these three data sets were made to check for consistency and validation of the crew-member observer data. In the present assessment, the comparison between the crew-member observer and NPF prawn population monitoring data sets did show some differences in the catch rates for some species. However, the catch rate trends across 'Years' showed similar patterns, especially for the more recent years where the crew-member observer program has continually improved in both the number of participating crew-member observers and the quality of data collected. The AFMA scientific observer data set showed quite large discrepancies when compared to the crew-member observer data set in some 'Regions' but not others. This was due to smaller numbers of catch records across a larger number of 'Regions' than the NPF prawn population monitoring survey. The crew-member observer data was therefore initially modelled separately. The AFMA scientific observer and NPF prawn population monitoring data sets were then combined and statistically compared with the crew-member observer data for catch rate trend analysis for the TEP and 'at risk' bycatch species where sufficient catch data was available.

There was a large amount of confounding between the data set variables, 'Gear Type' and 'Year', which caused model fitting problems. To ensure that appropriate models could be fitted, the data was reduced to a single 'Gear Type' (prawn trawl which represented more than 95% of the total data). Data recorded prior to 2002 was discarded as the data was collected across a small number of 'Regions' which changed through time.

For those species with sufficient data, GAMs were used to analyse the trend in catch rates through time. The catch was modelled using a GAM with a zero-inflated Poisson distribution (ziP) using the mgcv package in R. The models contained an offset term to represent 'Effort', and the estimated parameters included in the final model were 'Year', 'Region' and a spline term for 'Depth'. The 'Year' trend for each species was obtained by setting 'Depth' to the mean depth recorded (24m) and 'Region' to 6 (the 'Region' containing the most samples). The uncertainty was calculated by taking the confidence interval around the trend. For the rarest species, the above analysis procedures were not suitable. For these species, unmodelled catch rate data was plotted on a spatial and temporal scale to describe trends in catches.

Figure 5: Map of the Northern Prawn Fishery boundary in northern Australia showing the 10 banana prawn stock 'Regions'.



6 Results

6.1 Crew-member observer program

The summary of catch frequency data for the TEP and 'at risk' bycatch species for the crew-member observer data set is shown in Table 5. Only 'Region' data comparable with the NPF prawn population monitoring data is shown (i.e. Regions 4, 5, 6, 7, 8 and 10). The mean catch rate (number per km^2 swept area) was also calculated for each of the TEP and 'at risk' bycatch species in each 'Region' (Table 6). The incidence of catching TEP or 'at risk' bycatch species was relatively low for most species (less than 5% of trawls), only being recorded in a small number of the total 36,683 trawls assessed during the crew-member observer program from 2003 to 2019.

For the marine turtle group, the incidence of being caught was very low with none of the five species being recorded in more than 0.4% of trawls from 2003 to 2019. The Flatback Turtle (*Natator depressus*) was the most common species recorded from the crew-member observer program, although at less than one individual every 280 trawls (Table 5). There were also 121 trawls that caught a turtle that was not able to be identified to species. This is due to their large size and interaction with TEDs whereby individuals usually drop out of the net on winch-up, so many of the turtles caught were not photographed. The catches of marine turtles were widespread, being recorded from all of the 'Regions' within the NPF. Catches were generally low, less than one individual per 50 km^2 (Table 6).

The sea snake group showed higher incidences of being caught in trawls; with at least half of the 14 sea snake species being recorded in at least 2% of trawls during the crew-member observer program from 2003 to 2019 (Table 5). The most commonly caught species of sea snakes were *Disteira major*, *Lapemis curtis* and *Hydrophis elegans*; being recorded in 5%, 7% and 13% of trawls, respectively (Table 5). There was also 6% of the total number of trawls that recorded sea snakes where individuals were not identified to species. The maximum number of sea snakes of one species caught in a single trawl was 21 *Lapemis curtis*. Sea snakes, as a group, were caught across all 'Regions' of the NPF. One of the most common sea snake species; *Hydrophis elegans*, showed catches of one individual per 5 – 10 km^2 across most of the NPF coastal regions. Highest catches of this species, one individual per 1 – 2 km^2, were seen along the eastern side of the Gulf of Carpentaria ('Regions' 9 and 10) (Table 6). Several other sea snake species showed highest catches within this eastern 'Region'; *Aipysurus mosaicus*, *Disteira kingii*, *Disteira major*, *Enhydrina schistosa*, *Hydrophis ornatus* and *Lapemis curtis*. *Lapemis curtis* also showed the highest catches of any sea snake species, more than two individuals per km^2 within the Weipa and the Mitchell – Edward River 'Regions' (Table 6).

There were four species of syngnathids recorded by the crew-member observers; *Trachyrhamphus longirostris*, *Hippocampus zebra, Trachyrhamphus* sp A and *Trachyrhamphus* sp Short-tailed (Table 5). The most common species was *Trachyrhamphus longirostris*, occurring in about 4% (around 1,200) of trawls. However, another 225 trawls recorded catches of syngnathids where individuals were not identified to species as they were released immediately after capture (requirements for interactions with TEP species) and due to the difficulty in identifying syngnathids only from photographs. *Trachyrhamphus longirostris* was caught across all 'Regions' with highest mean catches of one individual per 2 – 5 km^2 around the southeastern Gulf of Carpentaria ('Region' 8 and 9) and one individual per 10 km^2 around Gove and Groote Eylandt ('Region' 3 – 5).

There were four species of sawfish recorded in the crew-member observer program from 2003 to 2019 with one species dominating the catches, the Narrow Sawfish (*Anoxypristis cuspidata*) (Table 5). This species was caught in at least 546 of the 36,683 trawls (around one individual every 70 trawls) recorded by crew-member observers, with up to five individuals in a single trawl. The Green Sawfish (*Pristis zijsron*) was recorded in at least 23 trawls while the Largetooth Sawfish (*Pristis*

pristis) and Dwarf Sawfish (*Pristis clavata*) were recorded in 14 and one trawl, respectively, during the crew-member observer program. Sawfishes were generally caught across most ‘Regions’. However, catches were variable with *Anoxypristis cuspidata* showing highest mean catches around the Joseph Bonaparte Gulf and Tiwi Islands to Gove (‘Region' 1 – 3) and the southeastern Gulf of Carpentaria (‘Region' 9), ranging from one individual per 4 – 10 km^2 and one individual per 2 km^2, respectively (Table 6).

Crew-member observers recorded three Porcupine Rays (*Urogymnus asperrimus*) from trawls in ‘Regions’ 4, 5, 6, 7, 8 and 10 since 2006 and another four caught outside these ‘Regions’. All seven of these being caught in the try-net gear around the Tiwi Islands, Gove, Groote Eylandt and west Mornington Island (Table 6).

The Squillidae group showed the highest incidence of being caught in trawls; in about 16% of all trawls or nearly 4,500 trawls since 2009 (Table 5). The most common species recorded was the Brown-striped Mantis Shrimp (*Dictyosquilla tuberculata*) with up to 460 individuals caught in a single trawl. This number was estimated from numbers of individuals collected from a portion of the total catch of that shot. The Brown-striped Mantis Shrimp showed highest mean catches of two to seven individuals per km^2 around the Tiwi Islands to Groote Eylandt (‘Regions’ 2 – 5) while Stephenson’s Mantis Shrimp, *Harpiosquilla stephensoni*, was caught more often (one individual per 2 – 5 km^2) around Joseph Bonaparte Gulf to Tiwi Islands (‘Regions’ 1 – 3) and on the eastern side of the Gulf of Carpentaria (‘Region’ 9) (Table 6).

Table 5: The proportion of trawls with no catch, number of trawls where at least one individual was caught and the maximum number of individuals in a single trawl for the TEP and 'at risk' bycatch species recorded during the 2003 – 2019 crew-member observer program.

Group	CAAB	Species	Proportion of Zeros	Trawls Present	Maximum Number
Dolphin	41116000	Delphinidae	>0.999	1	1
Marine Turtle	39020000	Cheloniidae	0.997	121	3
	39020001	*Caretta caretta*	>0.999	17	1
	39020002	*Chelonia mydas*	0.999	19	2
	39020003	*Eretmochelys imbricata*	>0.999	9	1
	39020004	*Lepidochelys olivacea*	0.998	69	1
	39020005	*Natator depressus*	0.996	132	2
Sea Snake	39125000	Hydrophiidae	0.94	2226	14
	39125001	*Acalyptophis peronii*	0.982	654	8
	39125003	*Aipysurus duboisii*	0.996	152	3
	39125004	*Aipysurus mosaicus*	0.977	841	4
	39125007	*Aipysurus laevis*	0.971	1066	4
	39125009	*Astrotia stokesii*	0.97	1131	3
	39125010	*Disteira kingii*	0.998	73	2
	39125011	*Disteira major*	0.945	2050	5
	39125013	*Enhydrina schistosa*	0.999	22	5
	39125018	*Hydrophis caerulescens*	1	0	0
	39125021	*Hydrophis elegans*	0.872	4743	11
	39125025	*Hydrophis mcdowelli*	0.999	45	4
	39125028	*Hydrophis ornatus*	0.978	831	8
	39125029	*Hydrophis pacificus*	0.985	553	3
	39125031	*Lapemis curtis*	0.927	2715	21
	39125033	*Pelamis platurus*	0.998	73	3
Syngnathid	37282000	Syngnathidae	0.993	225	6
	37282005	*Hippocampus histrix*	1	0	0
	37282006	*Trachyrhamphus bicoarctata*	1	0	0
	37282007	*Haliichthys taeniophorus*	1	0	0
	37282030	*Halicampus grayi*	1	0	0
	37282033	*Hippocampus kuda*	1	0	0
	37282042	*Choeroichthys brachysoma*	1	0	0
	37282063	*Festucalex scalaris*	1	0	0
	37282064	*Filicampus tigris*	1	0	0
	37282080	*Hippocampus zebra*	>0.999	2	1
	37282100	*Syngnathoides biaculeatus*	1	0	0
	37282101	*Trachyrhamphus longirostris*	0.961	1199	15
	37282110	*Hippocampus queenslandicus*	1	0	0
	37282998	*Trachyrhamphus* sp A	>0.999	2	1
	37282999	*Trachyrhamphus* sp Short-tailed	>0.999	13	2
Sawfish	37025000	Pristidae	0.996	133	3
	37025001	*Pristis zijsron*	0.999	23	1
	37025002	*Anoxypristis cuspidata*	0.985	546	5
	37025003	*Pristis pristis*	>0.999	14	1
	37025004	*Pristis clavata*	>0.999	1	1
Elasmobranch	37035027	*Urogymnus asperrimus*	>0.999	3	1
Invertebrate	28051030	*Dictyosquilla tuberculata*	0.836	4448	460
	28051039	*Harpiosquilla stephensoni*	0.997	85	14

Table 6: Mean catch rates (number per km²) of the TEP and 'at risk' bycatch species for each of the banana prawn fishing regions for the crew-member observer program from 2003 to 2019. Only TEP and 'at risk' bycatch species (or groups where individuals were not identified to species) that were recorded at least once during the program are shown.

Group	CAAB	Species	Region 1 (1676)	Region 2 (3590)	Region 3 (1343)	Region 4 (10600)	Region 5 (4667)	Region 6 (10603)	Region 7 (6508)	Region 8 (1967)	Region 9 (903)	Region 10 (2509)
Dolphin	41116000	Delphinidae	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Marine Turtle	39020000	Cheloniidae	<0.01	0.03	0.01	0.02	0.01	0.01	0.01	0.05	0.18	0.01
	39020001	*Caretta caretta*	<0.01	0.01	0.00	<0.01	0.00	0.01	0.01	<0.01	0.03	<0.01
	39020002	*Chelonia mydas*	<0.01	0.01	0.03	<0.01	<0.01	<0.01	0.02	0.05	0.00	0.01
	39020003	*Eretmochelys imbricata*	0.00	0.00	0.00	0.00	<0.01	<0.01	<0.01	0.00	0.00	0.01
	39020004	*Lepidochelys olivacea*	0.02	0.02	0.03	0.02	0.01	0.03	0.04	0.01	0.22	0.02
	39020005	*Natator depressus*	0.02	0.02	0.04	0.04	0.06	0.03	0.03	0.01	0.00	0.07
Sea Snake	39125000	Hydrophiidae	0.28	0.16	0.08	0.15	0.35	0.17	0.09	0.34	1.09	0.12
	39125001	*Acalyptophis peronii*	<0.01	<0.01	<0.01	<0.01	0.13	0.04	<0.01	0.02	0.09	0.04
	39125003	*Aipysurus duboisii*	<0.01	<0.01	<0.01	0.01	<0.01	0.01	0.01	<0.01	0.00	<0.01
	39125004	*Aipysurus mosaicus*	<0.01	0.03	0.02	0.03	0.17	0.02	<0.01	<0.01	0.38	<0.01
	39125007	*Aipysurus laevis*	0.01	<0.01	<0.01	0.01	0.12	0.07	0.08	0.01	0.02	0.01
	39125009	*Astrotia stokesii*	0.04	0.10	0.05	0.07	0.10	0.05	0.04	0.04	0.04	0.02
	39125010	*Disteira kingii*	<0.01	0.02	0.00	<0.01	<0.01	<0.01	<0.01	0.03	0.20	0.03
	39125011	*Disteira major*	0.14	0.11	0.03	0.05	0.22	0.17	0.05	0.04	0.41	0.05
	39125013	*Enhydrina schistosa*	0.00	0.00	0.00	0.00	0.00	0.00	<0.01	0.01	0.75	0.04
	39125021	*Hydrophis elegans*	0.31	0.37	0.22	0.39	0.19	0.17	0.17	0.19	0.84	0.45
	39125025	*Hydrophis mcdowelli*	0.01	0.00	0.00	0.00	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
	39125028	*Hydrophis ornatus*	0.01	0.03	<0.01	<0.01	0.04	0.06	0.03	0.01	0.19	0.25
	39125029	*Hydrophis pacificus*	<0.01	<0.01	<0.01	0.01	0.03	0.04	0.04	<0.01	0.05	0.01
	39125031	*Lapemis curtis*	0.28	0.63	0.02	0.01	0.47	0.04	0.02	0.90	2.27	1.84
	39125033	*Pelamis platurus*	0.00	0.00	0.00	<0.01	<0.01	<0.01	0.01	0.02	0.10	0.04
Syngnathid	37282000	Syngnathidae	0.01	0.01	0.09	0.01	0.01	0.01	0.01	0.10	0.16	0.01
	37282080	*Hippocampus zebra*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<0.01	0.00	<0.01
	37282101	*Trachyrhamphus longirostris*	0.01	0.04	0.08	0.10	0.10	0.07	0.07	0.16	0.47	0.06
	37282998	*Trachyrhamphus* sp A	0.00	0.00	0.00	0.00	0.00	<0.01	0.00	<0.01	0.00	0.00
	37282999	*Trachyrhamphus* sp Short Tailed	0.00	<0.01	0.00	<0.01	0.00	0.00	<0.01	0.01	0.00	<0.01

Sawfish	37025000	Pristidae	0.06	0.03	0.01	0.01	0.01	0.01	<0.01	0.01	0.03	0.01
	37025001	*Pristis zijsron*	0.01	0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.00	<0.01
	37025002	*Anoxypristis cuspidata*	0.19	0.23	0.11	0.04	0.02	0.02	0.02	0.07	0.67	0.10
	37025003	*Pristis pristis*	0.01	0.01	<0.01	<0.01	0.00	<0.01	<0.01	<0.01	0.00	<0.01
	37025004	*Pristis clavata*	<0.01	0.00	0.00	0.00	0.00	<0.01	0.00	0.00	0.00	0.00
Elasmobranch	37035027	*Urogymnus asperrimus*	0.00	0.02	0.01	<0.01	0.00	0.00	<0.01	0.00	0.00	0.00
Invertebrate	28051030	*Dictyosquilla tuberculata*	0.14	1.65	1.78	7.19	2.00	0.20	<0.01	0.20	0.02	0.00
	28051039	*Harpiosquilla stephensoni*	0.21	0.46	0.23	0.04	0.03	<0.01	<0.01	0.08	0.46	<0.01

6.2 AFMA scientific observer program

The summary of catch frequency data for the TEP and 'at risk' bycatch species for the AFMA scientific observer data set is shown in Table 7. Of the 6,662 trawls surveyed by AMFA scientific observers between 2005 and 2019, most TEP species (sea snakes, syngnathids, marine turtles, syngnathids and sawfishes) and 'at risk' bycatch species were recorded in less than 4% of all trawls. The mean catch rate (number per km^2 swept area) was also calculated for each of the TEP and 'at risk' bycatch species in each 'Region' and is shown in Table 8.

Marine turtles were recorded in a total of 24 trawls surveyed by AFMA scientific observers with the Flatback Turtle (*Natator depressus*) being the most common species caught with less than one individual per 500 trawls (Table 7). This species was caught mostly around the Tiwi Islands ('Region' 2), southern Gulf of Carpentaria ('Region' 7) and Weipa ('Region' 10). Mean catch for this species was one individual per 10 – 30 km^2 (Table 8). The Green Turtle (*Chelonia mydas*) and Olive Ridley Turtle (*Lepidochelys olivacea*) were also caught at about one individual per 10 – 30 km^2. However, these two species were mostly restricted to around the southern Gulf of Carpentaria ('Regions' 8 and 6, respectively).

The sea snakes were the most common TEP group surveyed by AFMA scientific observers in the NPF. Two species; *Hydrophis elegans* and *Lapemis curtis*, were each recorded in more than 570 trawls (in at least 10% of all trawls). There were also up to 12 individuals of each of these two species caught in a single trawl (Table 7). Highest mean catches of *Hydrophis elegans* (about one individuals per km^2) were around the south eastern and eastern Gulf of Carpentaria ('Region' 8 and 9) (Table 8). *Lapemis curtis* also showed highest catches (two to three individuals per km^2) around the south eastern and eastern Gulf of Carpentaria ('Region' 8 and 9) and one to two individuals per km^2 around southern Groote Eylandt ('Region' 5). The remaining sea snake species were recorded in 4% or less of trawls. Most of these species also showed highest mean catches in the southern Groote Eylandt region (*Aipysurus mosaicus*, *Aipysurus laevis*, *Astrotia stokesii* and *Disteira major*) and south eastern Gulf of Carpentaria (*Disteira kingii*, *Enhydrina schistosa*, *Hydrophis ornatus*, *Hydrophis pacificus* and *Pelamis platurus*) with catches up to one individual per 2 – 5 km^2 (Table 8).

The pipefish, *Trachyrhamphus longirostris*, was recorded in 91 of the 6,662 trawls (around 2% of all trawls) by AFMA scientific observers (Table 7). Similar to the crew-member observer program, this species showed highest mean catches of one individual per 4 – 5 km^2 around the south eastern Gulf of Carpentaria ('Region' 8 and 9) and one individual per 10 km^2 around Gove ('Region' 3). There were five other species of syngnathid recorded in the AFMA scientific observer program between 2005 and 2019; *Hippocampus histrix* (in one trawl), *Trachyrhamphus bicoarctata* (in 14 trawls), *Haliichthys taeniophorus* (in one trawl), *Choeroichthys brachysoma* (in two trawls) and *Filicampus tigris* (in five trawls). However, there were also 66 more trawls, with up to 36 individuals caught in a single trawl, where syngnathids were caught but not identified (due to difficulty in species identifications of this group).

The majority of sawfish recorded by AFMA scientific observers in the NPF were identified as the Narrow Sawfish (*Anoxypristis cuspidata*) (Table 7). This species accounted for 233 out of the 273 trawls where a sawfish was recorded; around 3.5% of all trawls (at least one individual every 28 trawls). Highest mean catches for this species, around one individual per km^2, were in the southeastern Gulf of Carpentaria ('Region' 8 and 9) and one individual per 3 – 5 km^2 in the western region of the NPF, from Joseph Bonaparte Gulf to Gove ('Region' 1 – 3) (Table 8). There were 27 Green Sawfish (*Pristis zijsron*), three Largetooth Sawfish (*Pristis pristis*) and one Dwarf Sawfish (*Pristis clavata*) recorded by AFMA scientific observers. The vast majority of sawfish were identified to species during the AFMA scientific observer program from 2005 to 2019.

None of the 'at risk' elasmobranch or teleost bycatch species were recorded by AFMA scientific observers between 2005 and 2019 (Table 7). The two Squillidae ‘at risk’ species; *Dictyosquilla tuberculata* and *Harpiosquilla stephensoni*, were recorded in about 3% and 1%, respectively, of all trawls (Table 7). The Brown-striped Mantis Shrimp, *Dictyosquilla tuberculata*, showed highest mean catches of up to six individuals per km^2 across a wide coastal area from the Joseph Bonaparte Gulf to south Groote Eylandt (‘Region’ 1 – 5). This species was also found within the southeastern Gulf of Carpentaria region (‘Region’ 8 and 9) with mean catches of one individual per 10 km^2 (Table 8).

Table 7: The proportion of trawls with no catch, number of trawls where at least one individual was caught and the maximum number of individuals in a single trawl for the TEP and 'at risk' bycatch species recorded during the AFMA scientific observer program; 2005 – 2019.

Group	CAAB	Species	Proportion of Zeros	Trawls Present	Maximum Number
Marine Turtle	39020000	Cheloniidae	0.999	5	2
	39020001	*Caretta caretta*	1	0	0
	39020002	*Chelonia mydas*	0.999	4	1
	39020003	*Eretmochelys imbricata*	>0.999	1	1
	39020004	*Lepidochelys olivacea*	>0.999	2	1
	39020005	*Natator depressus*	0.998	13	1
Sea Snake	39125000	Hydrophiidae	0.998	12	2
	39125001	*Acalyptophis peronii*	0.991	54	3
	39125003	*Aipysurus duboisii*	0.999	6	1
	39125004	*Aipysurus mosaicus*	0.988	74	4
	39125007	*Aipysurus laevis*	0.99	60	3
	39125009	*Astrotia stokesii*	0.978	132	5
	39125010	*Disteira kingii*	0.996	22	4
	39125011	*Disteira major*	0.967	200	4
	39125013	*Enhydrina schistosa*	0.998	10	4
	39125018	*Hydrophis caerulescens*	1	0	0
	39125021	*Hydrophis elegans*	0.904	576	13
	39125025	*Hydrophis mcdowelli*	0.997	21	3
	39125028	*Hydrophis ornatus*	0.974	158	10
	39125029	*Hydrophis pacificus*	0.994	36	2
	39125031	*Lapemis curtis*	0.894	636	12
	39125033	*Pelamis platurus*	0.998	13	2
Syngnathid	37282000	Syngnathidae	0.989	66	36
	37282005	*Hippocampus histrix*	>0.999	1	2
	37282006	*Trachyrhamphus bicoarctata*	0.998	14	1
	37282007	*Haliichthys taeniophorus*	>0.999	1	1
	37282030	*Halicampus grayi*	1	0	0
	37282033	*Hippocampus kuda*	1	0	0
	37282042	*Choeroichthys brachysoma*	>0.999	2	28
	37282063	*Festucalex scalaris*	1	0	0
	37282064	*Filicampus tigris*	0.999	5	1
	37282080	*Hippocampus zebra*	1	0	0
	37282100	*Syngnathoides biaculeatus*	1	0	0
	37282101	*Trachyrhamphus longirostris*	0.984	91	4
	37282110	*Hippocampus queenslandicus*	1	0	0
	37282998	*Trachyrhamphus* sp A	1	0	0
	37282999	*Trachyrhamphus* sp Short-tailed	1	0	0
Sawfish	37025000	Pristidae	0.999	9	2
	37025001	*Pristis zijsron*	0.996	27	1
	37025002	*Anoxypristis cuspidata*	0.961	233	4
	37025003	*Pristis pristis*	>0.999	3	1
	37025004	*Pristis clavata*	>0.999	1	1
Elasmobranch	37035027	*Urogymnus asperrimus*	1	0	0
Invertebrate	28051030	*Dictyosquilla tuberculata*	0.973	109	34
	28051039	*Harpiosquilla stephensoni*	0.992	33	4

Table 8: Mean catch rates (number per km²) of the TEP and 'at risk' bycatch species for each of the banana prawn fishing regions for the AFMA scientific observer program from 2005 to 2019. Only TEP and 'at risk' bycatch species (or groups where individuals were not identified to species) that were recorded at least once during the surveys are shown. Number of trawls shown in parenthesis.

Group	CAAB	Species	Region 1 (951)	Region 2 (1746)	Region 3 (186)	Region 4 (806)	Region 5 (233)	Region 6 (762)	Region 7 (573)	Region 8 (723)	Region 9 (160)	Region 10 (522)
Marine Turtle	39020000	Cheloniidae	<0.01	0.00	0.00	0.02	0.11	0.00	0.00	0.05	0.00	<0.01
	39020002	*Chelonia mydas*	0.00	<0.01	0.00	<0.01	0.00	<0.01	0.00	0.08	0.00	0.00
	39020003	*Eretmochelys imbricata*	0.00	<0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	39020004	*Lepidochelys olivacea*	0.00	<0.01	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
	39020005	*Natator depressus*	0.00	0.03	0.00	0.02	0.00	0.02	0.04	0.02	0.00	0.09
Sea Snake	39125000	Hydrophiidae	0.02	<0.01	0.00	0.01	0.00	<0.01	<0.01	0.01	0.02	0.00
	39125001	*Acalyptophis peronii*	0.00	<0.01	0.10	0.01	0.17	0.02	<0.01	0.01	0.20	0.04
	39125003	*Aipysurus duboisii*	<0.01	0.00	0.00	<0.01	0.01	0.00	0.00	0.00	0.00	0.01
	39125004	*Aipysurus mosaicus*	0.00	<0.01	0.01	0.02	0.54	0.02	<0.01	0.01	0.02	0.01
	39125007	*Aipysurus laevis*	0.00	0.00	0.00	0.12	0.19	0.05	0.03	<0.01	0.03	0.01
	39125009	*Astrotia stokesii*	0.05	0.04	0.06	0.08	0.19	0.03	0.01	0.02	0.03	0.05
	39125010	*Disteira kingii*	<0.01	0.01	0.00	0.01	0.00	<0.01	<0.01	0.05	0.16	0.03
	39125011	*Disteira major*	0.08	0.03	0.44	0.04	0.42	0.08	0.03	0.10	0.20	0.02
	39125013	*Enhydrina schistosa*	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.01
	39125021	*Hydrophis elegans*	0.22	0.20	0.45	0.37	0.20	0.14	0.14	0.72	1.27	0.39
	39125025	*Hydrophis mcdowelli*	0.01	<0.01	0.00	<0.01	0.01	<0.01	0.00	0.02	0.23	0.01
	39125028	*Hydrophis ornatus*	0.05	0.01	<0.01	0.01	0.09	0.06	0.03	0.60	1.13	0.37
	39125029	*Hydrophis pacificus*	0.01	<0.01	0.01	0.01	0.03	0.01	0.03	0.04	0.13	0.01
	39125031	*Lapemis curtis*	0.14	0.31	0.02	<0.01	1.22	0.05	0.10	2.04	2.64	0.96
	39125033	*Pelamis platurus*	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.14	0.06	0.02
Syngnathid	37282000	Syngnathidae	<0.01	<0.01	0.00	0.02	0.30	0.03	0.01	0.97	7.86	0.01
	37282005	*Hippocampus histrix*	0.00	0.00	0.00	<0.01	0.00	0.00	0.00	0.00	0.00	0.00
	37282006	*Trachyrhamphus bicoarctata*	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.02	0.00	0.00
	37282007	*Haliichthys taeniophorus*	0.00	<0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	37282042	*Choeroichthys brachysoma*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09
	37282064	*Filicampus tigris*	<0.01	0.00	0.00	<0.01	<0.01	0.00	0.00	0.00	0.25	0.01
	37282101	*Trachyrhamphus longirostris*	0.00	<0.01	0.07	0.03	0.05	0.03	0.04	0.18	0.23	0.03

Sawfish	37025000	Pristidae	<0.01	0.01	0.00	<0.01	0.03	0.00	0.00	0.00	0.00	0.00
	37025001	*Pristis zijsron*	0.03	0.01	0.02	<0.01	0.00	<0.01	0.01	0.06	0.00	0.00
	37025002	*Anoxypristis cuspidata*	0.28	0.25	0.19	0.07	0.02	0.02	0.02	0.69	1.16	0.05
	37025003	*Pristis pristis*	<0.01	<0.01	0.00	<0.01	0.00	0.00	0.00	0.00	0.00	0.00
	37025004	*Pristis clavata*	<0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Invertebrate	28051030	*Dictyosquilla tuberculata*	0.20	0.23	0.49	5.97	0.92	0.02	<0.01	0.07	0.10	0.00
	28051039	*Harpiosquilla stephensoni*	0.07	0.03	0.32	0.00	0.01	0.01	0.01	0.13	0.05	0.00

6.3 NPF prawn population monitoring surveys

The summary of catch frequency data for the TEP and 'at risk' bycatch species for the NPF prawn population monitoring surveys is shown in Table 9. Of the 8,709 trawls carried out during these surveys, only a small number of trawls recorded any of the TEP and 'at risk' bycatch species. Most of the TEP species (sea snakes, syngnathids, marine turtles, syngnathids and sawfishes) and 'at risk' bycatch species were recorded in less than 1.5% of all trawls. The mean catch rate (number per km^2 swept area) was also calculated for each of the TEP and 'at risk' bycatch species and is shown in Table 10. Most TEP and 'at risk' bycatch species were caught across the majority of 'Regions' sampled ('Region' 4, 5, 6, 7, 8 and 10).

Four of the five marine turtle species were only recorded once in the NPF prawn population monitoring surveys between 2002 and 2019 (Table 9). The Flatback Turtle (*Natator depressus*) was recorded in nine trawls, with another 18 trawls catching turtles that were not able to be unidentified. Marine turtles were more commonly caught along the eastern side of the Gulf of Carpentaria, around Karumba and Weipa ('Region' 8 and 10) with a mean catches of one individual per 15 – 30 km^2 (Table 10).

The most commonly caught sea snake species were *Lapemis curtis* and *Hydrophis elegans*, and these were caught in 7% or less of trawls (Table 9). These two species were recorded at around one individual every 15 trawls and had the highest maximum numbers of individuals caught in any one trawl; four and nine individuals, respectively. The other 12 species of sea snakes recorded in the NPF prawn population monitoring surveys were caught at less than one individual every 80 trawls. Most of the sea snake species were recorded across all of the six 'Regions' surveyed. However highest mean catches were recorded around south Groote Eylandt ('Region' 5) and along the eastern Gulf of Carpentaria coast ('Region' 8 and 10) for a number of species; *Acalyptophis peronii* (one individual per 5 – 7 km^2), *Disteira major* (one individual per 5 – 7 km^2) and *Lapemis curtis* (one individual per 1 – 2 km^2). *Hydrophis elegans* showed the most widespread catches from north and south Groote Eylandt (one to two individuals per km^2) in the west, to the southern Gulf of Carpentaria (one individual per km^2) and along the eastern Gulf of Carpentaria coast with one to two individuals per km^2 (Table 10).

Only three species of syngnathids were recorded more than once in catches during these surveys. The Straightstick Pipefish, *Trachyrhamphus longirostris*, was the most commonly caught species (in 115 trawls) with only four other species being recorded during the NPF prawn population monitoring surveys. However, many of the other syngnathids caught (in 46 other trawls) were not able to be identified to species due to the difficulty in positive identification from photographs. The syngnathids, as a group, were caught across most 'Regions' (Table 10). *Trachyrhamphus longirostris* showed higher mean catches around north Groote Eylandt ('Region' 4) and the southeastern Gulf of Carpentaria ('Region' 8) with one individual per 4 – 5 km^2 recorded.

Four species of sawfish were recorded from 2002 to 2019 during the NPF prawn population monitoring surveys (Table 9). The most common species; *Anoxypristis cuspidata*, was caught in 92 trawls (one individual every 94 trawls). The other three sawfish species were relatively uncommon, each species only being caught in one or three trawls from 2002 to 2019. *Anoxypristis cuspidata* was caught in all 'Regions' with highest mean catches (one individual per 3 km^2) recorded around Weipa ('Region' 10) and one individual per 7 – 9 km^2 recorded along the western to southern coast of the Gulf of Carpentaria ('Region' 4 – 7) (Table 10). The two sawfish species; *Pristis pristis* and *Pristis clavata*, were recorded in 'Region' 8 and 10 while *Pristis zijsron* was only caught in 'Region' 6.

None of the 'at risk' elasmobranch or teleost bycatch species were recorded during the NPF prawn population monitoring surveys.

The two ‘at risk’ Squillidae species were relatively common in trawls, occurring in about 40 trawls each from 2009 to 2019, with a maximum of 13 *Dictyosquilla tuberculata* individuals in a single trawl (Table 9). This invertebrate group also showed noticeable differences in mean catches across ‘Regions’. The Brown-striped Mantis Shrimp (*Dictyosquilla tuberculata*) was more common around north and south Groote Eylandt (‘Region’ 4 and 5) and southeastern Gulf of Carpentaria (‘Region’ 8) with catches of around one individual per 2 km^2 (Table 10). The Stephenson’s Mantis Shrimp (*Harpiosquilla stephensoni*) had similar mean catches of one individual per 2 km^2 but was mostly restricted to the southeastern Gulf of Carpentaria (‘Region’ 8).

Table 9: The proportion of trawls with no catch, number of trawls where at least one individual was caught and the maximum number of individuals in a single trawl for the TEP and 'at risk' bycatch species recorded during the NPF prawn population monitoring surveys; 2002 – 2019.

Group	CAAB	Species	Proportion of Zeros	Trawls Present	Maximum Number
Marine Turtle	39020000	Cheloniidae	0.998	18	1
	39020001	*Caretta caretta*	>0.999	1	1
	39020002	*Chelonia mydas*	>0.999	1	1
	39020003	*Eretmochelys imbricata*	>0.999	1	1
	39020004	*Lepidochelys olivacea*	>0.999	1	1
	39020005	*Natator depressus*	0.999	9	2
Sea Snake	39125000	Hydrophiidae	0.997	27	3
	39125001	*Acalyptophis peronii*	0.994	50	2
	39125003	*Aipysurus duboisii*	0.999	6	1
	39125004	*Aipysurus mosaicus*	0.995	44	2
	39125007	*Aipysurus laevis*	0.993	63	2
	39125009	*Astrotia stokesii*	0.994	51	2
	39125010	*Disteira kingii*	0.997	22	1
	39125011	*Disteira major*	0.987	111	2
	39125013	*Enhydrina schistosa*	0.999	11	2
	39125018	*Hydrophis caerulescens*	1	0	0
	39125021	*Hydrophis elegans*	0.94	521	4
	39125025	*Hydrophis mcdowelli*	>0.999	3	1
	39125028	*Hydrophis ornatus*	0.995	43	2
	39125029	*Hydrophis pacificus*	0.992	71	2
	39125031	*Lapemis curtis*	0.93	607	9
	39125033	*Pelamis platurus*	0.997	23	2
Syngnathid	37282000	Syngnathidae	0.995	46	3
	37282005	*Hippocampus histrix*	1	0	0
	37282006	*Trachyrhamphus bicoarctata*	1	0	0
	37282007	*Haliichthys taeniophorus*	>0.999	3	1
	37282030	*Halicampus grayi*	>0.999	4	1
	37282033	*Hippocampus kuda*	1	0	0
	37282042	*Choeroichthys brachysoma*	1	0	0
	37282063	*Festucalex scalaris*	1	0	0
	37282064	*Filicampus tigris*	>0.999	1	1
	37282080	*Hippocampus zebra*	1	0	0
	37282100	*Syngnathoides biaculeatus*	1	0	0
	37282101	*Trachyrhamphus longirostris*	0.987	115	3
	37282110	*Hippocampus queenslandicus*	>0.999	1	1
	37282998	*Trachyrhamphus* sp A	1	0	0
	37282999	*Trachyrhamphus* sp Short-tailed	1	0	0
Sawfish	37025000	Pristidae	1	0	0
	37025001	*Pristis zijsron*	>0.999	1	1
	37025002	*Anoxypristis cuspidata*	0.989	92	3
	37025003	*Pristis pristis*	>0.999	3	1
	37025004	*Pristis clavata*	>0.999	1	1
Elasmobranch	37035027	*Urogymnus asperrimus*	1	0	0
Invertebrate	28051030	*Dictyosquilla tuberculata*	0.991	41	13
	28051039	*Harpiosquilla stephensoni*	0.991	38	4

Table 10: Mean catch rates (number per km^2) of the TEP and 'at risk' bycatch species for each of the banana prawn fishing regions for the NPF prawn population monitoring surveys from 2002 to 2019. Only TEP and 'at risk' bycatch species (or groups where individuals were not identified to species) that were recorded at least once during the surveys are shown. Number of trawls shown in parenthesis.

Group	CAAB	Species	Region 4 (1270)	Region 5 (801)	Region 6 (1698)	Region 7 (1140)	Region 8 (2875)	Region 10 (919)
Marine Turtle	39020000	Cheloniidae	0.00	0.00	0.03	0.00	0.03	0.07
	39020001	*Caretta caretta*	0.00	0.00	0.00	0.00	0.00	0.01
	39020002	*Chelonia mydas*	0.00	0.00	0.00	0.00	<0.01	0.00
	39020003	*Eretmochelys imbricata*	0.00	0.01	0.00	0.00	0.00	0.00
	39020004	*Lepidochelys olivacea*	0.00	0.00	0.00	0.00	0.00	0.01
	39020005	*Natator depressus*	0.00	0.00	0.01	0.01	0.02	0.03
Sea Snake	39125000	Hydrophiidae	0.03	0.06	0.02	0.02	0.07	0.06
	39125001	*Acalyptophis peronii*	0.01	0.13	0.03	0.03	0.08	0.18
	39125003	*Aipysurus duboisii*	0.00	0.01	0.01	0.03	<0.01	0.00
	39125004	*Aipysurus mosaicus*	0.07	0.25	0.03	0.00	0.06	0.03
	39125007	*Aipysurus laevis*	0.00	0.09	0.11	0.14	0.10	0.09
	39125009	*Astrotia stokesii*	0.06	0.10	0.05	0.06	0.08	0.05
	39125010	*Disteira kingii*	0.00	0.00	0.00	0.01	0.06	0.08
	39125011	*Disteira major*	0.05	0.22	0.15	0.05	0.20	0.19
	39125013	*Enhydrina schistosa*	0.00	0.00	0.01	0.00	<0.01	0.12
	39125021	*Hydrophis elegans*	0.78	0.38	0.25	0.43	1.13	1.31
	39125025	*Hydrophis mcdowelli*	0.00	0.00	0.01	0.00	0.01	0.00
	39125028	*Hydrophis ornatus*	0.01	0.03	0.02	0.04	0.10	0.12
	39125029	*Hydrophis pacificus*	0.00	0.03	0.11	0.11	0.10	0.20
	39125031	*Lapemis curtis*	0.03	0.61	0.06	0.12	2.86	2.38
	39125033	*Pelamis platurus*	0.01	0.01	0.00	0.00	0.07	0.08
Syngnathid	37282000	Syngnathidae	0.01	0.08	0.05	0.04	0.09	0.16
	37282007	*Haliichthys taeniophorus*	0.00	0.00	0.01	0.00	0.01	0.00
	37282030	*Halicampus grayi*	0.00	0.00	0.02	0.00	<0.01	0.00
	37282064	*Filicampus tigris*	0.00	0.00	0.00	0.00	0.00	0.01
	37282101	*Trachyrhamphus longirostris*	0.25	0.09	0.11	0.13	0.22	0.06
	37282110	*Hippocampus queenslandicus*	0.00	0.00	0.00	0.00	0.00	0.01

Sawfish	37025000	Pristidae	0.00	0.00	0.00	0.00	0.00	0.00
	37025001	*Pristis zijsron*	0.00	0.00	0.01	0.00	0.00	0.00
	37025002	*Anoxypristis cuspidata*	0.11	0.13	0.12	0.12	0.06	0.39
	37025003	*Pristis pristis*	0.00	0.00	0.00	0.00	<0.01	0.02
	37025004	*Pristis clavata*	0.00	0.00	0.00	0.00	0.00	0.01
Invertebrate	28051030	*Dictyosquilla tuberculata*	0.41	0.45	0.00	0.00	0.38	0.00
	28051039	*Harpiosquilla stephensoni*	0.00	0.03	0.01	0.00	0.43	0.00

6.4 CSIRO scientific research and observer surveys

Most of the TEP and 'at risk' bycatch species have been recorded at least once within the NPF during previous CSIRO scientific research and observer surveys from 1976 to 2005 (Table 11). However similar to the other three data sets, the proportion of the total number of trawls (16,521 trawls) where TEP and 'at risk' bycatch species were recorded was very low (<6% of all trawls). The mean catch rate (number per km^2 swept area) was also calculated for each of the TEP and 'at risk' bycatch species and is shown in Table 12.

Of the five species of marine turtles caught, the Flatback Turtle (*Natator depressus*) was the most commonly caught (in 51 of the trawls). This species was caught more often around the northeastern Gulf of Carpentaria with mean catches of one individual per 5 km^2 ('Region' 10) (Table 12). The Loggerhead Turtle (*Caretta caretta*) also showed high mean catches of one individual per 25 km^2 in this region while the Hawksbill Turtle (*Eretmochelys imbricata*) was recorded at one individual per 7 km^2 in the southeastern Gulf of Carpentaria (Table 12).

The sea snake group was the most commonly caught TEP group with *Hydrophis elegans* and *Lapemis curtis* being the two species caught in the most trawls; 473 and 475 trawls (6% of trawls), respectively. These two species and *Acalyptophis peronii* also had the greatest number of individuals caught in one trawl; up to 15 *Hydrophis elegans*, 15 *Acalyptophis peronii* and 12 *Lapemis curtis* per trawl. *Aipysurus mosaicus*, *Astrotia stokesii*, *Disteira major* and *Hydrophis ornatus* were also relatively common; caught in about 1 – 2% of the total number of trawls. The sea snakes were also caught across all 'Regions'. The two species caught in the highest numbers; *Hydrophis elegans* and *Lapemis curtis*, both had highest mean catches (one to two individuals per km^2 and two to four individuals per km^2) along the eastern side of the Gulf of Carpentaria ('Regions' 8 – 10) (Table 12). Most of the other 13 species of sea snake recorded during the CSIRO scientific research and observer surveys (*Acalyptophis peronii, Aipysurus mosaicus, Aipysurus laevis, Astrotia stokesii, Disteira kingii*, *Disteira major*, *Enhydrina schistosa*, *Hydrophis mcdowelli* and *Hydrophis ornatus*) also showed highest mean catches in the south eastern Gulf of Carpentaria ('Regions' 8 – 10).

Most species of syngnathids were only caught in a few of the total number of trawls during the CSIRO scientific research and observer surveys (Table 11). The Thorny Seahorse (*Hippocampus histrix*) and the Straightstick Pipefish (*Trachyrhamphus longirostris*) were the two species caught most often, in 13 and 14 trawls, respectively. These two species showed catches of one individual per 4 – 5 km^2 around the Groote Eylandt ('Region' 4 and 5) and one individual per 2 – 3 km^2 in the southeastern Gulf of Carpentaria ('Region' 8). As there were very low numbers of most other species of syngnathids caught during the CSIRO scientific research and observer surveys, it is difficult to determine any regional pattern in catch rates. As a group, the syngnathids tended to show highest mean catches around the Tiwi Islands ('Region' 1), Groote Eylandt ('Region' 4 and 5) and in the southeastern Gulf of Carpentaria, Mornington to Karumba ('Region' 8) (Table 12).

The most common species of sawfish, the Narrow Sawfish (*Anoxypristis cuspidata*) was caught in a total of 172 trawls (2.6%) of the CSIRO scientific research and observer surveys. This species was caught across all 'Regions' of the NPF, with highest mean catches of four individuals per km^2 along the eastern coast of the Gulf of Carpentaria ('Region' 9) (Table 12). Catches of one individual per 3 – 8 km^2 were also seen in western regions of the NPF ('Region' 1 – 3). The Green Sawfish (*Pristis zijsron*) was caught in 13 trawls from these surveys between 1990 and 2005. This species was rarely recorded during the NPF prawn population monitoring surveys. However, during the crew-member observer program and AFMA scientific observer program it was recorded in 23 and 27 trawls, respectively. The Largetooth Sawfish (*Pristis pristis*) and Dwarf Sawfish (*Pristis clavata*) were rarely caught in the CSIRO scientific research and observer surveys (in two and one trawls, respectively). The Green Sawfish and Largetooth Sawfish showed highest mean catches of one individual per 20 km^2 around the southern Gulf of Carpentaria ('Region' 7) and Gove ('Region' 3), respectively.

However, the Dwarf Sawfish was only recorded around the Joseph Bonaparte Gulf (‘Region’ 1) at one individual per 100 km^2 (Table 12).

There were only six trawls during all of the CSIRO scientific research and observer surveys between 1990 and 2005 where the ‘at risk’ elasmobranch species, the Porcupine Ray (*Urogymnus asperrimus*) was recorded. However, these fish were widespread across the Gulf of Carpentaria from Gove in the west (‘Region’ 3) to Weipa in the east (‘Region’ 10) (Table 12).

The two ‘at risk’ teleost species, *Lepidotrigla spinosa and Lepidotrigla* sp A were recorded in two and 35 trawls, respectively, during the CSIRO scientific research and observer surveys from 1990 to 2005. Both of these species were recorded in low numbers, less than one individual per 100 km^2 with *Lepidotrigla spinosa* only recorded around Weipa (‘Region’ 10) and *Lepidotrigla* sp A recorded in the western and southern Gulf of Carpentaria (‘Region’ 4, 6 and 7) (Table 12).

Neither of the two Squillidae species was recorded in any of the CSIRO scientific research and observer surveys.

Table 11: The proportion of trawls with no catch, number of trawls where at least one individual was caught and the maximum number of individuals in a single trawl for the TEP and 'at risk' bycatch species recorded during the CSIRO scientific research and observer surveys.

Group	CAAB	Species	Proportion of zeros	Trawls Present	Maximum number
Marine Turtle	39020000	Cheloniidae	0.995	31	3
	39020001	*Caretta caretta*	0.999	7	2
	39020002	*Chelonia mydas*	>0.999	1	2
	39020003	*Eretmochelys imbricata*	>0.999	3	1
	39020004	*Lepidochelys olivacea*	0.995	34	1
	39020005	*Natator depressus*	0.992	51	2
Sea Snake	39125000	Hydrophiidae	0.983	145	12
	39125001	*Acalyptophis peronii*	0.995	45	15
	39125003	*Aipysurus duboisii*	0.998	14	1
	39125004	*Aipysurus mosaicus*	0.989	93	2
	39125007	*Aipysurus laevis*	0.992	67	2
	39125009	*Astrotia stokesii*	0.989	95	2
	39125010	*Disteira kingii*	0.995	45	2
	39125011	*Disteira major*	0.981	160	3
	39125013	*Enhydrina schistosa*	0.994	53	2
	39125018	*Hydrophis caerulescens*	>0.999	3	1
	39125021	*Hydrophis elegans*	0.944	473	15
	39125025	*Hydrophis mcdowelli*	0.999	8	1
	39125028	*Hydrophis ornatus*	0.988	99	8
	39125029	*Hydrophis pacificus*	0.996	31	2
	39125031	*Lapemis curtis*	0.944	475	12
	39125033	*Pelamis platurus*	>0.999	1	2
Syngnathid	37282000	Syngnathidae	0.999	5	7
	37282005	*Hippocampus histrix*	0.997	13	4
	37282006	*Trachyrhamphus bicoarctata*	>0.999	1	7
	37282007	*Haliichthys taeniophorus*	0.998	6	5
	37282030	*Halicampus grayi*	>0.999	1	1
	37282033	*Hippocampus kuda*	0.999	3	1
	37282042	*Choeroichthys brachysoma*	1	0	0
	37282063	*Festucalex scalaris*	0.999	2	1
	37282064	*Filicampus tigris*	>0.999	1	1
	37282080	*Hippocampus zebra*	1	0	0
	37282100	*Syngnathoides biaculeatus*	>0.999	1	2
	37282101	*Trachyrhamphus longirostris*	0.996	14	26
	37282110	*Hippocampus queenslandicus*	1	0	0
	37282998	*Trachyrhamphus* sp A	1	0	0
	37282999	*Trachyrhamphus* sp Short-tailed	1	0	0
Sawfish	37025000	Pristidae	0.995	31	3
	37025001	*Pristis zijsron*	0.998	13	2
	37025002	*Anoxypristis cuspidata*	0.974	172	4
	37025003	*Pristis pristis*	>0.999	2	1
	37025004	*Pristis clavata*	>0.999	1	1
Elasmobranch	37035027	*Urogymnus asperrimus*	0.999	6	1
Teleost	37288028	*Lepidotrigla spinosa*	0.999	2	1
	37288506	*Lepidotrigla* sp A	0.995	35	11
Invertebrate	28051030	*Dictyosquilla tuberculata*	1	0	0
	28051039	*Harpiosquilla stephensoni*	1	0	0

Table 12: Mean catch rates (number per km^2) of the TEP and 'at risk' bycatch species for each of the banana prawn fishing regions for the CSIRO scientific research and observer surveys from 1976 to 2005. Only TEP and 'at risk' bycatch species (or groups where individuals were not identified to species) that were recorded at least once during the surveys or trips are shown.

Group	CAAB	Species	Region 1 (201)	Region 2 (319)	Region 3 (699)	Region 4 (2661)	Region 5 (1513)	Region 6 (2650)	Region 7 (1868)	Region 8 (3776)	Region 9 (768)	Region 10 (2066)
Marine Turtle	39020000	Cheloniidae	0.00	0.00	0.02	0.02	<0.01	0.01	0.01	0.00	0.00	0.01
	39020001	*Caretta caretta*	0.00	0.00	0.00	<0.01	<0.01	<0.01	0.00	0.00	0.00	0.04
	39020002	*Chelonia mydas*	0.00	0.00	0.00	0.00	<0.01	0.00	0.00	0.00	0.00	0.00
	39020003	*Eretmochelys imbricata*	0.00	0.00	0.00	<0.01	0.00	0.00	0.00	0.15	0.00	0.00
	39020004	*Lepidochelys olivacea*	0.00	0.00	0.03	0.01	0.01	0.01	0.01	<0.01	0.00	0.00
	39020005	*Natator depressus*	0.00	0.00	0.03	0.02	0.07	<0.01	0.01	0.04	0.00	0.21
Sea Snake	39125000	Hydrophiidae	0.03	0.01	0.04	0.06	0.14	0.10	0.06	0.02	0.11	0.26
	39125001	*Acalyptophis peronii*	0.00	0.00	0.00	<0.01	0.02	0.03	0.10	0.09	0.05	0.26
	39125003	*Aipysurus duboisii*	0.00	0.00	0.00	<0.01	<0.01	0.04	<0.01	<0.01	0.11	0.02
	39125004	*Aipysurus mosaicus*	0.00	0.00	0.00	0.05	0.18	0.01	<0.01	0.59	0.63	0.09
	39125007	*Aipysurus laevis*	0.00	0.00	0.00	<0.01	0.15	0.09	0.04	0.04	0.26	0.11
	39125009	*Astrotia stokesii*	0.00	0.11	0.10	0.02	0.15	0.08	0.05	0.15	1.04	0.08
	39125010	*Disteira kingii*	0.00	0.00	0.00	0.00	<0.01	0.00	0.02	0.28	0.10	0.07
	39125011	*Disteira major*	0.10	0.00	0.02	0.02	0.13	0.13	0.08	0.16	0.29	0.07
	39125013	*Enhydrina schistosa*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.84	1.26	0.04
	39125018	*Hydrophis caerulescens*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.21	0.00
	39125021	*Hydrophis elegans*	0.15	0.00	0.22	0.27	0.18	0.16	0.24	1.65	1.45	1.50
	39125025	*Hydrophis mcdowelli*	0.00	0.00	0.00	0.00	0.00	0.00	<0.01	0.06	0.10	0.00
	39125028	*Hydrophis ornatus*	0.00	0.00	0.02	0.10	0.09	0.15	0.23	0.06	0.06	0.23
	39125029	*Hydrophis pacificus*	0.00	0.00	0.00	0.01	0.01	0.02	0.04	<0.01	0.00	0.00
	39125031	*Lapemis curtis*	0.02	0.13	0.00	0.00	0.45	0.00	0.00	4.42	2.95	1.59
	39125033	*Pelamis platurus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00
Syngnathid	37282000	Syngnathidae	7.46	0.00	0.00	0.05	0.16	0.00	0.00	0.03	0.00	0.03
	37282005	*Hippocampus histrix*	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.51	0.00	0.34
	37282006	*Trachyrhamphus bicoarctata*	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00
	37282007	*Haliichthys taeniophorus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25
	37282030	*Halicampus grayi*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
	37282033	*Hippocampus kuda*	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.00	0.00	0.03

	37282063	*Festucalex scalaris*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
	37282064	*Filicampus tigris*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	37282100	*Syngnathoides biaculeatus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
	37282101	*Trachyrhamphus longirostris*	0.00	0.00	0.00	0.22	0.18	0.00	0.00	0.52	0.00	0.04
Sawfish	37025000	Pristidae	<0.01	0.00	0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.08	<0.01
	37025001	*Pristis zijsron*	0.00	<0.01	<0.01	0.01	0.02	<0.01	0.05	0.02	0.00	<0.01
	37025002	*Anoxypristis cuspidata*	0.14	0.36	0.12	0.08	0.06	0.06	0.05	0.10	4.05	0.08
	37025003	*Pristis pristis*	0.01	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	37025004	*Pristis clavata*	0.02	<0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Elasmobranch	37035027	*Urogymnus asperrimus*	0.00	0.00	0.02	0.01	0.02	0.12	0.00	0.00	0.00	0.00
Teleost	37288028	*Lepidotrigla spinosa*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<0.01
	37288506	*Lepidotrigla* sp A	0.00	0.00	0.00	<0.01	0.00	0.01	0.01	0.00	0.00	0.00

6.5 Distribution and abundance

The commercial fishing effort distribution (boat days per six nautical mile grid) for the banana and tiger prawn seasons for the years 2002 – 2004, 2005 – 2007, 2008 – 2010, 2011 – 2013, 2014 – 2016 and 2017 – 2019 are shown in Figure 6 and Figure 7. Commercial fishing effort in the NPF extended from the Joseph Bonaparte Gulf in the west to Weipa in the east for both banana prawn (1st) and tiger prawn (2nd) seasons. The banana prawn season showed similar fishing effort distribution from the 2002 – 2004 period to the 2017 – 2019 period with most of the effort concentrated in the shallow coastal band around the Tiwi Islands, Coburg Peninsula, Gove and along the south-east to east Gulf of Carpentaria coastline between Mornington Island and Weipa. There was a lack of fishing effort in the Joseph Bonaparte Gulf in 2008 – 2010 (Figure 6). Similar to previous years, there has been a marked clustering of effort in the Gulf of Carpentaria around Weipa, Edward – Mitchell River, Karumba, east and west Mornington Island. Fishing effort distribution for the tiger prawn fishery has changed little between 2002 – 2004 and the 2017 – 2019 period, with most of the effort along the offshore coastal regions of the western and southern Gulf of Carpentaria (Figure 7). There was some tiger prawn effort in the western Joseph Bonaparte Gulf in the 2002 – 2004 and 2005 – 2007 periods however the effort was reduced in the following years with more effort being seen around the Tiwi Islands and Weipa region from 2008 – 2010 to 2017 – 2019 periods. The highest tiger prawn effort was seen around the north Groote Eylandt region.

For each of the TEP and 'at risk' bycatch species, as well as the unidentified individuals of each group, pooled distribution data show the geographical distribution for each species (grey circles represent a position where a species was recorded) (Figure 8 to Figure 15). In addition, standardised catch rates (in number per km^2), were calculated from pooled data and averaged to the six nautical mile grid and plotted across the NPF region for both the banana prawn and tiger prawn seasons separately (Figure 8 to Figure 15). These plots are used to identify areas of highest catches of each species or group. Importantly, in some instances where one or more individuals were caught in a short trawl (such as a banana trawl) in a six nautical mile grid that had low effort distribution (such as only one or a few trawls being recorded in that grid), the mean catch rate for that grid will be disproportionally high.

6.5.1 Dolphins

During the 2013 tiger prawn season only, one dolphin was caught in a trawl within the Joseph Bonaparte Gulf region (Figure 8). The dolphin was not identified to species and it was released alive.

6.5.2 Marine turtles

The marine turtles were recorded throughout the coastal region of the NPF from the Joseph Bonaparte Gulf in the west to Weipa in the east and they were caught during both the banana prawn and tiger prawn seasons (Figure 9 a). Catch rates of marine turtles as a group were highest around Weipa and Tiwi Islands (up to 17 individuals per km^2) during the banana prawn season and up to seven individuals per km^2 around Groote Eylandt during the tiger prawn season.

The catches of ‘Unidentified Cheloniidae’ were highest during the banana prawn season, up to 11 individuals per km^2 around the Tiwi Islands and south of Weipa however most catches along the southeastern side of the Gulf of Carpentaria (including Weipa) were less than two individuals per km^2 (Figure 9 b). Lower catches were recorded during the tiger prawn season, less than one individual per km^2, with the majority of catches taken along the west and south coastal regions of the Gulf of Carpentaria. The difference is catch rates between fishing season is likely to be a result of the differences in fishery effort distribution and duration of trawl. Each of the five species of marine turtles recorded in the NPF between 2002 and 2019 were caught during both the banana and tiger prawn seasons (Figure 9 c – g).

The recorded distribution for most of the marine turtle species were widespread, from the Joseph Bonaparte Gulf to Weipa, however the Hawksbill Turtle (*Eretmochelys imbricata*) showed a more restricted catch distribution within the Gulf of Carpentaria with only one catch record outside this region (Figure 9 c – g). Mean catch rates varied between species with the Hawksbill Turtle (*Eretmochelys imbricata*) recorded at up to one individual per two km^2. The Loggerhead Turtle (*Caretta caretta*) and Green Turtle (*Chelonia mydas*) showed catch rates of one to two individuals per km^2, highest around the southeastern and south Gulf of Carpentaria, respectively. The most common species of turtles recorded were the Flatback Turtle (*Natator depressus*) and Olive Ridley Turtle (*Lepidochelys olivacea*) with catch rates of up to three and 17 individuals per km^2, respectively. These two species were mostly recorded around the west and south Gulf of Carpentaria regions.

6.5.3 Sea snakes

The sea snakes, as a group, were recorded across almost the entire coastal and offshore region of the NPF (Figure 10 a). Temporal differences in sea snake catches between the banana prawn and tiger prawn seasons were due to the changes in fishing effort distribution between the seasons. The highest catches of sea snakes were recorded around the southeastern and eastern Gulf of Carpentaria, up to 92 individuals per km^2 during the banana prawn season and up to 26 individuals per km^2 during the tiger prawn season. Most of the species of sea snakes were widely distributed throughout the coastal region of the NPF; from the Joseph Bonaparte Gulf in the west to the Weipa region in the east (Figure 10 c – p).

Catches of 'Unidentified Hydrophiidae' were comparable within both the banana prawn and tiger prawn seasons across the Gulf of Carpentaria. Catch rates of up to 32 individuals per km^2 were recorded in the Joseph Bonaparte Gulf, Tiwi Islands and along the entire coast of the Gulf of Carpentaria (Figure 10 b). However, catch rates of about one individual per 2 km^2 were more common. These unidentified sea snakes were mostly sea snake captures that were not photographed by crew-member observers and would therefore likely be from a broad range of the species that occur in the NPF.

Several species of sea snakes were caught in relatively high numbers across the NPF region; *Disteira major*, *Hydrophis elegans* and *Lapemis curtis*, with catch rates of up to 36 to 92 individuals per km^2 (Figure 10 i,k,o). Higher mean catch rates were generally seen during the banana prawn seasons compared to the tiger prawn seasons and across most of the NPF coastal region. While *Disteira major* showed high catch rates across most of the coastal regions of the NPF, *Hydrophis elegans* and *Lapemis curtis* were caught more in the southeastern and eastern Gulf of Carpentaria region (Figure 10 i,k,o).

The less common sea snake species showed similar widespread distributions across the NPF coastline. Their highest catch rates were restricted to smaller regions. Mean catch rates of up to 11 to 19 individuals per km^2 were seen for *Acalyptophis peronii*, *Disteira kingii* and *Hydrophis ornatus* along the eastern coastline of the Gulf of Carpentaria (Figure 10 c,h,m). Up to five to nine individuals per km^2 were recorded for *Aipysurus mosaicus*, *Aipysurus laevis*, *Astrotia stokesii*, *Hydrophis pacificus* and *Pelamis platurus* (Figure 10 e,f,g,n,p). *Aipysurus mosaicus* showed highest catches around south Groote Eylandt, north Mornington Island and eastern Gulf of Carpentaria. Highest catches were seen along the southern coastline of the Gulf of Carpentaria for *Aipysurus laevis* while *Astrotia stokesii* was recorded in highest numbers around the southeastern Gulf of Carpentaria and around the Tiwi Islands in the west. *Hydrophis pacificus* was recorded in highest numbers in the southern and eastern region of the Gulf of Carpentaria. *Pelamis platurus* was generally restricted to the southeastern and eastern regions of the Gulf of Carpentaria and was recorded more often in the banana prawn season compared to the tiger prawn season (Figure 10 p). There was also a marked seasonal difference in *Enhydrina schistosa* catches, up to four individuals per km^2, with nearly all captures recorded during the banana prawn season in the close inshore coastal region around

Weipa and Edward River (Figure 10 j). *Aipysurus duboisii* and *Hydrophis mcdowelli* were caught in the lowest numbers, up to only one to two individuals per km^2. These two species occur across the NPF, though the majority of catches were restricted to the southern Gulf of Carpentaria for *Aipysurus duboisii* and southeastern Gulf of Carpentaria and Joseph Bonaparte Gulf for *Hydrophis mcdowelli* (Figure 10 d,l).

There were several species of sea snakes that were not recorded by the crew-member observer program, AFMA scientific observer program or NPF prawn population monitoring surveys between 2002 and 2019 but are known to occur within the NPF from previous Museum records and CSIRO scientific research and observer surveys. These species (*Hydrelaps darwiniensis*, *Hydrophis atriceps*, *Hydrophis caerulescens*, *Hydrophis fasciatus*, *Hydrophis inornatus* and *Parahydrophis mertoni*) have a more inshore estuarine habitat preference and are therefore unlikely to be recorded in NPF prawn trawls (Figure 10 q – v).

6.5.4 Syngnathids

The syngnathid group has a wide distribution within the NPF; from Fog Bay in the west to Torres Strait in the east (Figure 11 a). However, a high proportion of syngnathids caught were not identified to species due to species identification difficulties. Therefore, the catch rates of individual species may not reflect accurate levels. As a result of subsampling, a few trawl catches recorded or estimated very high numbers of syngnathids during the banana prawn season, up to 140 individuals per km^2 around the Edward River to Mitchell River region. Most syngnathid species were caught at less than ten individuals per km^2 during both the banana prawn and tiger prawn seasons.

Most of the 'Unidentified Syngnathidae' were caught along the coastal region from Gove to Weipa during both the banana and tiger prawn seasons (Figure 11 b). Catch rates were also similar between the fishing seasons, up to six individuals per km^2 (excluding the few inflated mean catch rates in a few grids along the eastern side of the Gulf of Carpentaria).

There were 11 syngnathid species recorded during the crew-member observer program, AFMA scientific observer program and NPF prawn population monitoring surveys from 2002 to 2019. Most species were recorded in only a few trawls in low numbers and having restricted distributions across the NPF. There was less than one individual per 100 km^2 recorded for *Hippocampus histrix* around the north Groote Eylandt region however it has been also recorded around Mornington Island and Torres Strait region in previous surveys (Figure 11 c). *Choeroichthys brachysoma*, *Hippocampus zebra* and *Trachyrhamphus* sp A were recorded around Weipa, Weipa and Mornington Island and Mornington Island and Vanderlins in the southern Gulf of Carpentaria, respectively, at mean catch rates of up to 12 to 25 individuals per km^2 (Figure 11 g,i,l). *Trachyrhamphus bicoarctata*, *Halicampus grayi* and *Trachyrhamphus* sp Short-tailed showed quite restricted distributions around the southern Gulf of Carpentaria region with mean catch rates of one individual per 1 – 5 km^2 (Figure 11 d,f,m). The two pipefishes, *Haliichthys taeniophorus* and *Filicampus tigris*, and the seahorse, *Hippocampus queenslandicus*, showed mean catch rates of five to twelve individuals per km^2 with similar restricted distributions around the southern Gulf of Carpentaria for *Haliichthys taeniophorus* and eastern Gulf of Carpentaria for *Filicampus tigris* and *Hippocampus queenslandicus* (Figure 11 e,h,k).

The most common Syngnathidae caught in the NPF was *Trachyrhamphus longirostris*, which was recorded across most of the coastal region of the NPF, from Fog Bay in the west to Weipa in the east (Figure 11 j). This species was recorded in both the banana prawn and tiger prawn seasons and although catch rates were up to six individuals per km^2 in the banana prawn season and one to two individuals per km^2 in the tiger prawn season, catches were generally consistent throughout most of the Gulf of Carpentaria coast and from Gove to Tiwi Islands (Figure 11 j).

There were three species of Syngnathidae that were not recorded by the crew-member observer program, AFMA scientific observer program or NPF prawn population monitoring surveys between 2002 and 2019 but have been recorded within the NPF previously from Museum records and CSIRO scientific research and observer surveys. These species (*Hippocampus kuda*, *Festucalex scalaris and Syngnathoides biaculeatus*) showed restricted distributions around Groote Eylandt, Weipa or Torres Strait waters (Figure 11 n,o,p).

6.5.5 Sawfishes

The sawfishes showed a widespread distribution throughout both the inshore and offshore coastal regions of the NPF, from western Joseph Bonaparte Gulf to the eastern side of the Gulf of Carpentaria up to Weipa (Figure 12 a). Lower mean catches were generally recorded during the tiger prawn season, with most catches at less than one individual per km^2, compared to up to one to five individuals per km^2 during the banana prawn season. Anomalous high catches up to 43 individuals per km^2 were taken in a low effort trawled grid around the Edward River – Mitchell River (Figure 12 a). As with the sea snake and syngnathid groups, there was a significant proportion of sawfish individuals that were not identified to species level thus included in the 'Unidentified Pristidae' (Figure 12 a). These unidentified catch records were mostly recorded during the tiger prawn season, likely due to difficulties in identifying large animals at night that are not being brought on board. Most of these individuals were recorded around the Tiwi Islands and within the coastal regions of the Gulf of Carpentaria between Gove and Mornington Island with catch rates around one individual per 10 – 100 km^2 (Figure 12 b).

The majority of 'Unidentified Pristidae' are likely to be one species, the Narrow Sawfish (*Anoxypristis cuspidata*), as this was the most common sawfish species recorded in the NPF between 2002 and 2019. Around 92% of all sawfishes recorded are this species. The distribution of *Anoxypristis cuspidata* was widespread, from western Joseph Bonaparte Gulf to Weipa in the east (Figure 12 d). Although catch rates were recorded at up to 43 individuals per km^2 during the banana prawn season and up to 14 individuals per km^2 during the tiger prawn season, most trawl catches were much less than five individual per km^2 and one individual per km^2 per season, respectively. During the banana prawn season, highest catch rates were seen around the Gove to north Groote Eylandt and the east side of the Gulf of Carpentaria from the Mitchell River to Weipa regions. During the tiger prawn season, highest catch rates were seen in the western Joseph Bonaparte Gulf, Tiwi Islands and Mornington Island.

The Green Sawfish (*Pristis zijsron*) had catch rates of up to three individuals per km^2 around the Tiwi Islands with much lower mean catch rates of less than one individual per 6 – 8 km^2 within the Joseph Bonaparte Gulf and western side of the Gulf of Carpentaria, mostly during the tiger prawn season (Figure 12 c). The other two species of sawfishes recorded from 2002 to 2019, the Largetooth Sawfish (*Pristis pristis*) and Dwarf Sawfish (*Pristis clavata*), showed a patchy distribution across the NPF region from Joseph Bonaparte Gulf to Weipa (Figure 12 e,f). *Pristis pristis* showed highest catch rates of one individual per 2 – 8 km^2 in the Joseph Bonaparte Gulf, Tiwi Islands, Gove, southeastern Gulf of Carpentaria and Weipa regions while *Pristis clavata* showed lower mean catch rates of one individual per 10 – 20 km^2 in the Joseph Bonaparte Gulf and Weipa regions.

6.5.6 Elasmobranchs

There were few catch records available for the one 'at risk' elasmobranch species, the Porcupine Ray (*Urogymnus asperrimus*). This species was caught mainly along the western coast of the Gulf of Carpentaria and off the Tiwi Islands during the tiger prawn season only (Figure 13 a). However, historical distribution records show that the species occurs along the majority of coastline within the Gulf of Carpentaria around to Weipa in the east. In addition, all seven catch records between 2002 and 2019 were from try-net gear.

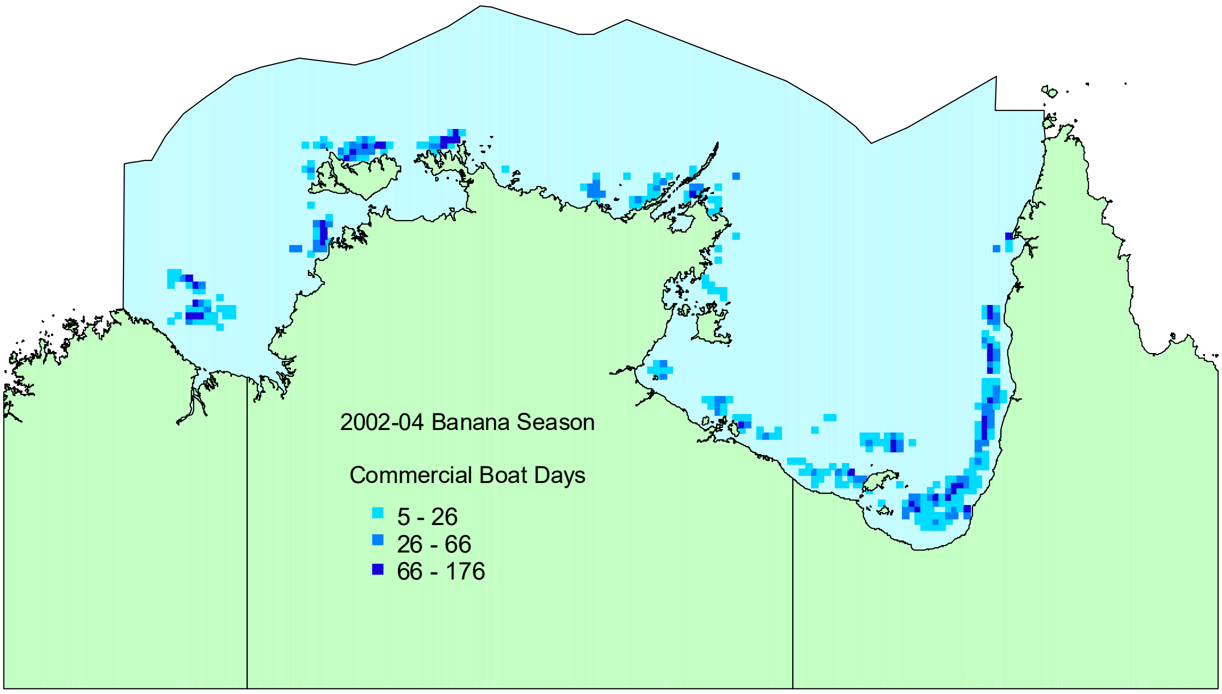
6.5.7 Teleosts

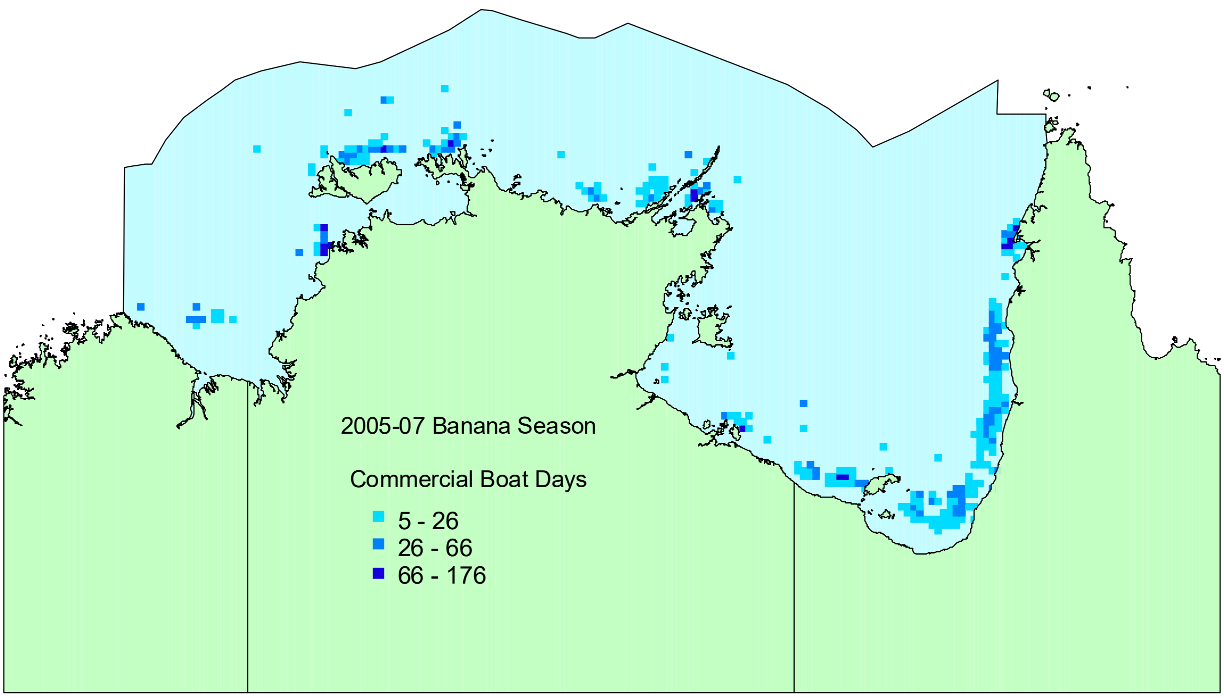
The two 'at risk' teleost species of *Lepidotrigla* (*Lepidotrigla spinosa* and *Lepidotrigla* sp A) were not recorded during the crew-member observer program, AFMA scientific observer program or NPF prawn population monitoring surveys from 2002 to 2019. These species were only caught within the NPF region during the previous CSIRO scientific research and observer surveys prior to 2002 (Figure 14 a,b). *Lepidotrigla spinosa* was caught around the Weipa region while *Lepidotrigla* sp A was found between Gove and north Groote and in offshore waters north-east of Vanderlins.

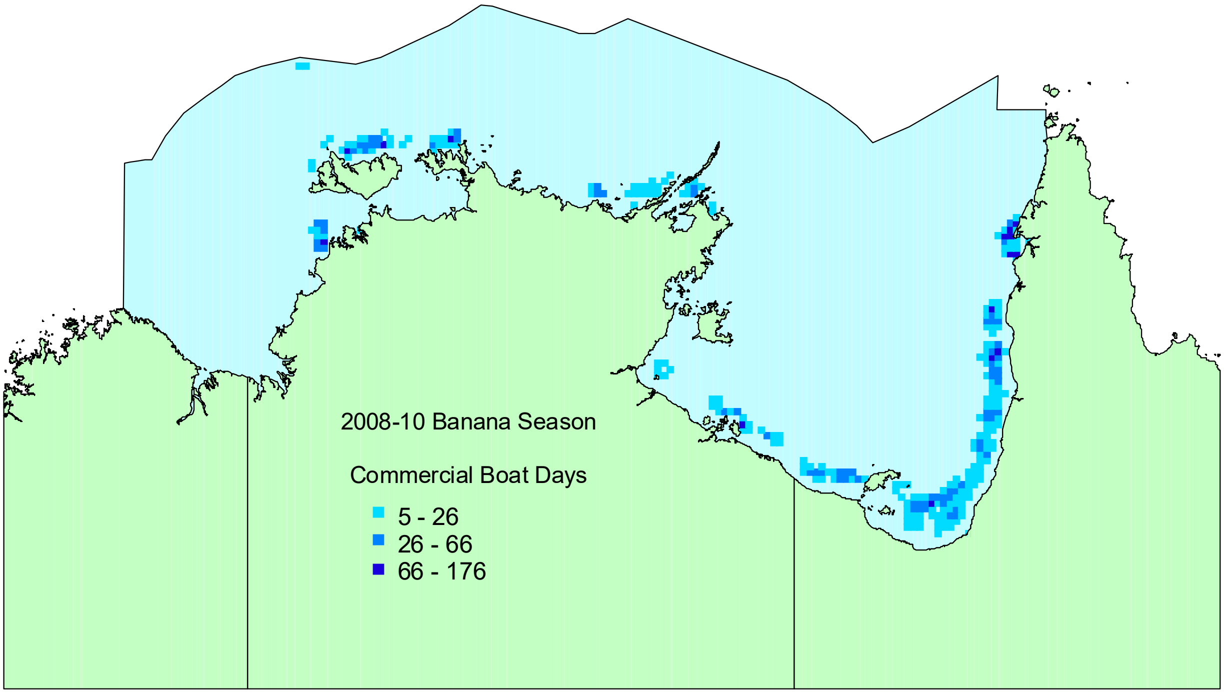
6.5.8 Invertebrates

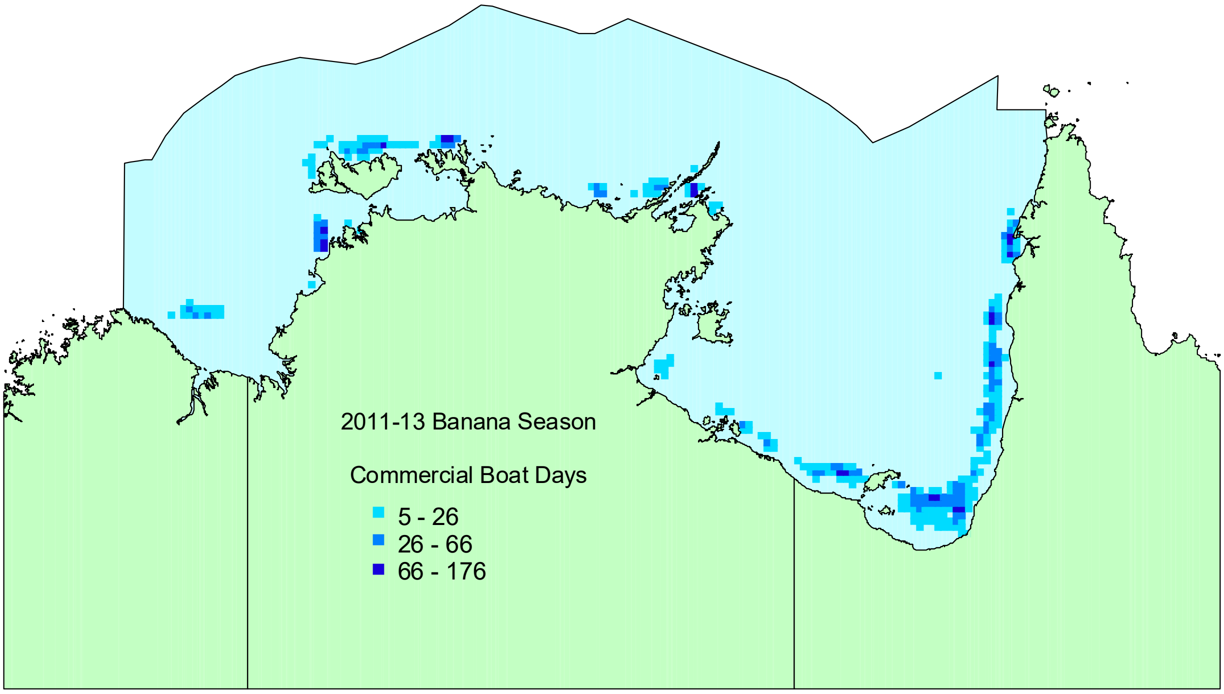
The two 'at risk' Squillidae species that were being monitored during the crew-member observer program, AFMA scientific observer program and NPF prawn population monitoring surveys all showed widespread distributions across the NPF region (Figure 15 a,b). The Brown-striped Mantis Shrimp (*Dictyosquilla tuberculata*) was recorded from Joseph Bonaparte Gulf in the west to south of Weipa in the east during the banana prawn season. During the tiger prawn season, it was recorded from Joseph Bonaparte Gulf east to Karumba. Highest catch rates for this species, up to 50 individuals per km^2, were recorded around the Wessel Islands, from Gove to north Groote Eylandt and around Karumba. Few have been recorded along the eastern side of the Gulf of Carpentaria (Figure 15 a). Stephenson’s Mantis Shrimp (*Harpiosquilla stephensoni*) was more commonly caught in the banana prawn season around the Tiwi Islands, Gove, southeastern and eastern Gulf of Carpentaria, with few being recorded along the western side. Highest mean catch rates were up to 16 individuals per km^2 for this species and catch rates were higher and more consistent during the banana prawn season compared to the tiger prawn season (Figure 15 b).

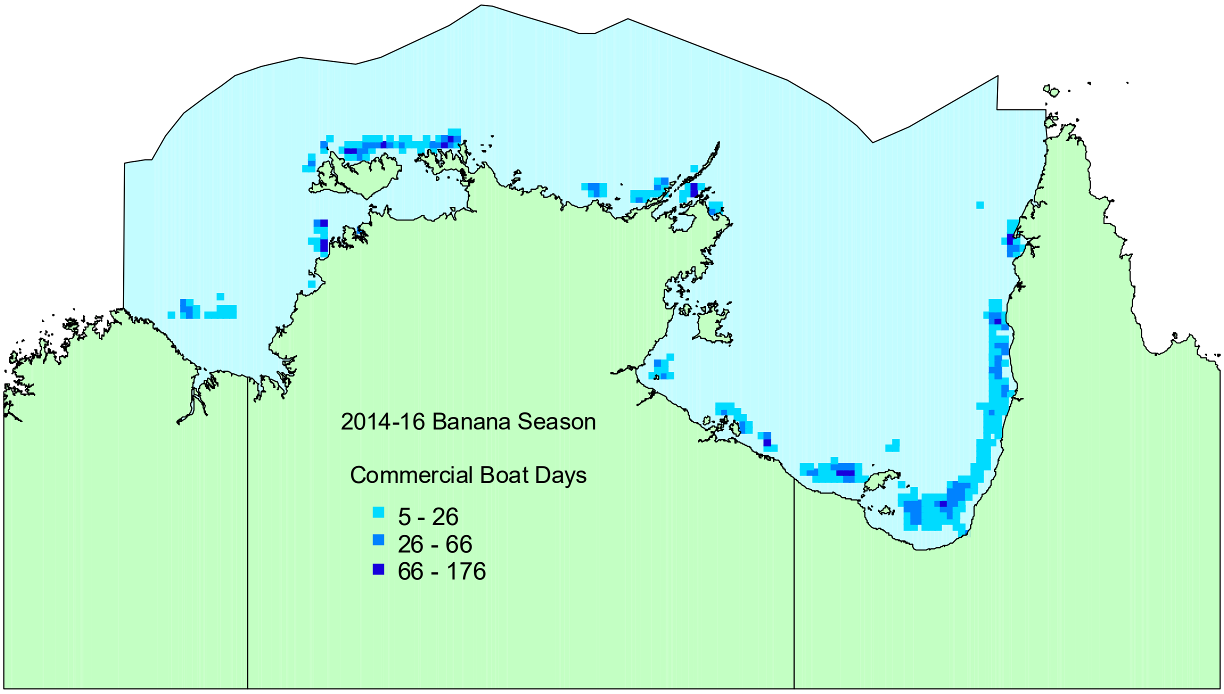
Figure 6: Maps showing the NPF commercial trawl effort distribution (boat days ≥5 days) in each 6 nautical mile grid for the 2002-04, 2005-07, 2008-10, 2011-13, 2014-16 and 2017-19 banana prawn seasons across the Northern Prawn Fishery.


2002-04 Banana Season
Commercial Boat Days
5 - 26
26 - 66
66 - 176


2005-07 Banana Season
Commercial Boat Days
5 - 26
26 - 66
66 - 176


2008-10 Banana Season
Commercial Boat Days
5 - 26
26 - 66
66 - 176


2011-13 Banana Season
Commercial Boat Days
5 - 26
26 - 66
66 - 176


2014-16 Banana Season
Commercial Boat Days
5 - 26
26 - 66
66 - 176

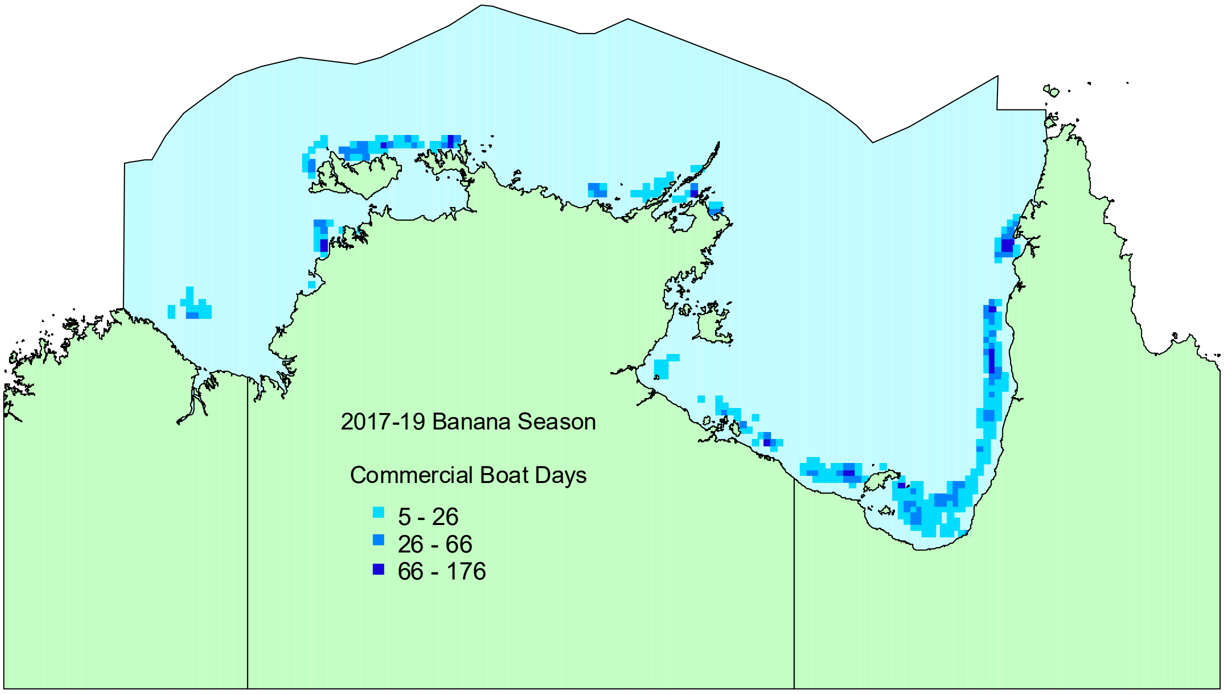
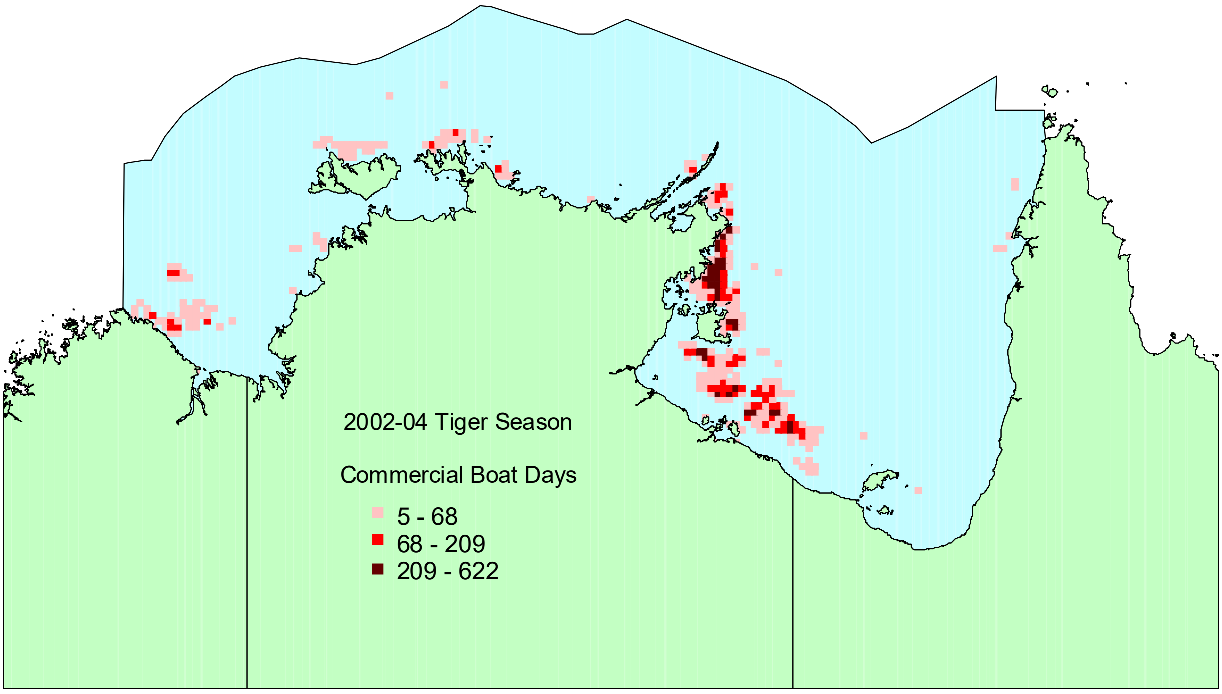
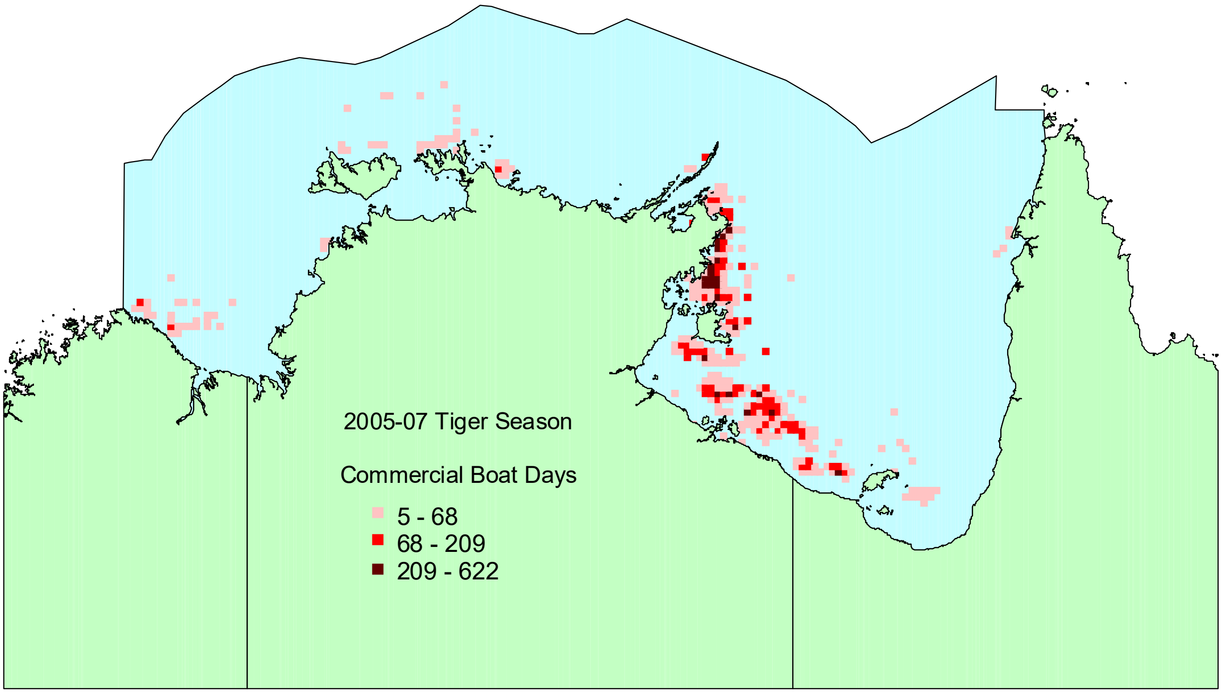
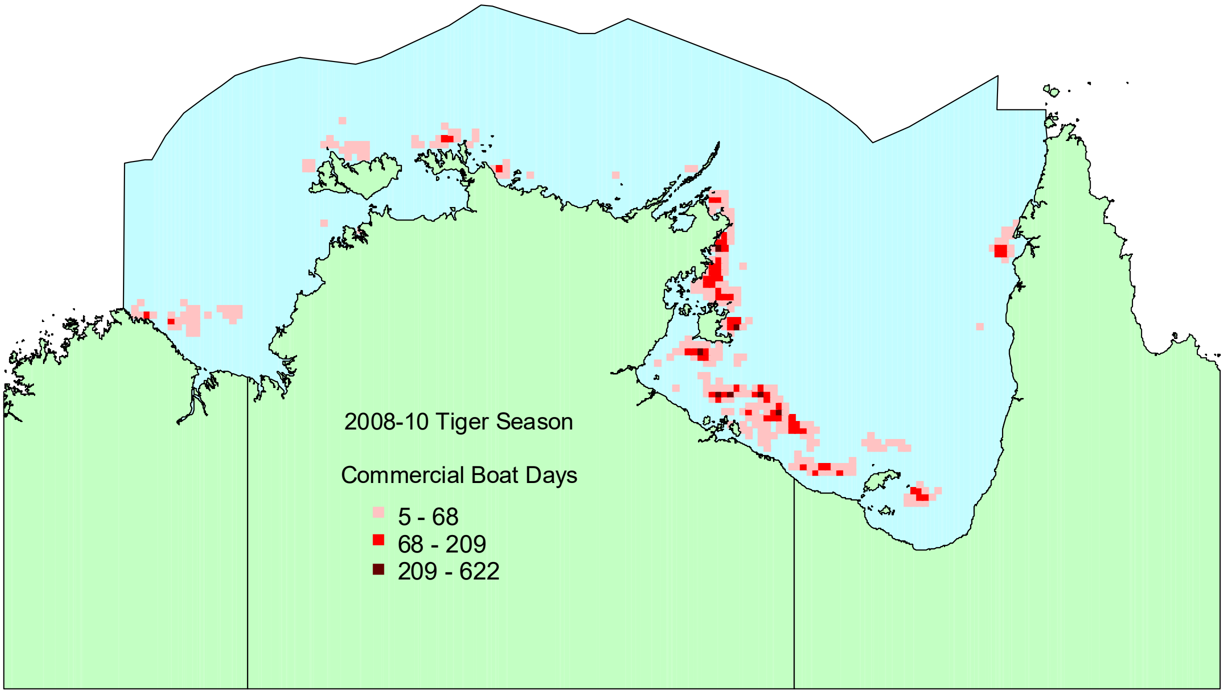
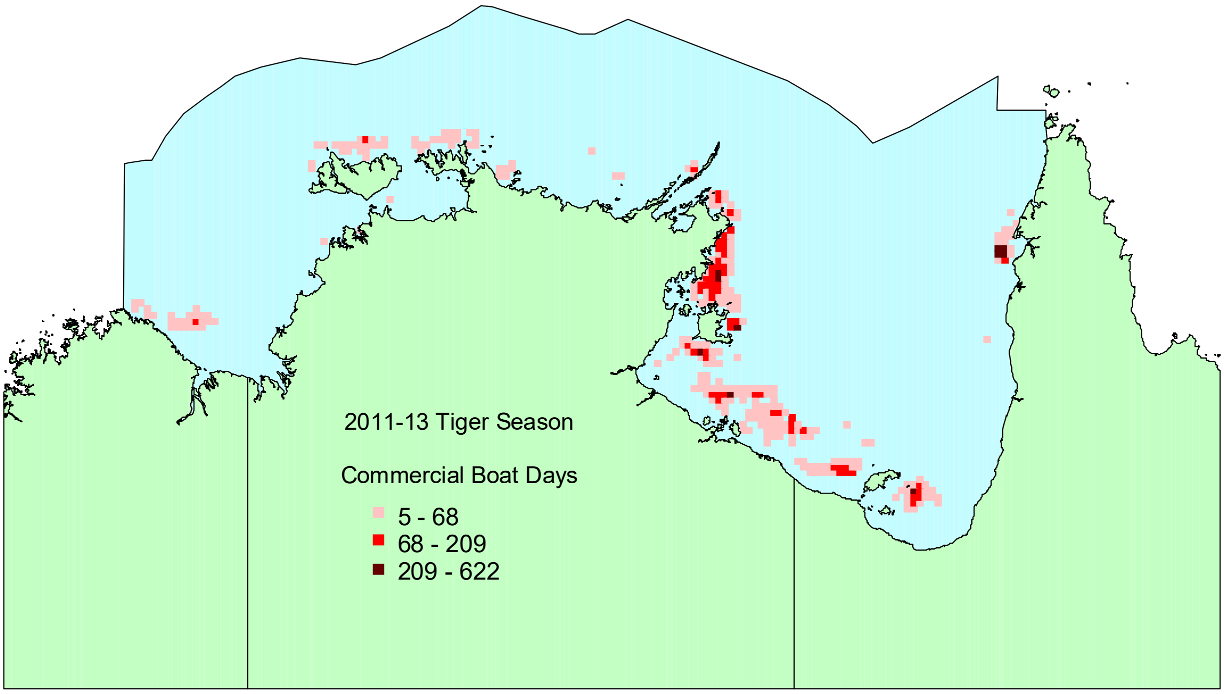

2017-19 Banana Season
Commercial Boat Days
5 - 26
26 - 66
66 - 176

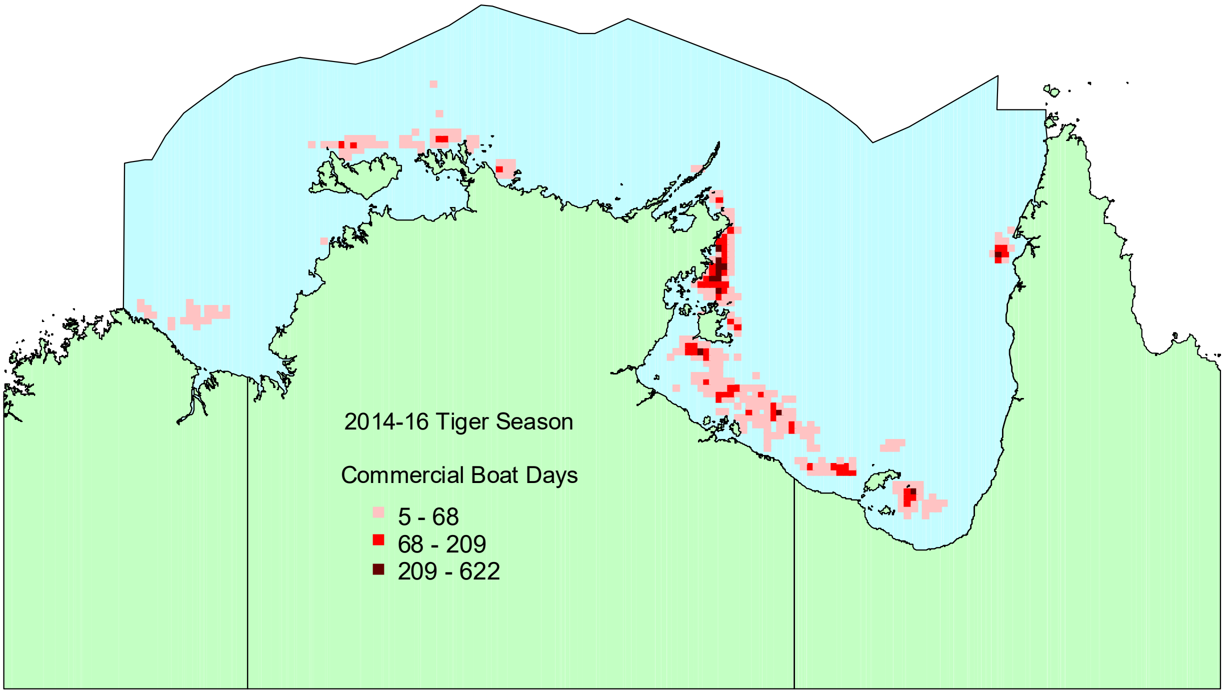
Figure 7: Maps showing the NPF commercial trawl effort distribution (boat days ≥5 days) in each 6 nautical mile grid for the 2002-04, 2005-07, 2008-10, 2011-13, 2014-16 and 2017-19 tiger prawn seasons across the Northern Prawn Fishery.


2002-04 Tiger Season
Commercial Boat Days
5 - 68
68 - 209
209 - 622


2005-07 Tiger Season
Commercial Boat Days
5 - 68
68 - 209
209 - 622


2008-10 Tiger Season
Commercial Boat Days
5 - 68
68 - 209
209 - 622


2011-13 Tiger Season
Commercial Boat Days
5 - 68
68 - 209
209 - 622


2014-16 Tiger Season
Commercial Boat Days
5 - 68
68 - 209
209 - 622

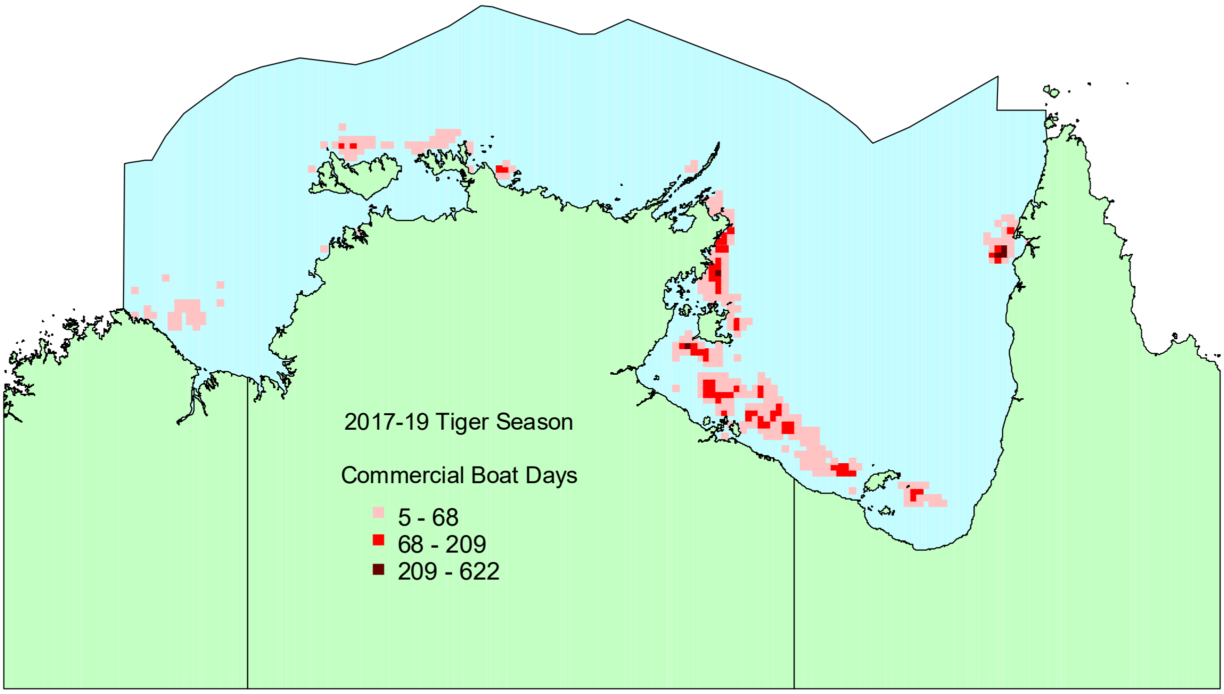
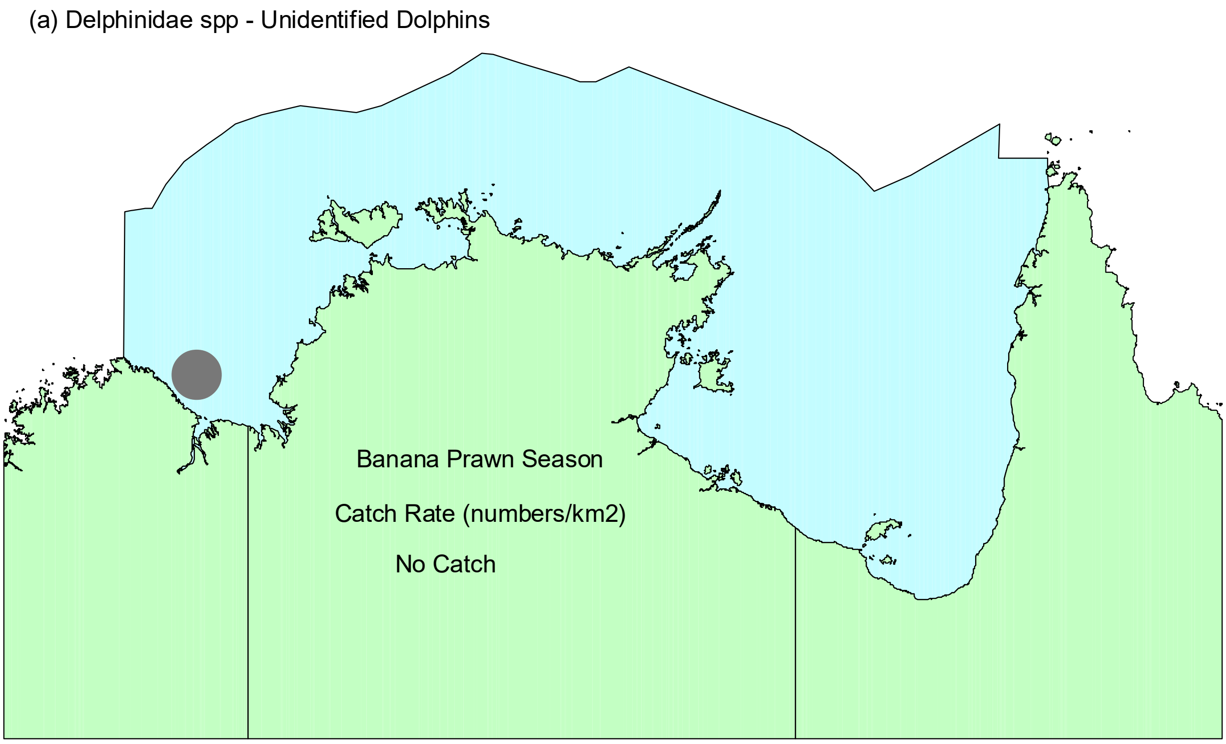

2017-19 Tiger Season
Commercial Boat Days
5 - 68
68 - 209
209 - 622

Figure 8: Following maps showing the catch records (grey circles represent a position where a species has been recorded; presence data) and overall catch rates (numbers per km^2) during the banana (Top) and tiger (Bottom) prawn seasons for the dolphins; (a) Unidentified Delphinidae. Presence data includes all records from the crew-member observer program, AFMA scientific observer program, NPF prawn population monitoring surveys and CSIRO scientific research and observer surveys in the NPF. Catch rate data only includes data collected from the crew-member observer program, AFMA scientific observer program and the NPF prawn population monitoring surveys from 2002 to 2019.


(a) Delphinidae spp - Unidentified Dolphins
Banana Prawn Season
Catch Rate (numbers/km2)
No Catch

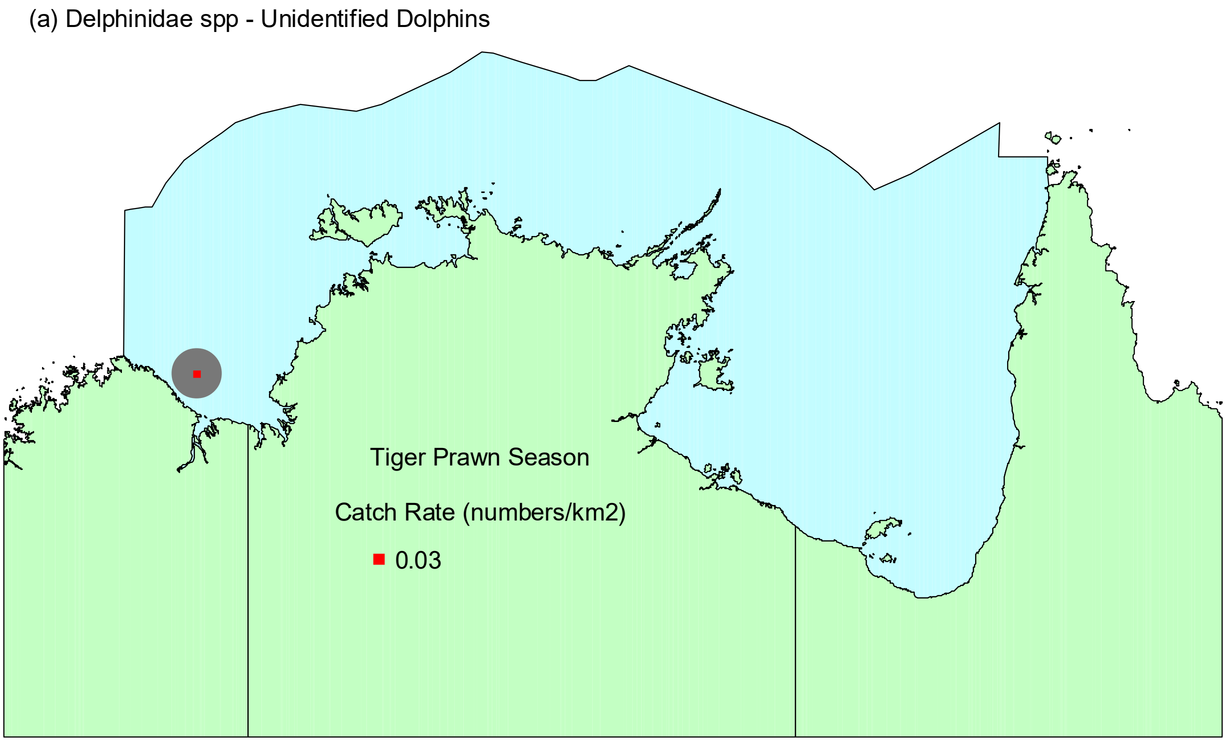
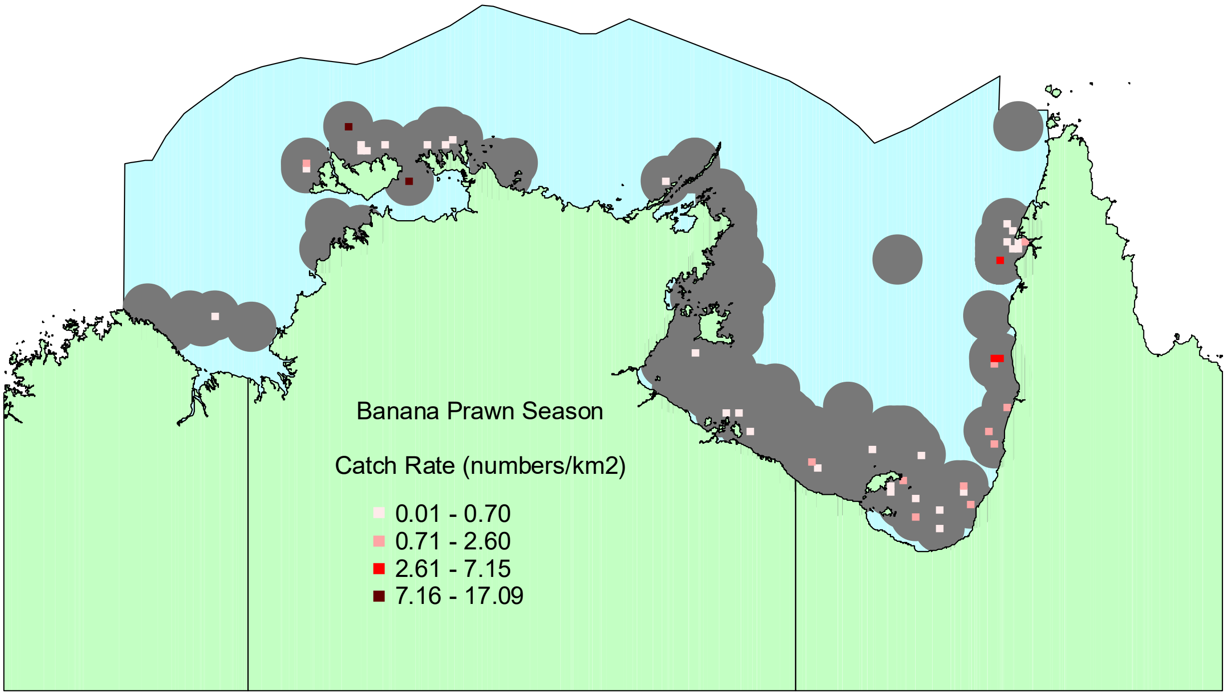
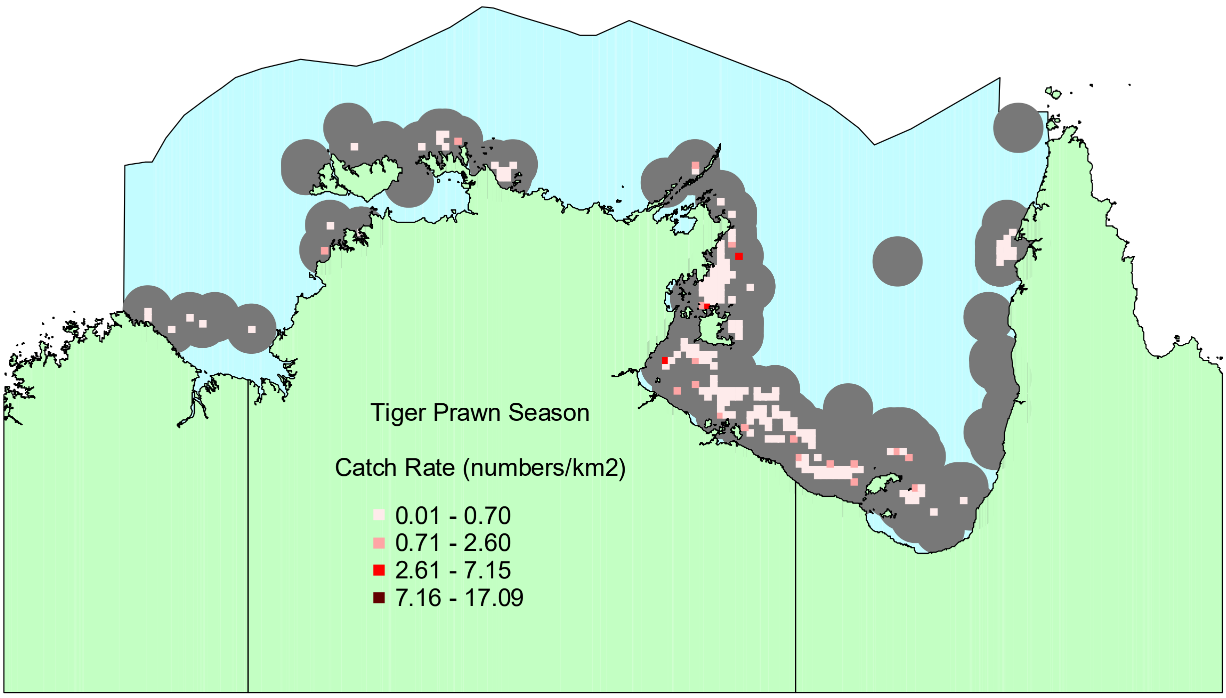

(a) Delphinidae spp - Unidentified Dolphins
Tiger Prawn Season
Catch Rate (numbers/km2)
0.03

Figure 9: Following maps showing the catch records (grey circles represent a position where a species has been recorded; presence data) and overall catch rates (numbers per km^2) during the banana (Top) and tiger (Bottom) prawn seasons for the marine turtles; (a) All Marine Turtles combined, (b) Unidentified Cheloniidae, (c) *Caretta caretta*, (d) *Chelonia mydas*, (e) *Eretmochelys imbricata*, (f) *Lepidochelys olivacea* and (g) *Natator depressus*. Presence data includes all records from the crew-member observer program, AFMA scientific observer program, NPF prawn population monitoring surveys and CSIRO scientific research and observer surveys in the NPF. Catch rate data only includes data collected from the crew-member observer program, AFMA scientific observer program and the NPF prawn population monitoring surveys from 2002 to 2019.

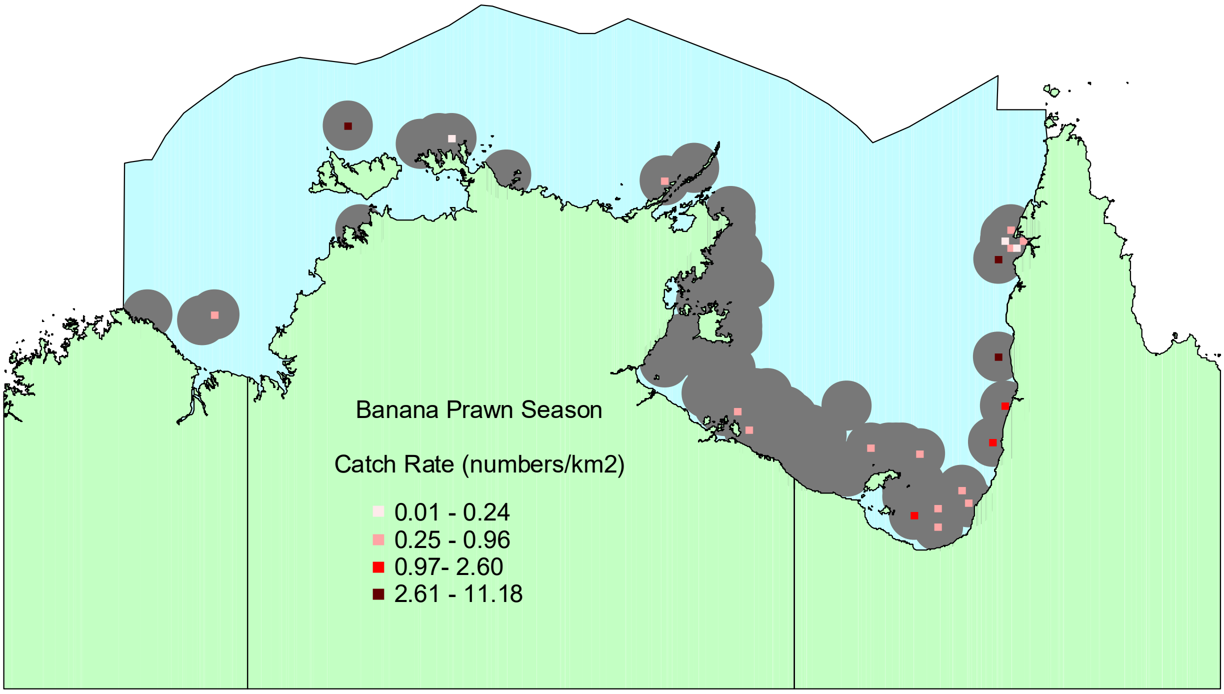
(a) Cheloniidae Group - All Marine Turtles



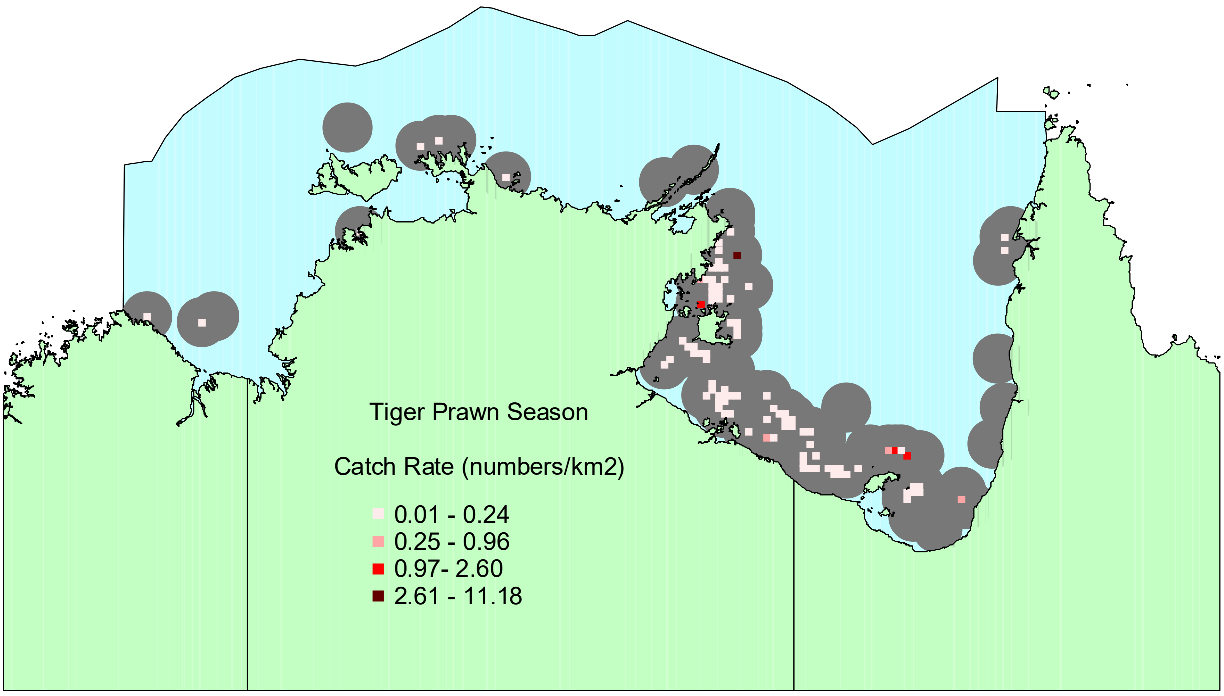
(a) Cheloniidae Group - All Marine Turtles



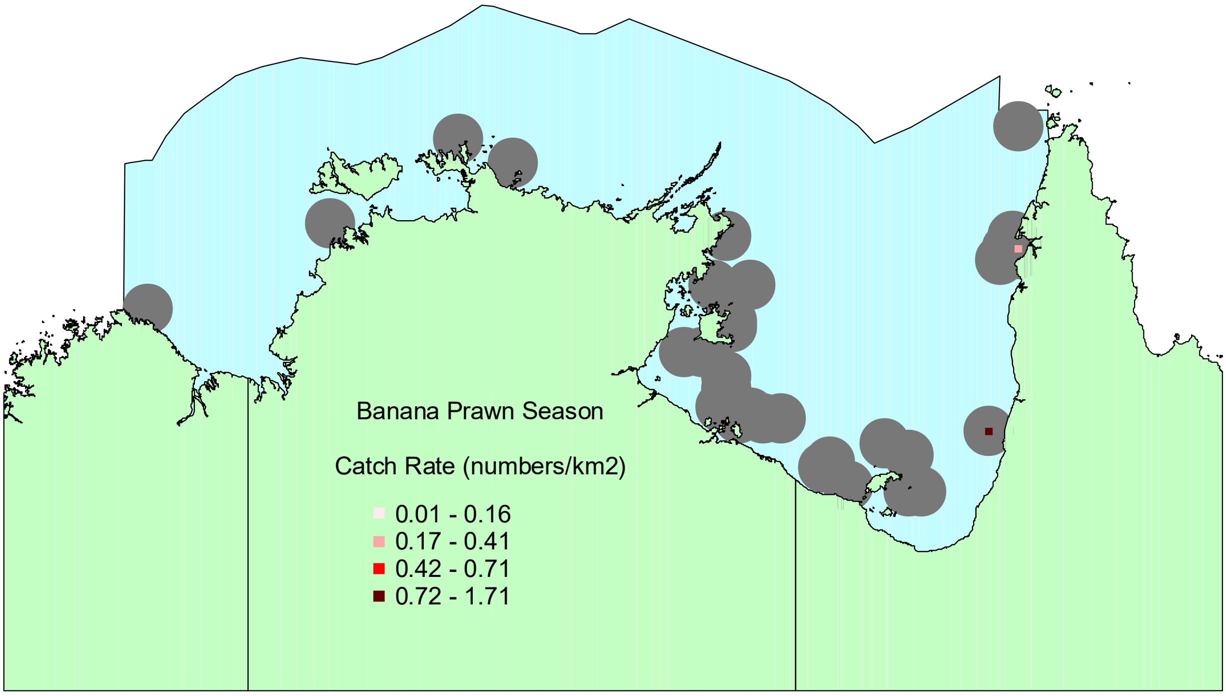
(b) Cheloniidae spp - Unidentified Marine Turtles



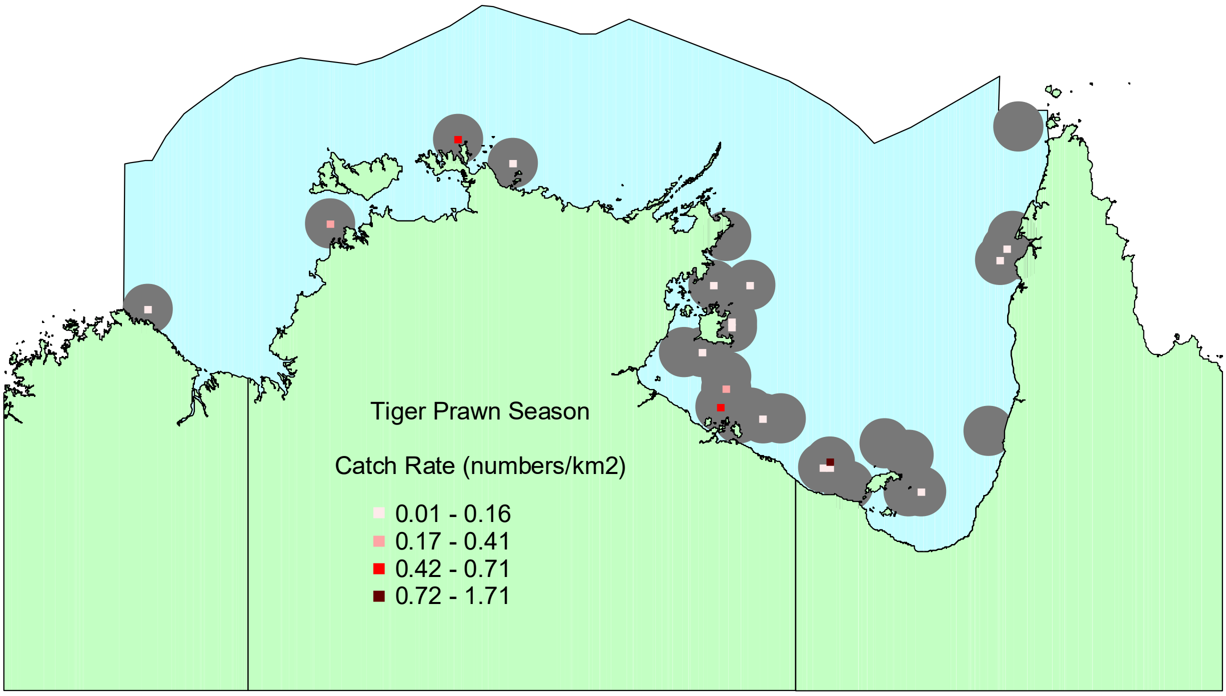
(b) Cheloniidae spp - Unidentified Marine Turtles



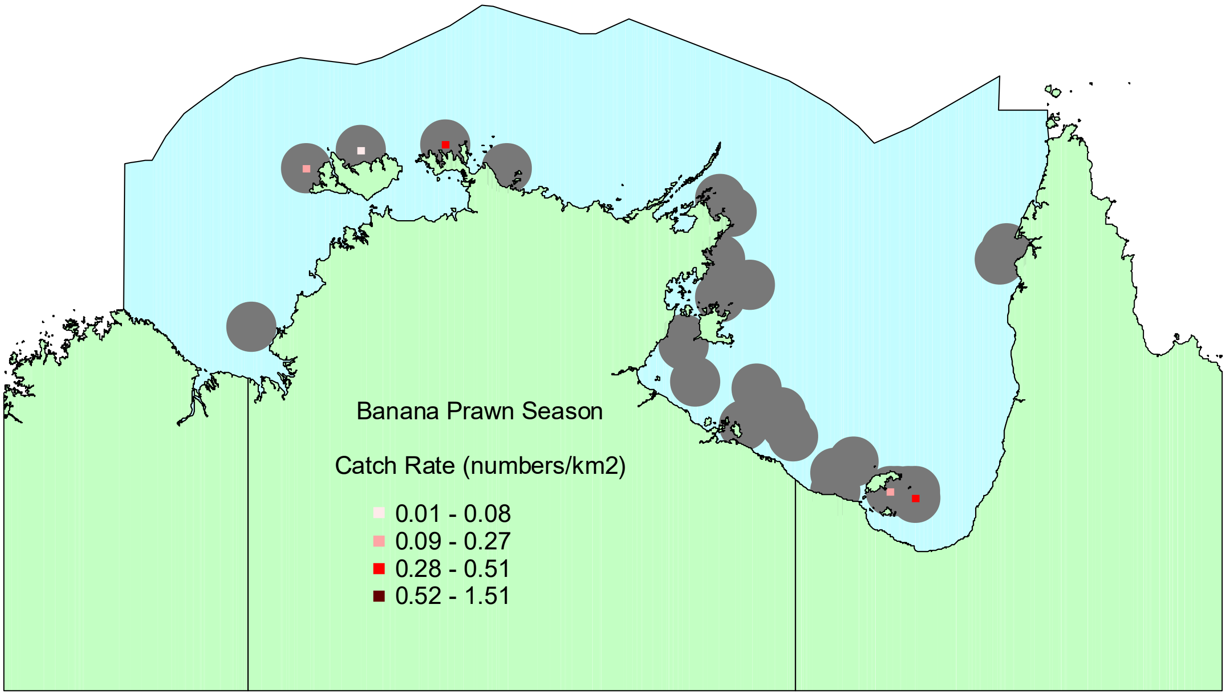
(c) Caretta caretta - Loggerhead Turtle



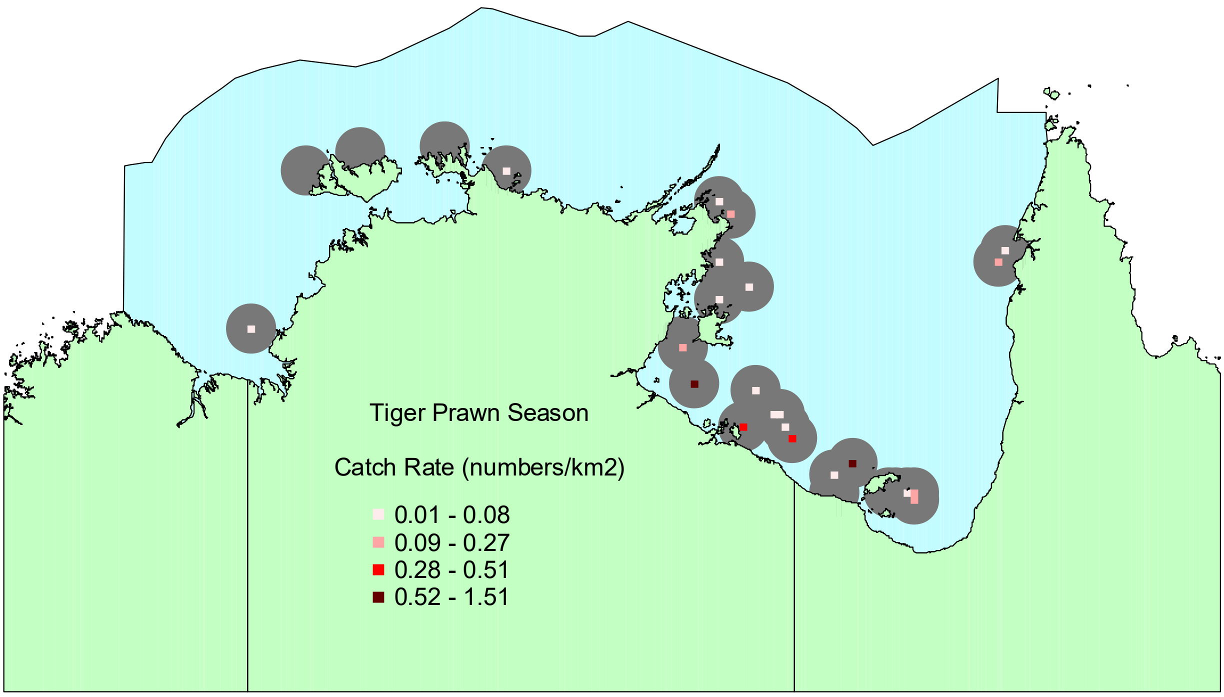
(c) Caretta caretta - Loggerhead Turtle



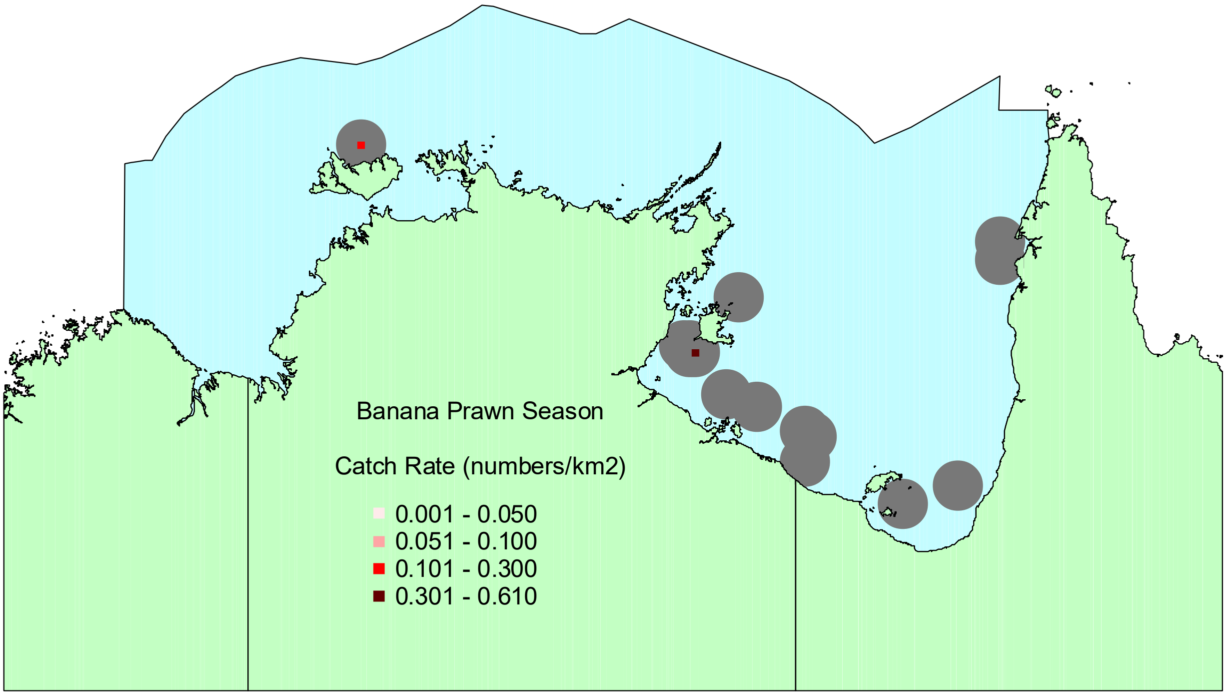
(d) Chelonia mydas - Green Turtle



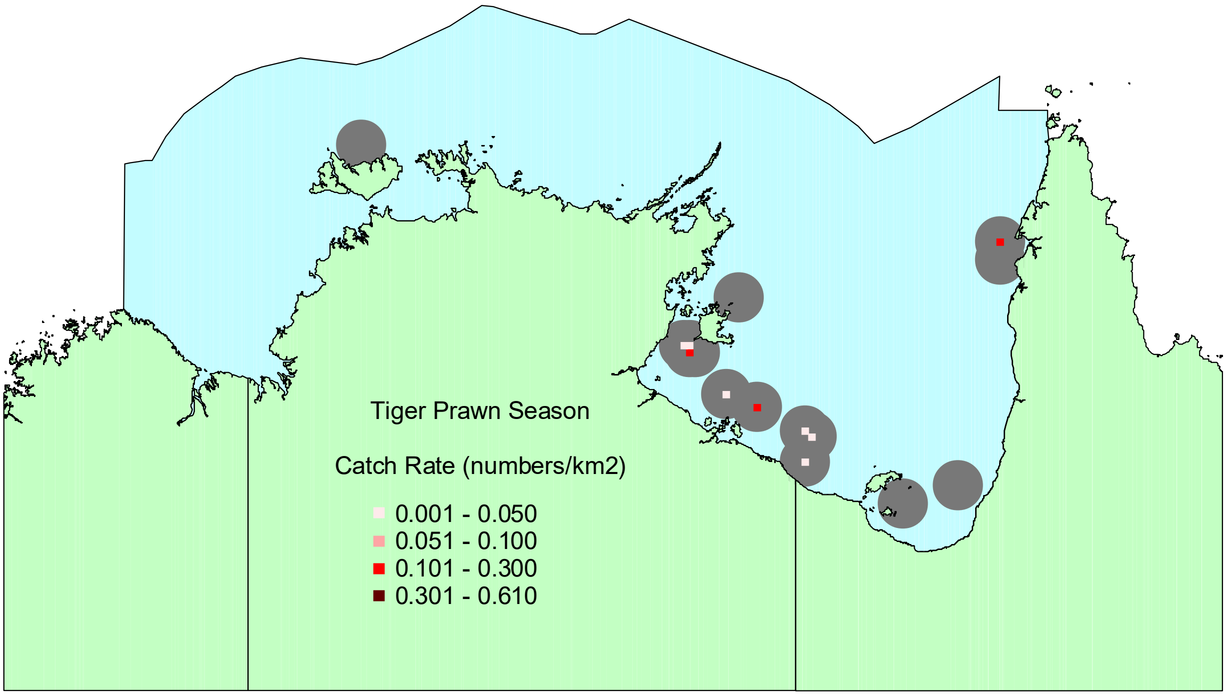
(d) Chelonia mydas - Green Turtle



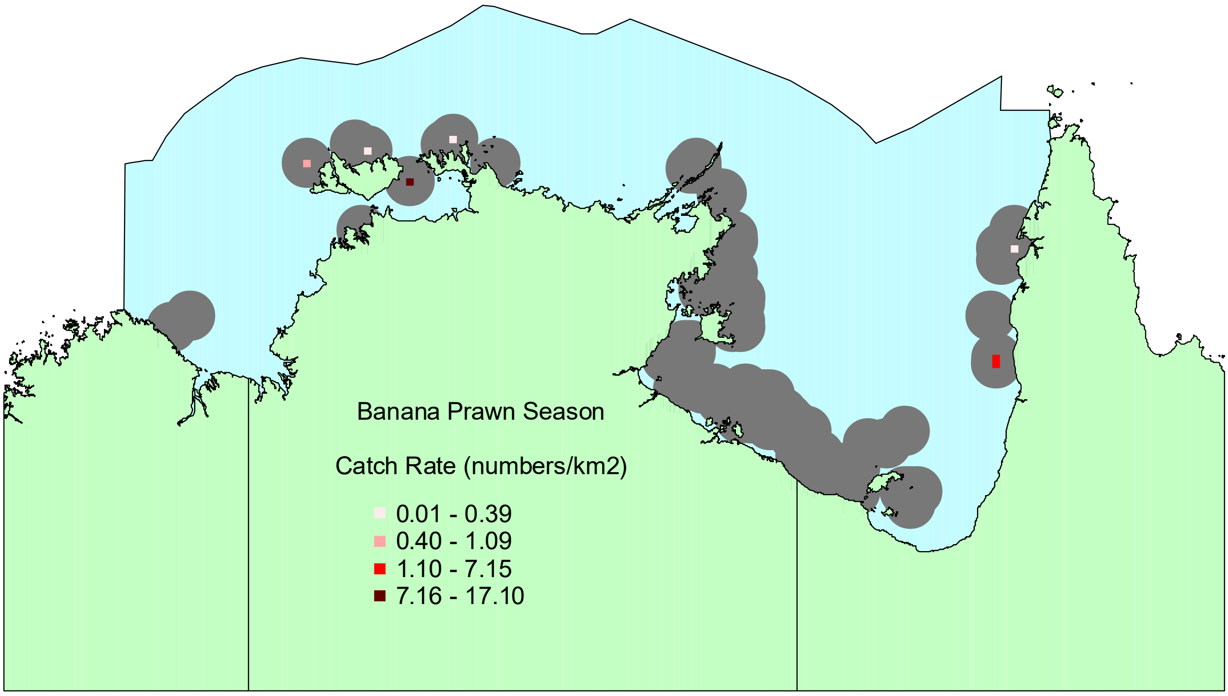
(e) Eretmochelys imbricata - Hawksbill Turtle



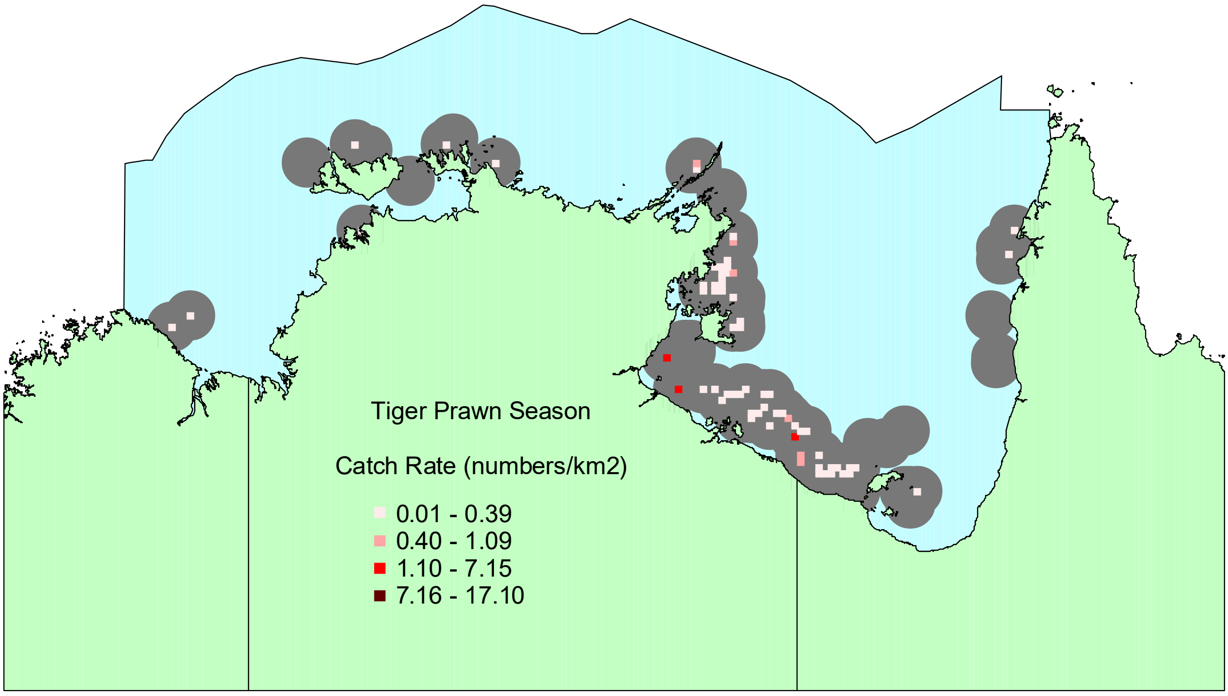
(e) Eretmochelys imbricata - Hawksbill Turtle



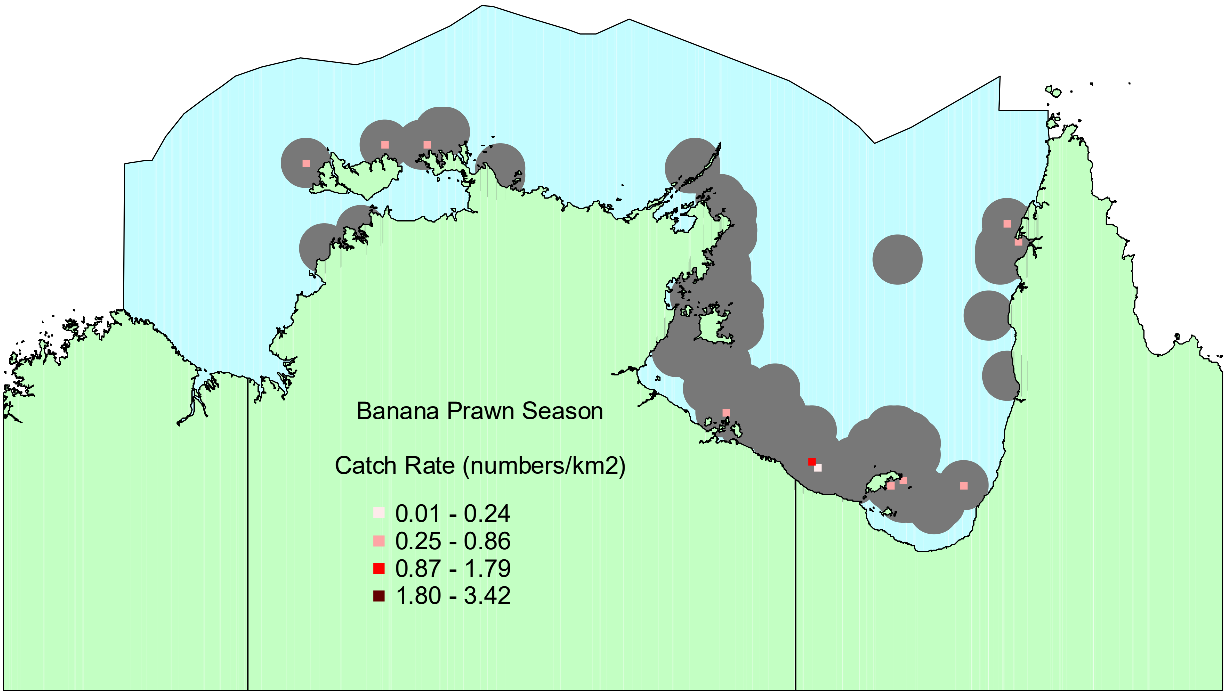
(f) Lepidochelys olivacea - Olive Ridley Turtle



(f) Lepidochelys olivacea - Olive Ridley Turtle



(g) Natator depressus - Flatback Turtle



(g) Natator depressus - Flatback Turtle

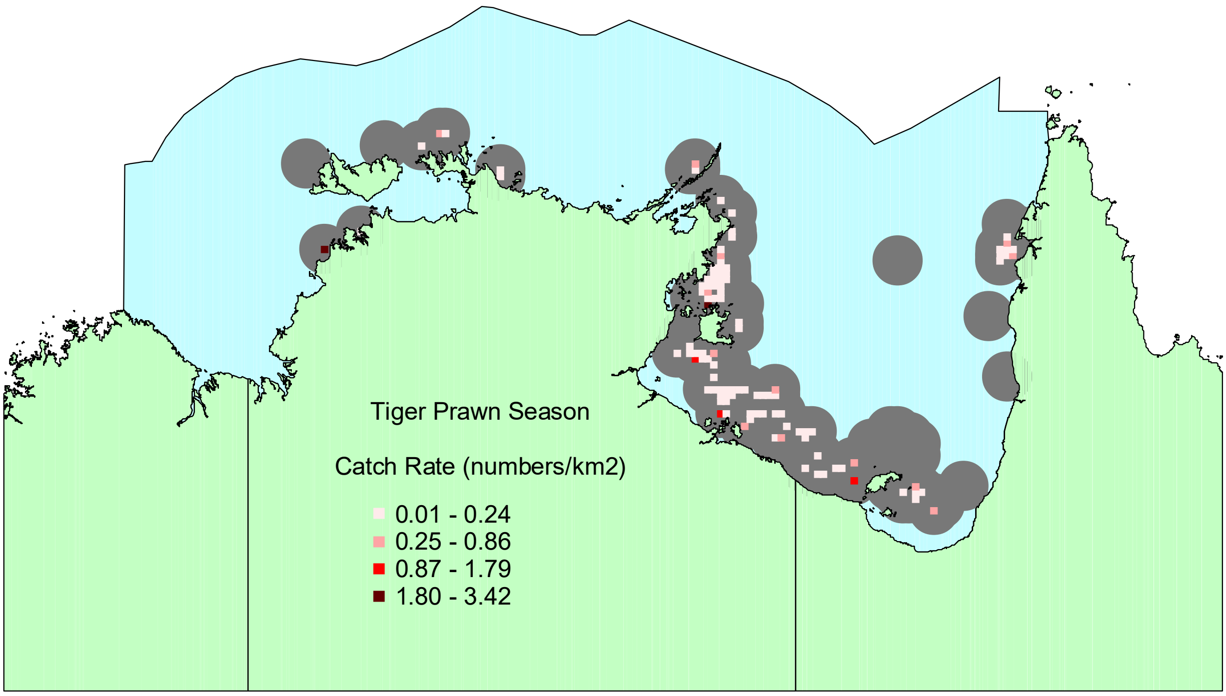
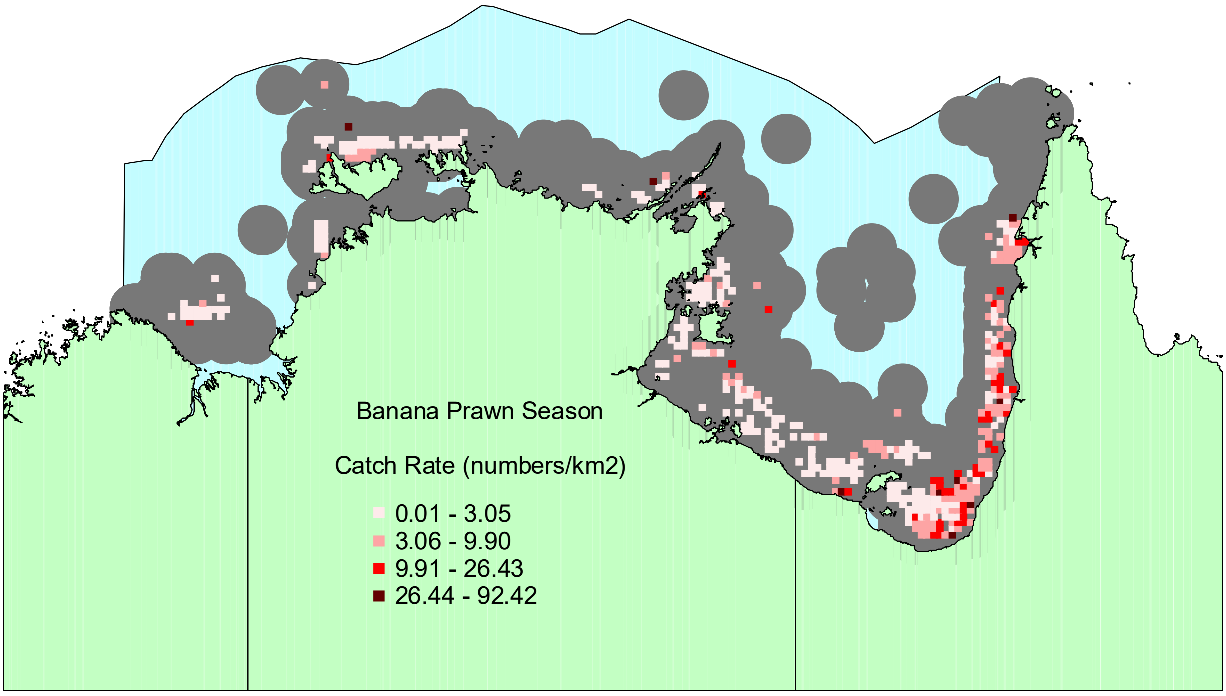
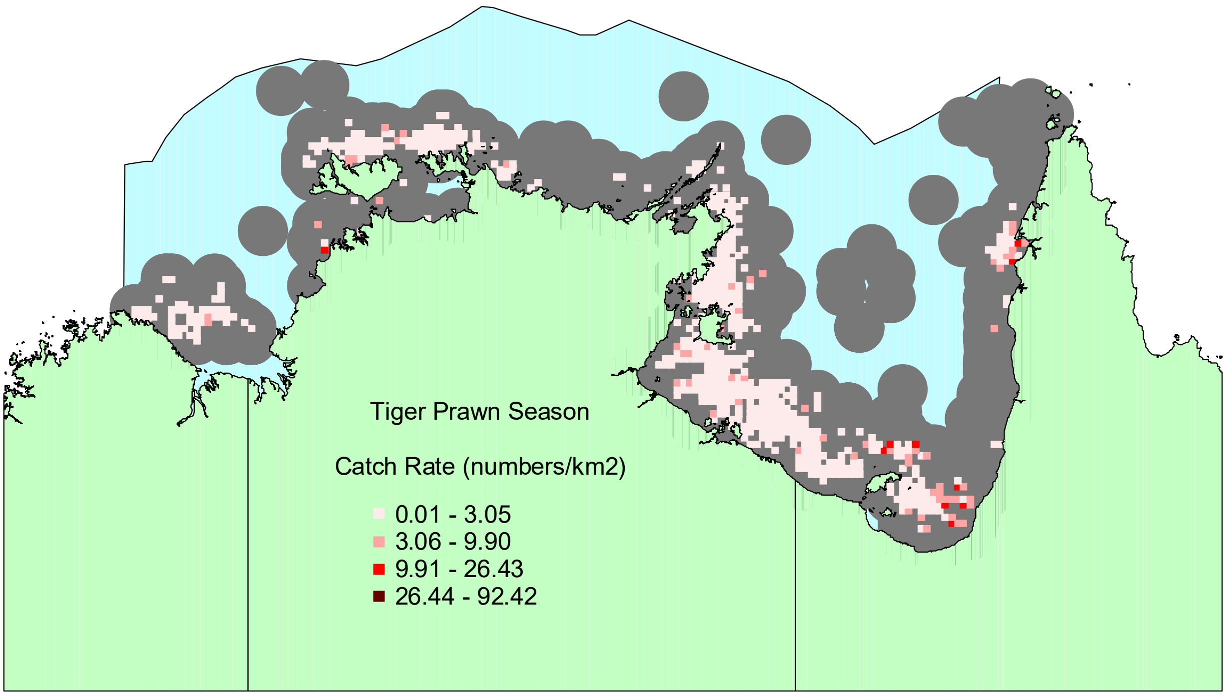


Figure 10: Following maps showing the catch records (grey circles represent a position where a species has been recorded; presence data) and overall catch rates (numbers per km^2) during the banana (Top) and tiger (Bottom) prawn seasons for the sea snakes; (a) All Sea Snakes combined, (b) Unidentified Hydrophiidae, (c) *Acalyptophis peronii*, (d) *Aipysurus duboisii*, (e) *Aipysurus mosaicus*, (f) *Aipysurus laevis*, (g) *Astrotia stokesii*, (h) *Disteira kingii*, (i) *Disteira major*, (j) *Enhydrina schistosa*, (k) *Hydrophis elegans*, (l) *Hydrophis mcdowelli*, (m) *Hydrophis ornatus*, (n) *Hydrophis pacificus*, (o) *Lapemis curtis*, (p) *Pelamis platurus*, (q) *Hydrelaps darwiniensis*, (r) *Hydrophis atriceps*, (s) *Hydrophis caerulescens*, (t) *Hydrophis inornatus*, (u) *Parahydrophis mertoni* and (v) *Hydrophis fasciatus*. Presence data includes all records from the crew-member observer program, AFMA scientific observer program, NPF prawn population monitoring surveys, CSIRO scientific research and observer surveys and Museum records in the NPF. Catch rate data only includes data collected from the crew-member observer program, AFMA scientific observer program and the NPF prawn population monitoring surveys from 2002 to 2019. Maps (q) to (v) only show presence data as no individuals were caught from 2002 to 2019.

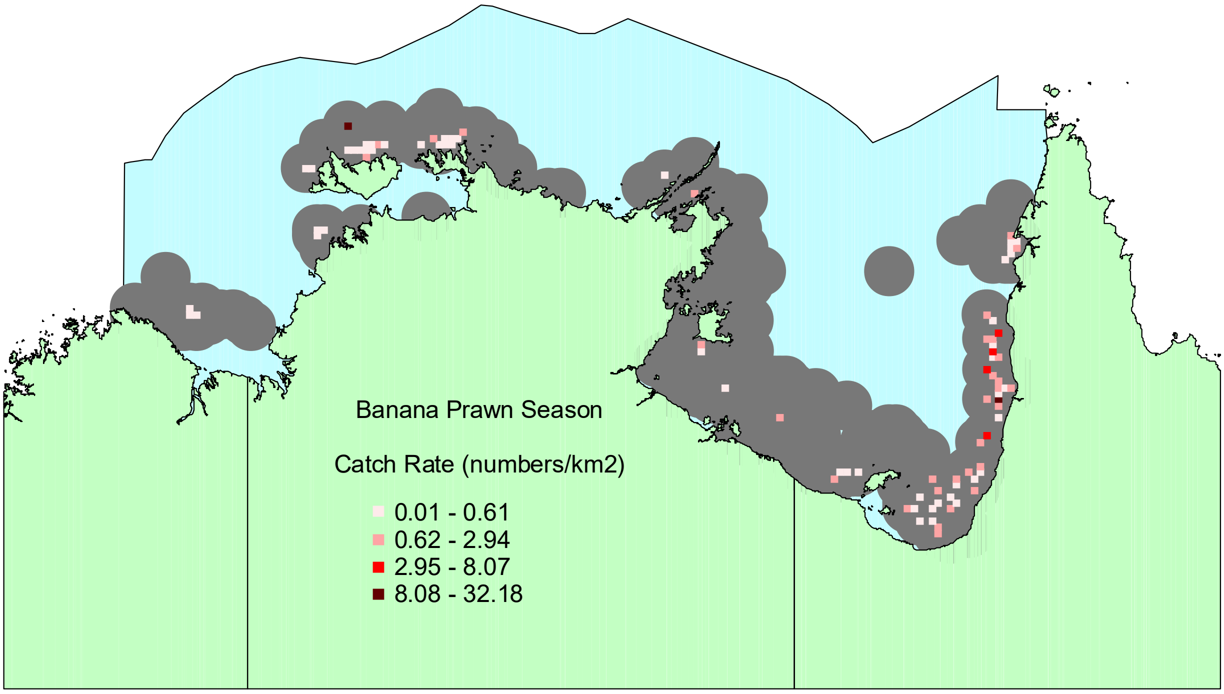
(a) Hydrophiidae Group - All Sea Snakes



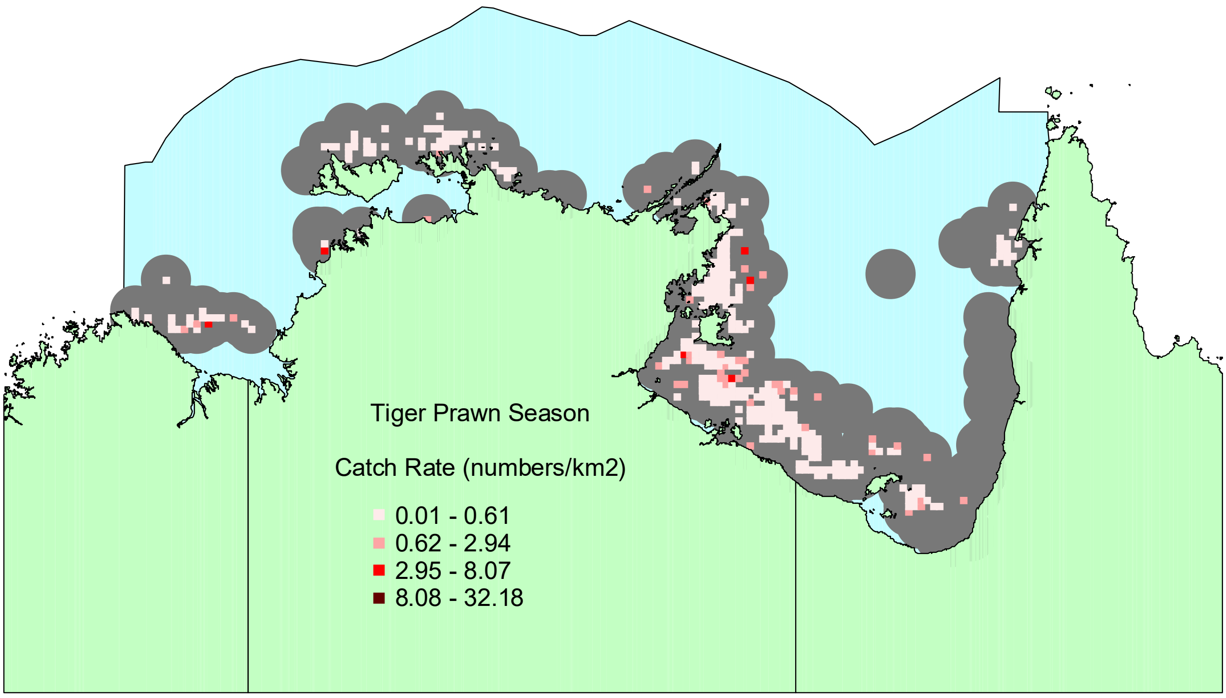
(a) Hydrophiidae Group - All Sea Snakes



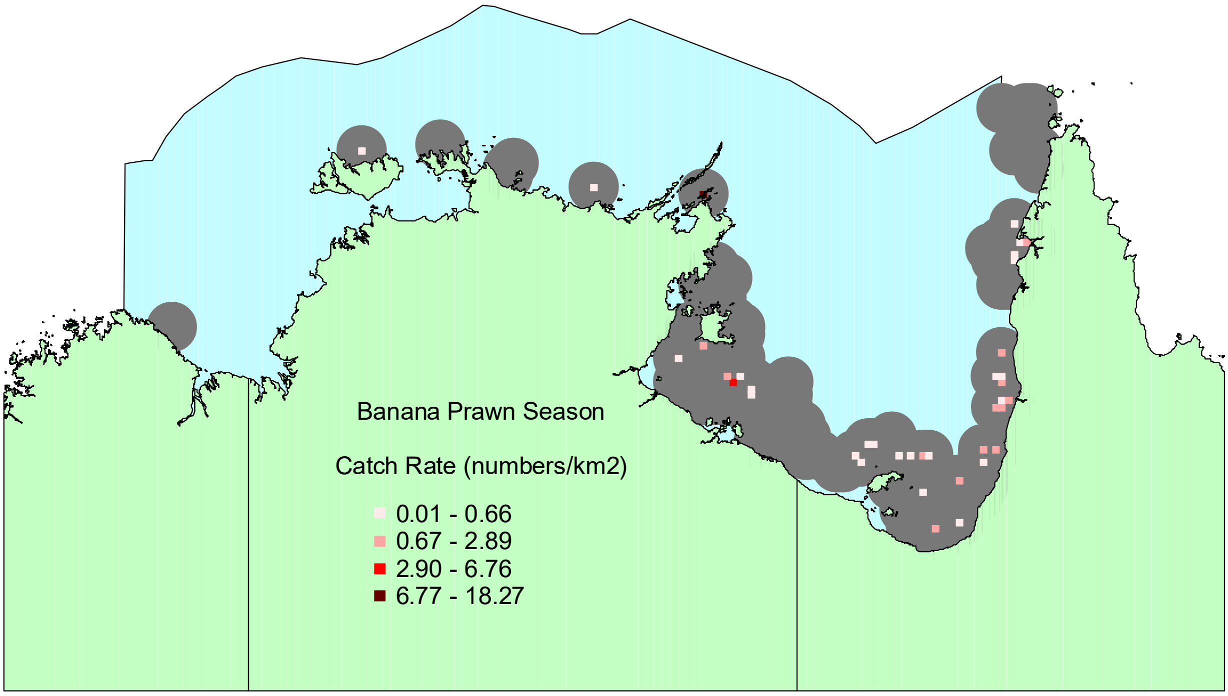
(b) Hydrophiidae spp - Unidentified Sea Snakes



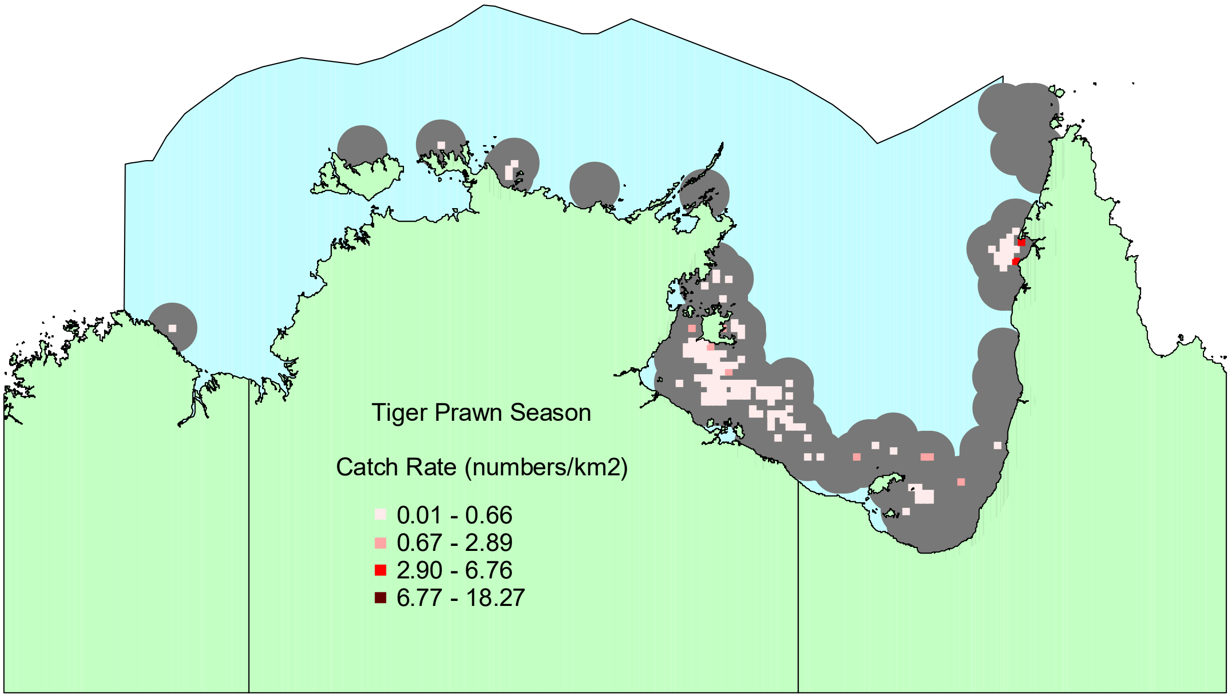
(b) Hydrophiidae spp - Unidentified Sea Snakes



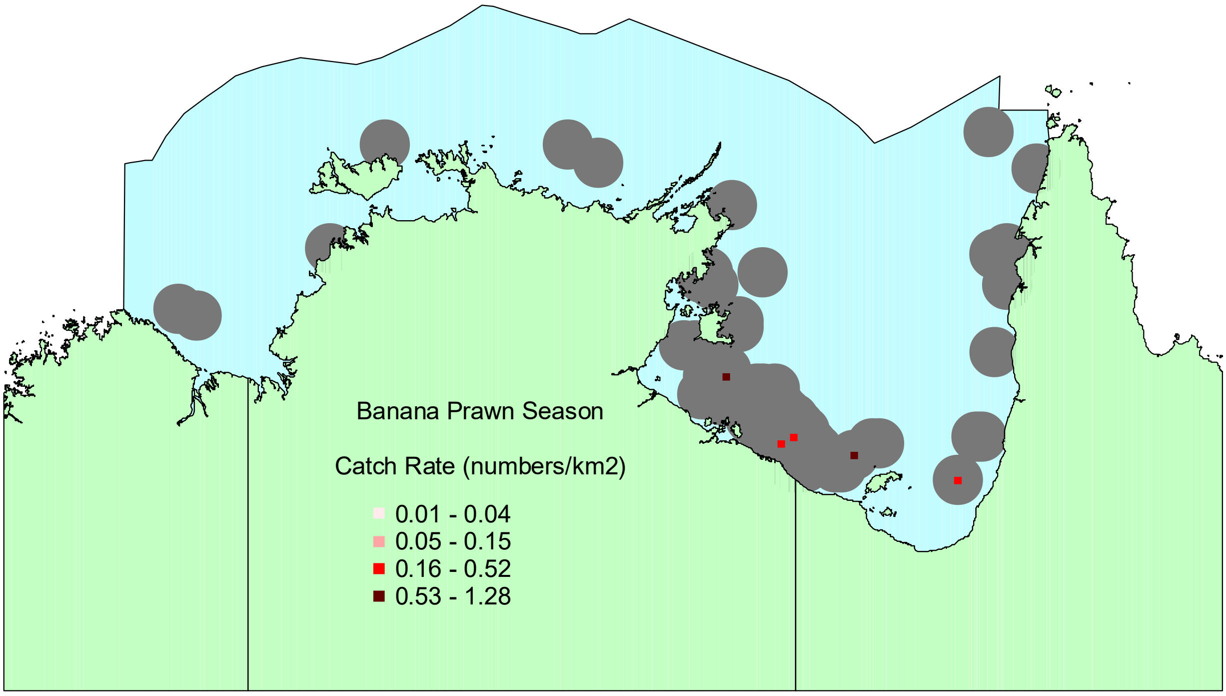
(c) Acalyptophis peronii - Horned Sea Snake



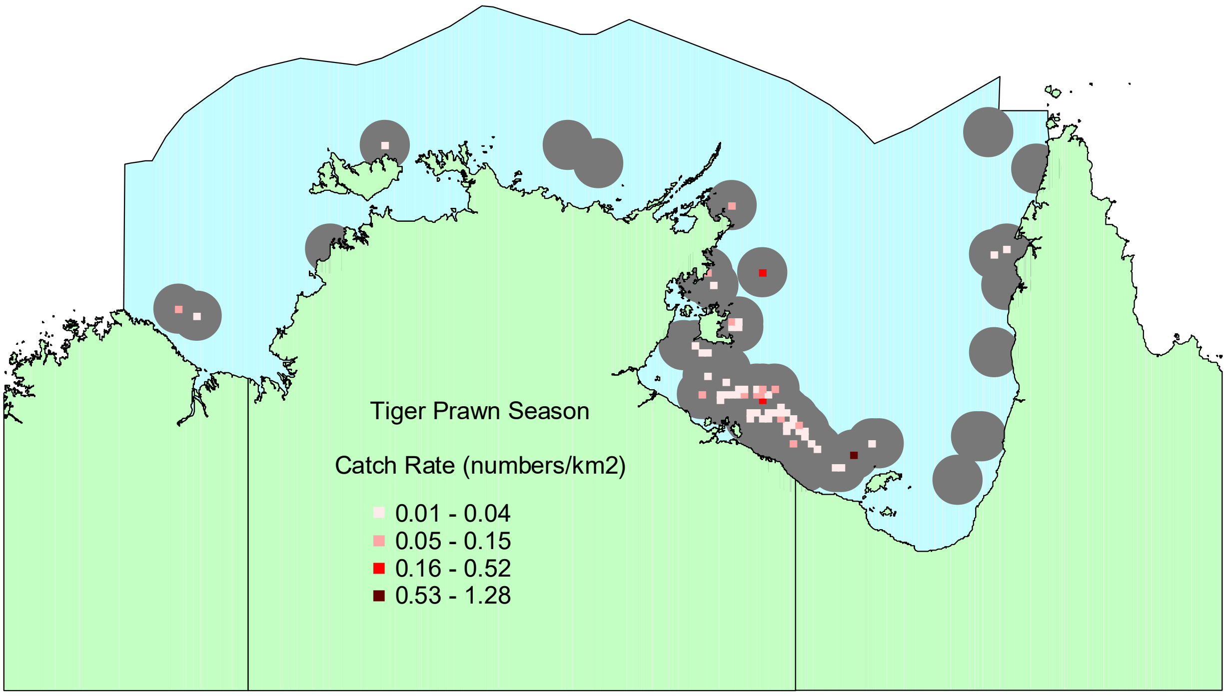
(c) Acalyptophis peronii - Horned Sea Snake



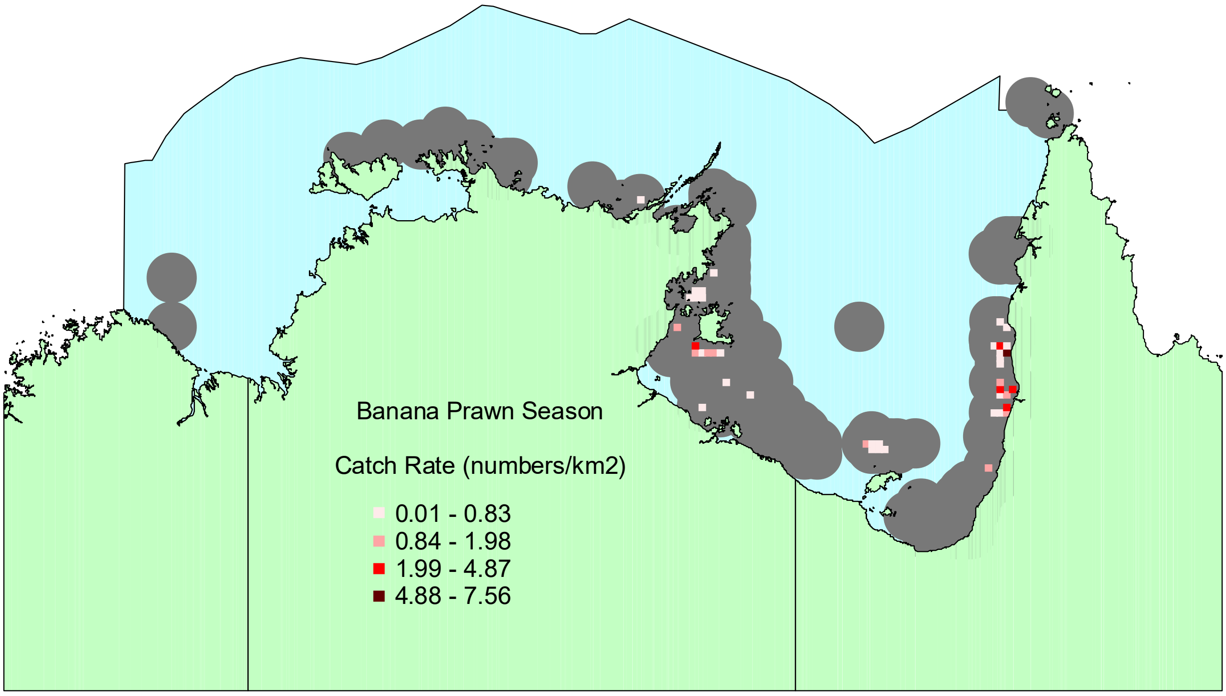
(d) Aipysurus duboisii - Dubois Sea Snake



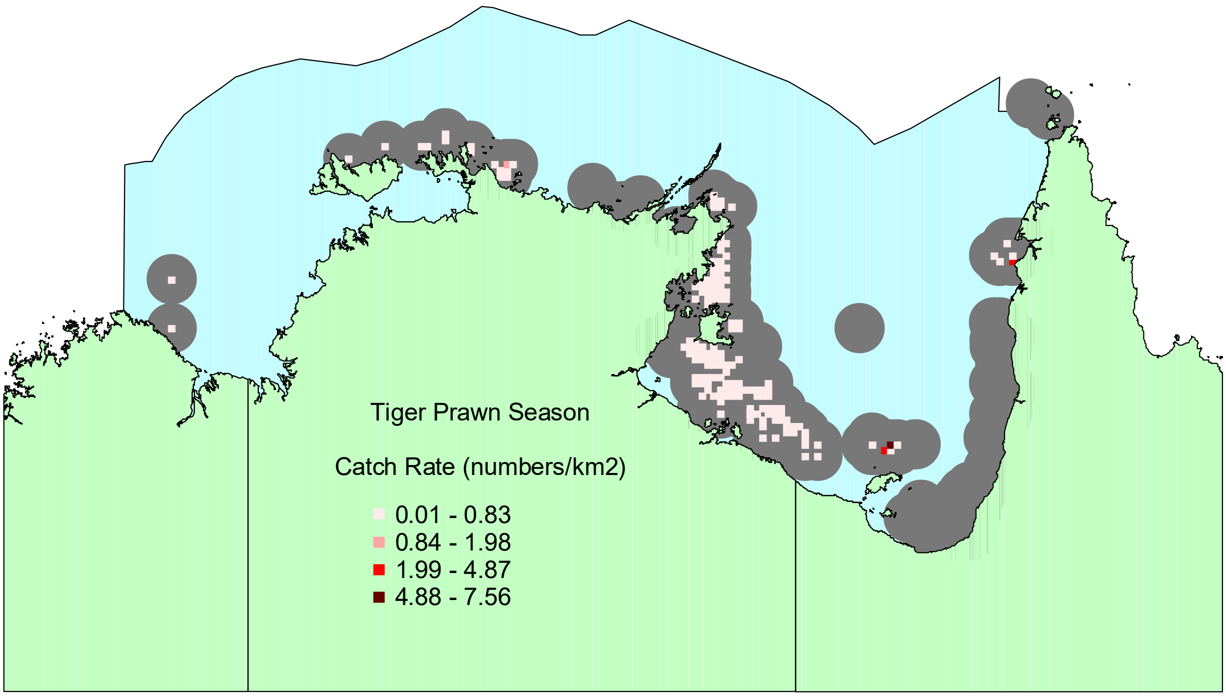
(d) Aipysurus duboisii - Dubois Sea Snake



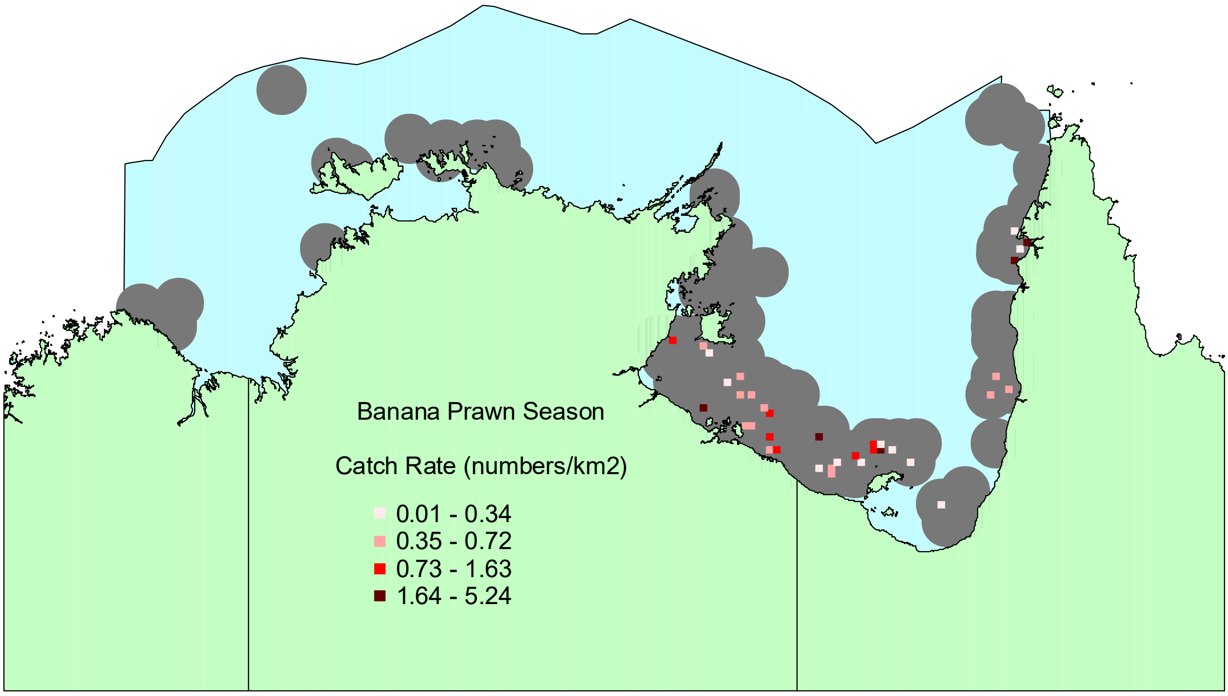
(e) Aipysurus mosaicus - Mosaic Sea Snake



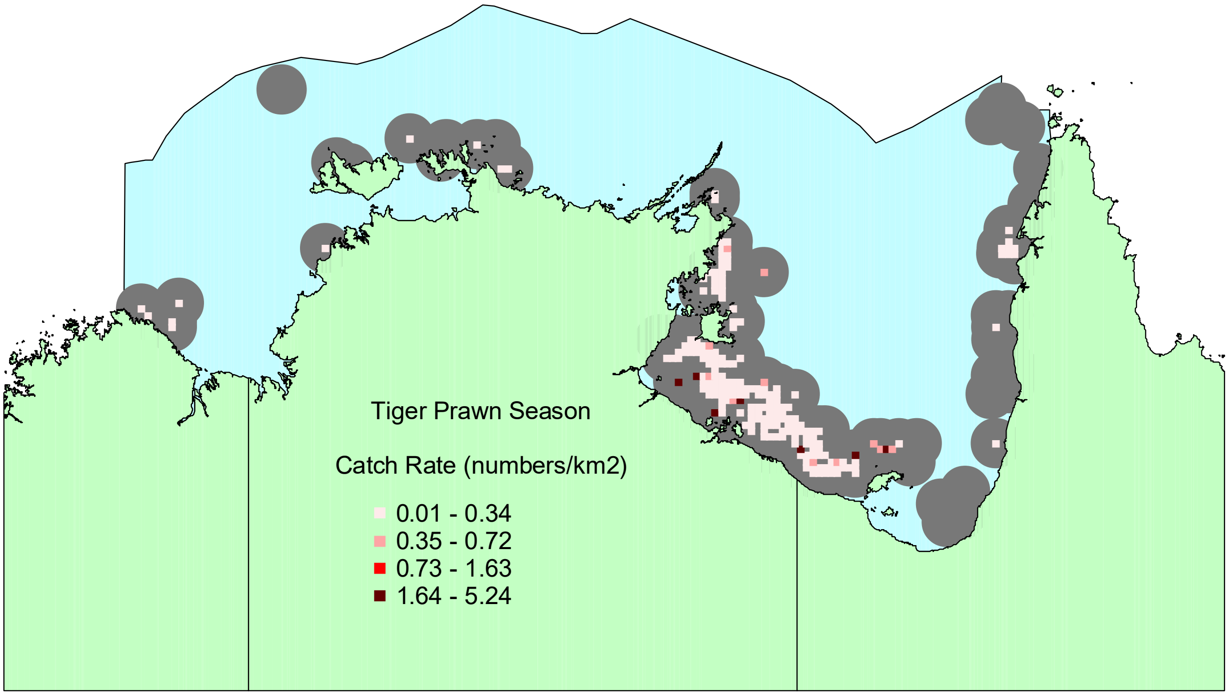
(e) Aipysurus mosaicus - Mosaic Sea Snake



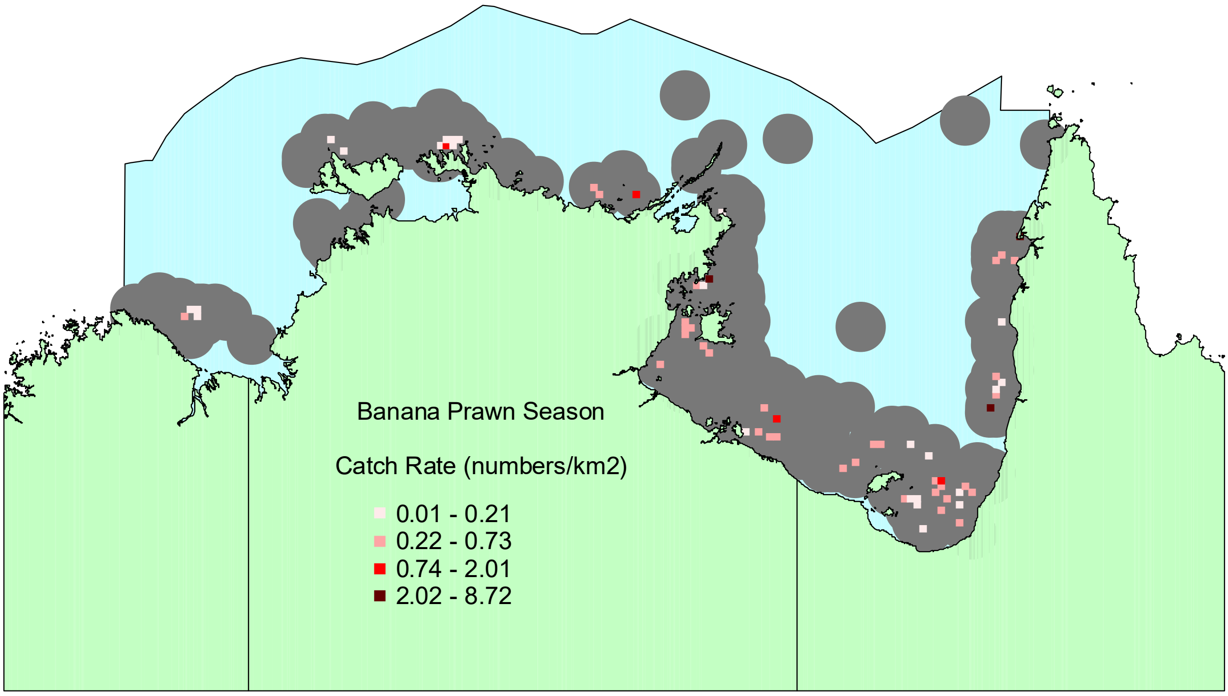
(f) Aipysurus laevis - Olive Sea Snake



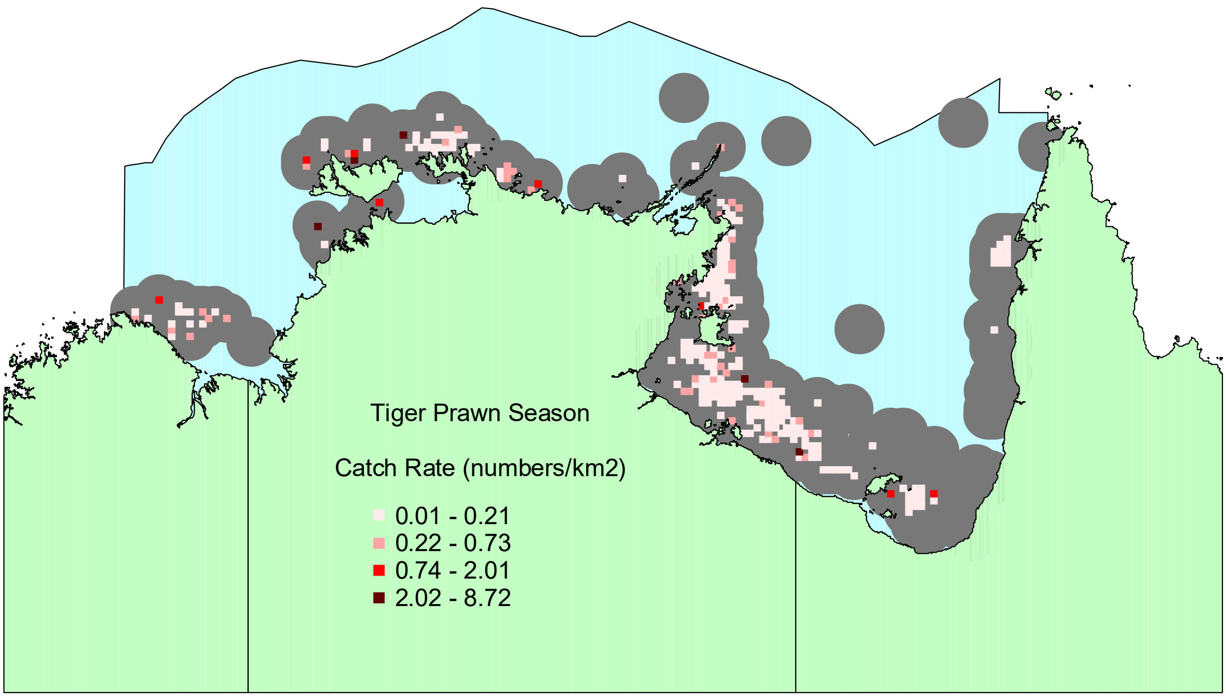
(f) Aipysurus laevis - Olive Sea Snake



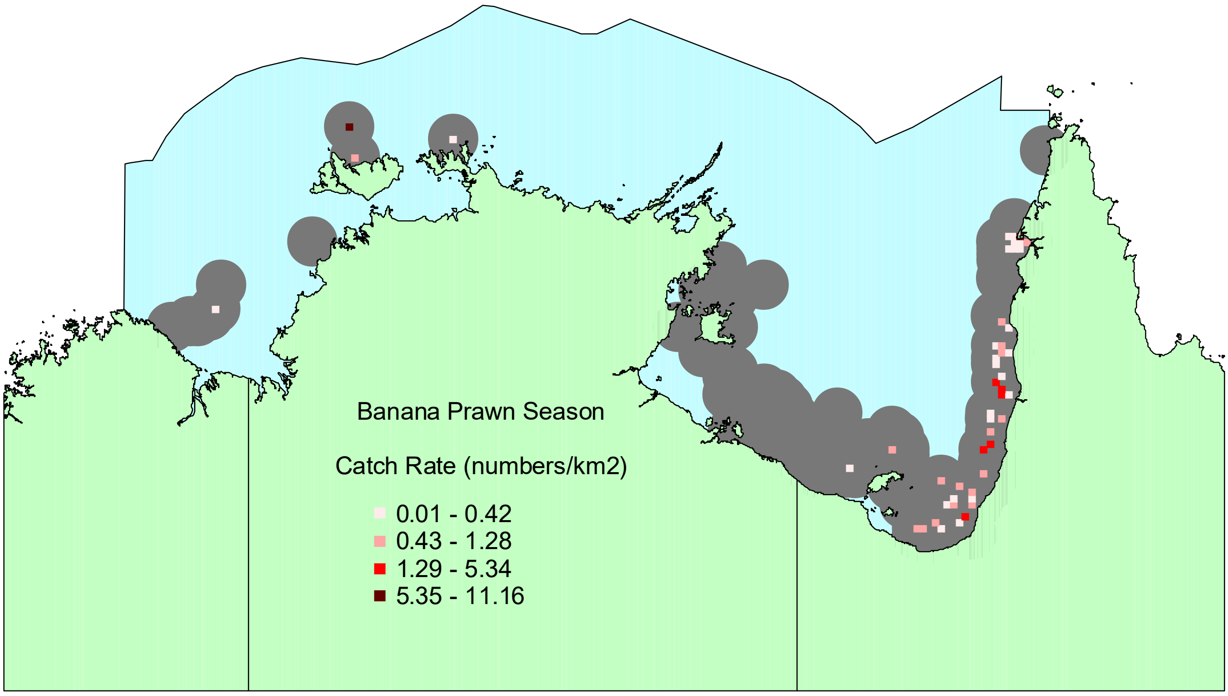
(g) Astrotia stokesii - Stokes Sea Snake



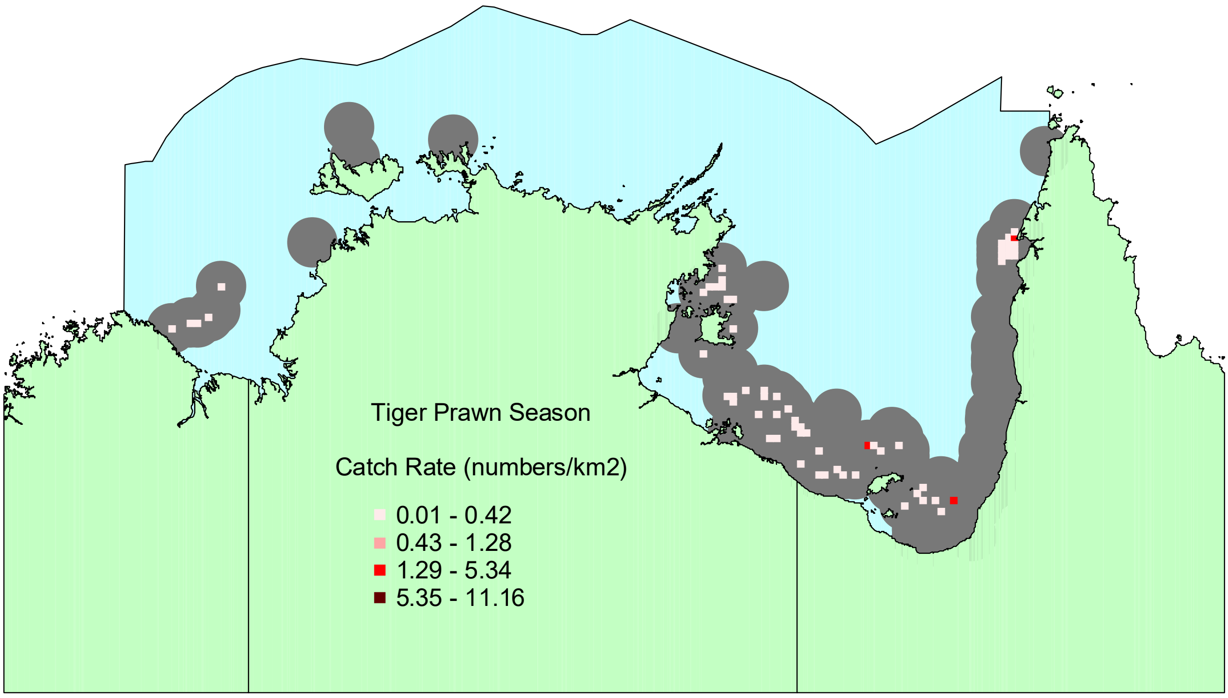
(g) Astrotia stokesii - Stokes Sea Snake



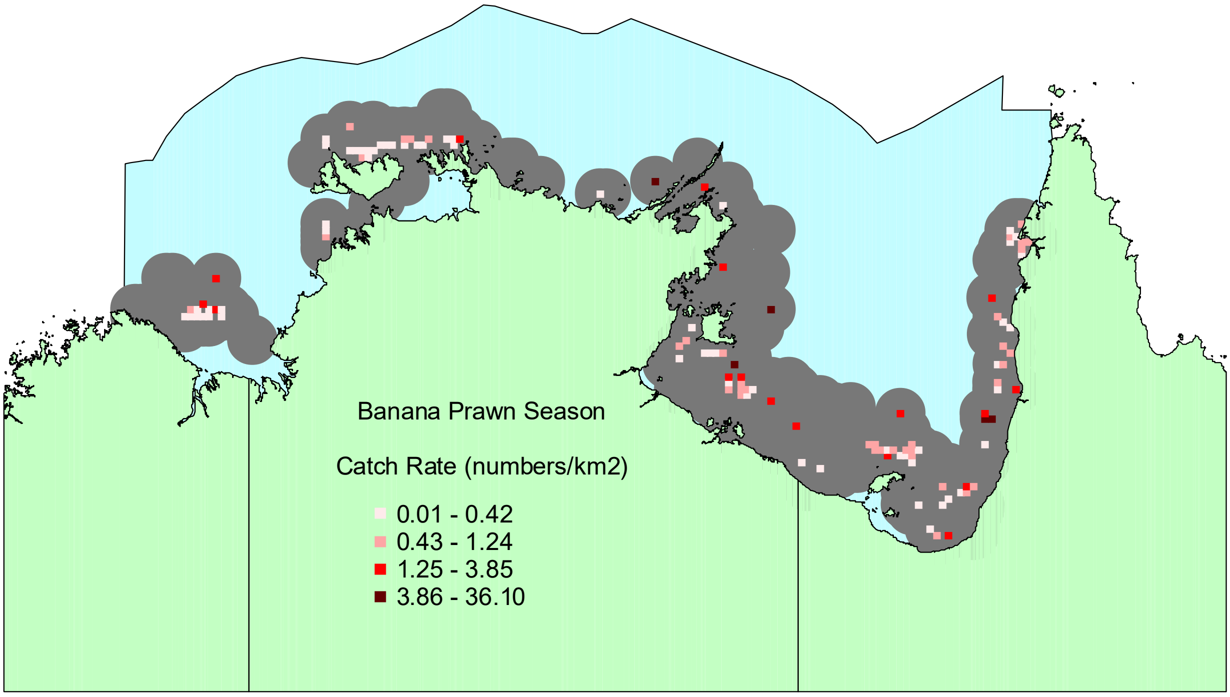
(h) Disteira kingii - Spectacled Sea Snake



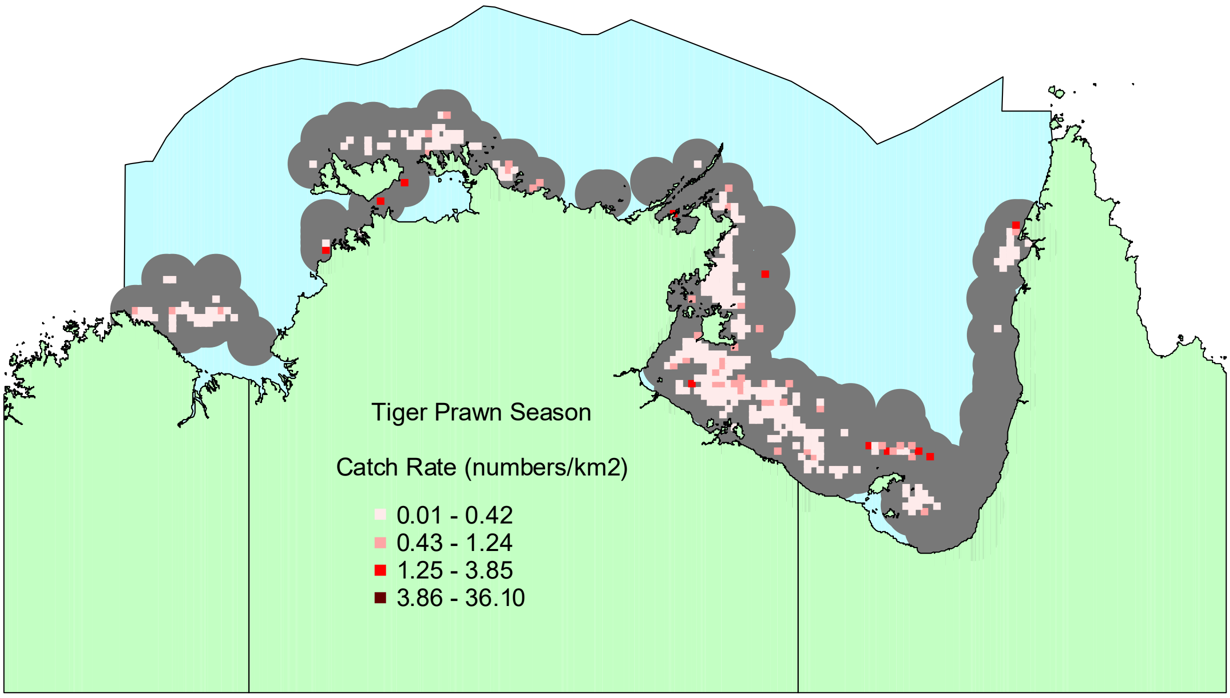
(h) Disteira kingii - Spectacled Sea Snake



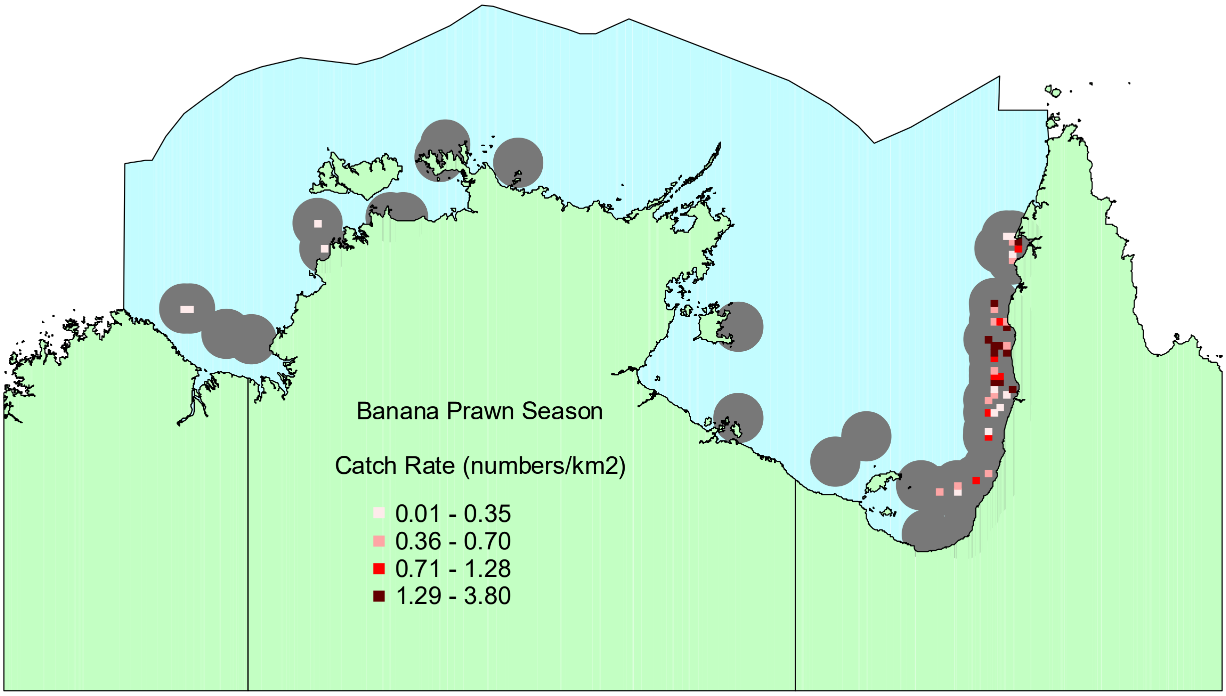
(i) Disteira major - Olive-headed Sea Snake



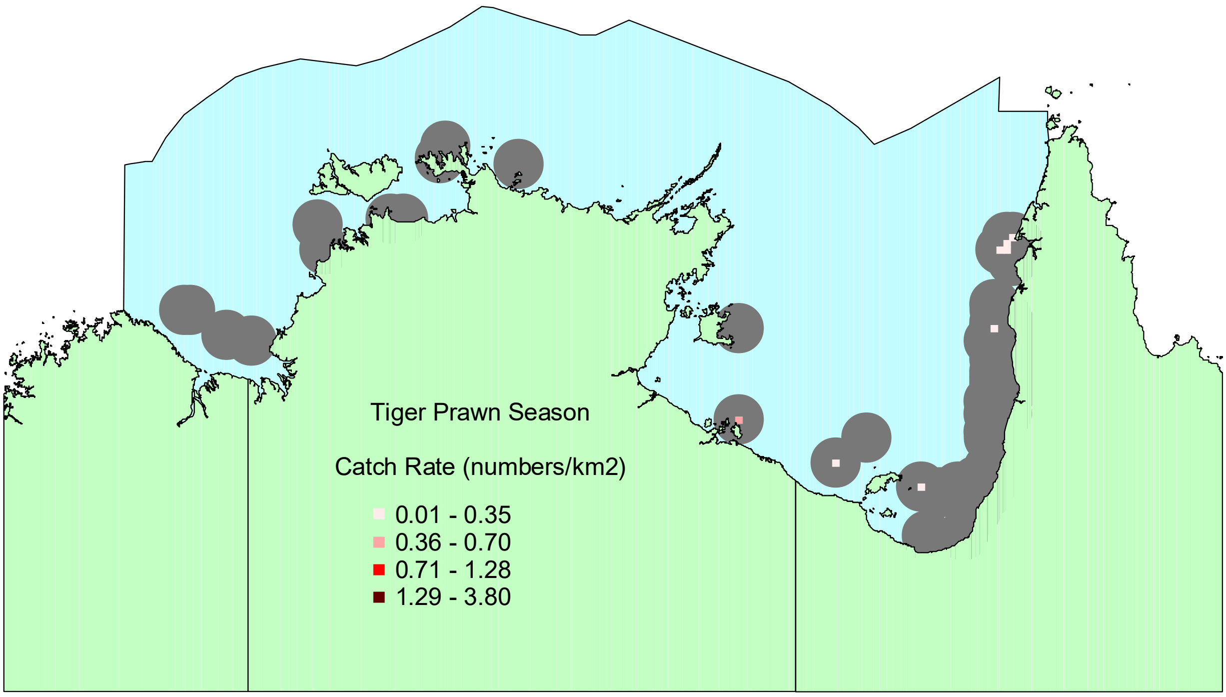
(i) Disteira major - Olive-headed Sea Snake



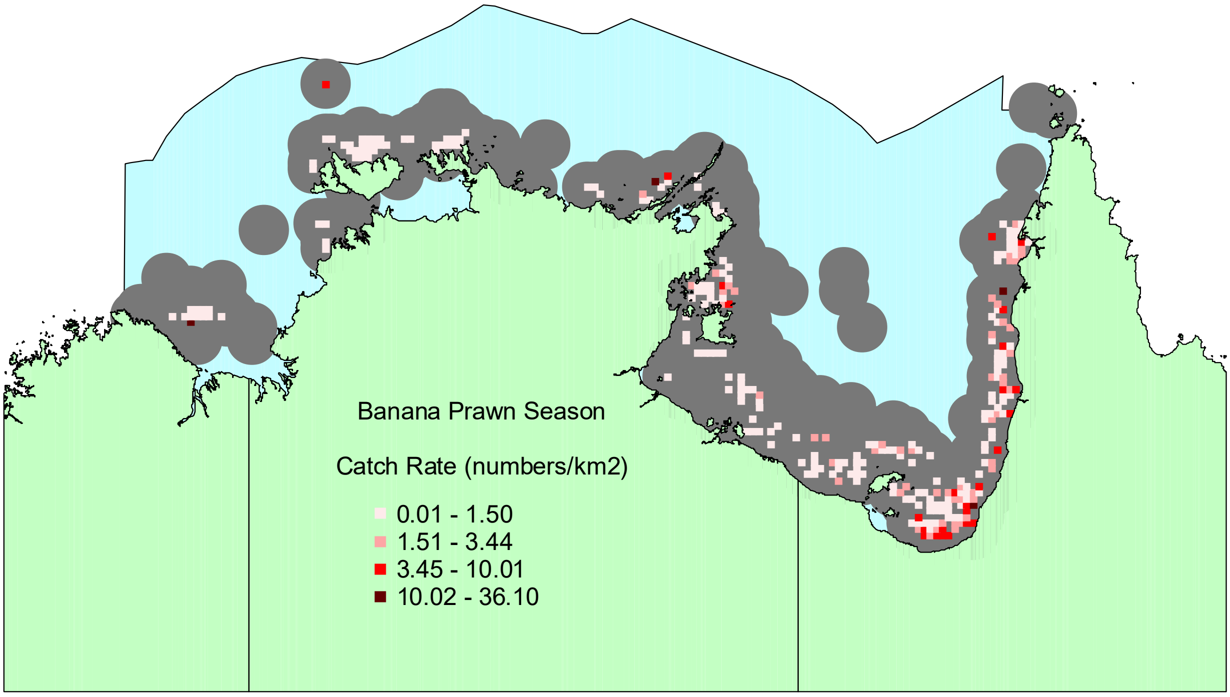
(j) Enhydrina schistosa - Beaked Sea Snake



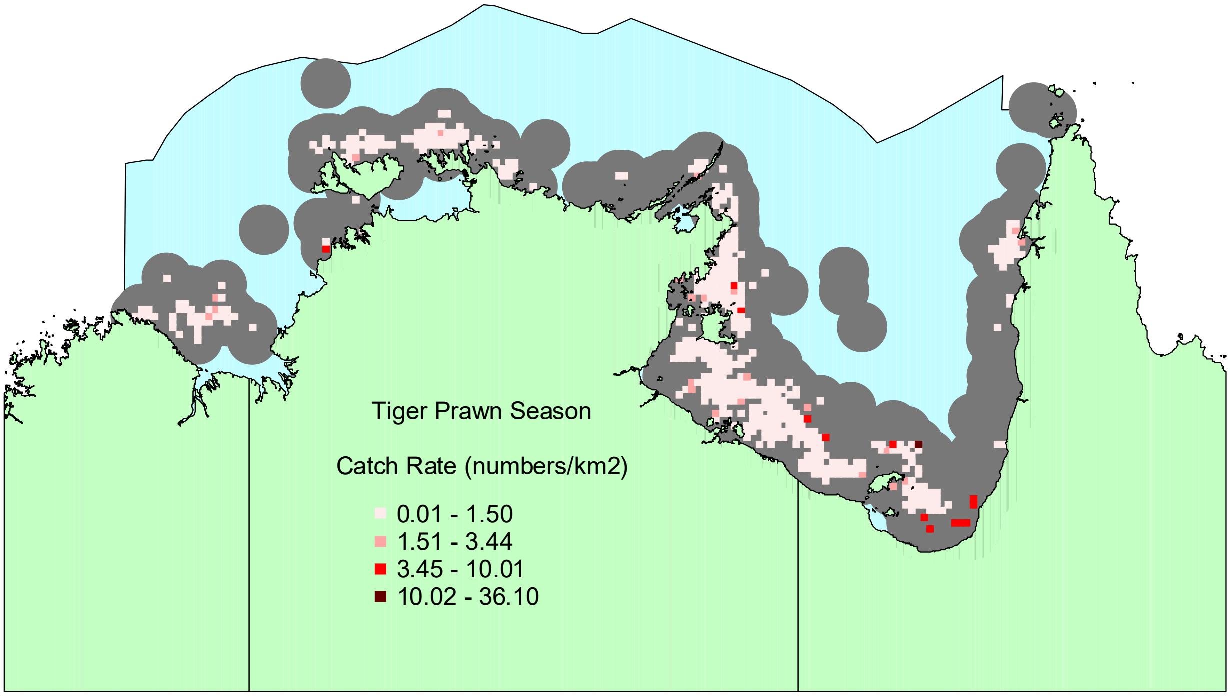
(j) Enhydrina schistosa - Beaked Sea Snake



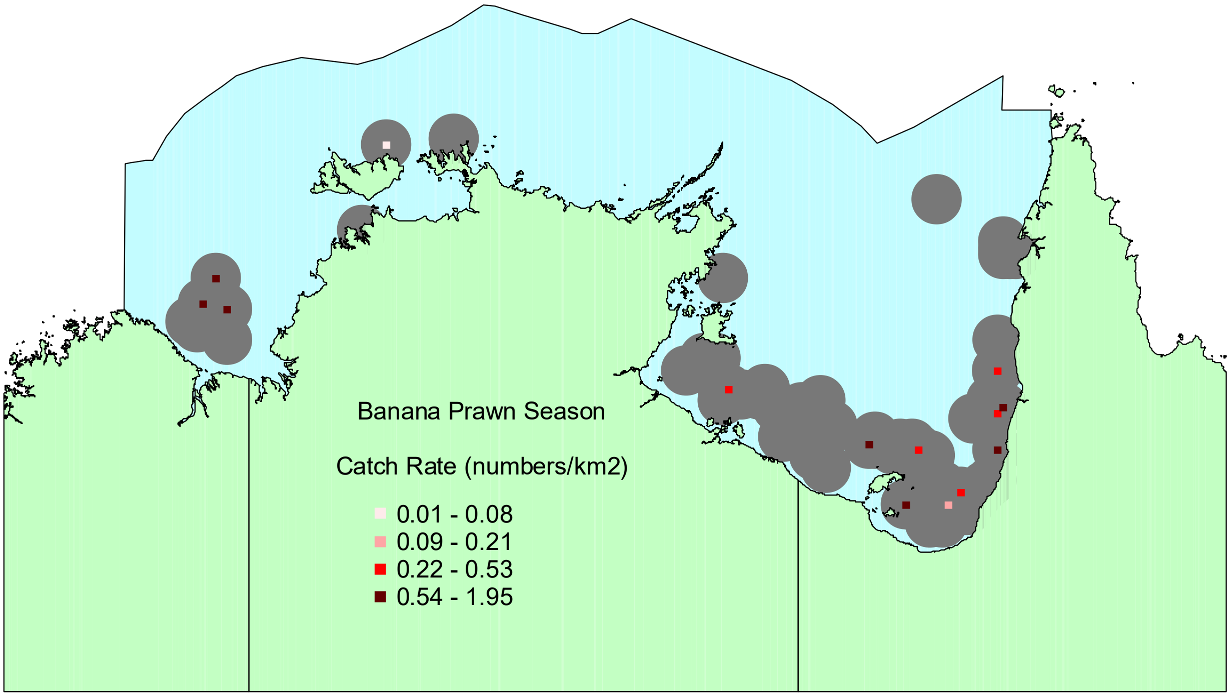
(k) Hydrophis elegans - Elegant Sea Snake



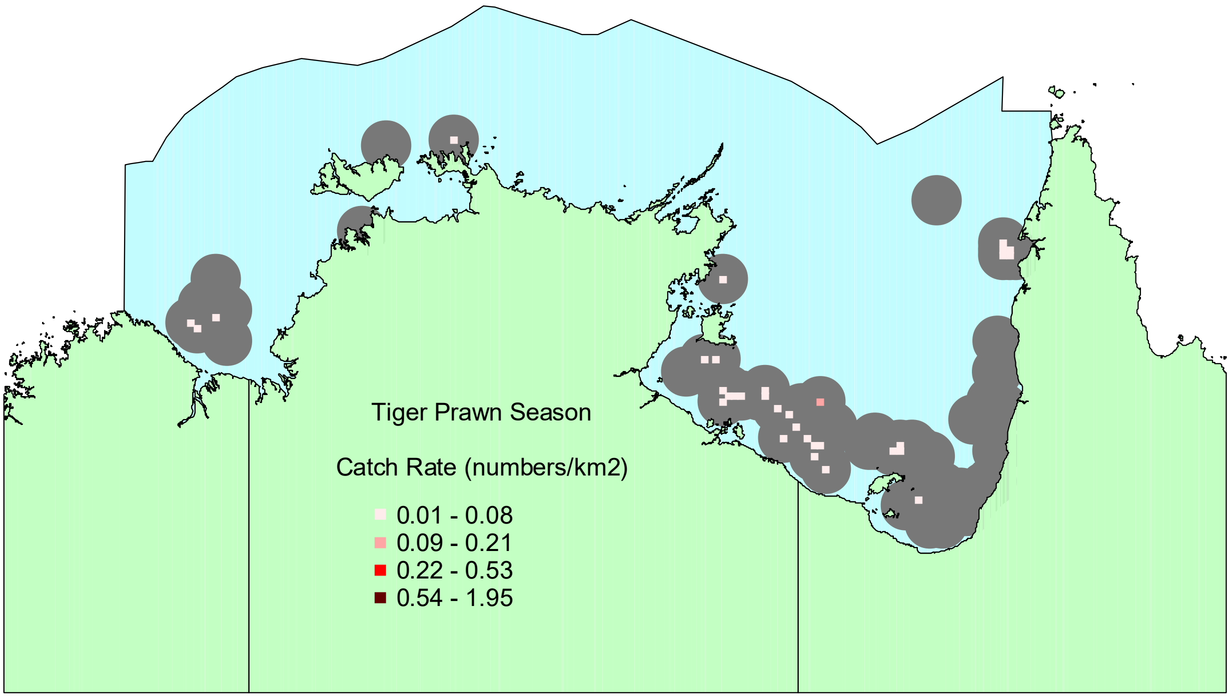
(k) Hydrophis elegans - Elegant Sea Snake



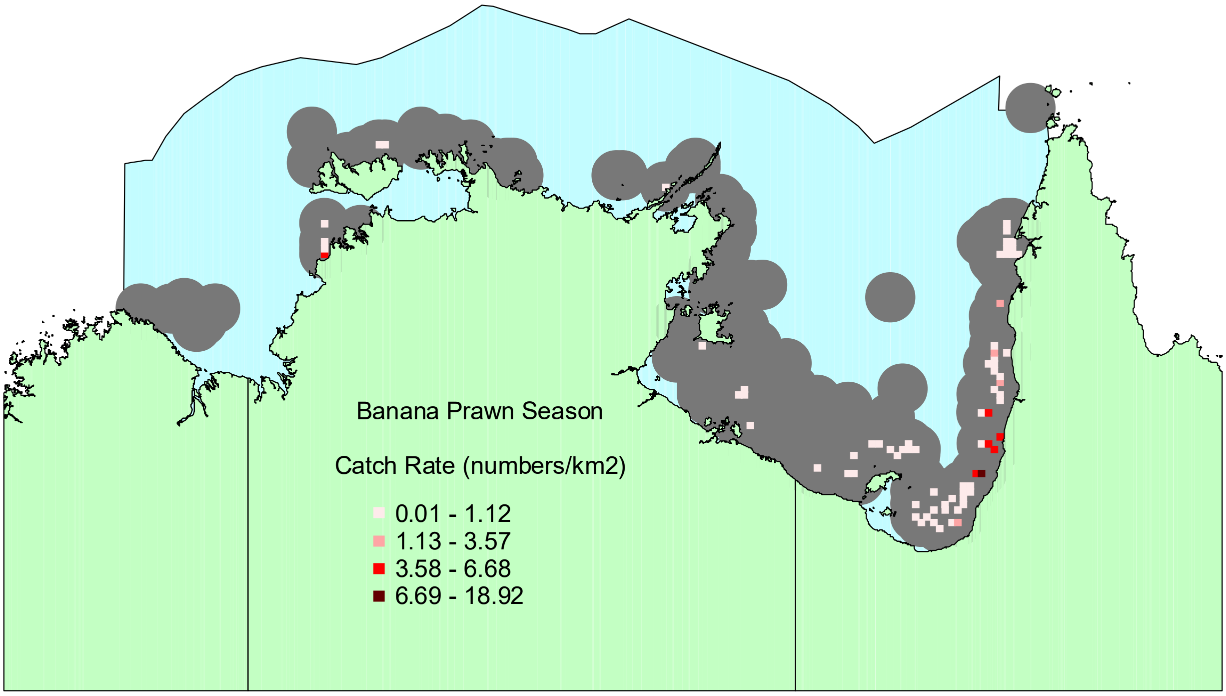
(I) Hydrophis mcdowelli - Small-headed Sea Snake



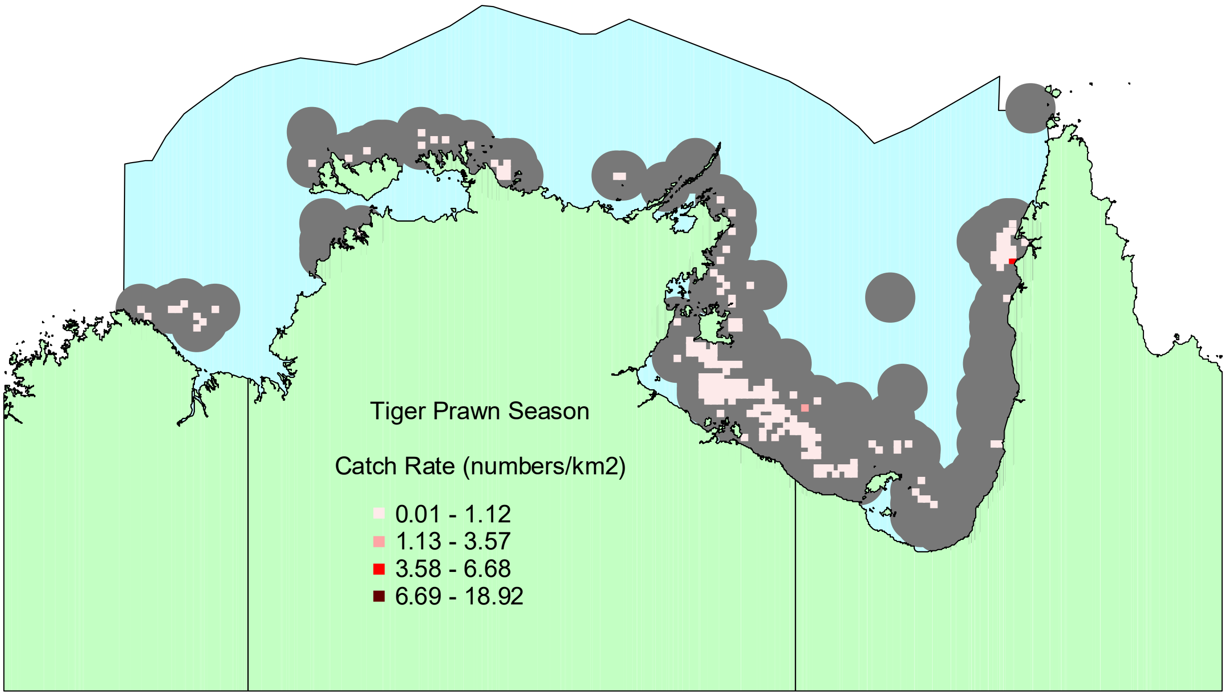
(I) Hydrophis mcdowelli - Small-headed Sea Snake



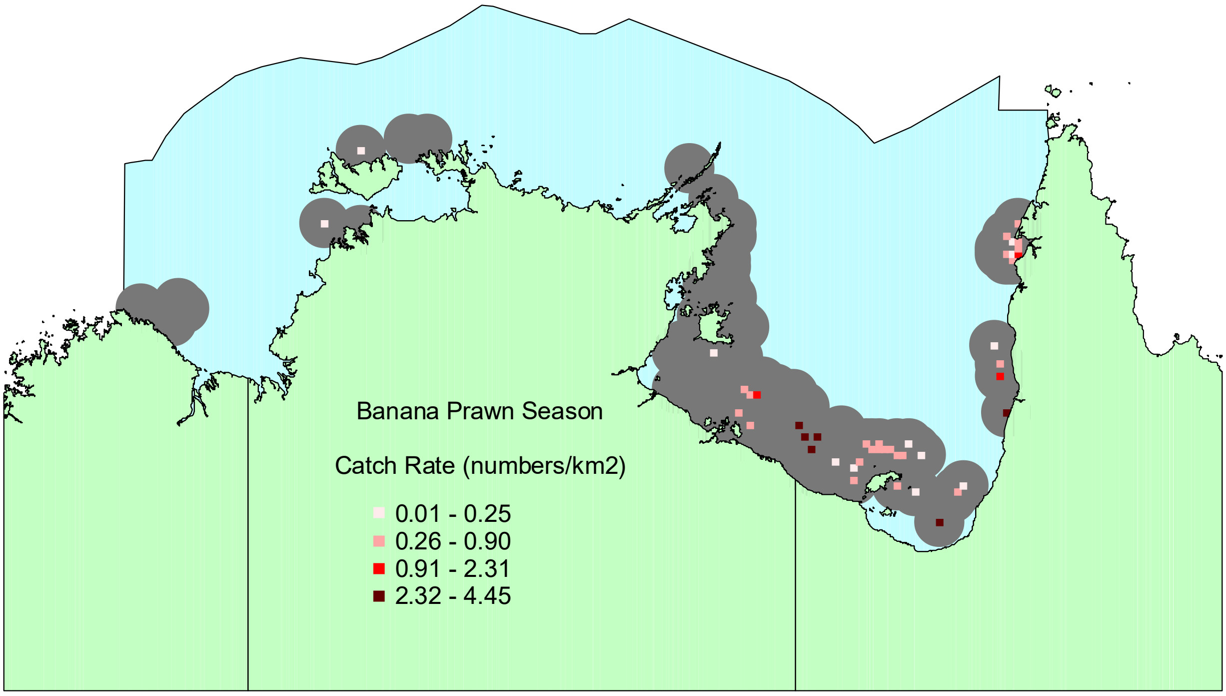
(m) Hydrophis ornatus - Ornate Sea Snake



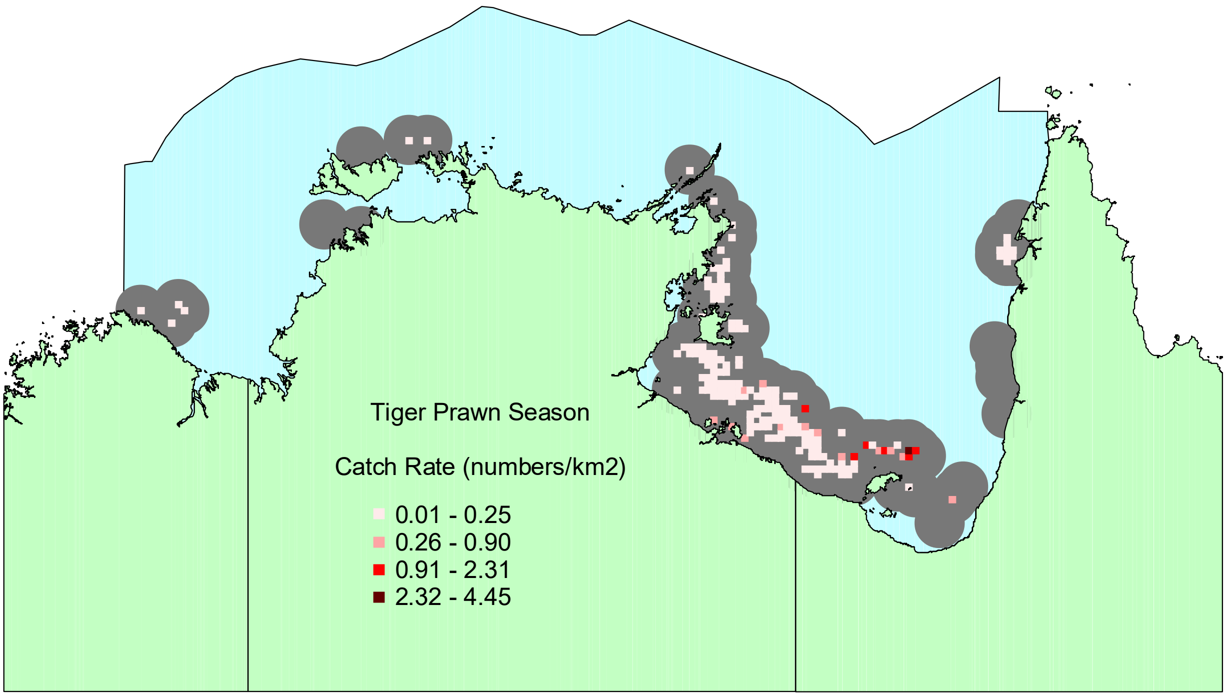
(m) Hydrophis ornatus - Ornate Sea Snake



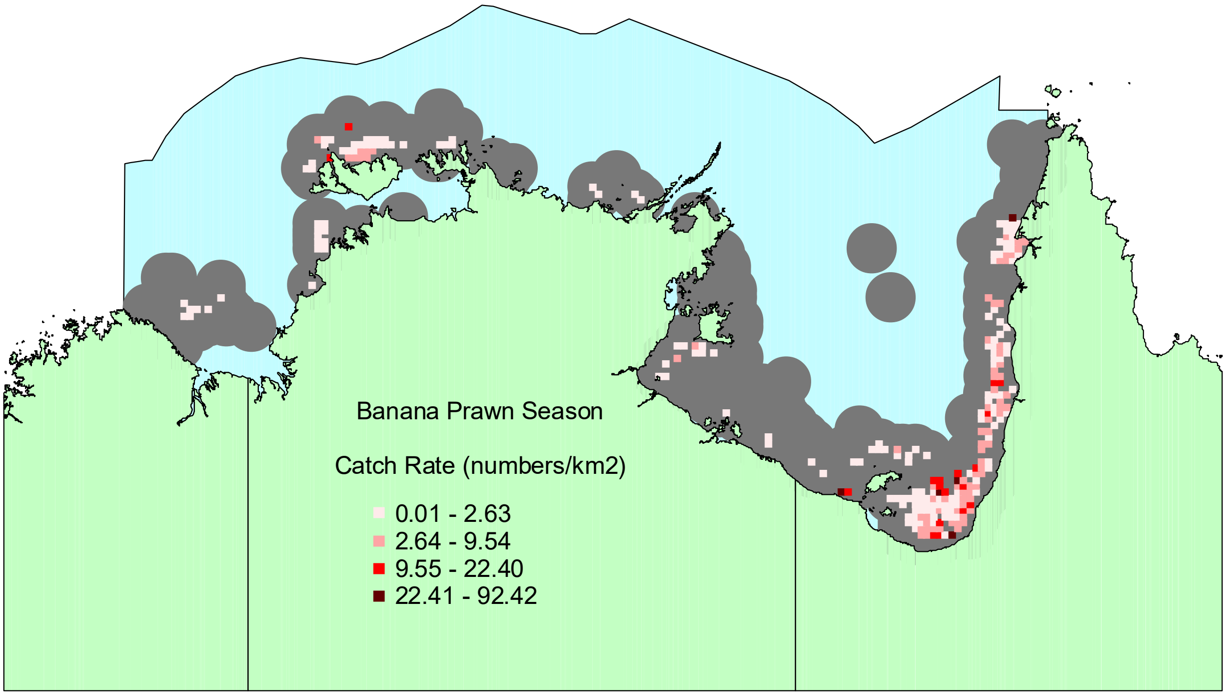
(n) Hydrophis pacificus - Large-headed Sea Snake



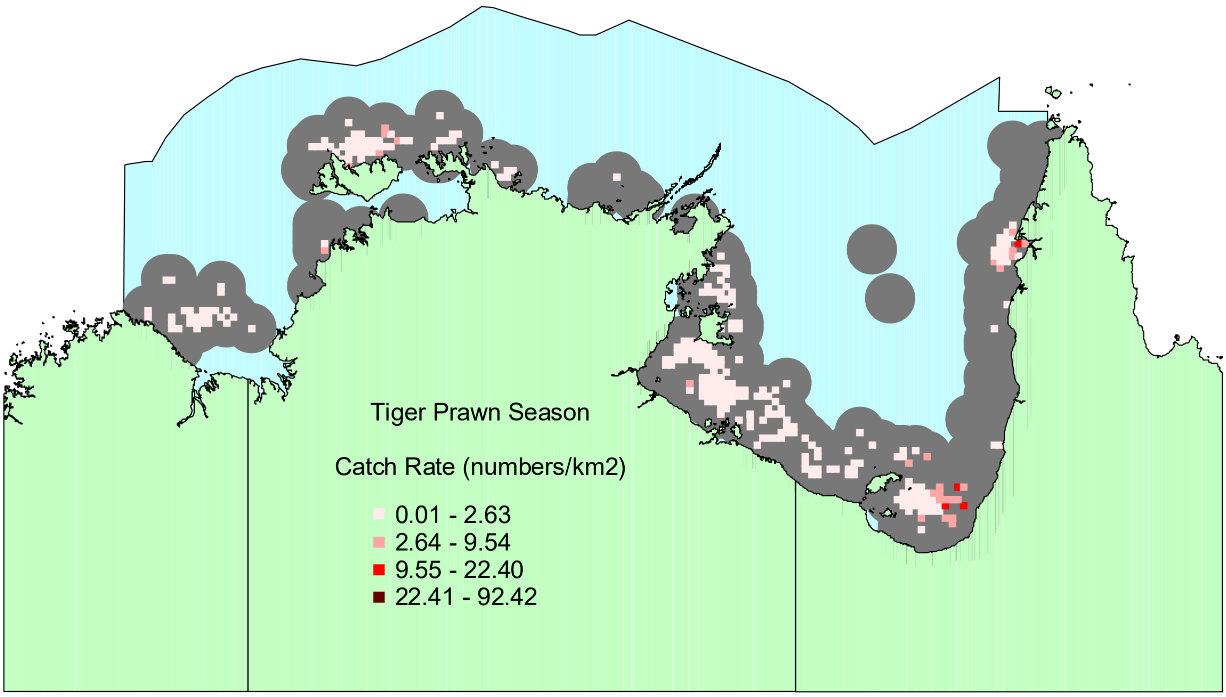
(n) Hydrophis pacificus - Large-headed Sea Snake



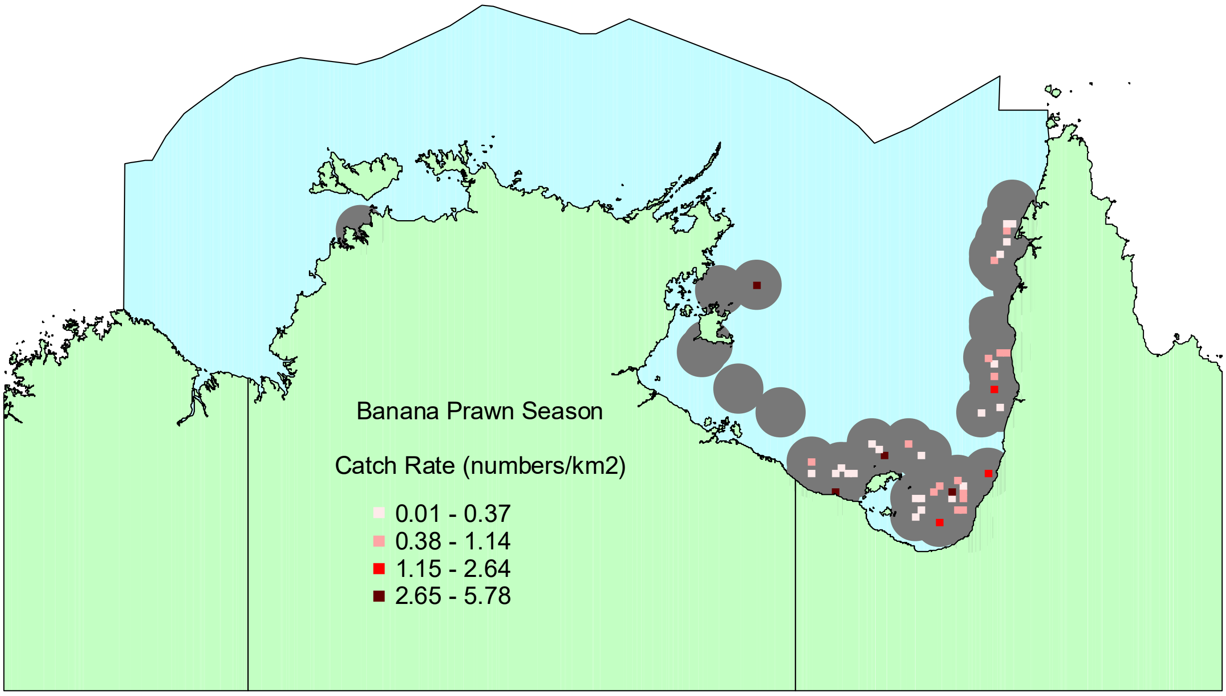
(o) Lapemis curtis - Spine-bellied Sea Snake



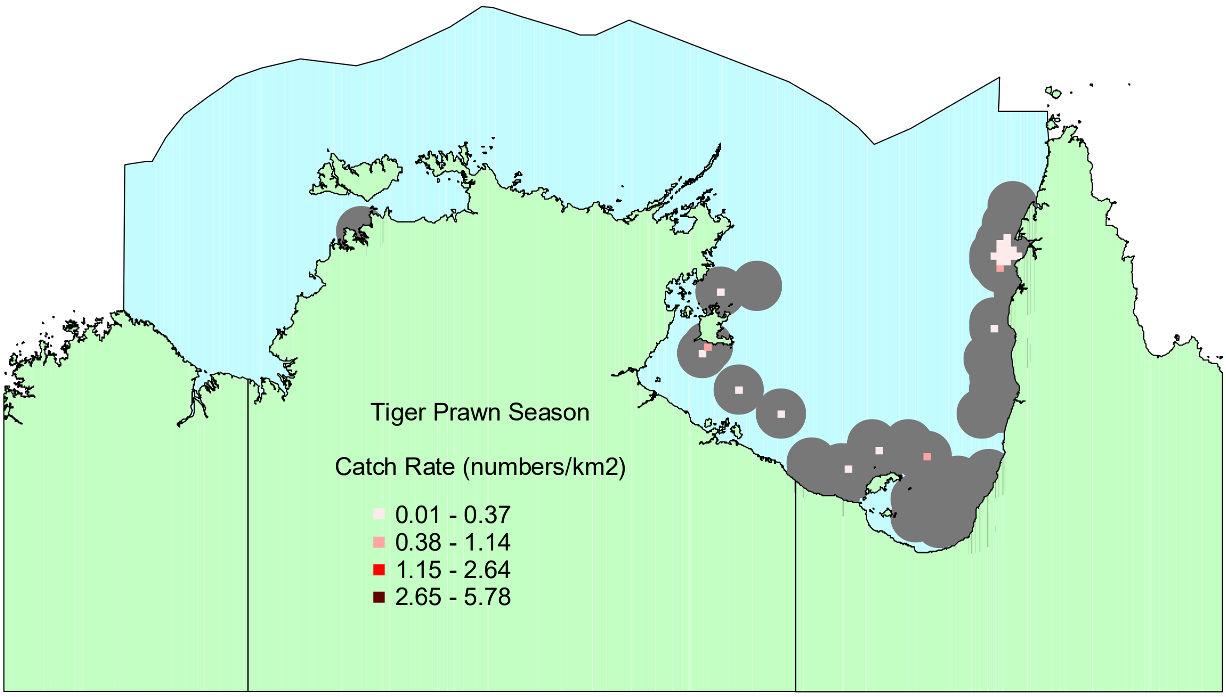
(o) Lapemis curtis - Spine-bellied Sea Snake



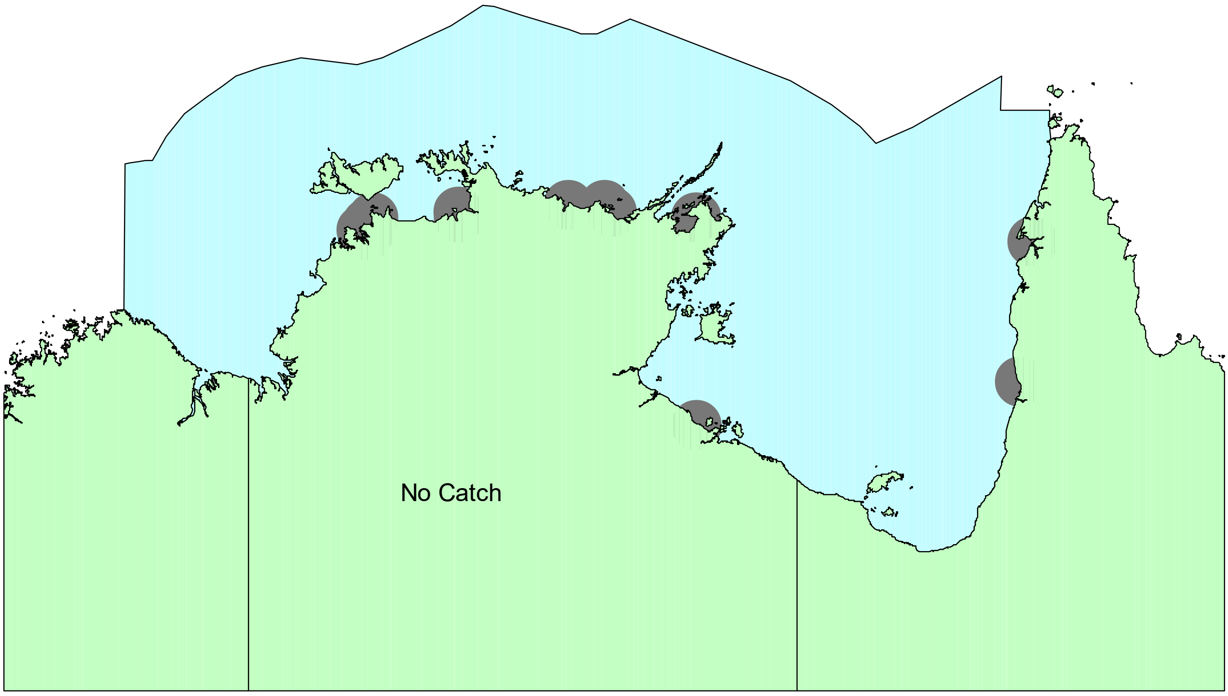
(p) Pelamis platurus - Yellow-bellied Sea Snake



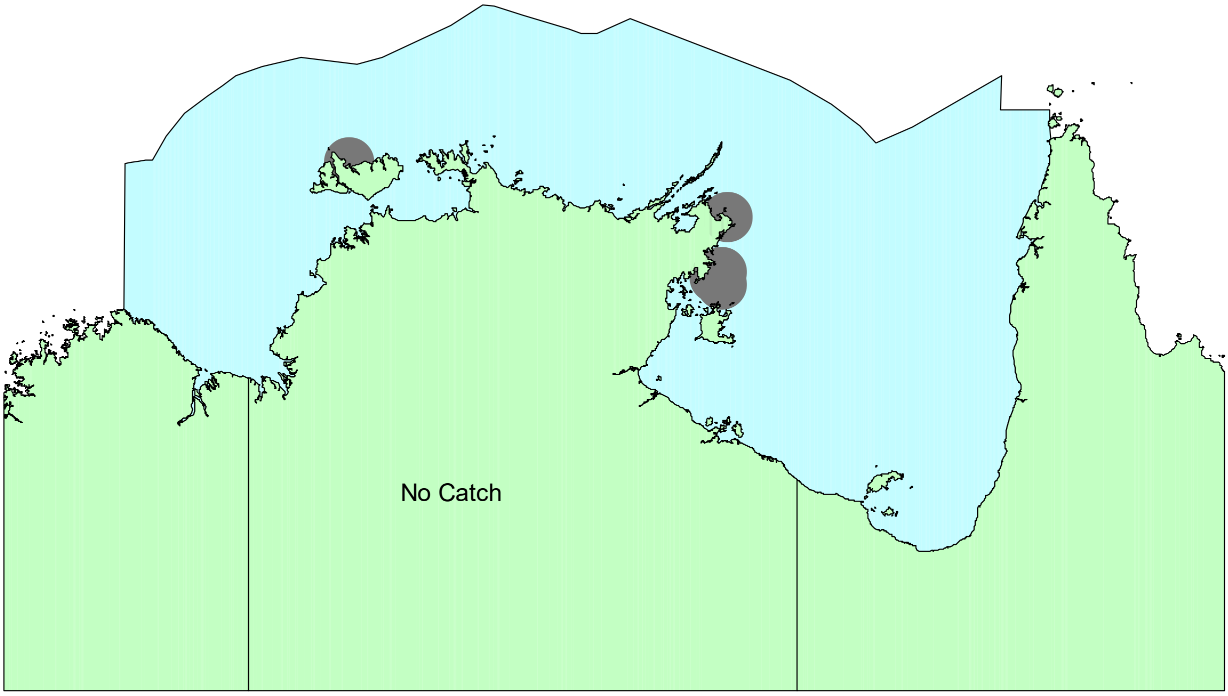
(p) Pelamis platurus - Yellow-bellied Sea Snake



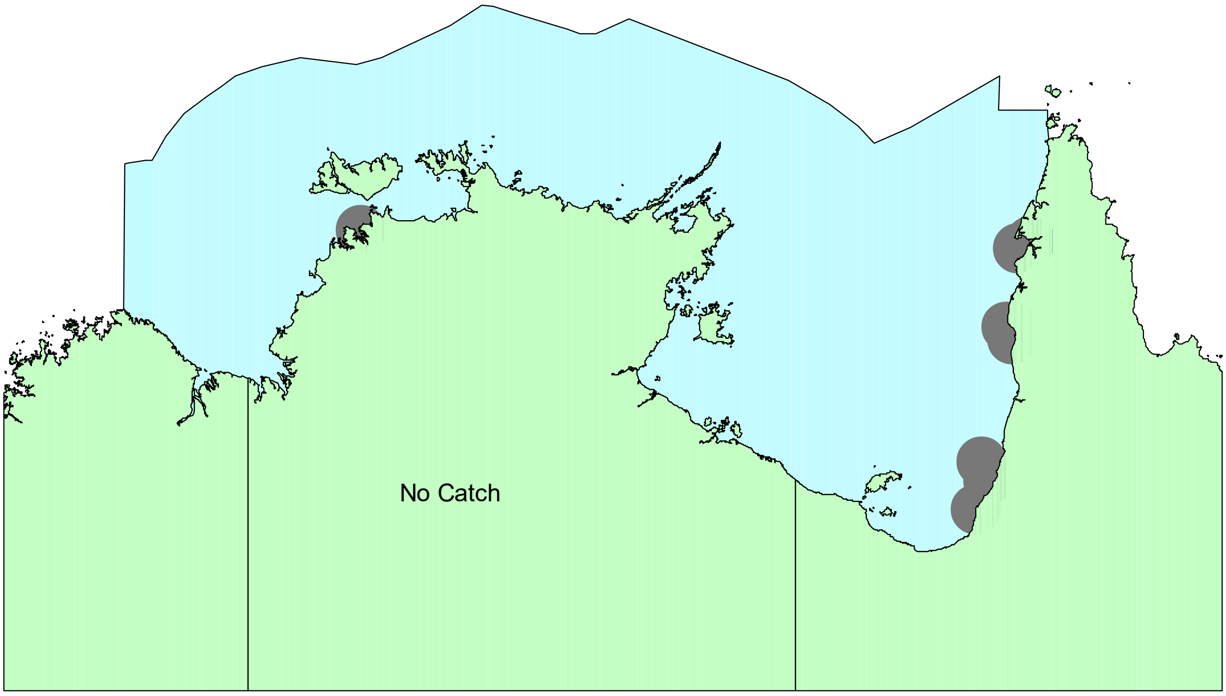
(q) Hydrelaps darwiniensis - Sea Snake



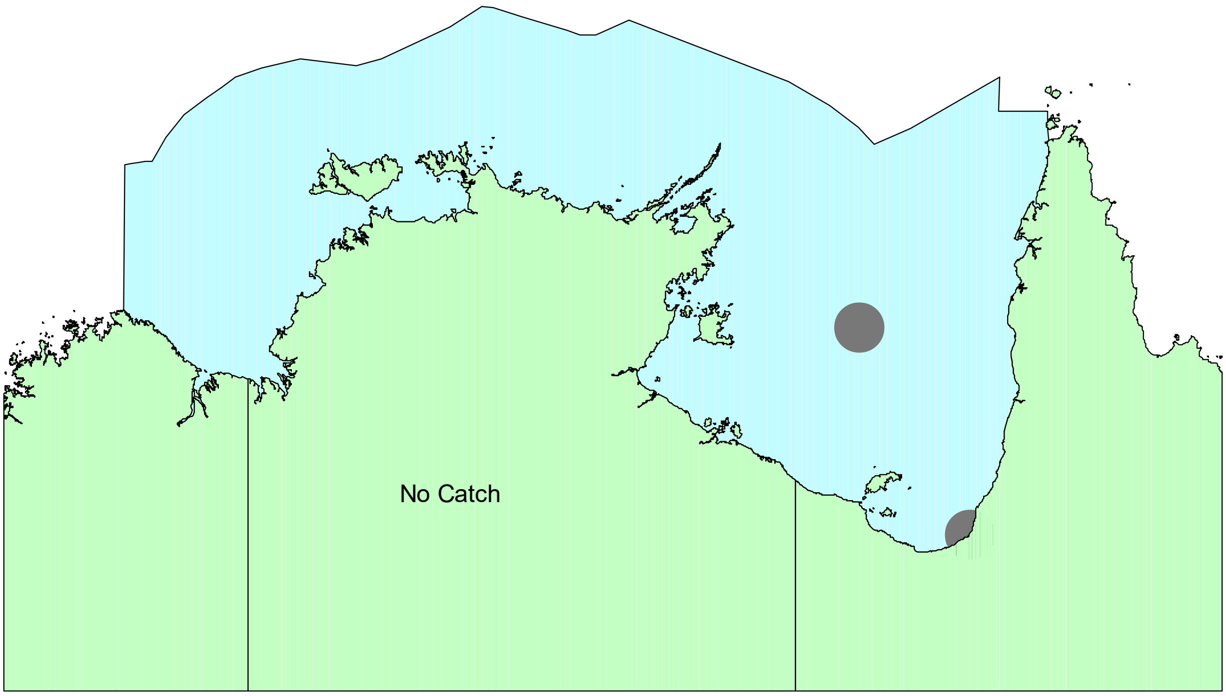
(r) Hydrophis atriceps - Sea Snake



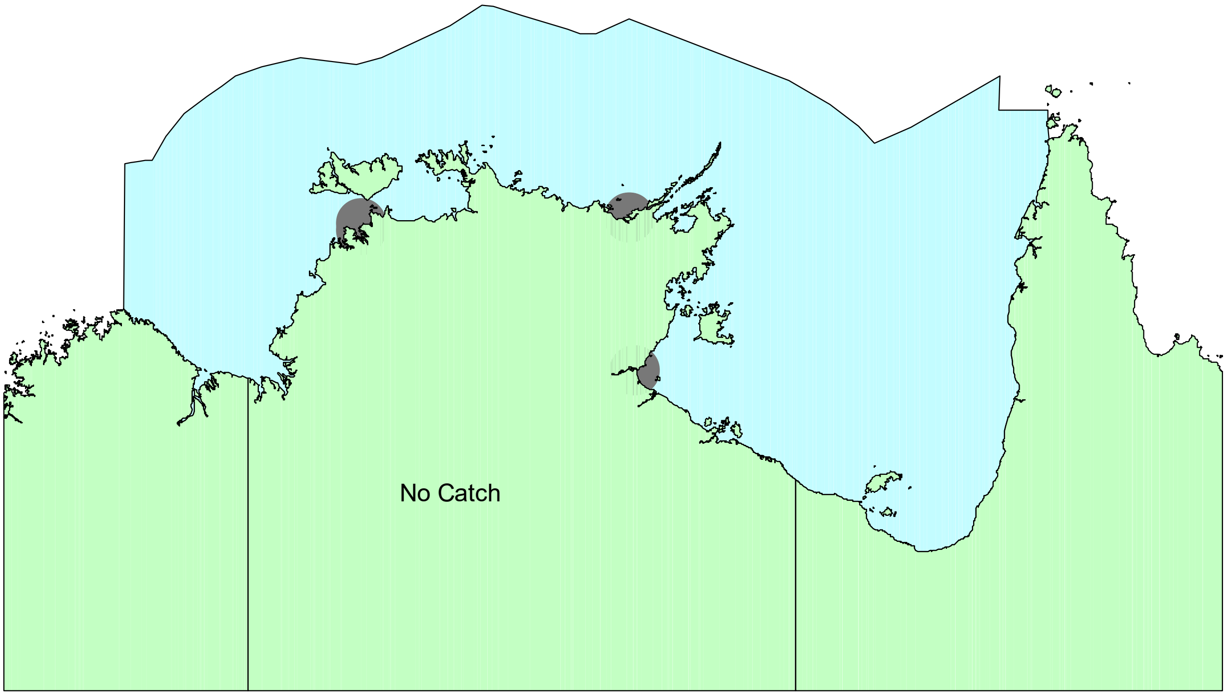
(s) Hydrophis caerulescens - Sea Snake



(t) Hydrophis inornatus - Sea Snake



(u) Parahydrophis mertoni - Sea Snake



(v) Hydrophis fasciatus - Sea Snake

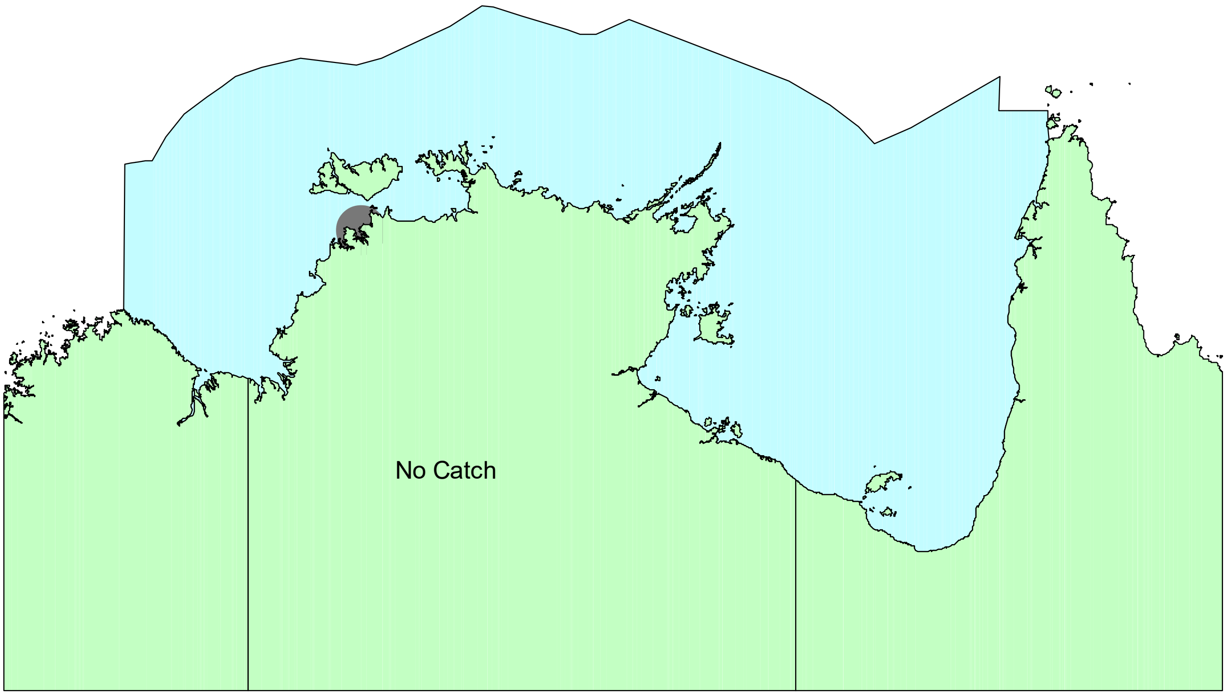
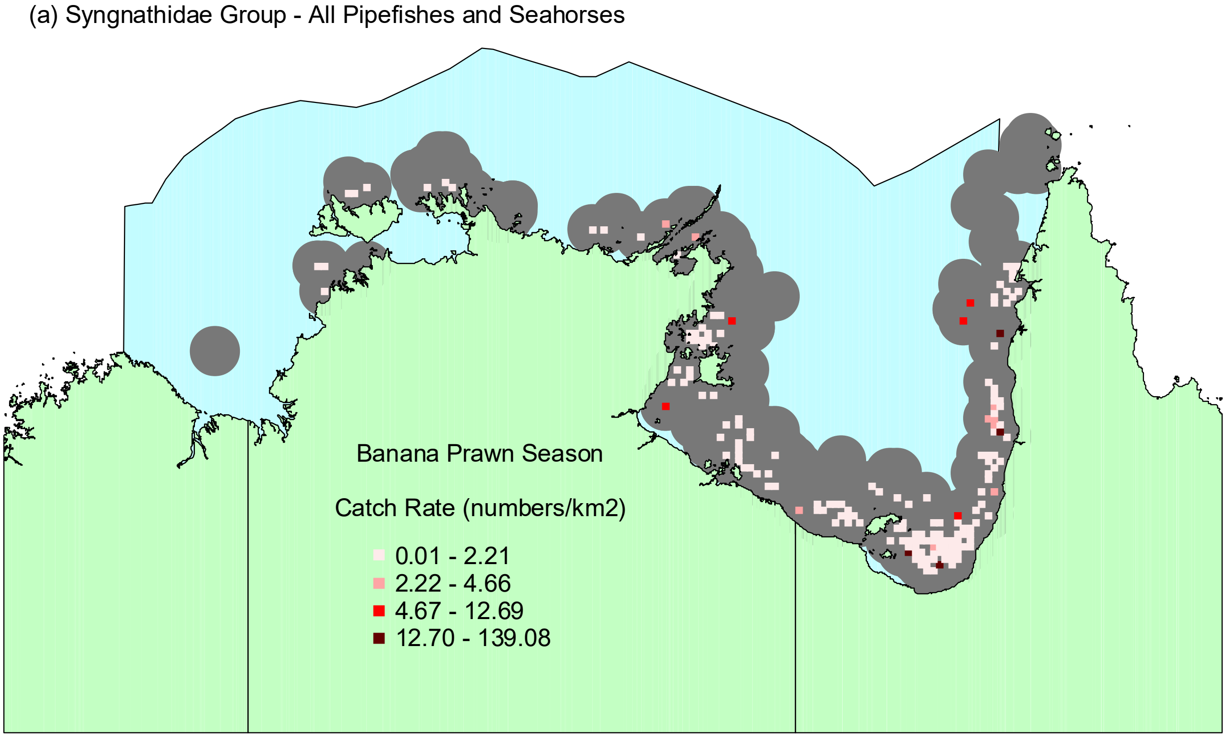
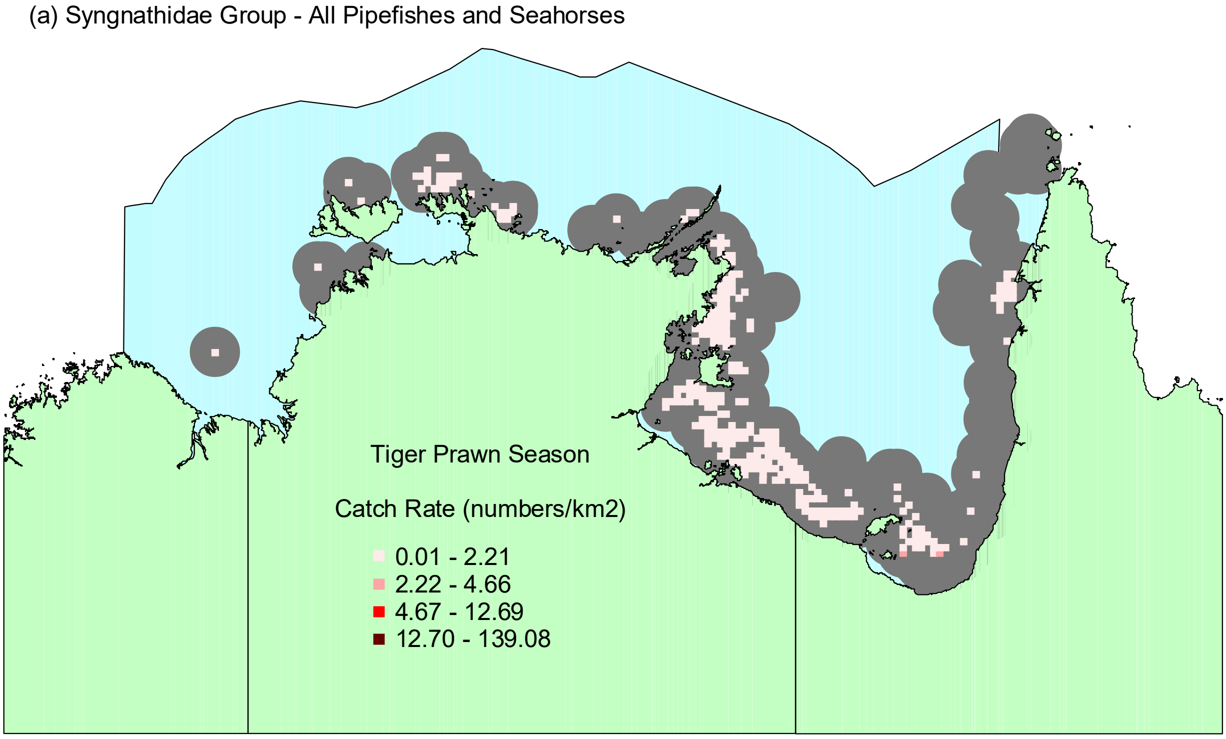
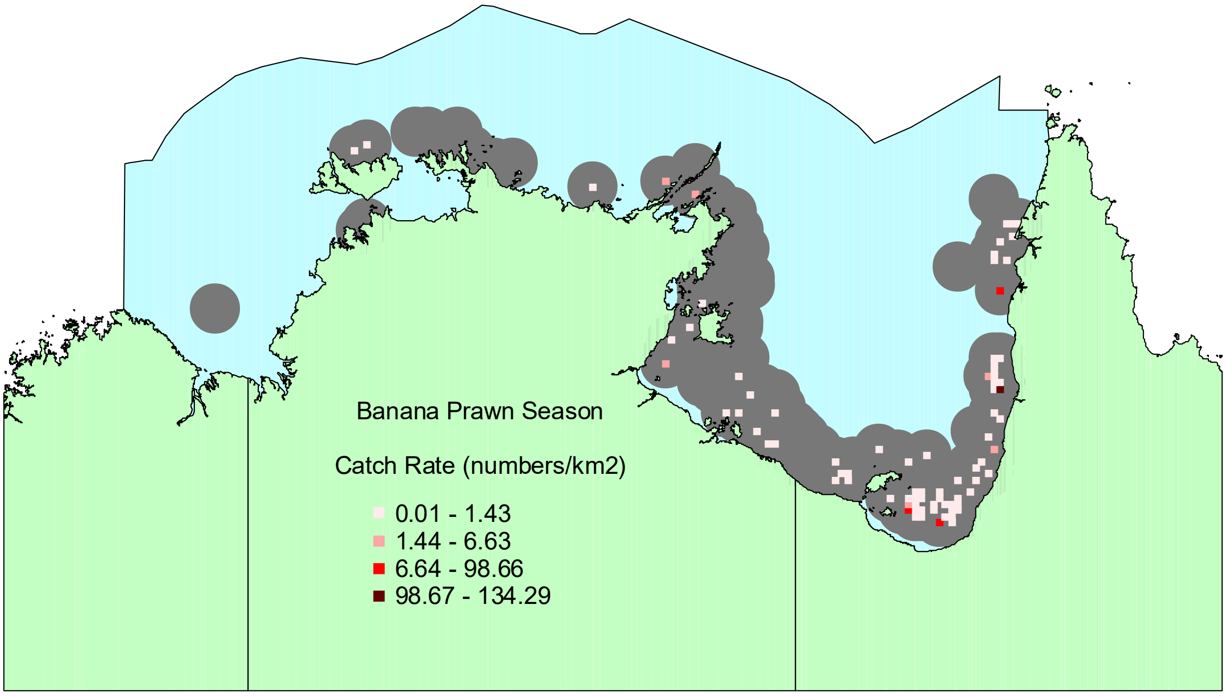


Figure 11: Following maps showing the catch records (grey circles represent a position where a species has been recorded; presence data) and overall catch rates (numbers per km^2) during the banana (Top) and tiger (Bottom) prawn seasons for the pipefishes and seahorses; (a) All Pipefishes and Seahorses combined, (b) Unidentified Pipefishes and Seahorses, (c) *Hippocampus histrix*, (d) *Trachyrhamphus bicoarctata*, (e) *Haliichthys taeniophorus*, (f) *Halicampus grayi*, (g) *Choeroichthys brachysoma*, (h) *Filicampus tigris*, (i) *Hippocampus zebra*, (j) *Trachyrhamphus longirostris*, (k) *Hippocampus queenslandicus*, (l) *Trachyrhamphus* sp A, (m) *Trachyrhamphus* sp Short-tail, (n) *Hippocampus kuda*, (o) *Festucalex scalaris* and (p) *Syngnathoides biaculeatus*. Presence data includes all records from the crew-member observer program, AFMA scientific observer program, NPF prawn population monitoring surveys and CSIRO scientific research and observer surveys in the NPF. Catch rate data only includes data collected from the crew-member observer program, AFMA scientific observer program and the NPF prawn population monitoring surveys from 2002 to 2019. Maps (n) to (p) only show presence data as no individuals were caught from 2002 to 2019.

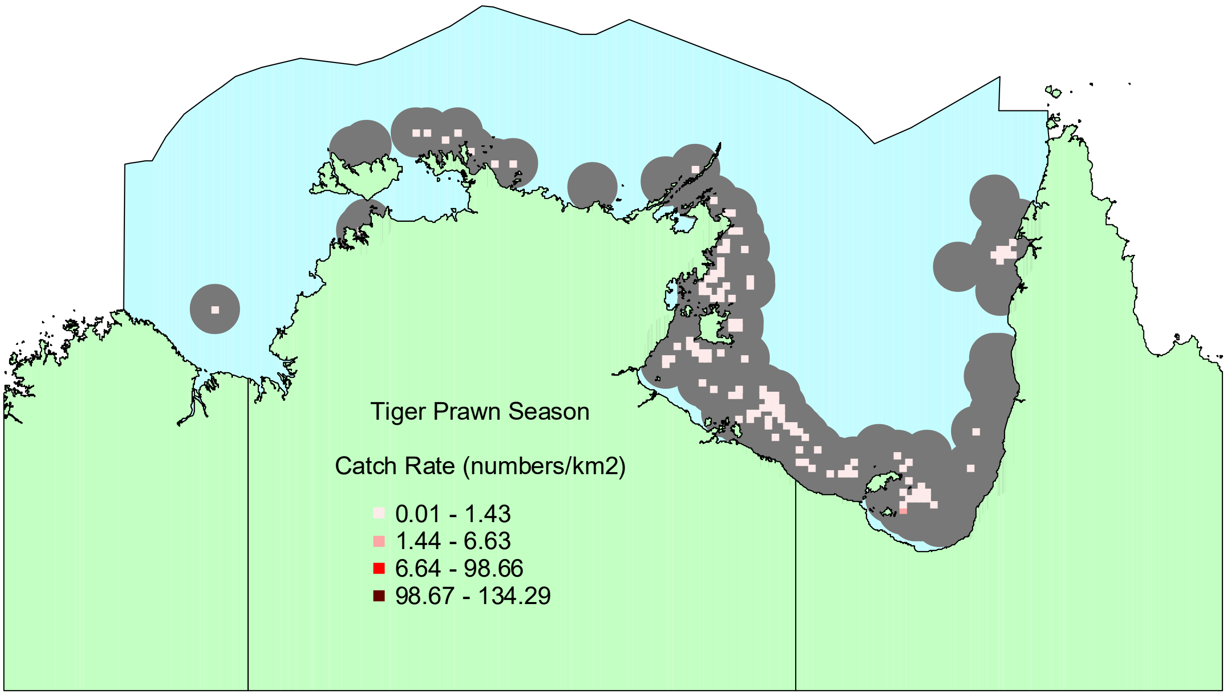

(a) Syngnathidae Group - All Pipefishes and Seahorses
Banana Prawn Season
Catch Rate (numbers/km2)
0.01 - 2.21
2.22 - 4.66
4.67 - 12.69
12.70 - 139.08


(a) Syngnathidae Group - All Pipefishes and Seahorses
Tiger Prawn Season
Catch Rate (numbers/km2)
0.01 - 2.21
2.22 - 4.66
4.67 - 12.69
12.70 - 139.08

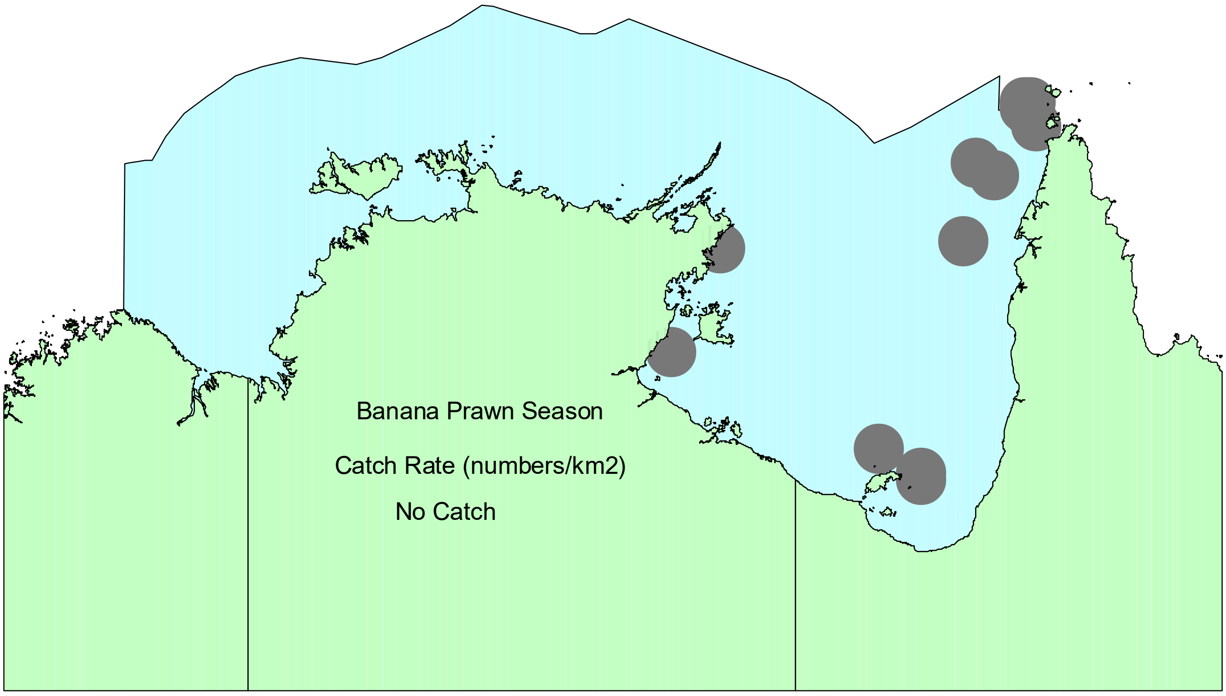
(b) Syngnathidae spp - Unidentified Pipefishes and Seahorses



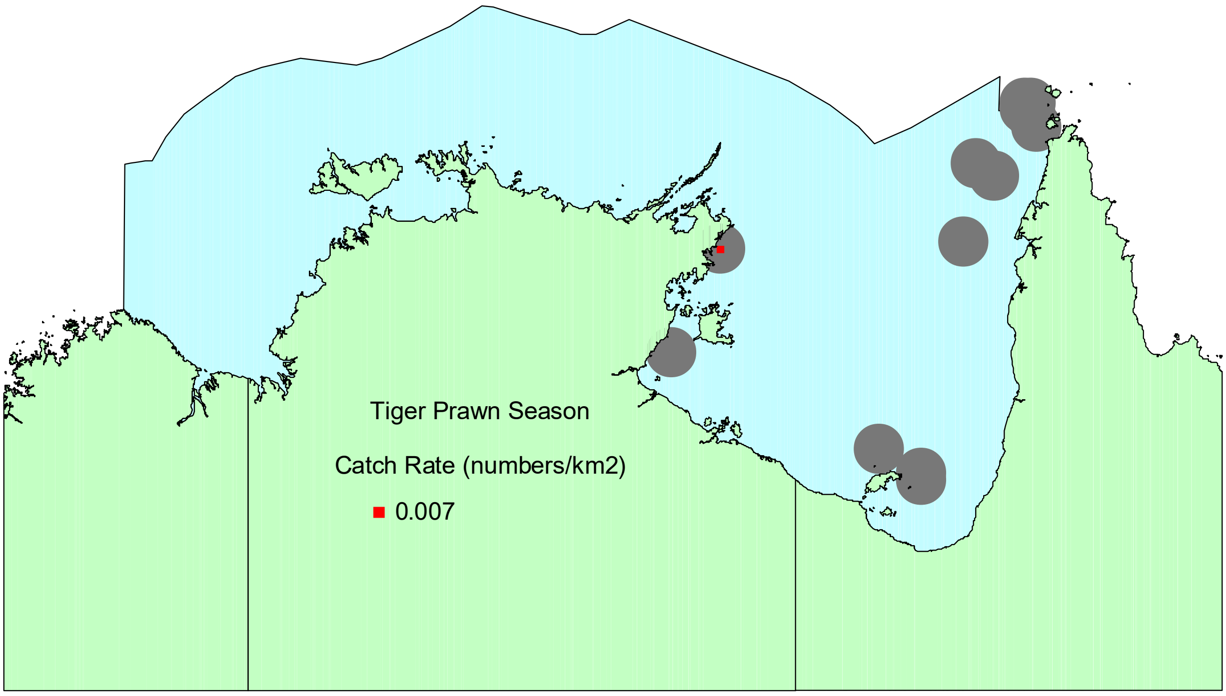
(b) Syngnathidae spp - Unidentified Pipefishes and Seahorses



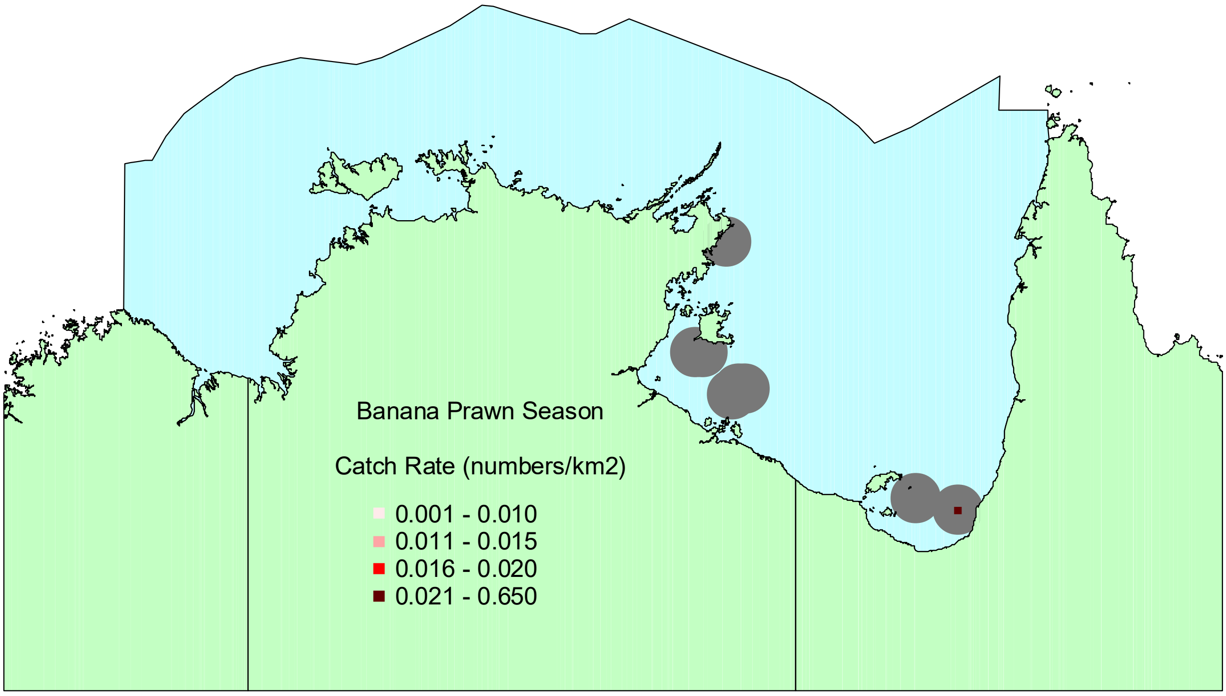
(c) Hippocampus histrix - Thorny Seahorse



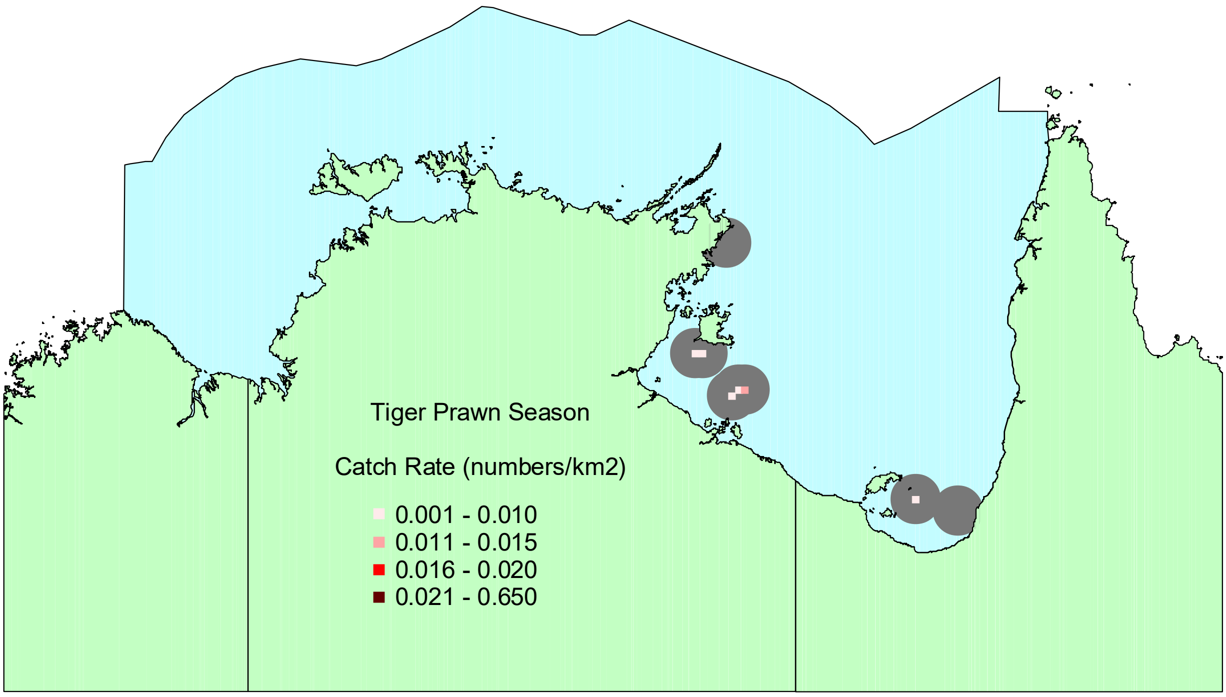
(c) Hippocampus histrix - Thorny Seahorse



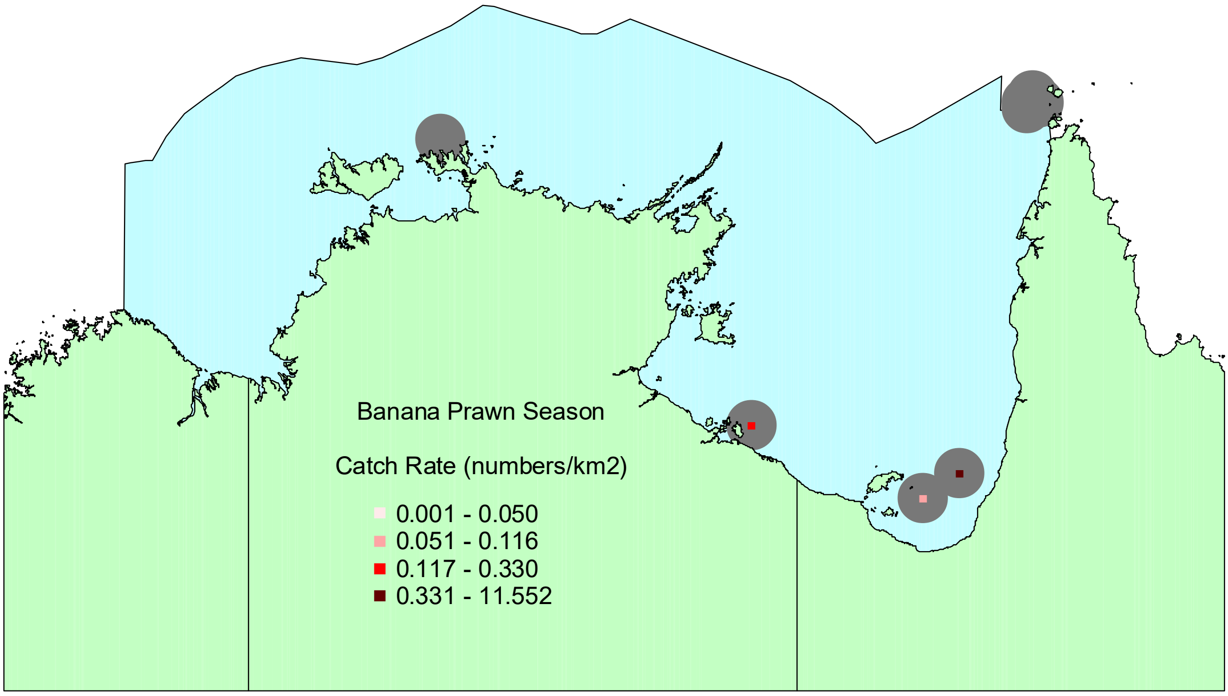
(d) Trachyrhamphus bicoarctata - Double-ended Pipefish



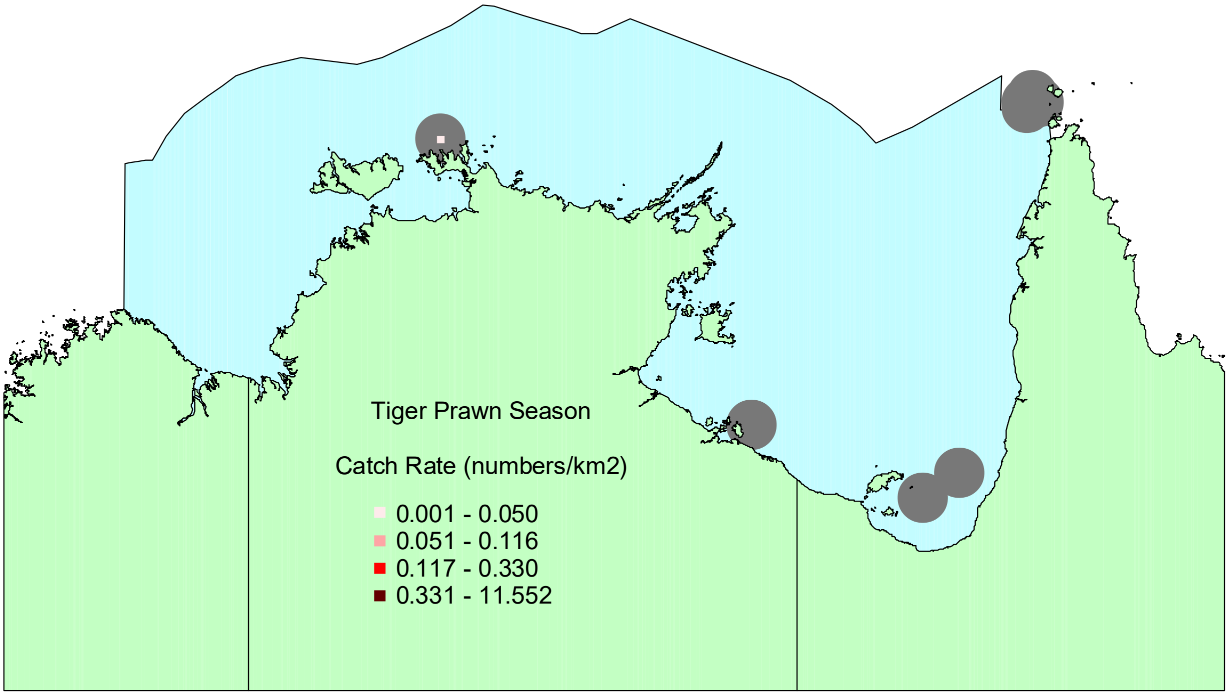
(d) Trachyrhamphus bicoarctata - Double-ended Pipefish



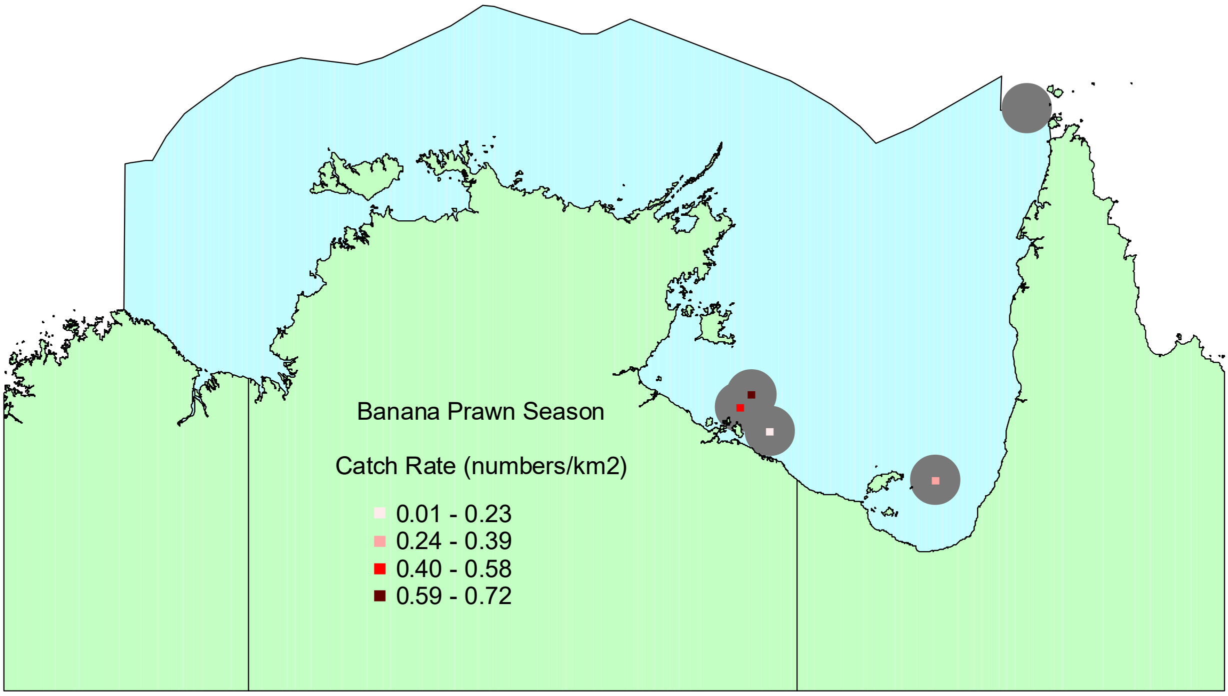
(e) Haliichthys taeniophorus - Ribboned Pipefish



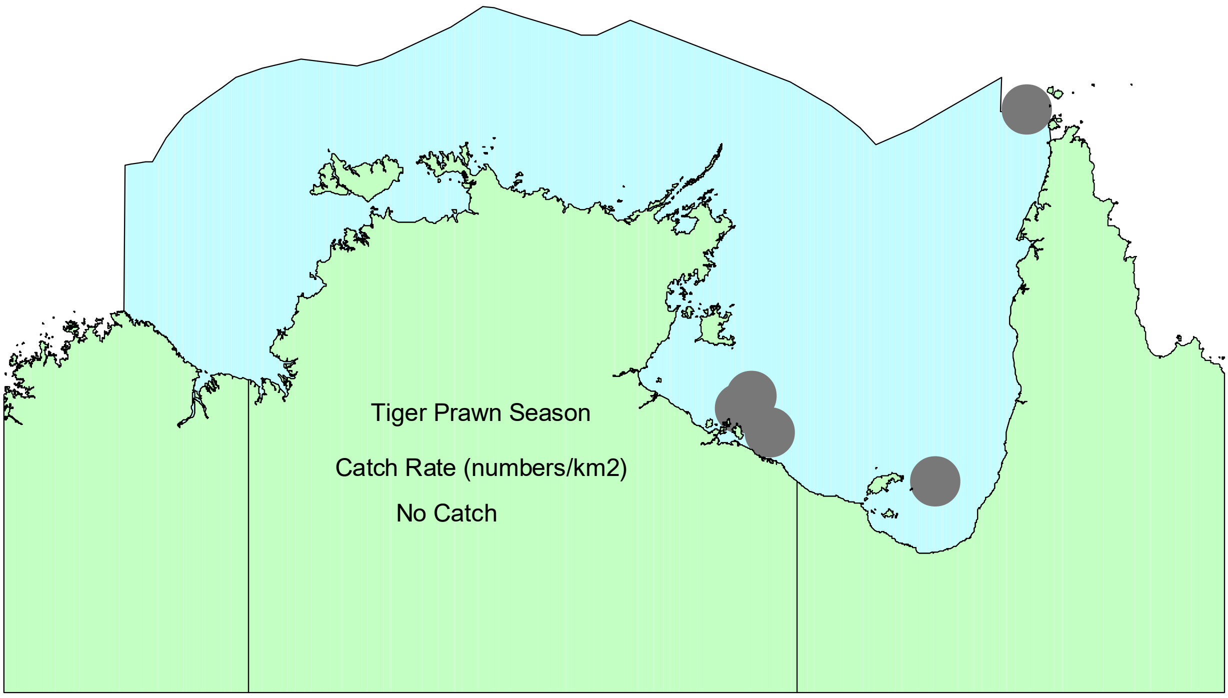
(e) Haliichthys taeniophorus - Ribboned Pipefish



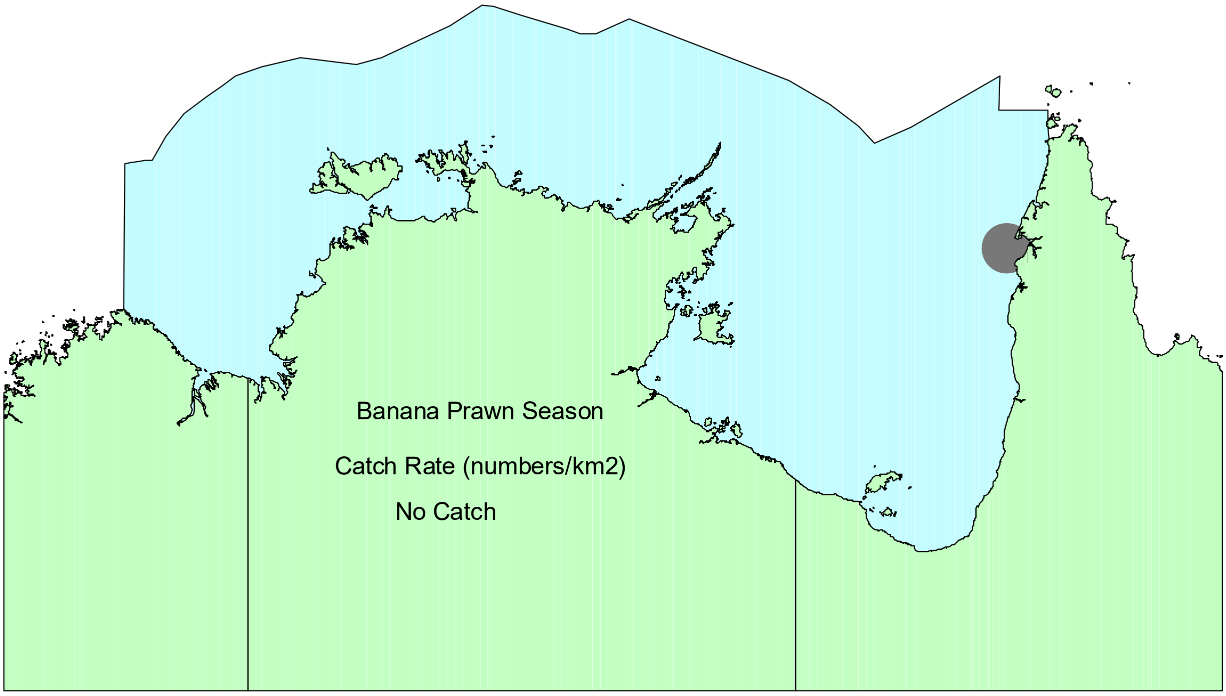
(f) Halicampus grayi - Gray's Pipefish



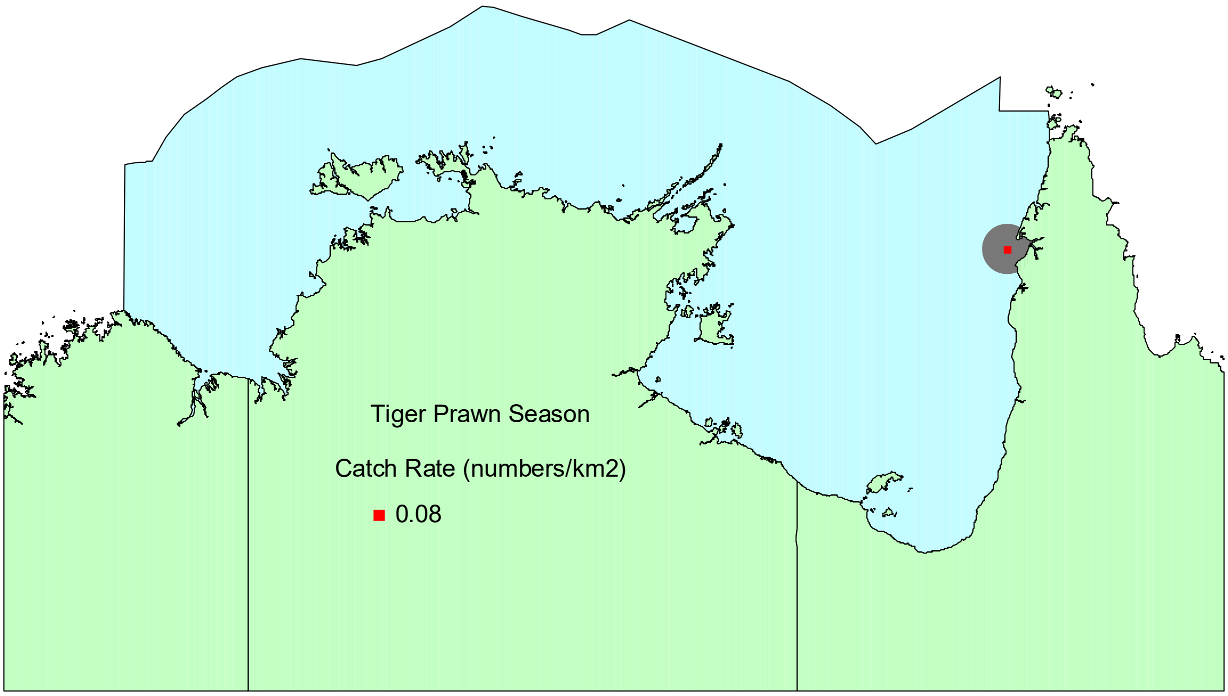
(f) Halicampus grayi - Gray's Pipefish



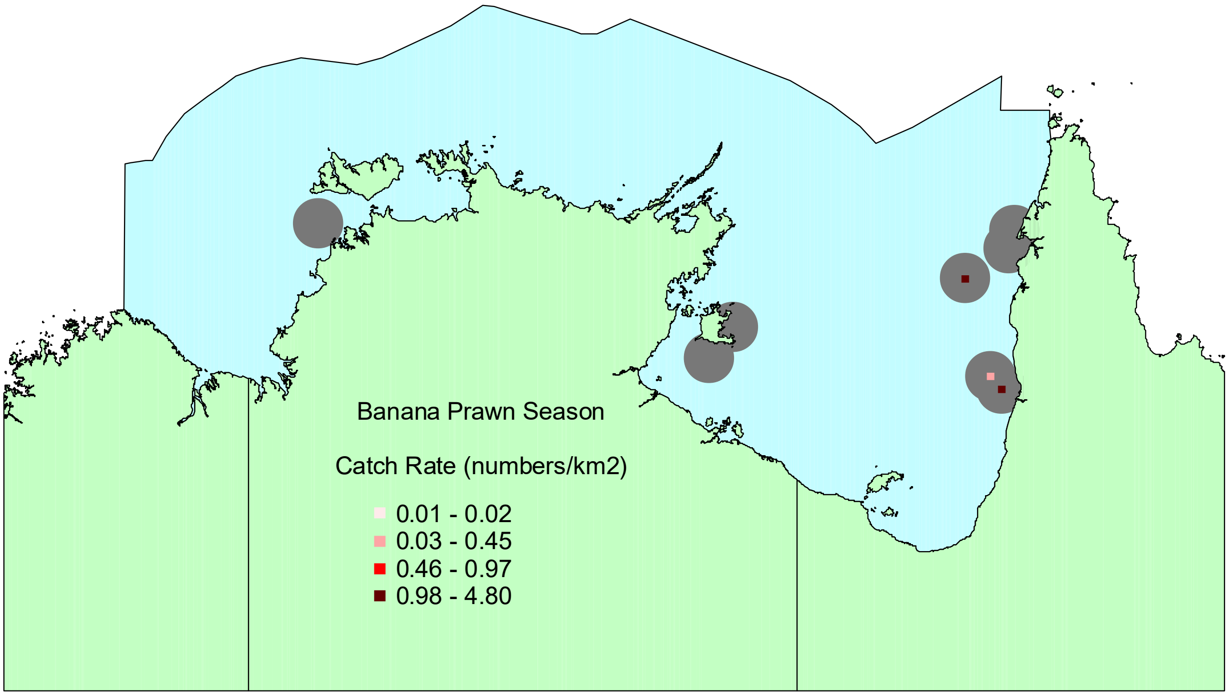
(g) Choeroichthys brachysoma - Pacific Short-bodied Pipefish



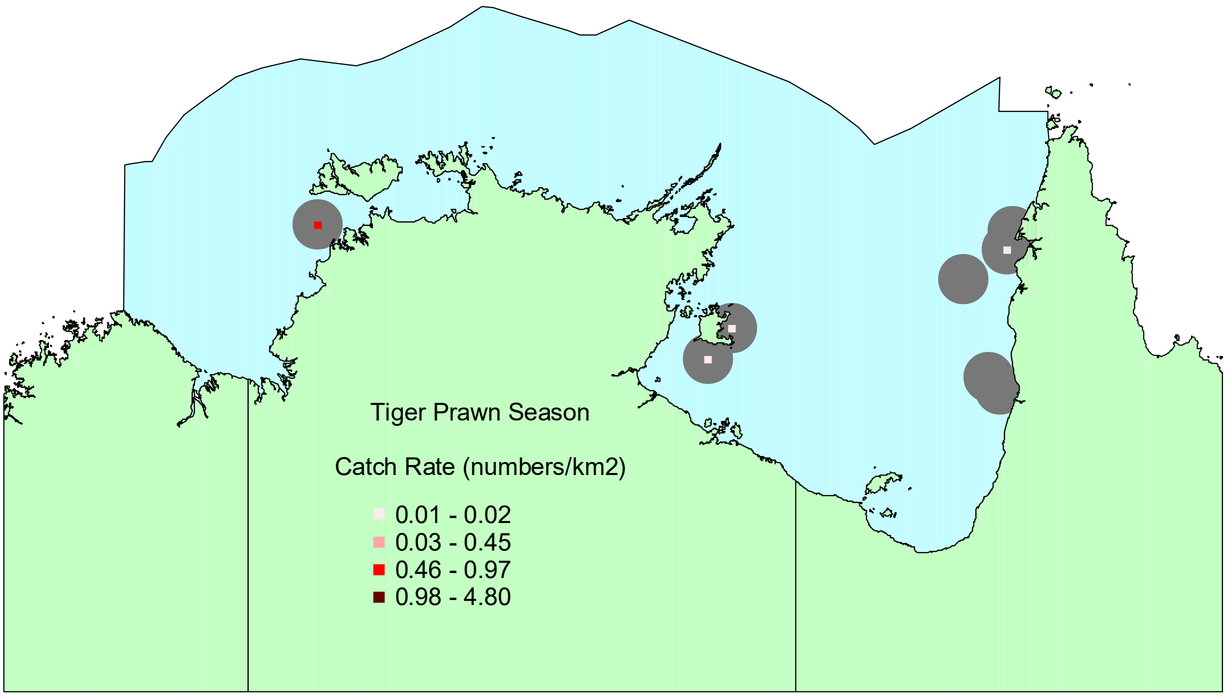
(g) Choeroichthys brachysoma - Pacific Short-bodied Pipefish



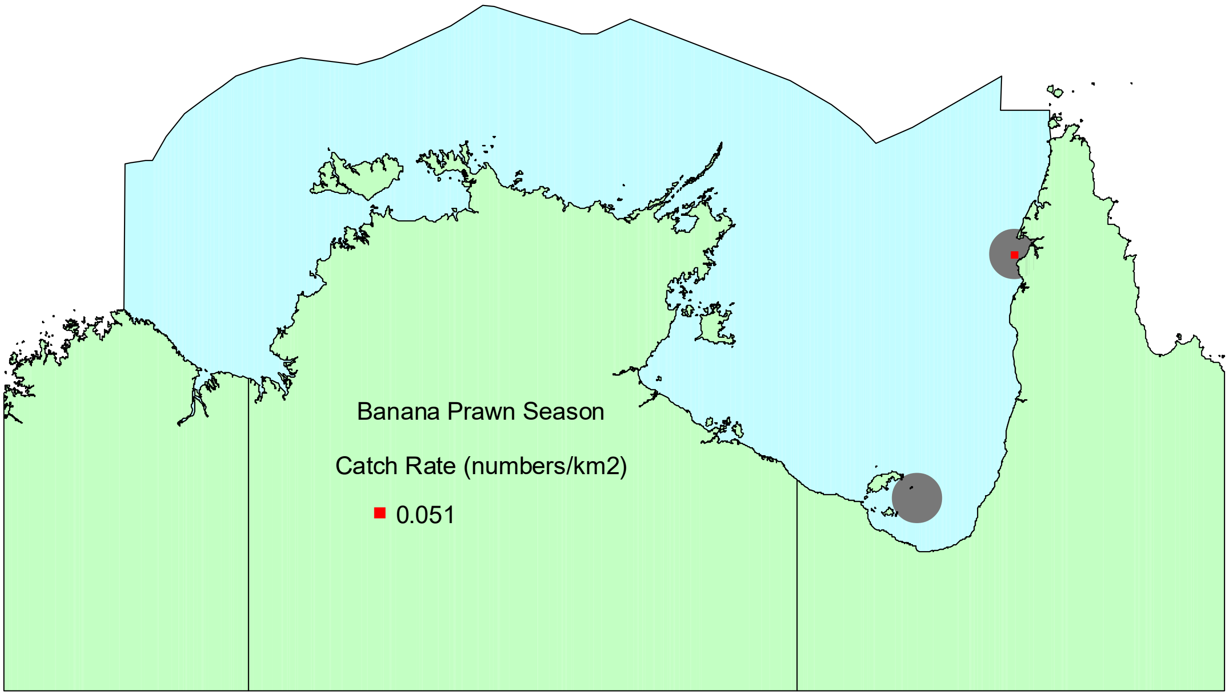
(h) Filicampus tigris - Tiger Pipefish



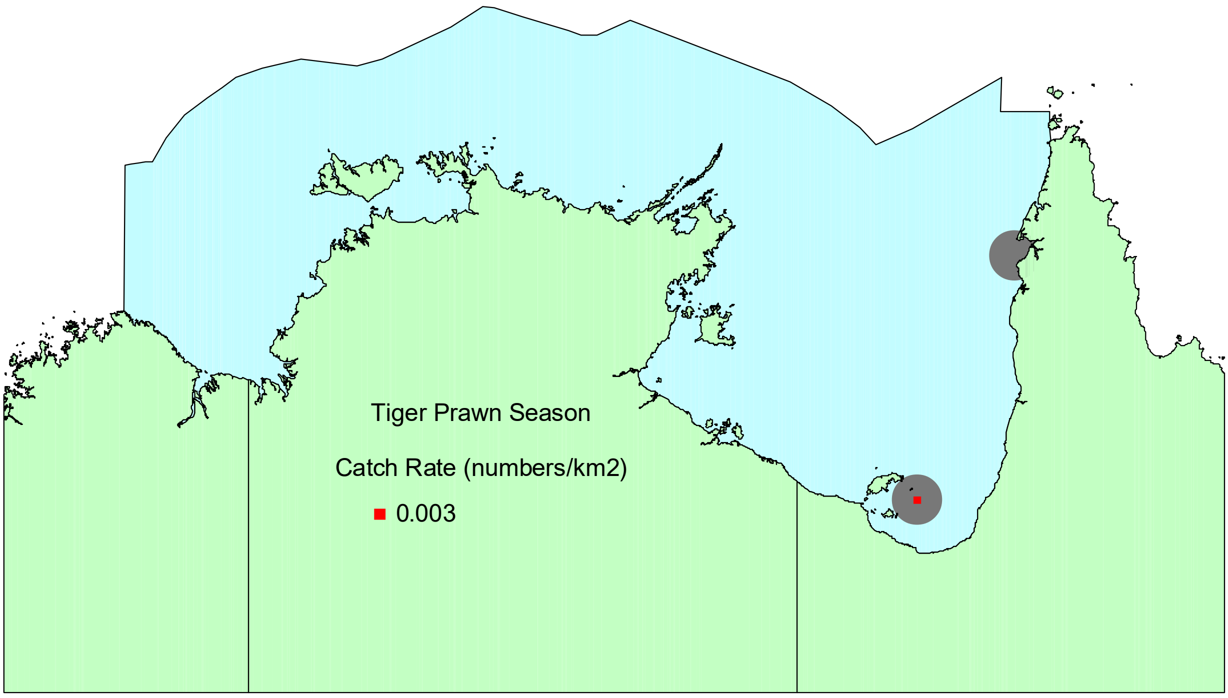
(h) Filicampus tigris - Tiger Pipefish



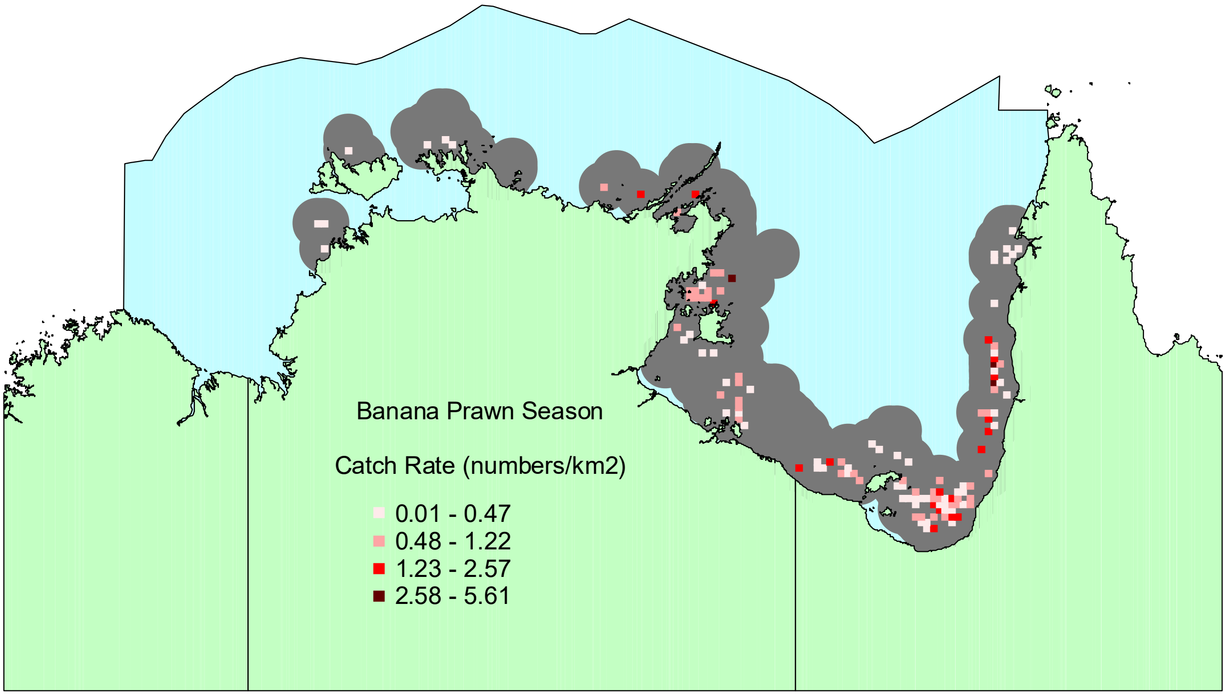
(i) Hippocampus zebra - Zebra Seahorse



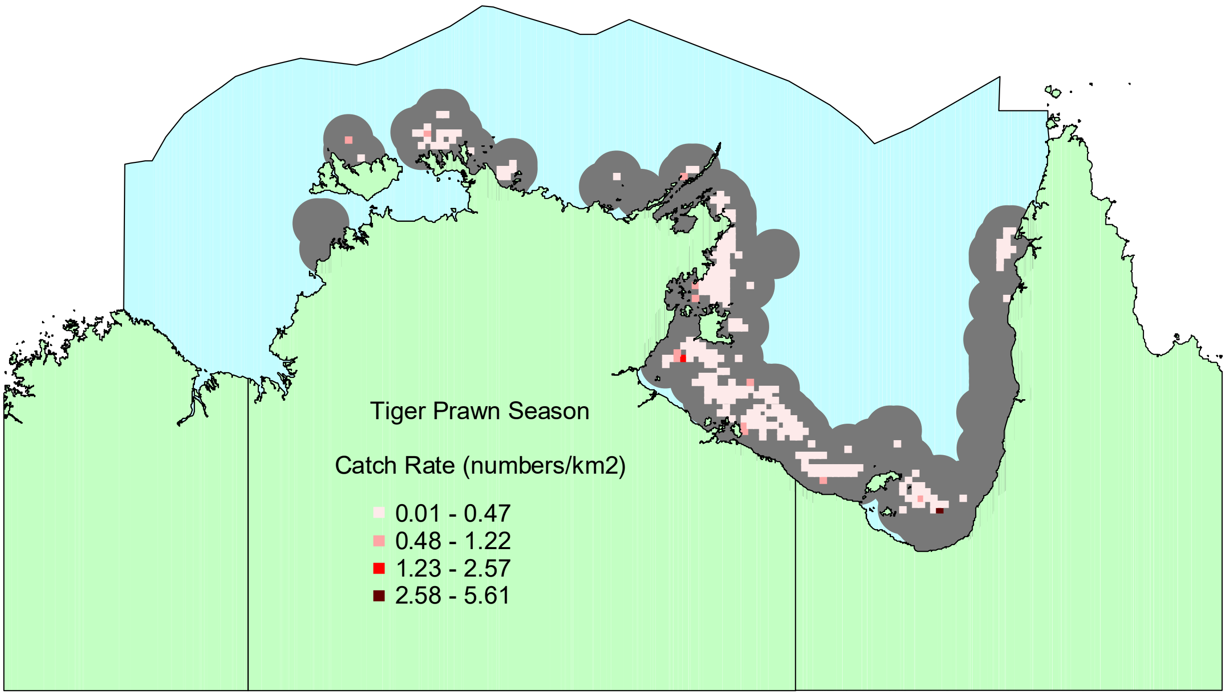
(i) Hippocampus zebra - Zebra Seahorse



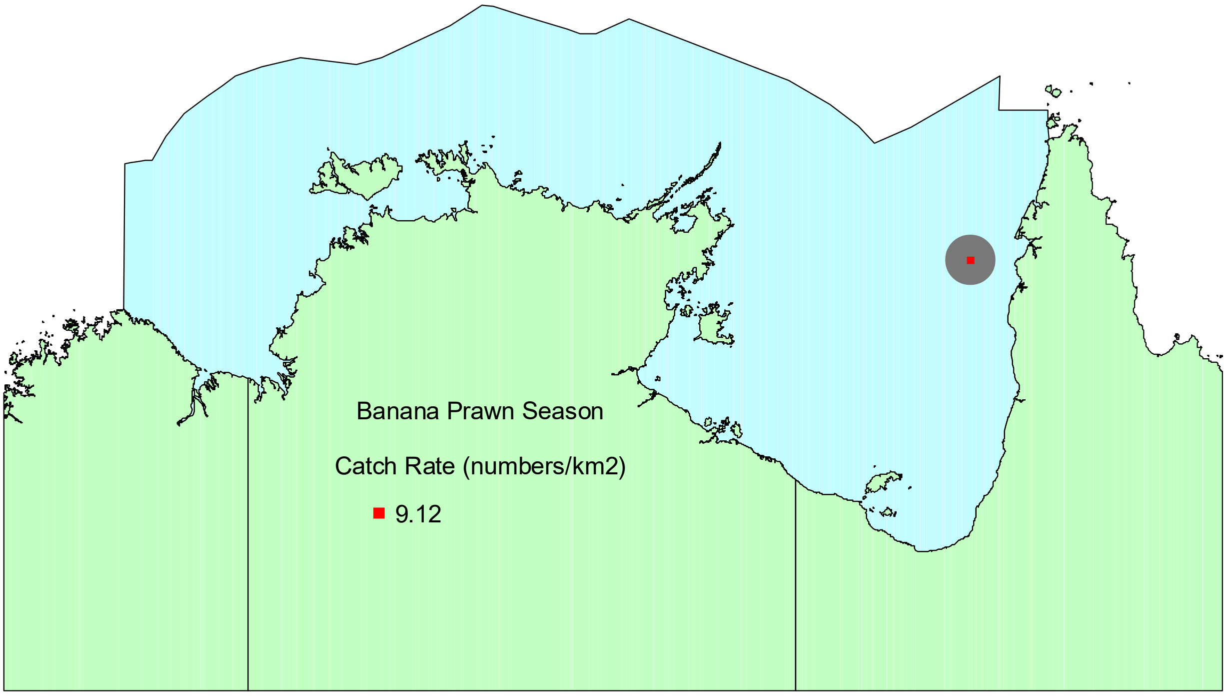
(j) Trachyrhamphus longirostris - Straightstick Pipefish



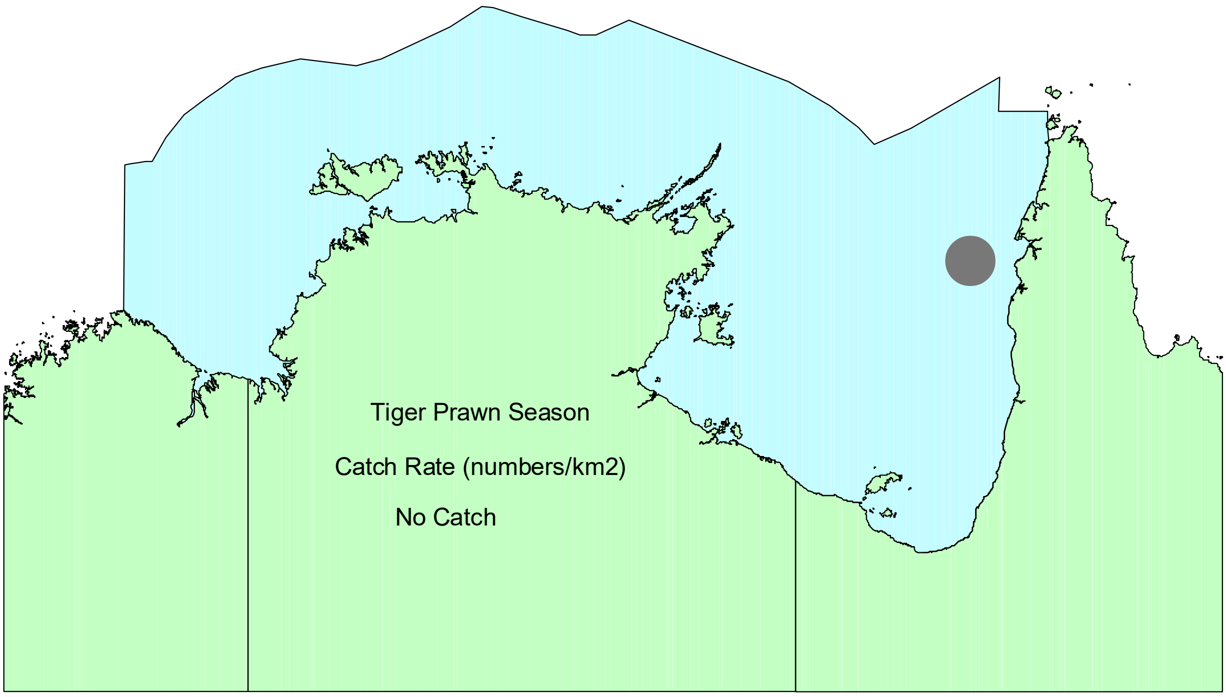
(j) Trachyrhamphus longirostris - Straightstick Pipefish



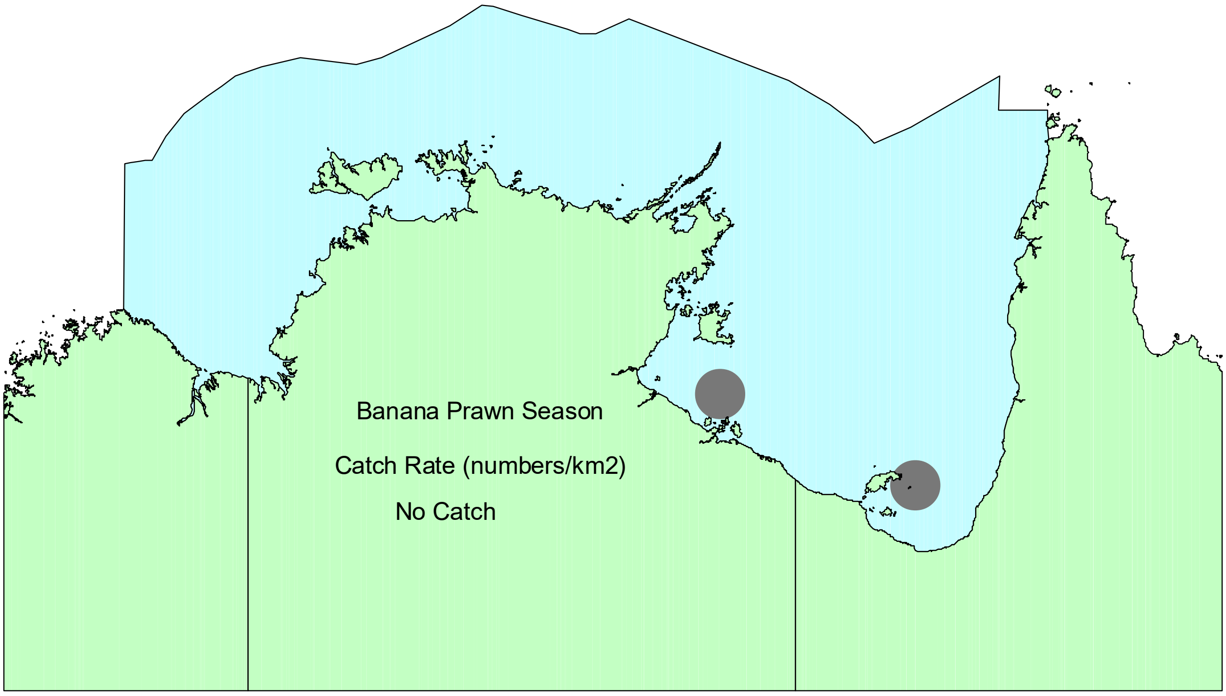
(k) Hippocampus queenslandicus - Queensland Seahorse



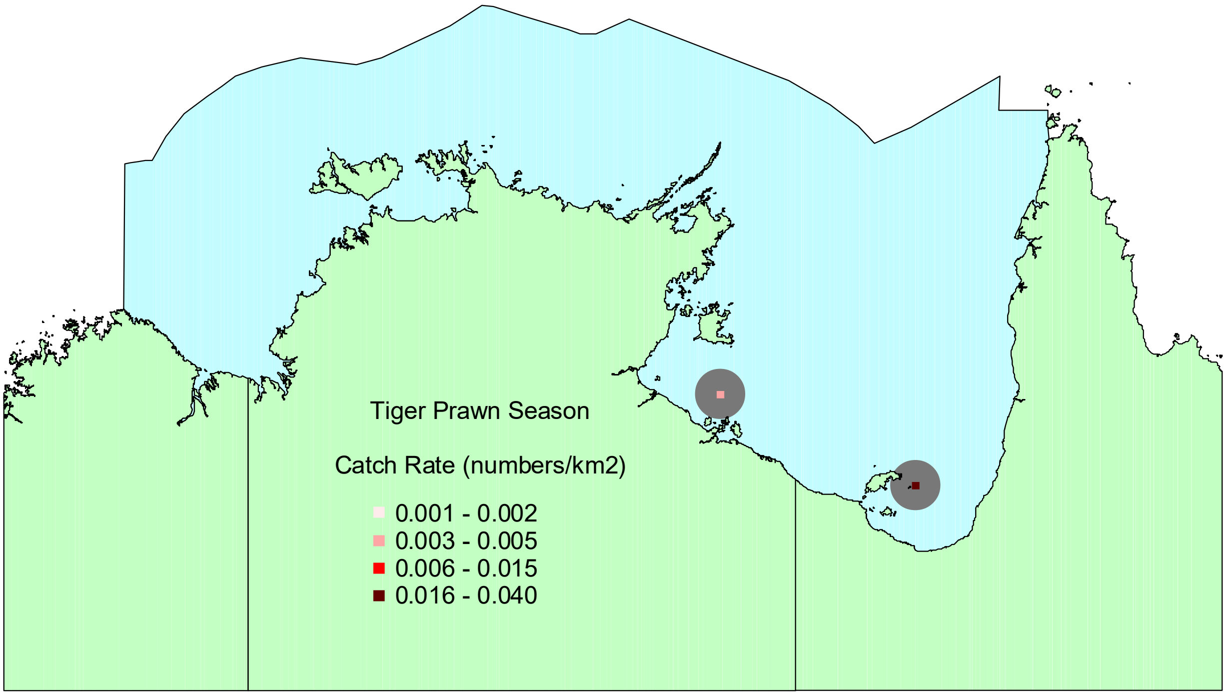
(k) Hippocampus queenslandicus - Queensland Seahorse



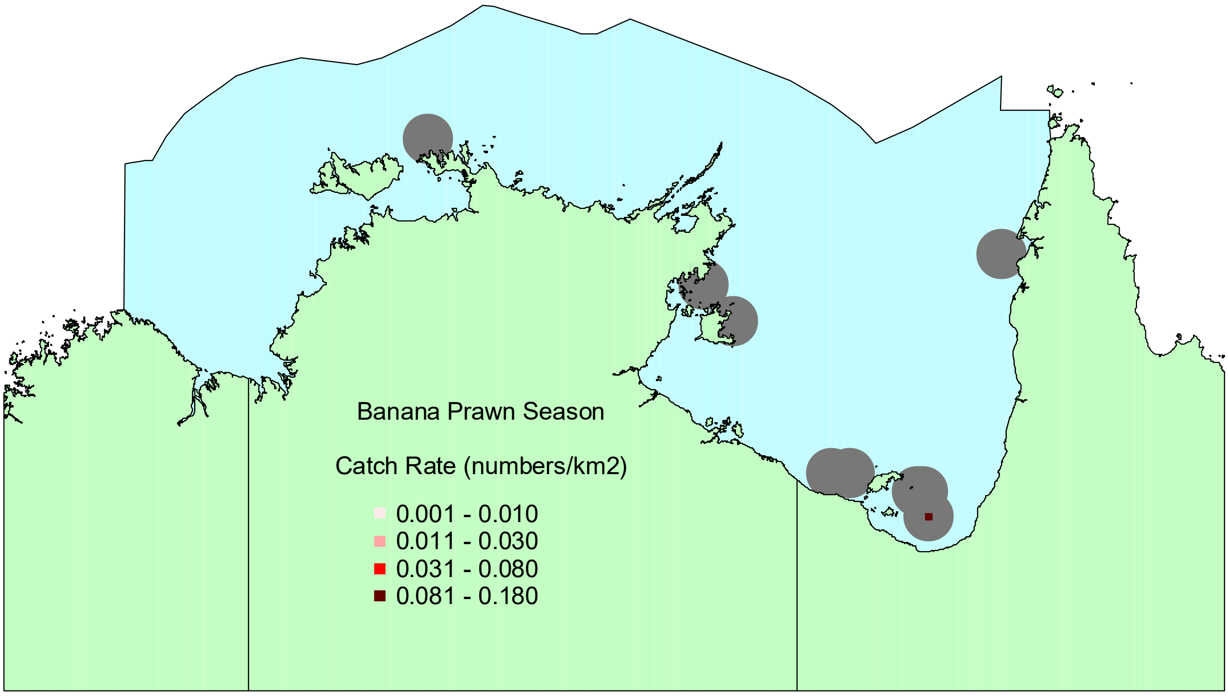
(l) Trachyrhamphus sp A - Pipefish



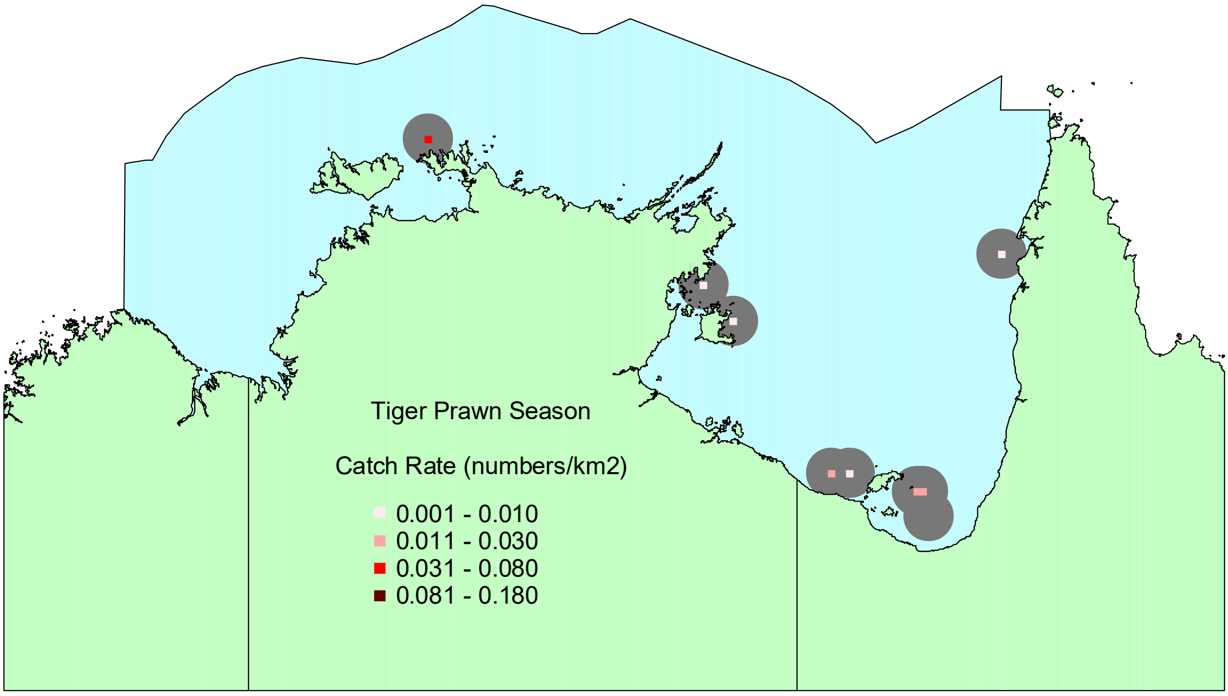
(l) Trachyrhamphus sp A - Pipefish



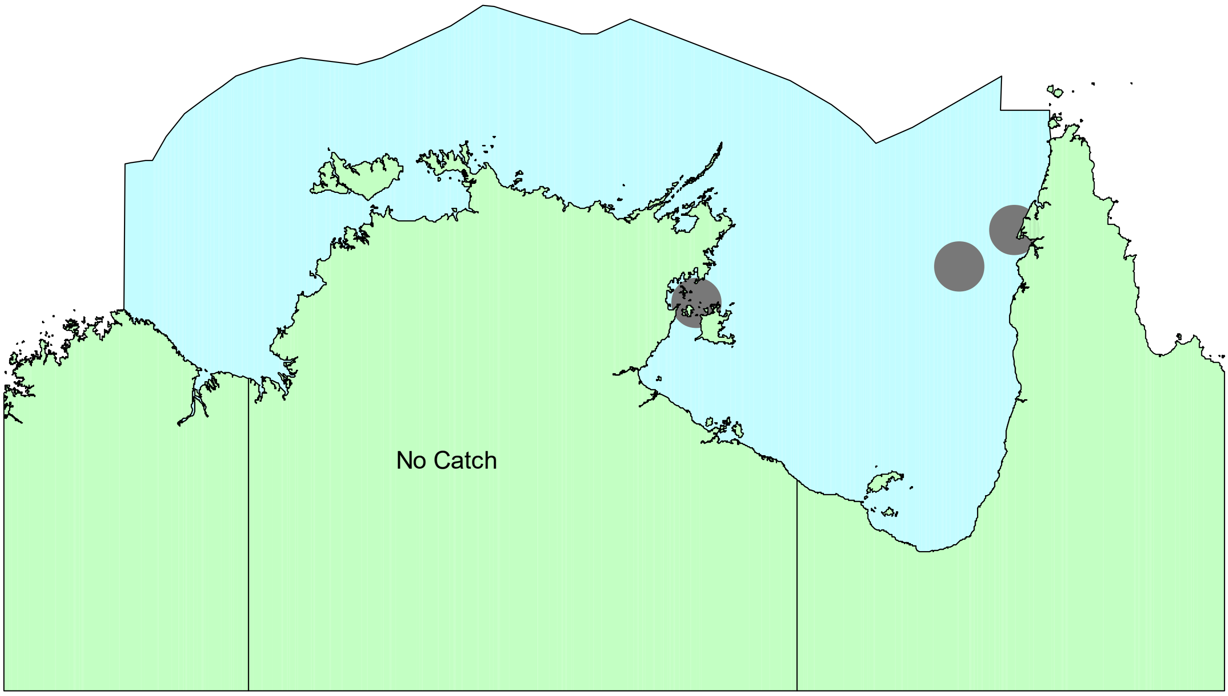
(m) Trachyrhamphus sp Short-tailed - Pipefish



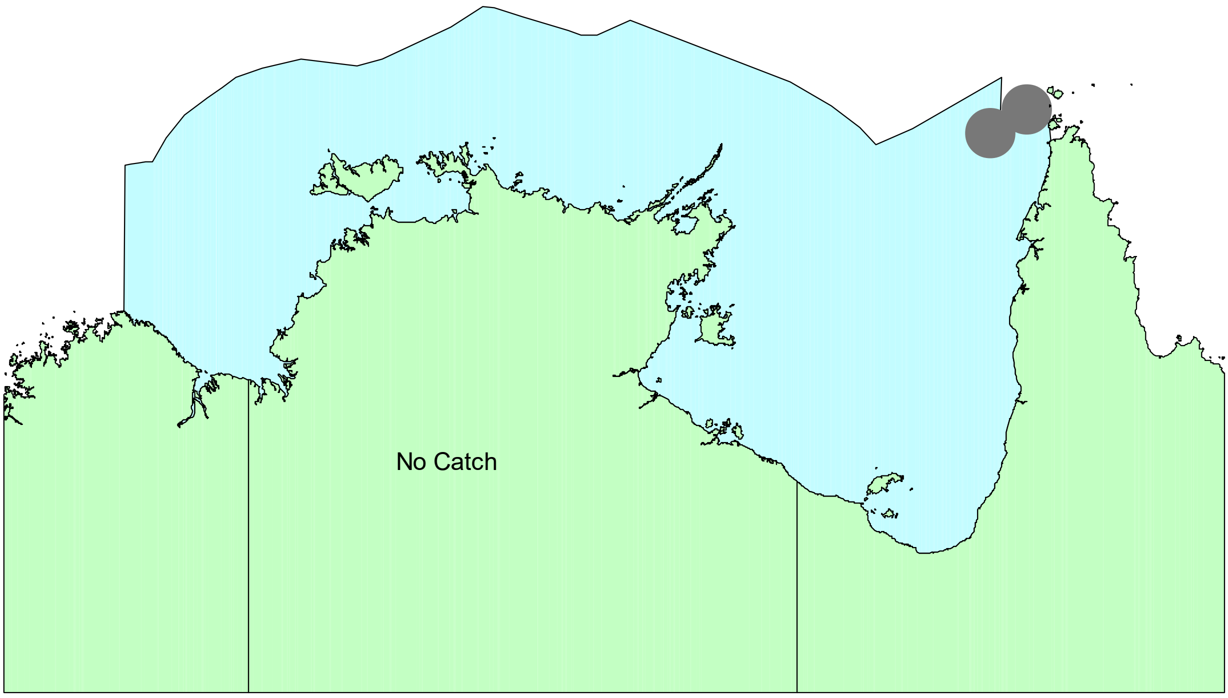
(m) Trachyrhamphus sp Short-tailed - Pipefish



(n) Hippocampus kuda - Spotted Seahorse



(o) Festucalex scalaris - Ladder Pipefish



(p) Syngnathoides biaculeatus - Alligator Pipefish

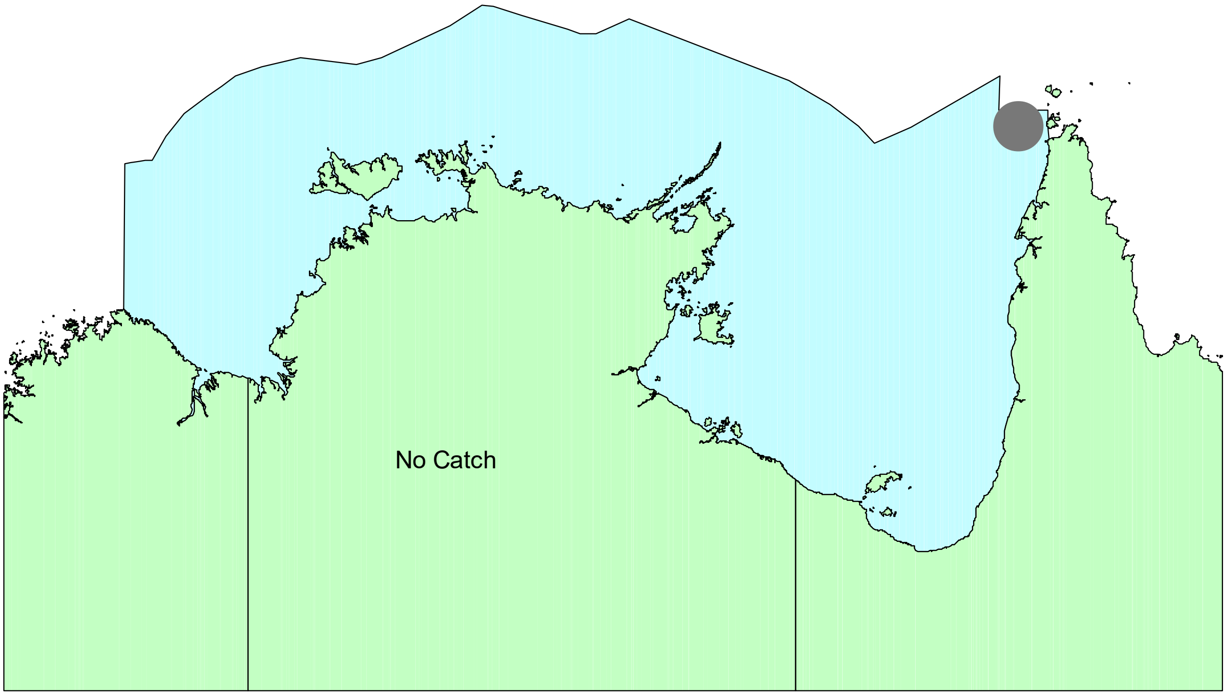
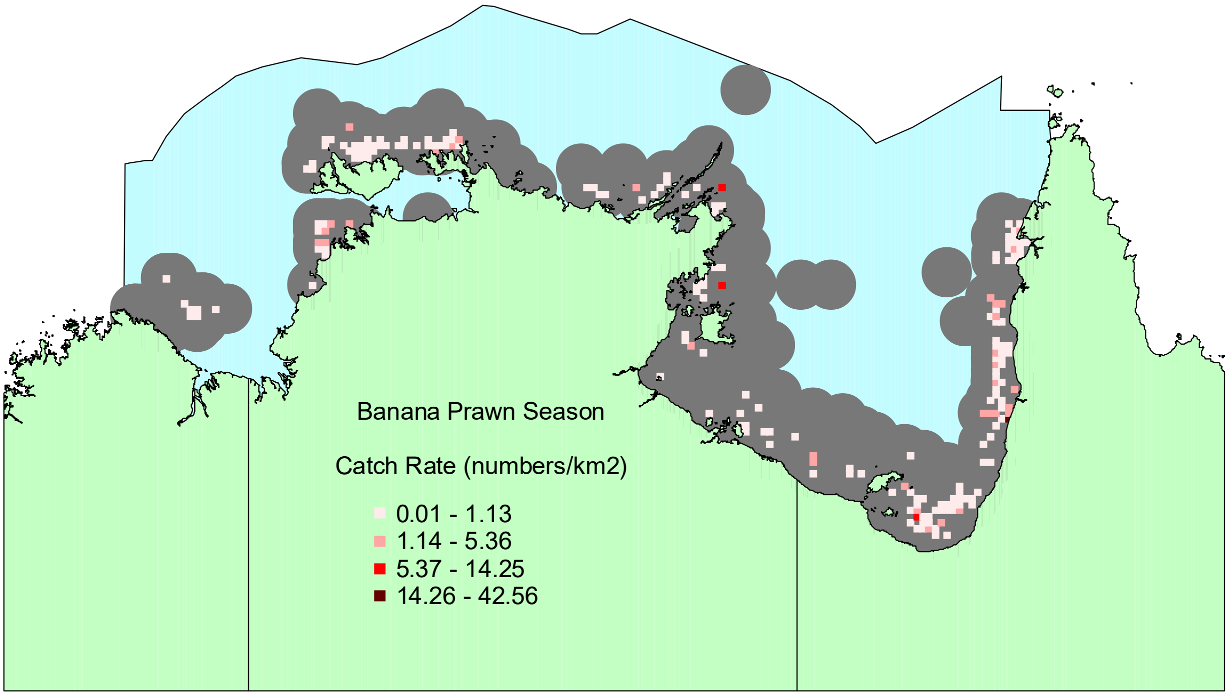
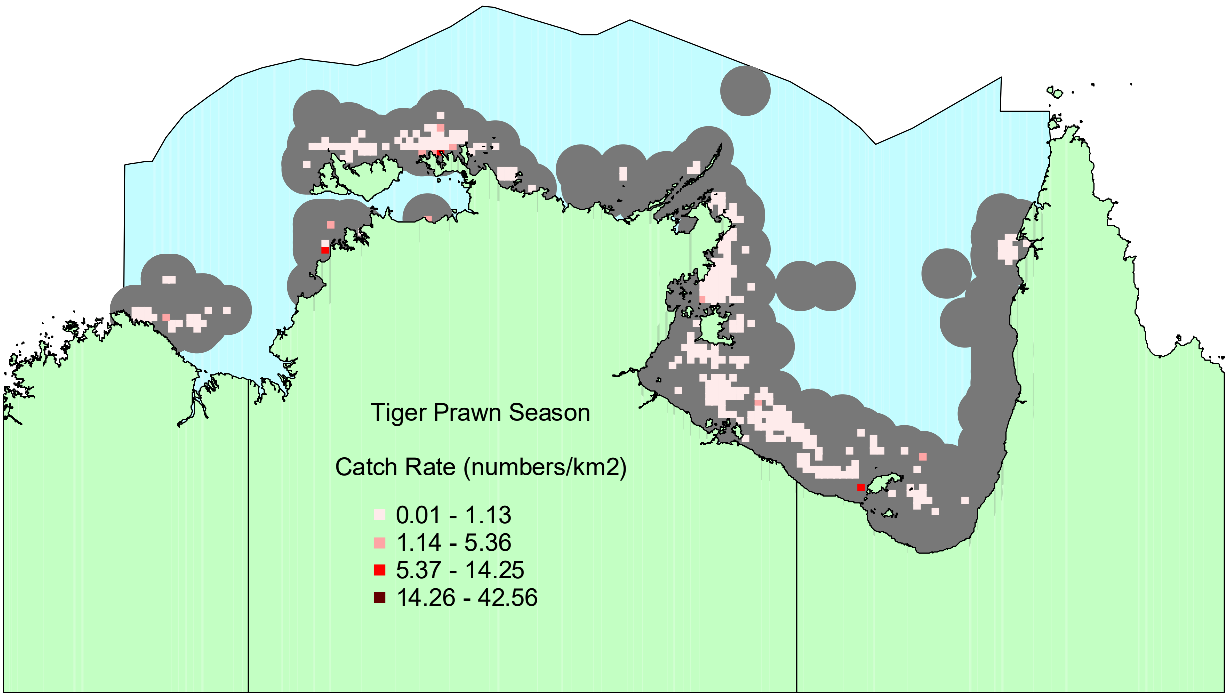


Figure 12: Following maps showing the catch records (grey circles represent a position where a species has been recorded; presence data) and overall catch rates (numbers per km^2) during the banana (Top) and tiger (Bottom) prawn seasons for the sawfishes; (a) All Sawfishes combined, (b) Unidentified Pristidae, (c) *Pristis zijsron*, (d) *Anoxypristis cuspidata*, (e) *Pristis pristis* and (f) *Pristis clavata*. Presence data includes all records from the crew-member observer program, AFMA scientific observer program, NPF prawn population monitoring surveys and CSIRO scientific research and observer surveys in the NPF. Catch rate data only includes data collected from the crew-member observer program, AFMA scientific observer program and the NPF prawn population monitoring surveys from 2002 to 2019.

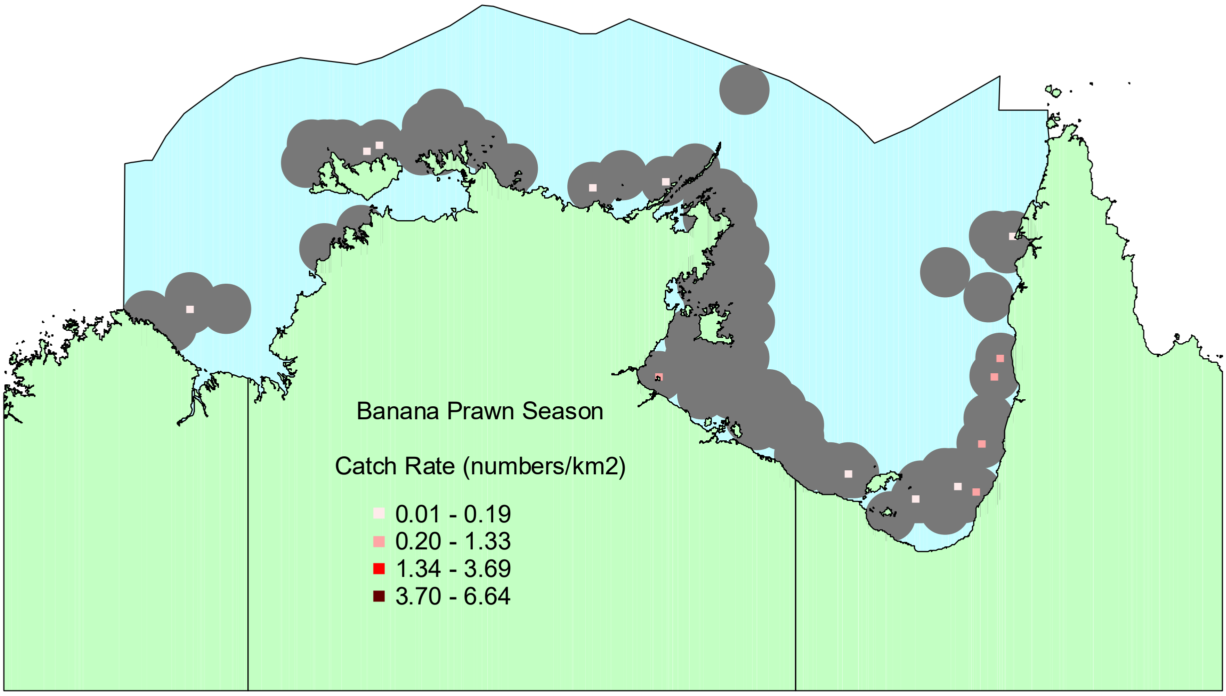
(a) Pristidae Group - All Sawfishes



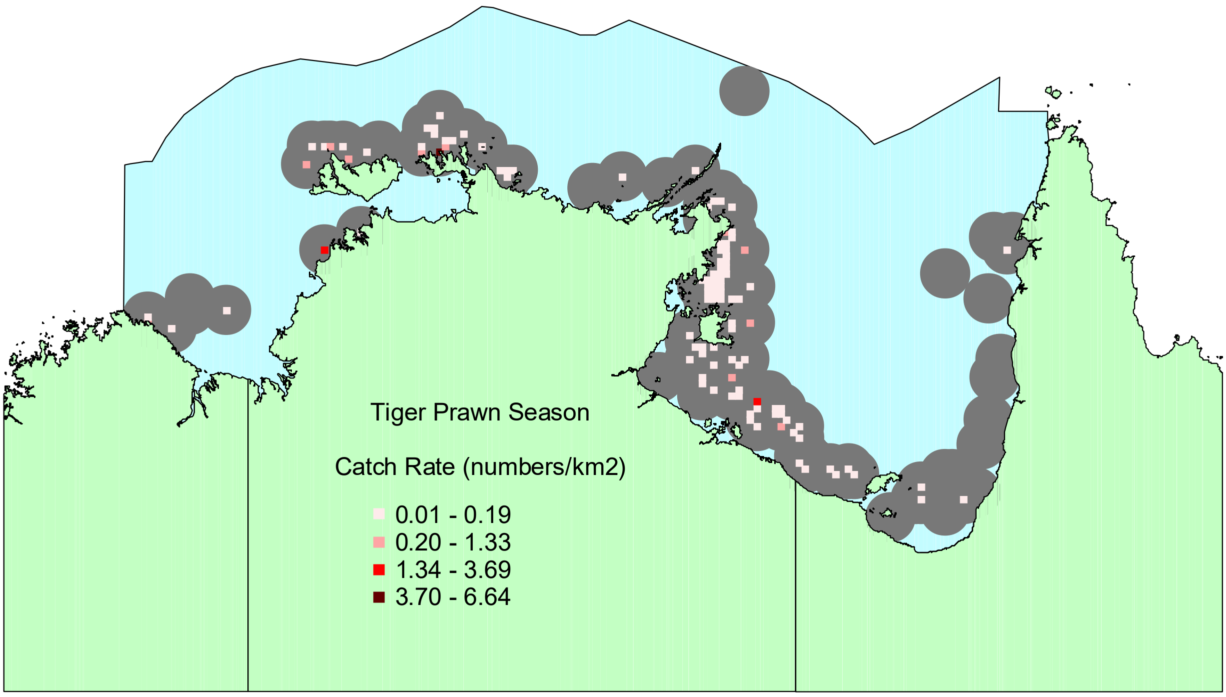
(a) Pristidae Group - All Sawfishes



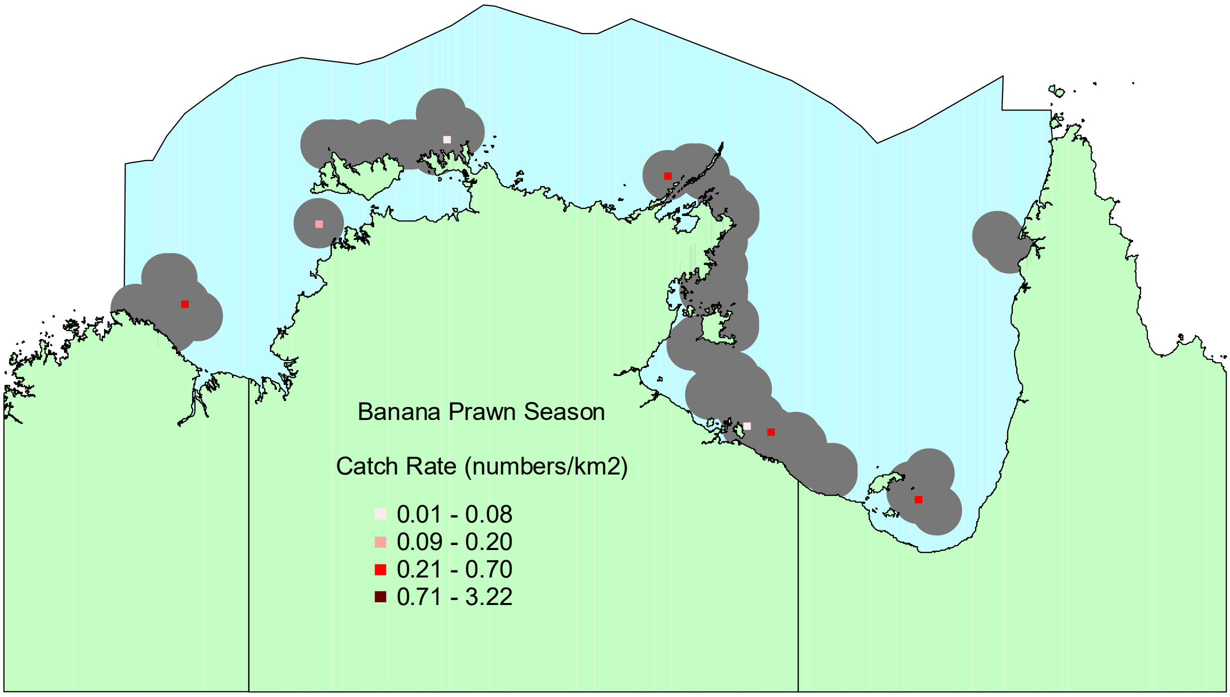
(b) Pristidae spp - Unidentified Sawfishes



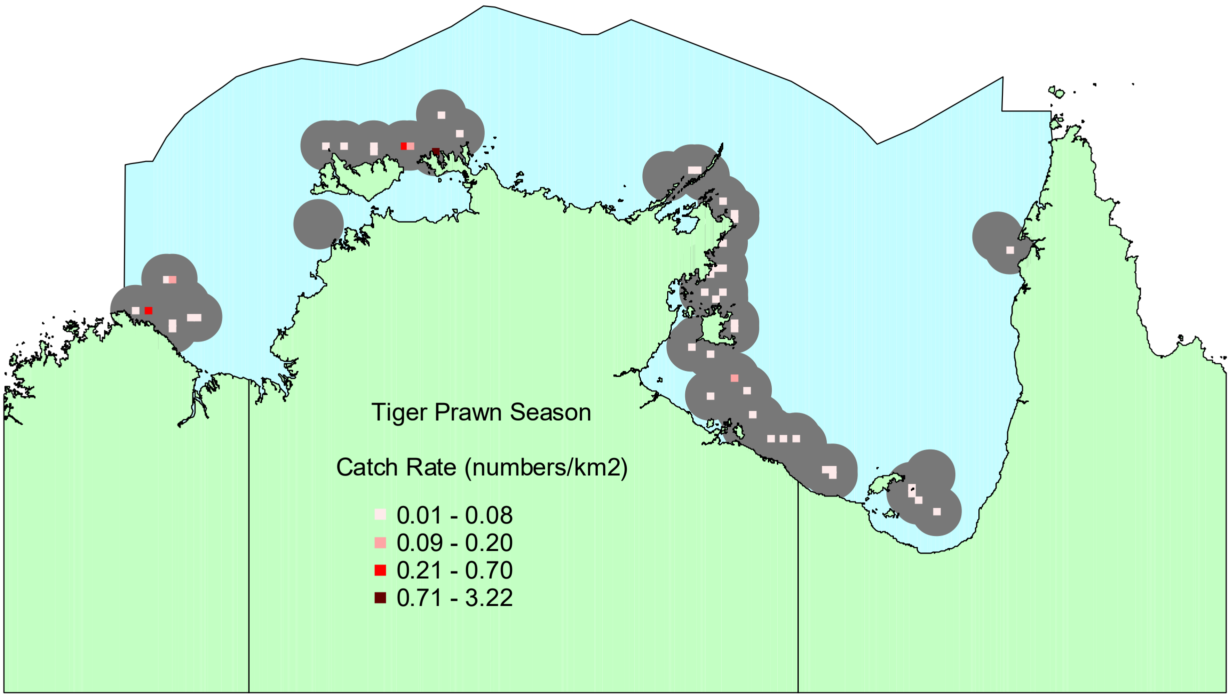
(b) Pristidae spp - Unidentified Sawfishes



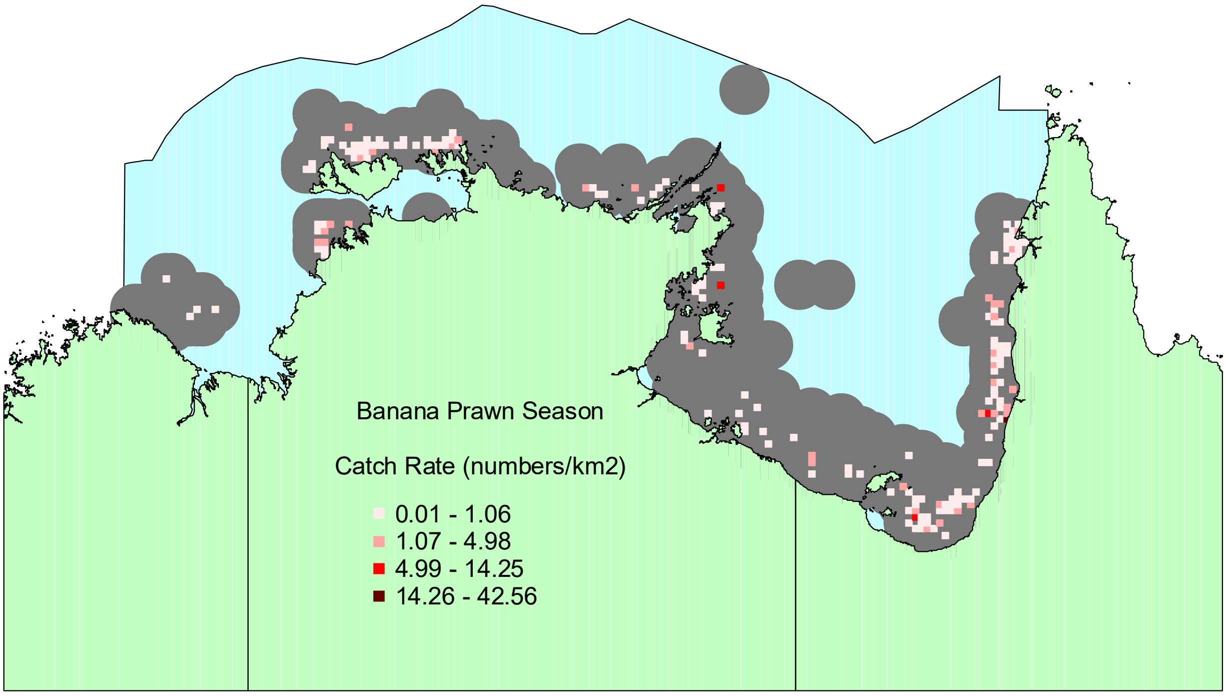
(c) Pristis zijsron - Green Sawfish



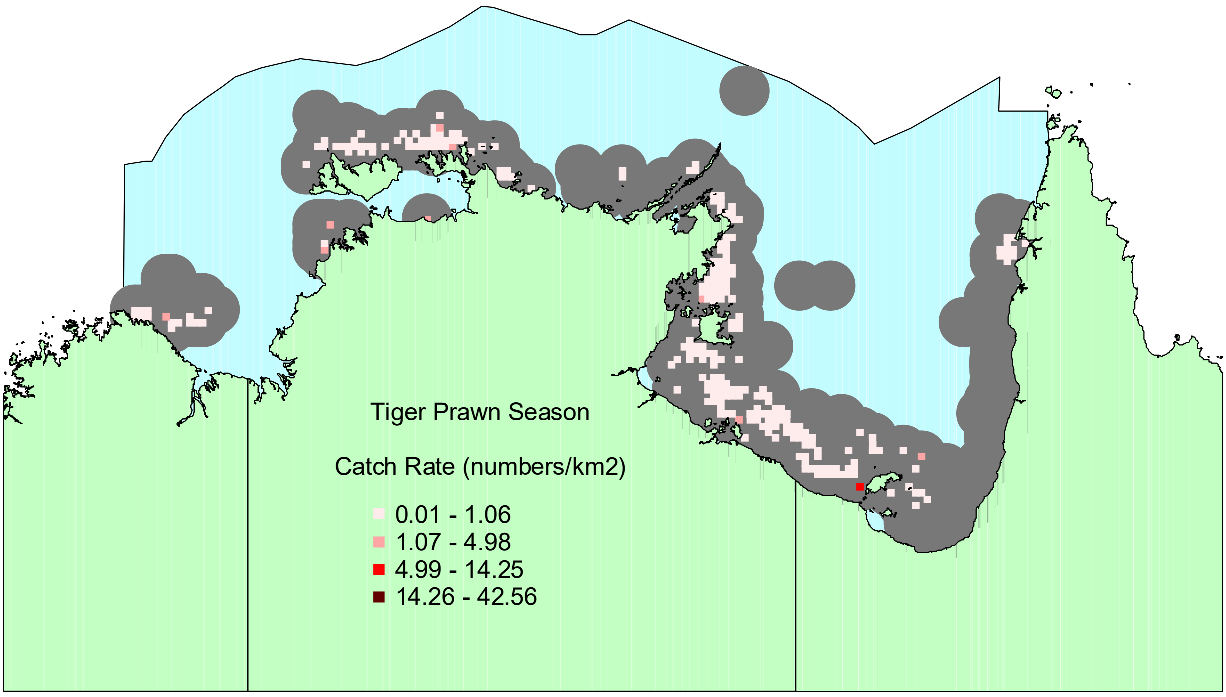
(c) Pristis zijsron - Green Sawfish



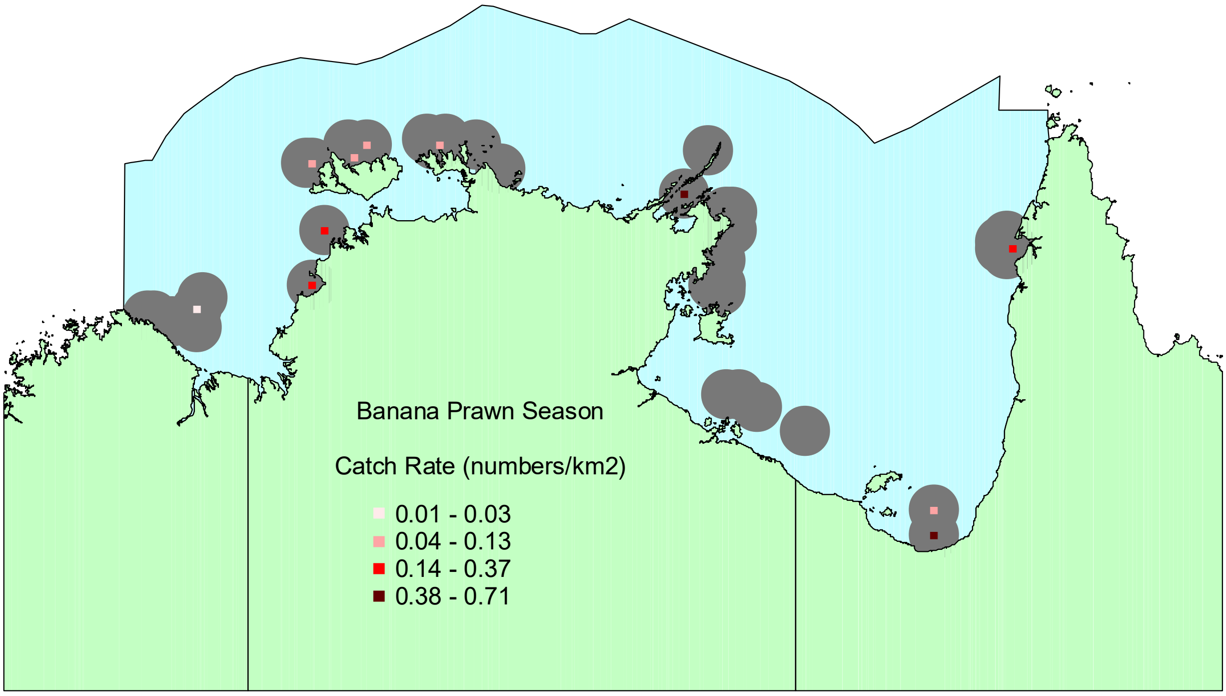
(d) Anoxypristis cuspidata - Narrow Sawfish



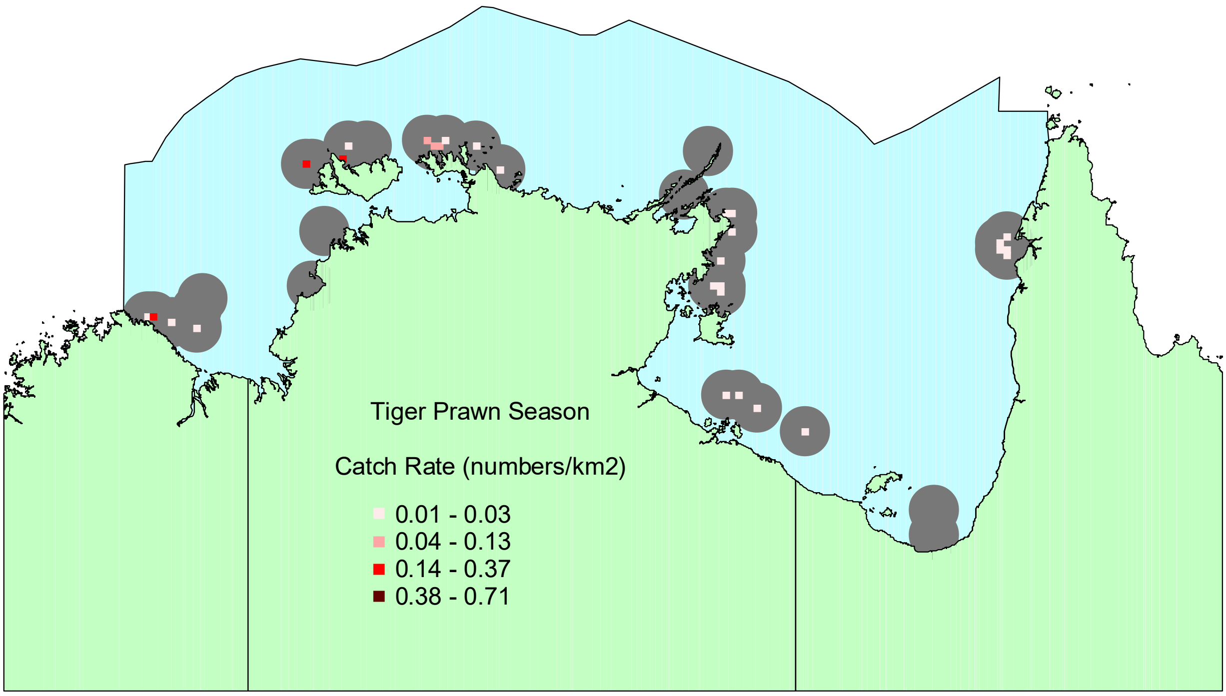
(d) Anoxypristis cuspidata - Narrow Sawfish



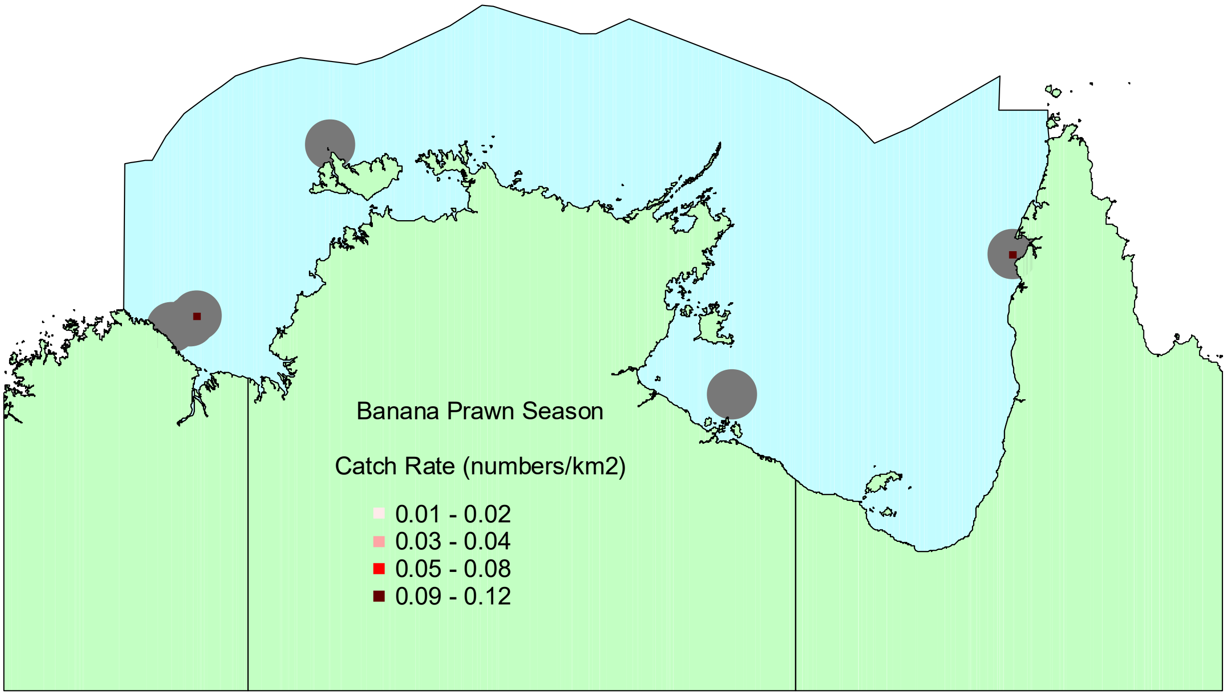
(e) Pristis pristis - Largetooth Sawfish



(e) Pristis pristis - Largetooth Sawfish



(f) Pristis clavata - Dwarf Sawfish



(f) Pristis clavata - Dwarf Sawfish

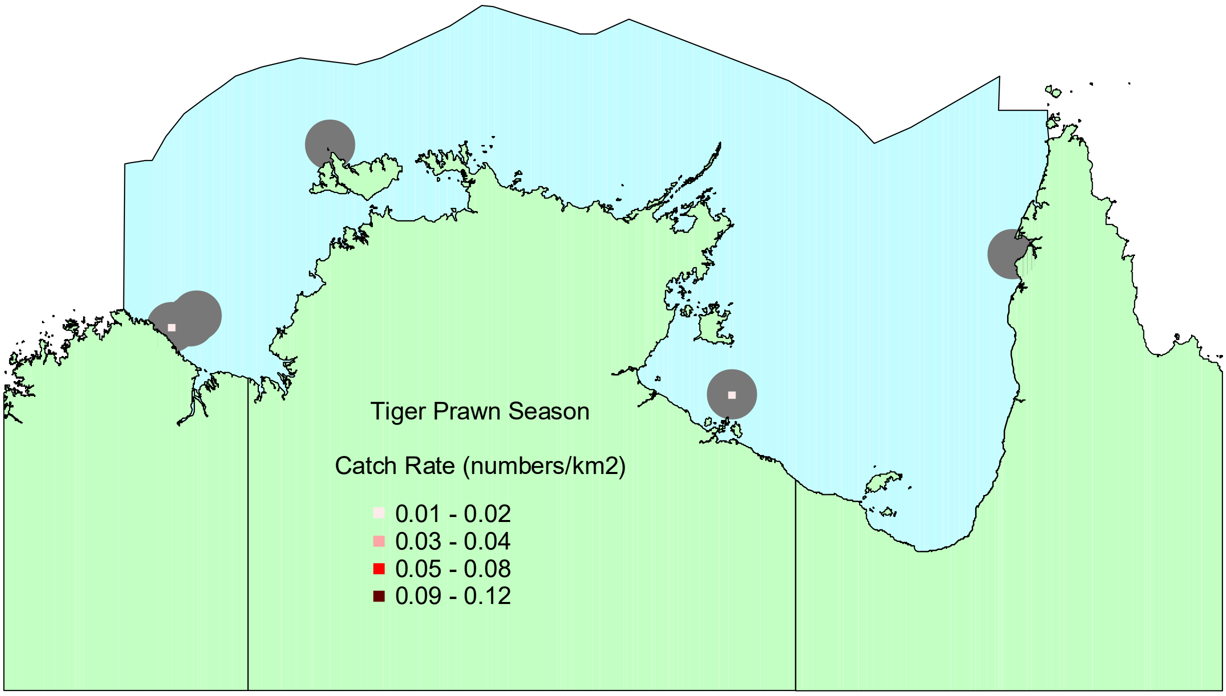
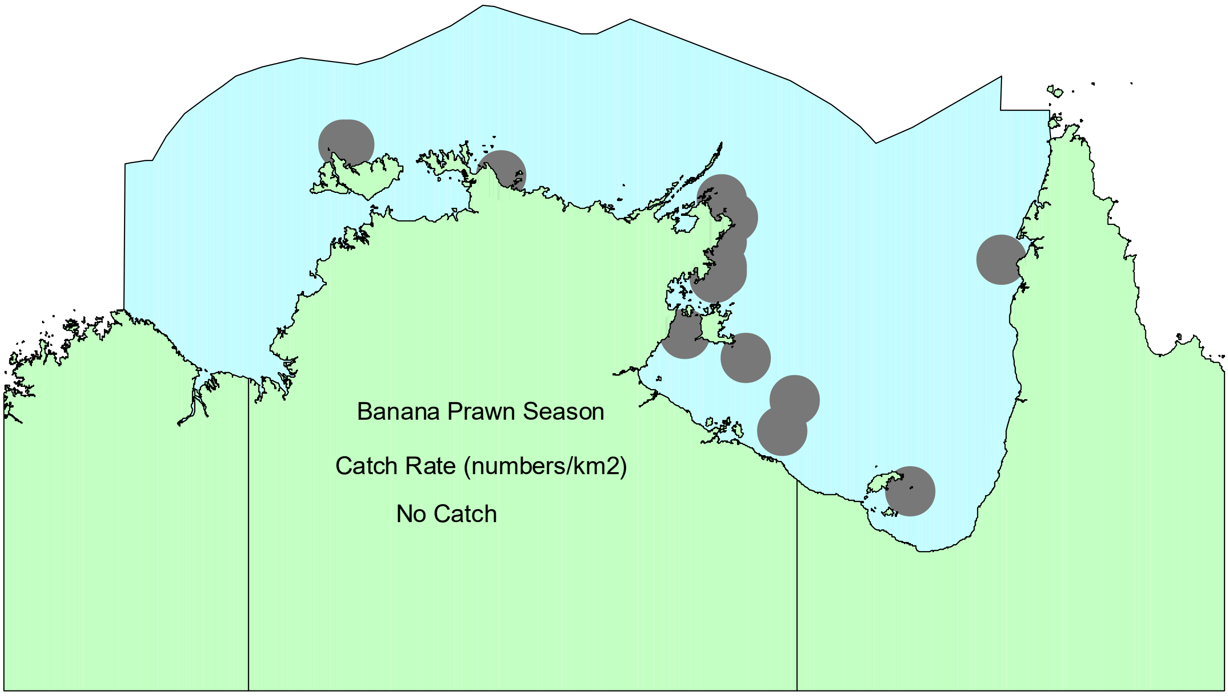


Figure 13: Following maps showing the catch records (grey circles represent a position where a species has been recorded; presence data) and overall catch rates (numbers per km^2) during the banana (Top) and tiger (Bottom) prawn seasons for the elasmobranch; (a) *Urogymnus asperrimus*. Presence data includes all records from the crew-member observer program, AFMA scientific observer program, NPF prawn population monitoring surveys and CSIRO scientific research and observer surveys in the NPF. Catch rate data only includes data collected from the crew-member observer program, AFMA scientific observer program and the NPF prawn population monitoring surveys from 2002 to 2019.

(a) Urogymnus asperrimus - Porcupine Ray



(a) Urogymnus asperrimus - Porcupine Ray

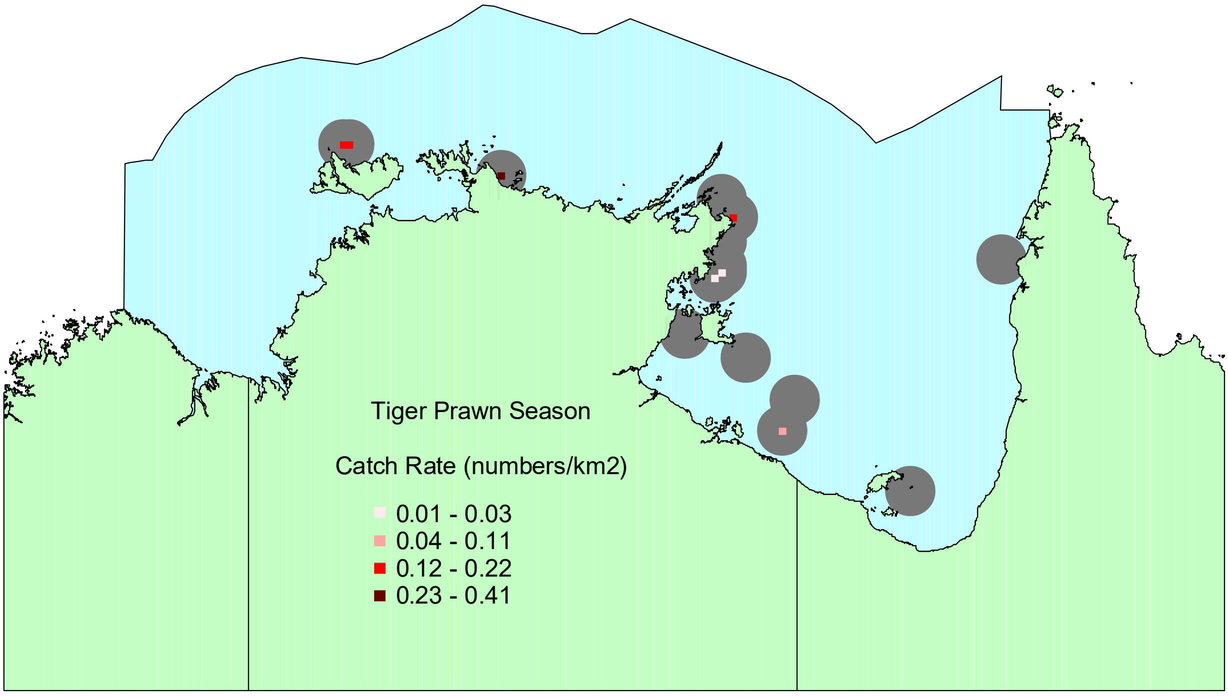
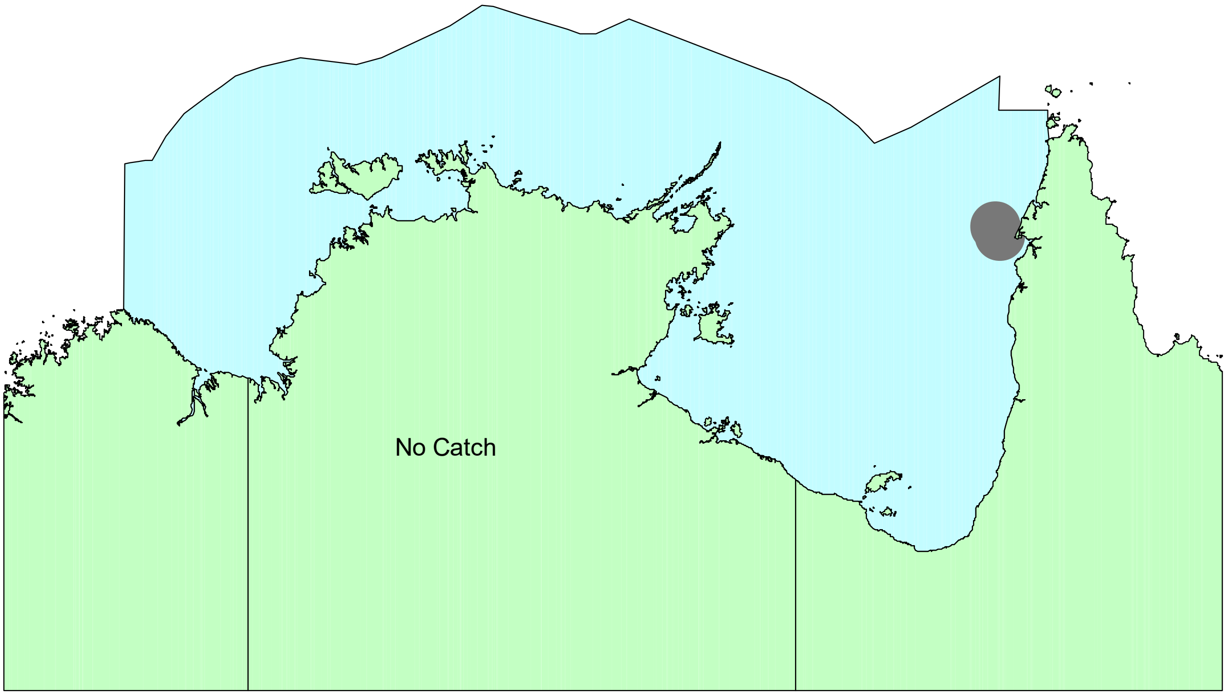


Figure 14: Following maps showing the catch records (grey circles represent a position where a species has been recorded; presence data) for the teleosts; (a) *Lepidotrigla spinosa* and (b) *Lepidotrigla* sp A. Presence data includes all records from the crew-member observer program, AFMA scientific observer program, NPF prawn population monitoring surveys and CSIRO scientific research and observer surveys in the NPF from 1976 to 2019.

(a) Lepidotrigla spinosa - Shortfin Gurnard



(b) Lepidotrigla sp A - Gurnard

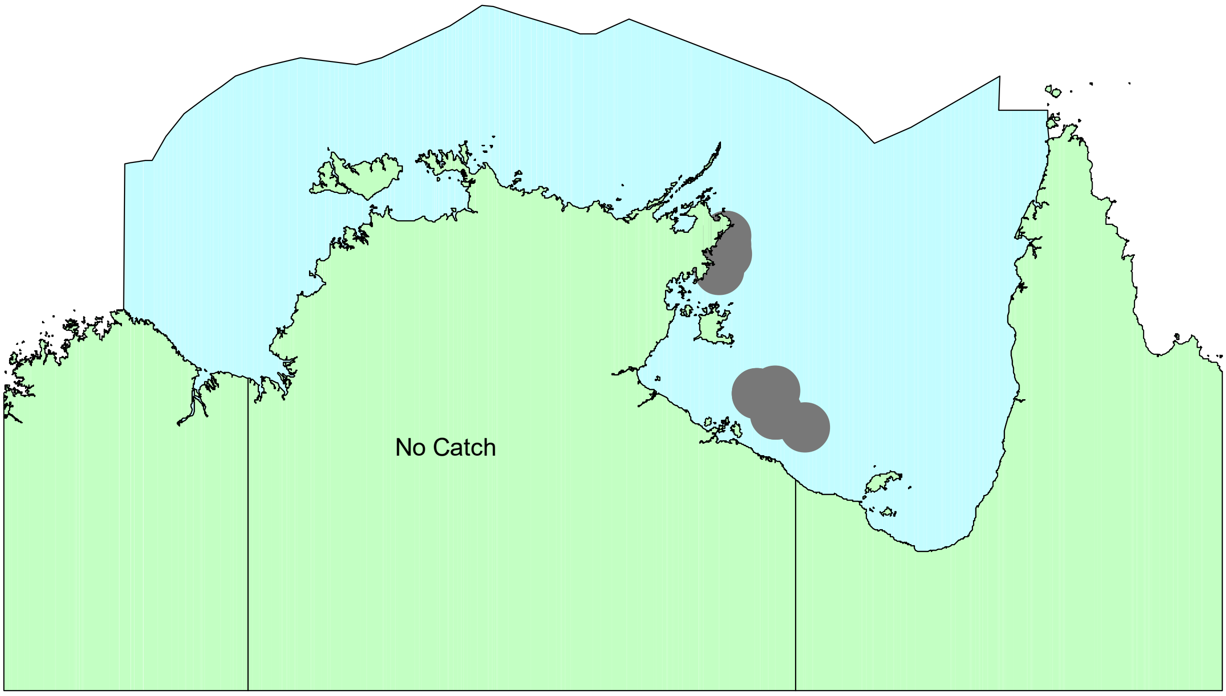
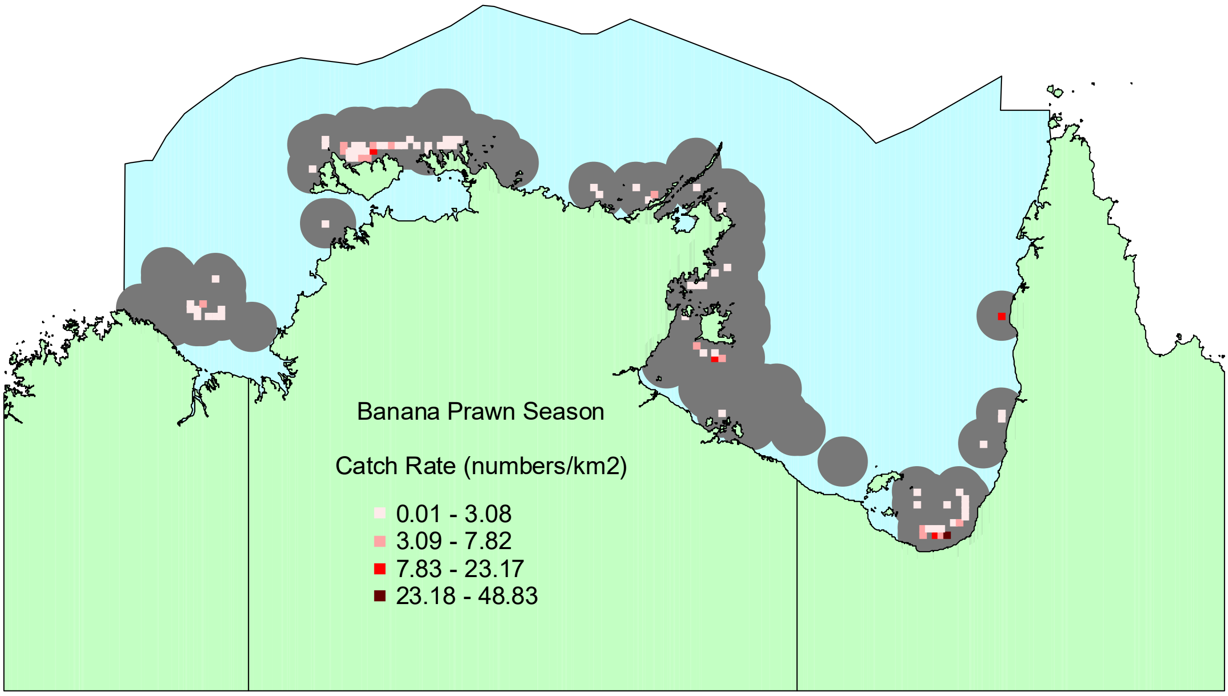
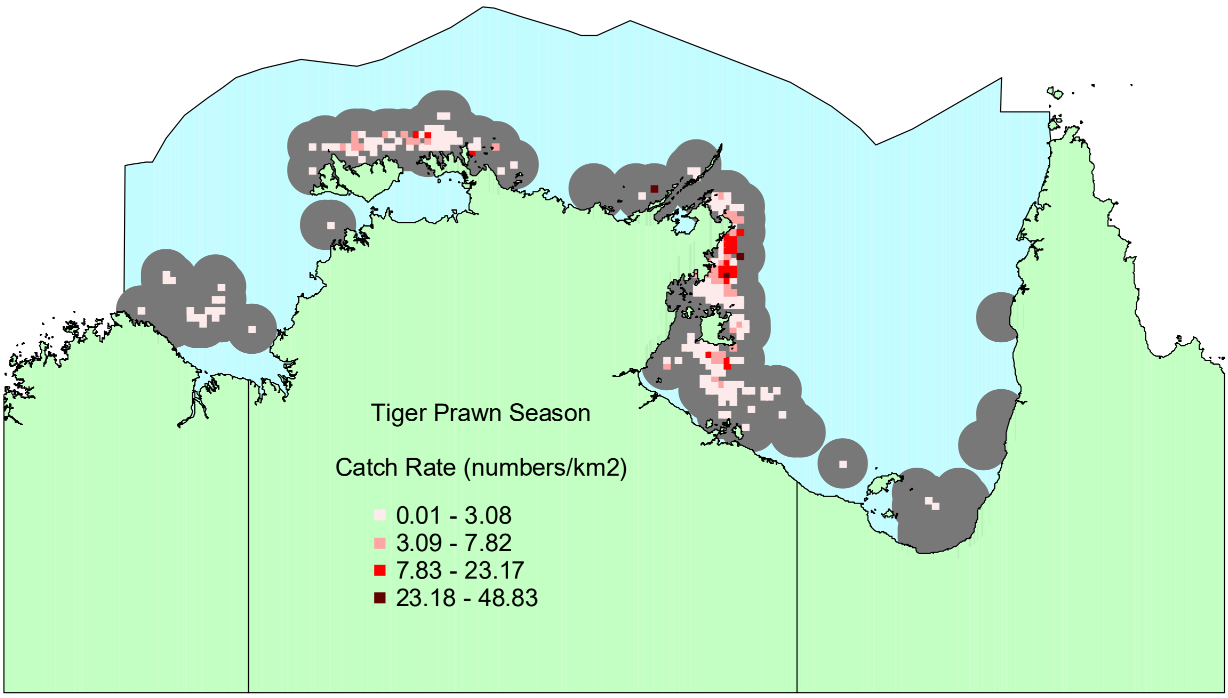


Figure 15: Following maps showing the catch records (grey circles represent a position where a species has been recorded; presence data) and overall catch rates (numbers per km^2) during the banana (Top) and tiger (Bottom) prawn seasons for the mantis shrimps; (a) *Dictyosquilla tuberculata* and (b) *Harpiosquilla stephensoni*. Presence data includes all records from the crew-member observer program, AFMA scientific observer program, NPF prawn population monitoring surveys and CSIRO scientific research and observer surveys in the NPF. Catch rate data only includes data collected from the crew-member observer program, AFMA scientific observer program and the NPF prawn population monitoring surveys from 2002 to 2019.

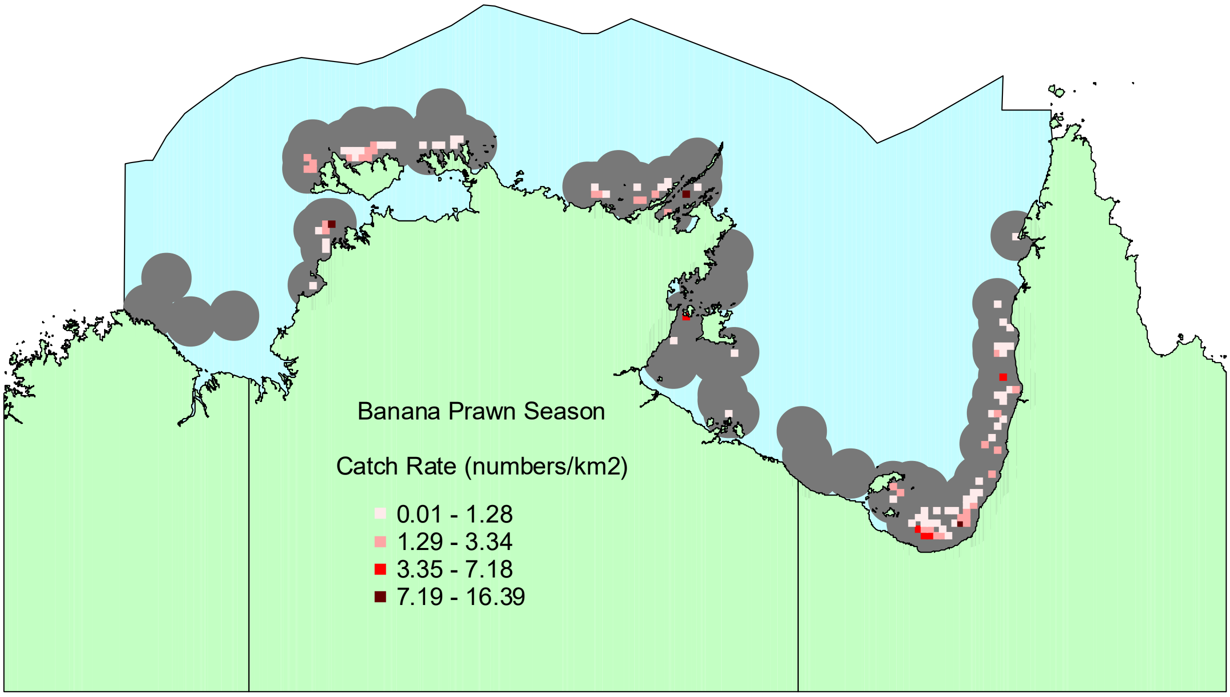
(a) Dictyosquilla tuberculata - Brown-striped Mantis Shrimp



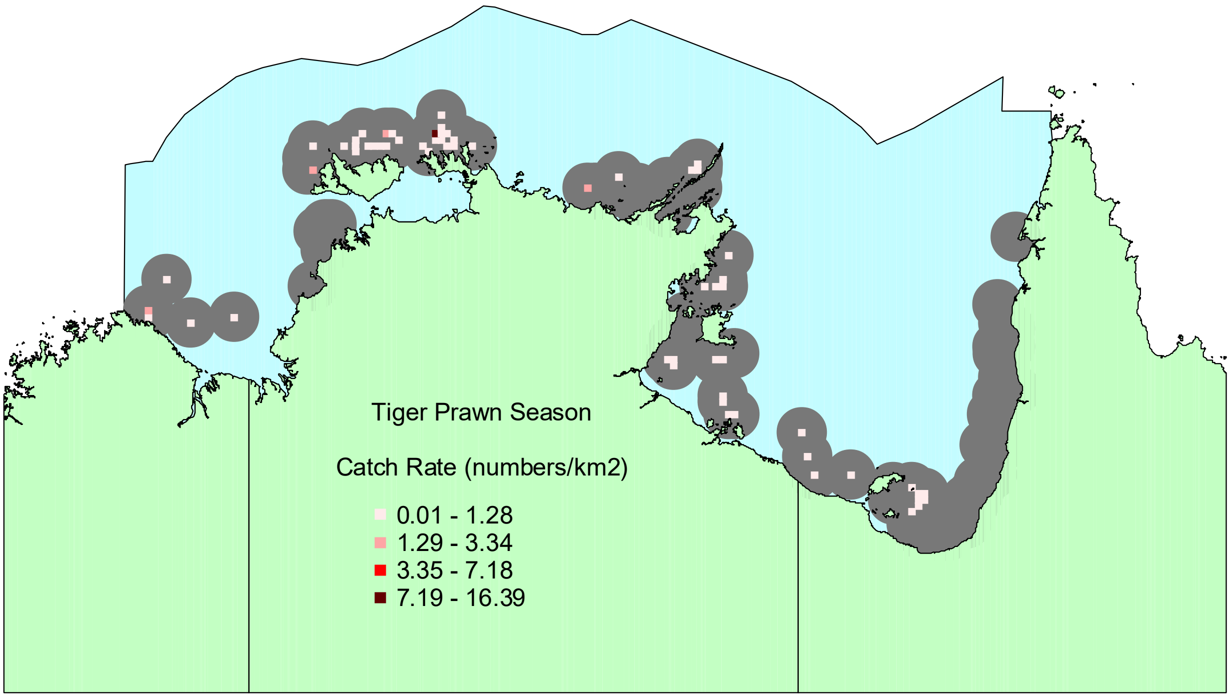
(a) Dictyosquilla tuberculata - Brown-striped Mantis Shrimp



(b) Harpiosquilla stephensoni - Stephenson's Mantis Shrimp



(b) Harpiosquilla stephensoni - Stephenson's Mantis Shrimp



6.6 Raw catch data

Mean catch rates (non-modelled) were plotted separately by ‘Region’ (Figure 16) and by ‘Year’ (Figure 17) for the crew-member observer, AFMA scientific observer and NPF prawn population monitoring data to assess and verify the quality of the crew-member observer data against the AFMA scientific observer and NPF prawn population monitoring data sets.

The catch rates recorded by the crew-member observers for the ‘unidentified' individuals for the sea snake and sawfish groups were generally higher than those recorded by AFMA scientific observers and during the NPF prawn population monitoring surveys (Table 13). This was a result of the difference in data recording procedures between the programs. Species identification was carried out by scientific observers onboard vessels during the AFMA scientific observer program and NPF prawn population monitoring surveys therefore resulting in a higher proportion of individuals identified to species (Table 13). For all taxa, predominantly the crew-member observers were trained to photograph and record data of each individual caught. For large species that are often difficult to photograph in field situations (such as marine turtles and sawfishes), crew-member observers were training to carry out on-vessel identification. The photographs collected were then later used by CSIRO scientific staff to identify all individuals to species. In cases where photographs were not taken or the photographs did not aid in species identification, lower species-specific catch rates and higher catch rates for the unidentified individuals of a group resulted from the crew-member observer data.

The marine turtle group, both 'Unidentified Cheloniidae' and each species, showed varied mean catch rates across 'Regions' for each of the crew-member observer, AFMA scientific observer and NPF prawn population monitoring data sets (Figure 16). However, the mean catches across ‘Regions’ were relatively consistent between the three data sets. Most of the ‘Unidentified Cheloniidae’ catches from the crew-member observer program were recorded around the eastern side of the Gulf of Carpentaria (‘Region’ 9). The crew-member observer program also recorded low mean catches of the most common species, the Flatback Turtle (*Natator depressus*) in this ‘Region’. Catch rates across the 'Years' from 2003 to 2019 showed a distinct decline for the ‘Unidentified Cheloniidae’ group as crew-member observers improved in species identification capacity and data recording (photographs) (Figure 17). For the Green Turtle (*Chelonia mydas*), there has been a downward trend in catch rates over 2015 to 2019. However, catch rates were still within the range from earlier years. There were too few catch records of marine turtles from the AFMA scientific observer program and NPF prawn population monitoring surveys to show any trends across 'Regions' and 'Years' for comparison with the crew-member observer data (Figure 16; Figure 17).

The sea snakes were one of the most noticeable group that showed disparity between the crew-member observer and AFMA scientific observer and NPF prawn population monitoring surveys in the proportion of individuals identified to species level (Table 13). The mean catch rate of 'Unidentified Hydrophiidae' was higher across all 'Regions' and all 'Years' for the crew-member observer program but reasonably similar between the AFMA scientific observer and NPF prawn population monitoring data sets (Figure 16; Figure 17). Therefore, the actual catch rates recorded by the crew-member observer program for the more common sea snake species such as *Hydrophis elegans* and *Lapemis curtis*, would likely be under-estimated due to the higher proportion of ‘Unidentified Hydrophiidae’ recorded.

There were strong similarities between the three data sets in the catch rates for most of the sea snake species. Although the actual values for catches in some 'Regions' and 'Years' were higher in one data set than others, the trends across 'Regions' and 'Years' showed consistency. There were some exceptions such as for *Hydrophis elegans*, *Hydrophis pacificus* and *Lapemis curtis*, where catches recorded from the AFMA scientific observer and NPF prawn population monitoring surveys were similar between these two data sets but considerably higher than those recorded from the crew-member observer program (Figure 16; Figure 17). The catch rates for most sea snake species appeared to be stable or slightly increasing over the last three years; 2017 to 2019. Two species (*Aipysurus duboisii* and *Aipysurus mosaicus*) did show some decline in catch rates for one of the data sets however this decline was not evident nor to levels lower than the other data sets. One of the more common species; *Disteira major*, did show a consistent decline in catch rates from 2017 to 2019 from all three data sets.

The Syngnathidae group are difficult to identify with the exception of one common species, the Straightstick Pipefish (*Trachyrhamphus longirostris*). These identification problems resulted in a large number of 'Unidentified Syngnathidae' compared to the number of individuals identified to species level for all three data sets (Figure 16; Figure 17). The catch rates for both the 'Unidentified Syngnathidae' and *Trachyrhamphus longirostris* were generally comparable over ‘Region’ and ‘Years’ between the crew-member observer program and the AFMA scientific observer and NPF prawn population monitoring surveys (Figure 16; Figure 17). Apart from a few 'Region' and 'Year' outliers, the crew-member observer program showed quite similar catch rate trends for this species to the AFMA scientific observer and NPF prawn population monitoring catch data. This catch rate consistency indicates that the crew-member observer program is quite successful at accurately recording catches of the one Syngnathidae species which can be identified in the field.

The sawfishes were another group where the proportion of individuals identified to species was much lower in the crew-member observer program compared to the AFMA scientific observer and NPF prawn population monitoring surveys (Table 13). The crew-member observer catches of 'Unidentified Pristidae' were generally higher across most 'Regions' and 'Years' (Figure 16; Figure 17). The crew-member observer program, AFMA scientific observer program and NPF prawn population monitoring surveys recorded very few individuals of the Dwarf Sawfish (*Pristis clavata*). Mean catch rates of the Green Sawfish (*Pristis zijsron*) were low across all 'Regions' and 'Years' but were generally similar between the crew-member observer and NPF prawn population monitoring data sets (Figure 16; Figure 17). However, catch rates recorded in the AFMA scientific observer program were significantly higher over the recent years (2013 – 2019) compared to the crew-member observer program and NPF prawn population monitoring surveys. In addition, there has been a distinct decline in mean catch rates of the Green Sawfish over this time period from the AFMA scientific observer program. The Largetooth Sawfish (*Pristis pristis*) appeared to show relatively low but stable catch rates over the recent years from 2013 to 2019.

The Narrow Sawfish (*Anoxypristis cuspidata*) made up about 92% of the catch composition for the sawfish group in the NPF between 2002 and 2019. While the catch rates of this species recorded by the crew-member observer program were consistently lower than catches recorded during the AFMA scientific observer program and NPF prawn population monitoring surveys, when combined with the 'Unidentified Pristidae' catch, they showed comparable catch rate trends across both ‘Regions’ and 'Years' from 2003 to 2019.

There were too few individuals recorded for the 'at risk' elasmobranch species (*Urogymnus asperrimus*) and no catches recorded for the two ‘at risk’ teleost species (*Lepidotrigla spinosa* and *Lepidotrigla* sp A) to show any catch rate trends across the 'Regions' and 'Years' for either the crew-member observer program, AFMA scientific observer program or the NPF prawn population monitoring surveys (Figure 16; Figure 17).

The Brown-striped Mantis Shrimp (*Dictyosquilla tuberculata*) had higher catch rates recorded by the crew-member observer program across all ‘Years’ and within most 'Regions' compared to the AFMA scientific observer program and NPF prawn population monitoring surveys (except for ‘Regions’ along the east side of the Gulf of Carpentaria) (Figure 16; Figure 17). Catches have shown to be variable between years from 2009 to 2019. There have been some years where catch rates have been considerably low (2014, 2016, 2017 and 2019) however the general trend is of increasing catches over the last ten years. The crew-member observer catches of the Stephenson's Mantis Shrimp (*Harpiosquilla stephensoni*) have been steadily increasing since 2009 to 2016 with the last three years (2017 – 2019) there has been a trend of declining catches. Similarly, catch rates recorded during the NPF prawn population monitoring surveys have been considerably higher and in decline from 2012 to 2019.

Although there were some discrepancies in actual catch rates between the crew-member observer program and AFMA scientific observer program and NPF prawn population monitoring surveys, the trends in catch rates across 'Regions' and 'Years' were generally similar for many TEP and 'at risk' species. Data consistency indicates that the data recorded and collected from the crew-member observer program were reliable to identify catch rate trends and for use in sustainability assessments, especially in the last few years of data collection.

Table 13: Summary of the total numbers of individuals recorded and the percentage of those individuals identified to species level for each of the TEP and 'at risk' bycatch groups from each of the four data sources.

Data Source	Group	Total Number of Individuals	Number Identified to Species	Percentage of Individuals Identified to Species																		
				Pre-02	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Mean
Crew-member Observer	Dolphin	1	0	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	0.0
	Turtle	434	289	-	-	45	100	-	29	40	80	17	80	73	63	68	77	78	70	77	84	71	66.6
	Sea Snake	27708	23893	-	-	63	72	79	77	56	29	43	55	84	78	96	88	95	95	95	98	95	86.2
	Syngnathidae	2075	1749	-	-	-	100	-	0	46	27	24	74	88	77	81	71	93	85	87	87	94	84.3
	Sawfish	1368	1149	-	-	61	86	100	68	29	40	60	57	89	84	90	98	96	90	88	90	99	84.0
	Elasmobranch	20	14	-	-	-	100	-	-	-	-	0	100	100	100	100	-	100	100	100	-	100	70.0
	Squillidae	60333	59819	-	-	-	-	-	-	-	-	14	54	100	100	100	100	100	92	100	100	100	99.1
AFMA Scientific Observer	Turtle	36	27	-	-	-	-	100	-	100	100	100	100	67	50	50	0	-	100	100	-	75	75.0
	Sea Snake	3265	3244	-	-	-	-	100	-	99	100	98	99	99	100	100	99	100	99	100	98	100	99.4
	Syngnathidae	376	220	-	-	-	-	-	-	3	95	91	67	33	66	92	73	60	97	100	93	77	58.5
	Sawfish	357	347	-	-	-	-	86	-	100	100	100	87	100	96	87	100	100	100	100	100	98	97.2
	Elasmobranch	5	5	-	-	-	-	-	-	100	-	-	-	-	-	-	-	-	100	-	-	-	100.0
	Squillidae	3496	3067	-	-	-	-	-	-	-	-	-	100	100	100	100	100	100	40	100	100	100	87.7
NPF Prawn Monitoring	Turtle	32	14	-	-	-	50	-	-	50	0	100	-	67	33	0	50	0	50	-	60	33	43.8
	Sea Snake	2094	2059	-	79	100	94	98	97	100	100	98	99	98	100	99	96	100	99	100	99	100	98.3
	Syngnathidae	185	132	-	0	100	0	-	-	25	35	75	67	50	84	62	60	94	100	87	62	91	71.4
	Sawfish	101	101	-	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	-	100	100.0
	Squillidae	142	142	-	-	-	-	-	-	-	-	-	-	-	100	100	100	100	100	-	100	100	100.0
CSIRO Scientific Survey	Turtle	261	222	85	-	-	100	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	85.1
	Sea Snake	2719	2472	91	-	91	91	90	-	-	-	-	-	-	-	-	-	-	-	-	-	-	90.9
	Syngnathidae	71	60	86	-	-	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	84.5
	Sawfish	389	347	88	-	100	100	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	89.2
	Elasmobranch	9	9	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100.0

6.7 GAM modelled catch rate trends

Fourteen species caught during the crew-member observer program were able to be modelled for catch rate trends from 2003 to 2019: one marine turtle species (*Natator depressus*) ten sea snake species (*Acalyptophis peronii*, *Aipysurus duboisii*, *Aipysurus mosaicus*, *Aipysurus laevis*, *Astrotia stokesii*, *Disteira major*, *Hydrophis elegans*, *Hydrophis ornatus*, *Hydrophis pacificus* and *Lapemis curtis*), one syngnathid (*Trachyrhamphus longirostris*), one sawfish species (*Anoxypristis cuspidata*) and one invertebrate species (*Dictyosquilla tuberculata*). This was dependent on the number of catch records available for each species recorded from the crew-member observer program. Most species had too few catch records for the data to fit the model.

When the AFMA scientific observer and NPF prawn population monitoring data sets were combined, models were successfully fit to five species of sea snake; *Astrotia stokesii, Disteira major*, *Hydrophis elegans*, *Hydrophis ornatus* and *Lapemis curtis* and one species of syngnathid; *Trachyrhamphus longirostris*. This was due to the much smaller number of catch records in the AFMA scientific observer and NPF prawn population monitoring data sets for each species compared to the crew-member observer data set. Furthermore, the NPF prawn population monitoring surveys are only distributed within six 'Regions' while the AFMA scientific observer program was spread over the entire 10 'Regions'. The inclusion of the AFMA scientific observer data also expanded the model coverage across eight 'Regions' (addition of 'Regions' 1 and 2) instead of the six 'Regions' when only the NPF prawn population monitoring data was used.

From the crew-member observer data, the catch trend for the Flatback Turtle (*Natator depressus*) showed a slight, but not significant increase over the collection period from 2003 to 2019 (Figure 18). Some years recorded a drop in catches (2012 – 2013 and 2016 – 2017) but this was followed by increases in the subsequent years.

There was a statistically significant increase in the catch rate trend for the sea snake, *Acalyptophis peronii*, over the last 12 years of crew-member observer data collection. Catches have steadily increased from less than one individual per 100 km^2 in 2008 to a high of one individual per 20 km^2 in 2019 (Figure 19).

Aipysurus duboisii showed a relatively stable catch rate trend across the 2009 to 2017 crew-member observer data collection period (Figure 20). In the last two years (2018 – 2019), the catches have dropped slightly, but the change was not statistically significant.

The crew-member observer data for *Aipysurus mosaicus* showed a statistically stable catch rate trend across the 2003 to 2019 period with slightly higher catches in some years (2005 and 2016) of between one individual per 20 – 40 km^2 and lower catches in 2008 to 2010 (Figure 21). In the last three years (2017 – 2019) catches have been slightly lower than the previous year however still higher than the 2008 to 2010 period.

The catch rate trend for *Aipysurus laevis* from the crew-member observer catches were variable across the data collection period of 2003 to 2019 (Figure 22). There were significantly higher catches recorded during the 2005 – 2006 and 2015 – 2016 years followed by a significant decline in the following years. In the last three years (2017 – 2019) catches have also been slightly lower, but not significant, than the two previous years however still higher than the 2008 to 2010 period.

As *Astrotia stokesii* was one of the most common species of sea snakes recorded in the NPF, the models were successfully fit to both the crew-member observer data and the combined AFMA scientific observer and NPF prawn population monitoring data (Figure 23). Although the catch rates were slightly higher in the crew-member observer data, there was a similar trend from 2003 to 2017 and a slight drop in catches over the last two years (2018 – 2019).

Catches for *Disteira major* during the crew-member observer program varied significantly from 2003 to 2019 (Figure 24). From highest levels seen during the data collection period (2003 – 2005), there was a decline to lowest catches from 2008 to 2010. This was followed by an increase in catches from 2011 to 2018. The catch rate trend dropped again in 2019 to levels similar to the earlier decline during 2009 and 2010. There were sufficient catch records on this species to fit models to the combined AFMA scientific observer and NPF prawn population monitoring data. Catches were consistently lower and less variable compared to the crew-member observer data but did follow a comparable trend over the years.

The catch rate trends for *Hydrophis elegans* did show a similar pattern between the crew-member observer data and the combined AFMA scientific observer and NPF prawn population monitoring survey data (Figure 25). As *Hydrophis elegans* was one of the most common species of sea snakes recorded in the NPF, the models were successfully fit to both the crew-member observer data and the combined AFMA scientific observer and NPF prawn population monitoring data. The trends in catch rates for each data set were similar across the data collection period (2003 – 2019) with significant variation between the years. There was an increase in catches between 2003 and 2006 followed by a significant decline during 2007 to 2010. Catches increased slightly in 2012 where they remained relatively stable through to 2016. There was an increase in catch rates in 2017 followed by a gradual decline over the next two years (2018 – 2019) to levels similar to previous years.

The crew-member observer data showed a stable catch trend for *Hydrophis ornatus* with little annual variation in catches over the data collection period from 2003 to 2019 (Figure 26). The combined AFMA scientific observer and NPF prawn population monitoring data sets however showed some variation across the years with generally higher catch rates in most years compared to the crew-member observer data. Although the 95% confidence intervals were large for most years, there was a relatively stable trend over the same period.

While catches were noticeably lower in 2010, the catch rates observed for *Hydrophis pacificus* between 2011 and 2019 were quite stable with a slight increase in the last three years (Figure 27). However, the 95% confidence intervals were also relatively large for all years, indicating variability in catch rates within years.

The only other sea snake species where models were successfully fit to both the crew-member observer and the combined AFMA scientific observer and NPF prawn population monitoring data sets was *Lapemis curtis*. Catch trends across nearly all years showed strong similarities between the data sets (Figure 28). Catch rates were high across the earlier years (2003 – 2007) but there was also high variability within those years (associated large 95% confidence intervals in catch rates for both the crew-member observer and combined AFMA scientific observer and NPF prawn population monitoring data sets). Catches have remained relatively stable from 2008 to 2015 followed by a slight increase from 2016 to 2019 for both data sets.

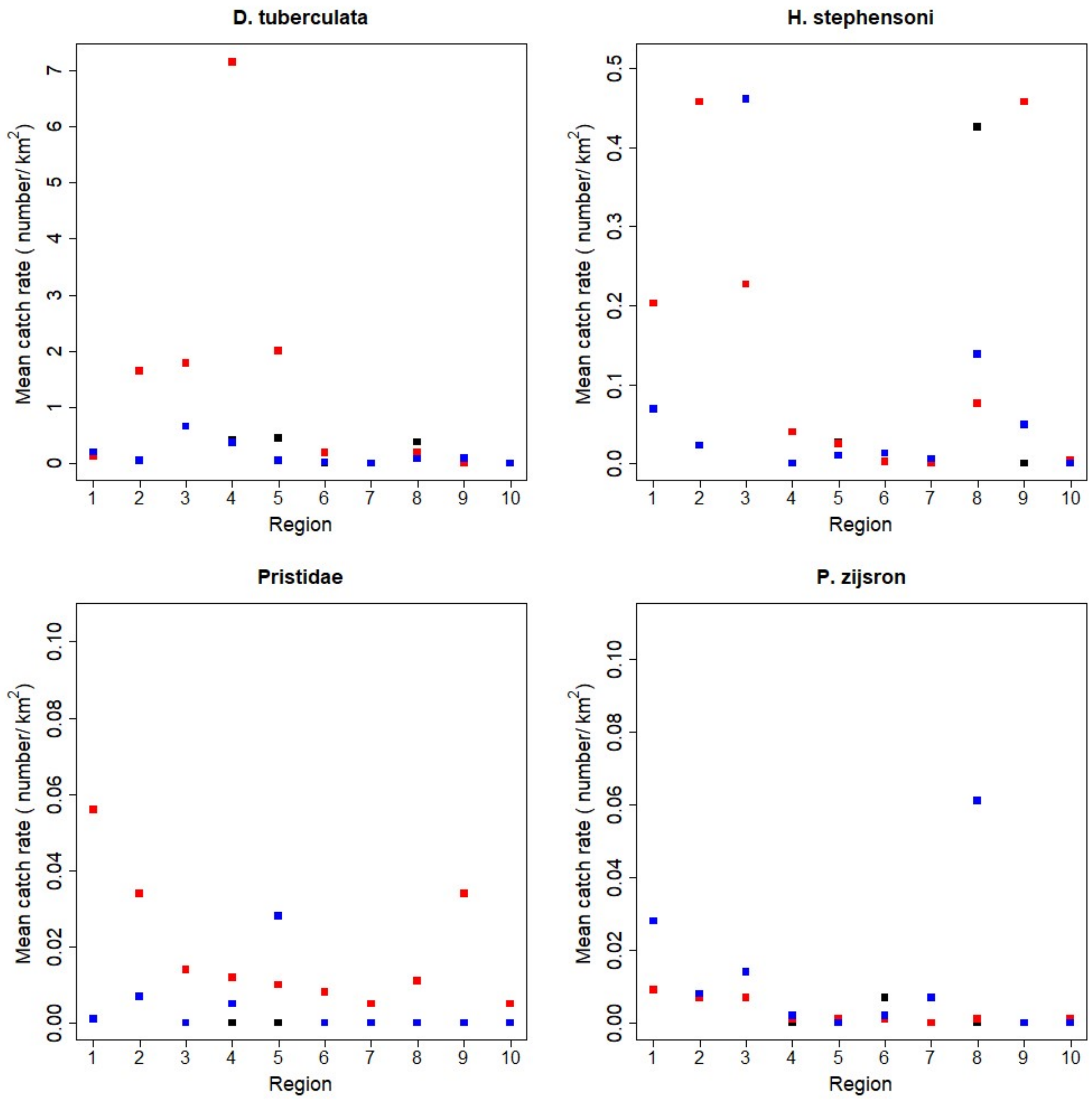
Although a large proportion of the Syngnathidae catches were not identified to species, *Trachyrhamphus longirostris* is one of the few species that is easily identified and therefore catches would not be under-estimated by the 'Unidentified Syngnathidae' grouping. The crew-member observer catches have shown a general increasing trend from 2010 to 2015 with some variation across years with lower catches in 2011 and 2014 (Figure 29). A similar trend was also seen in the combined AFMA scientific observer and NPF prawn population monitoring data, although the catch rates were slightly higher and larger associated 95% confidence intervals. In 2016 there was a marked decline in the catches seen in both the crew-member observer data and combined AFMA scientific observer and NPF prawn population monitoring data. While catches remained stable from 2016 to 2019 in the combined AFMA scientific observer and NPF prawn population monitoring data, the crew-member observer data showed an increase in the catch trend over the same years.

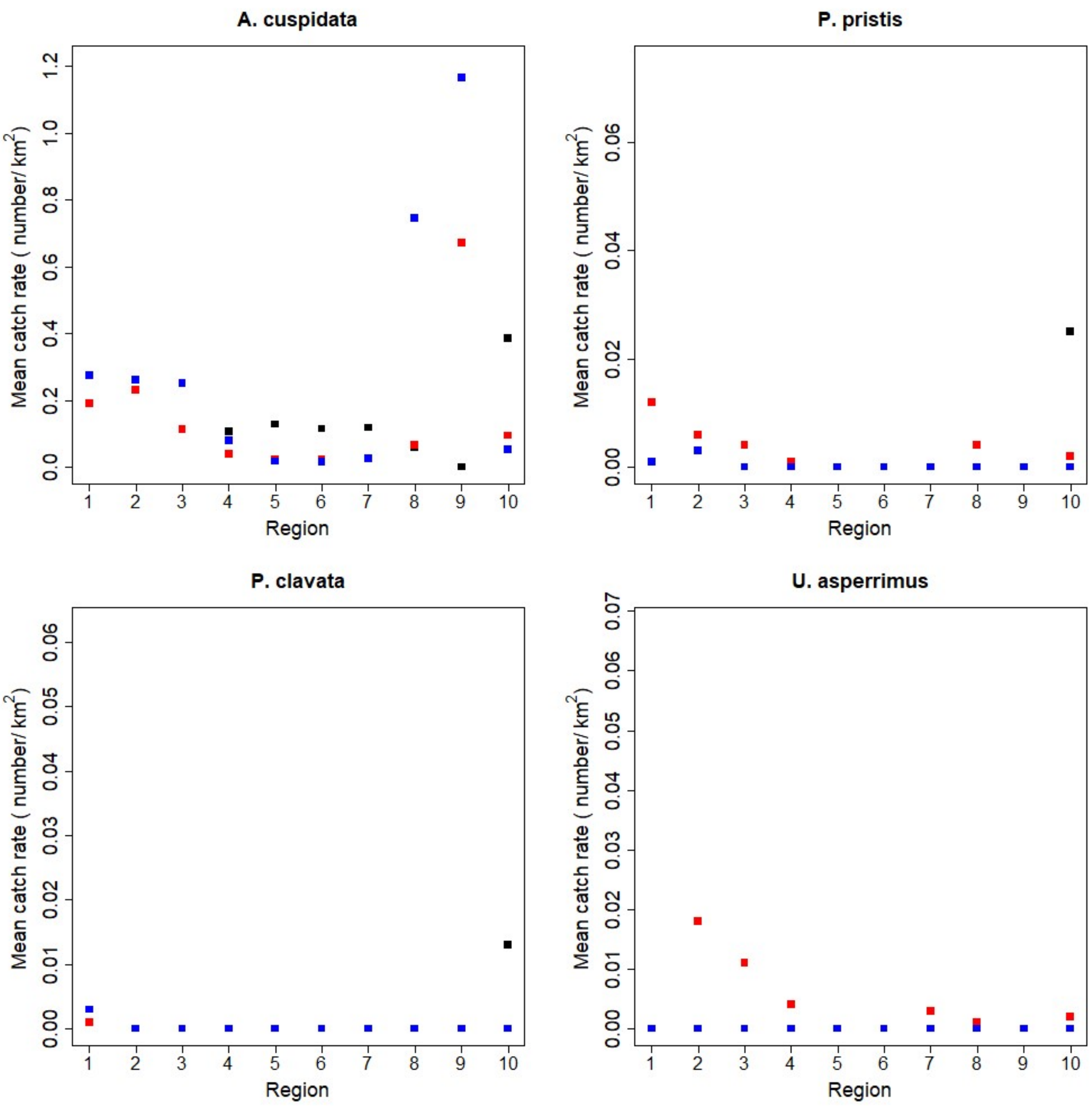
The catch rates for the Narrow Sawfish (*Anoxypristis cuspidata*) recorded by the crew-member observers showed a relatively stable trend across the years of 2010 to 2019 (Figure 30). The mean catch rates for each of the years were within the 95% confidence intervals for all years indicating that there has not been an increase or decline in the catches over the data collection period. However, the 95% confidence intervals were relatively large also suggesting catches were variable within the years.

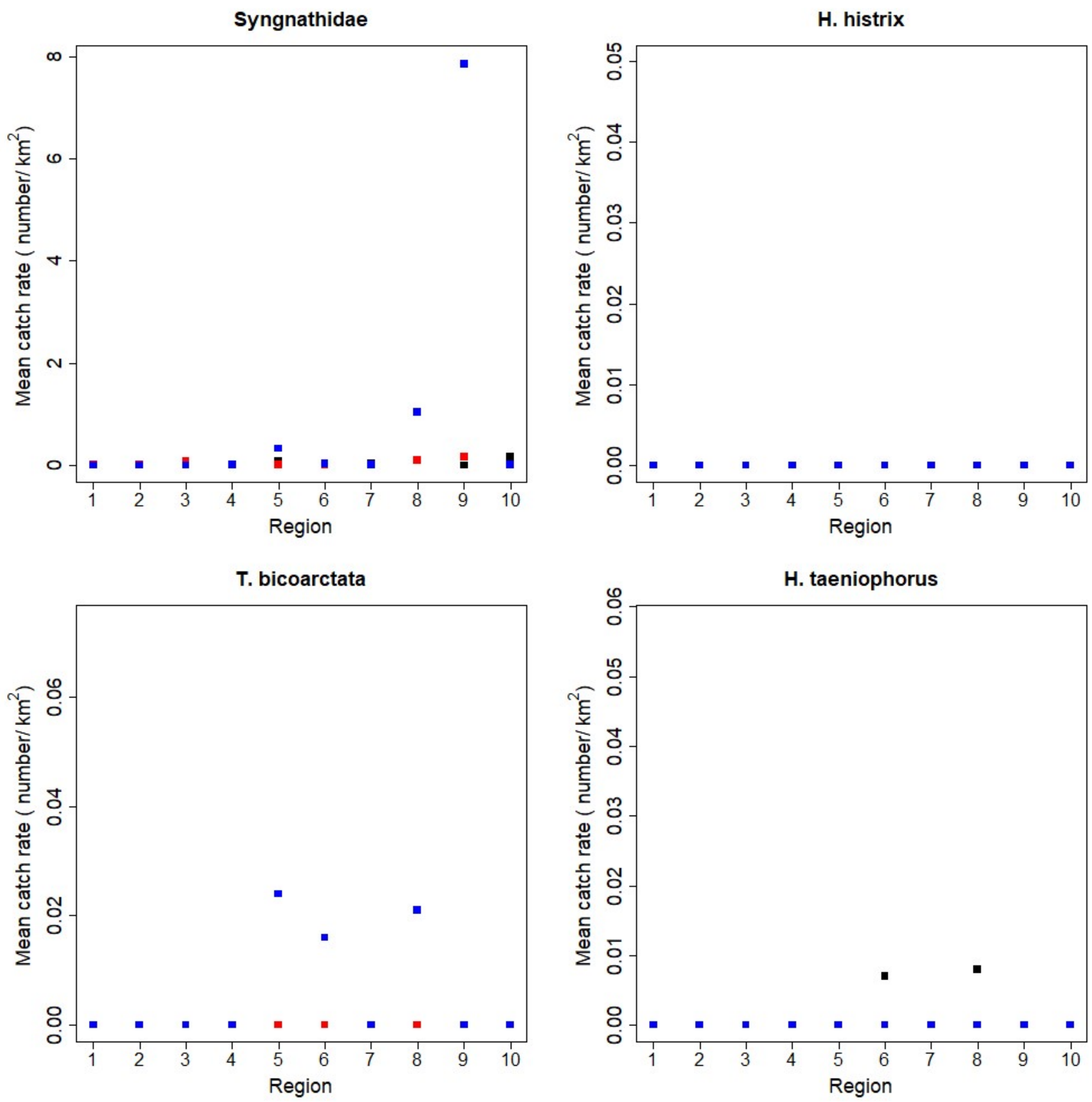
There was a strong increase in the catch rate trend for the Brown-striped Mantis Shrimp (*Dictyosquilla tuberculata*) seen in the crew-member observer data over the 2010 – 2019 data collection period (Figure 31). Some annual variation was seen with declines in catches in 2014, 2016 and 2017 however within year variation was relatively low (small 95% confidence intervals around all yearly catch rate means). The significant increase in catch rates from 2010 to 2015 for this species is likely partly due to the improvements of the crew-member observers in identifying and recording these small species that are often difficult to spot in the large catches of trawl bycatch that are landed.

For the remaining TEP and 'at risk' bycatch species, the models could not be fit to either the crew-member observer data or the combined AFMA scientific observer and NPF prawn population monitoring data due to low numbers of these species recorded between 2003 and 2019.

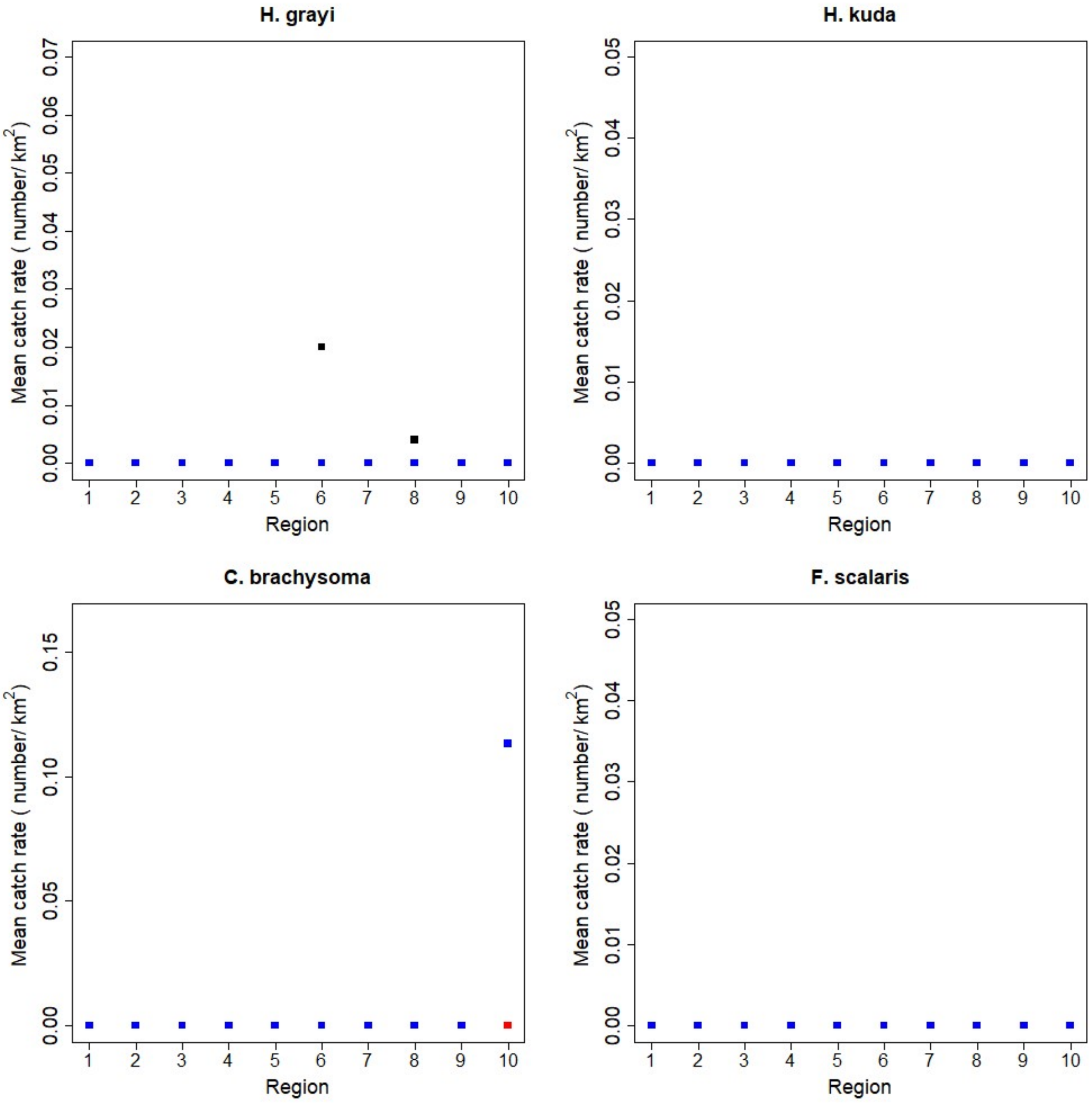
Figure 16: Mean catch rates (numbers per km^2) of the TEP and 'at risk' bycatch species from the (a) crew-member observer program (red points), (b) AFMA scientific observer program (blue points) and (c) NPF prawn population monitoring surveys (black points) by 'Regions' from 2003 to 2019.

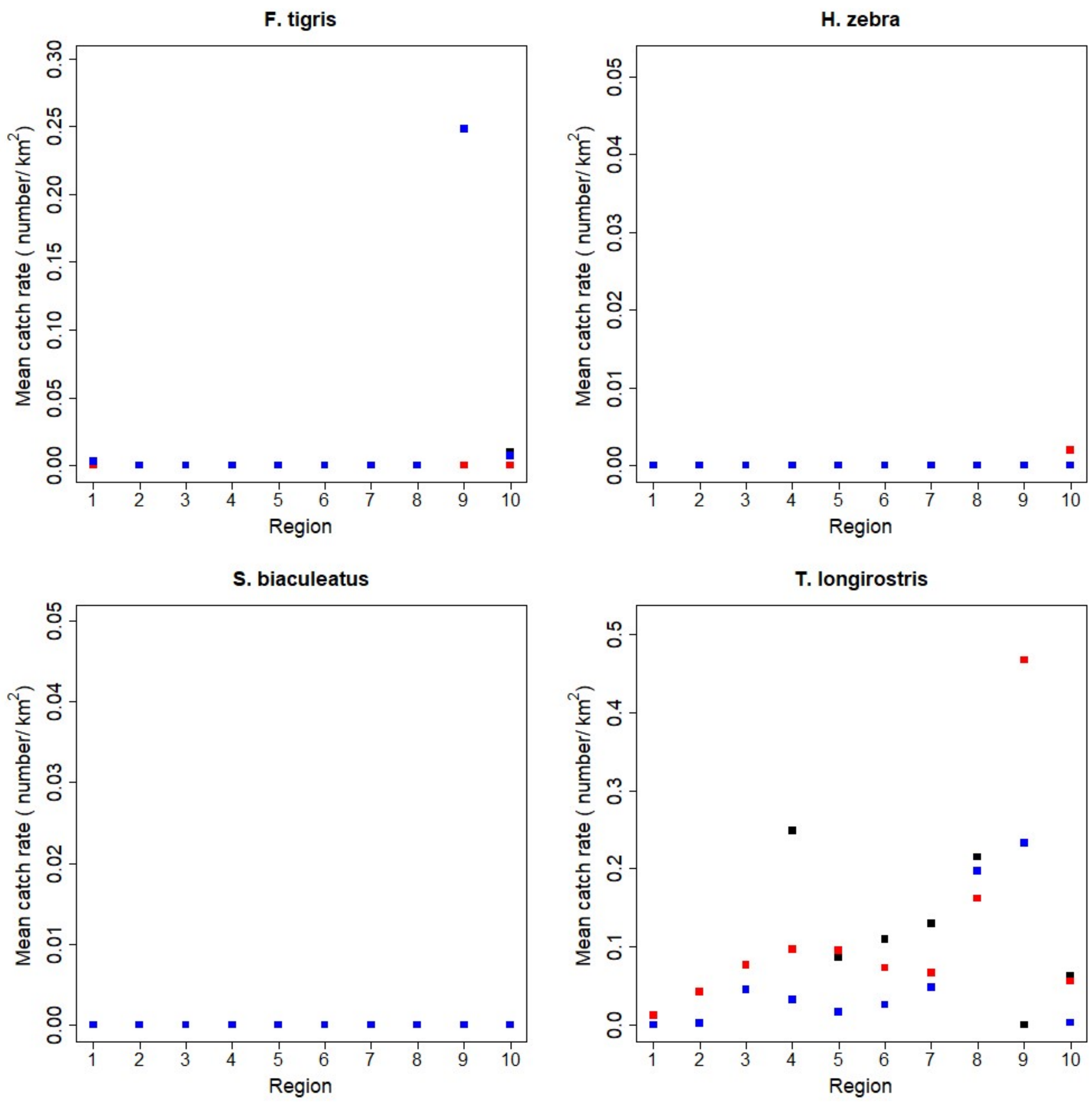


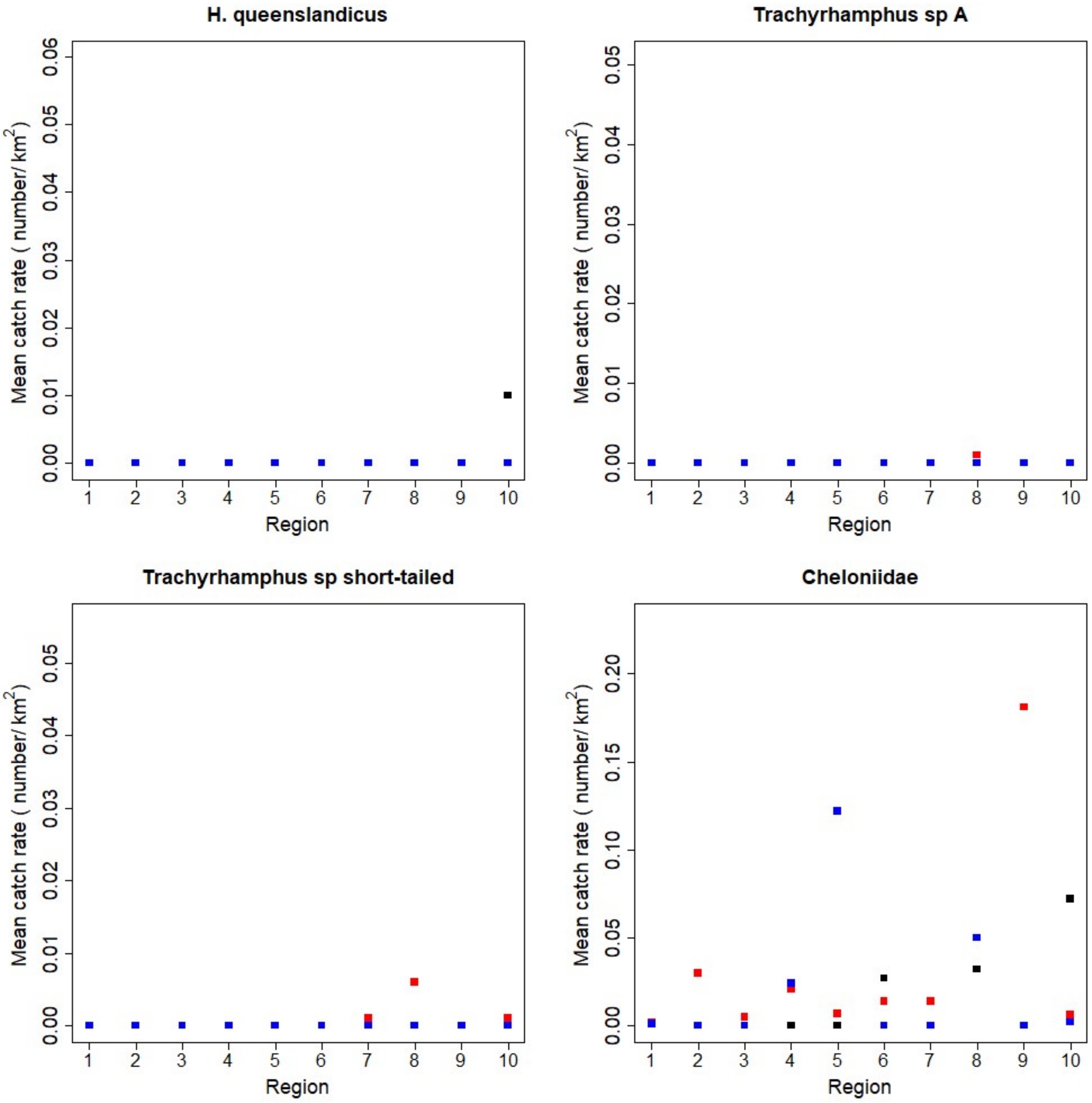

A. cuspidata
P. pristis
P. clavata
U. asperrimus
Mean catch rate (number/ km2)
Region
1 2 3 4 5 6 7 8 9 10
0.0 0.2 0.4 0.6 0.8 1.0 1.2
0.00 0.02 0.04 0.06
0.00 0.01 0.02 0.03 0.04 0.05 0.06
0.00 0.01 0.02 0.03 0.04 0.05 0.06 0.07

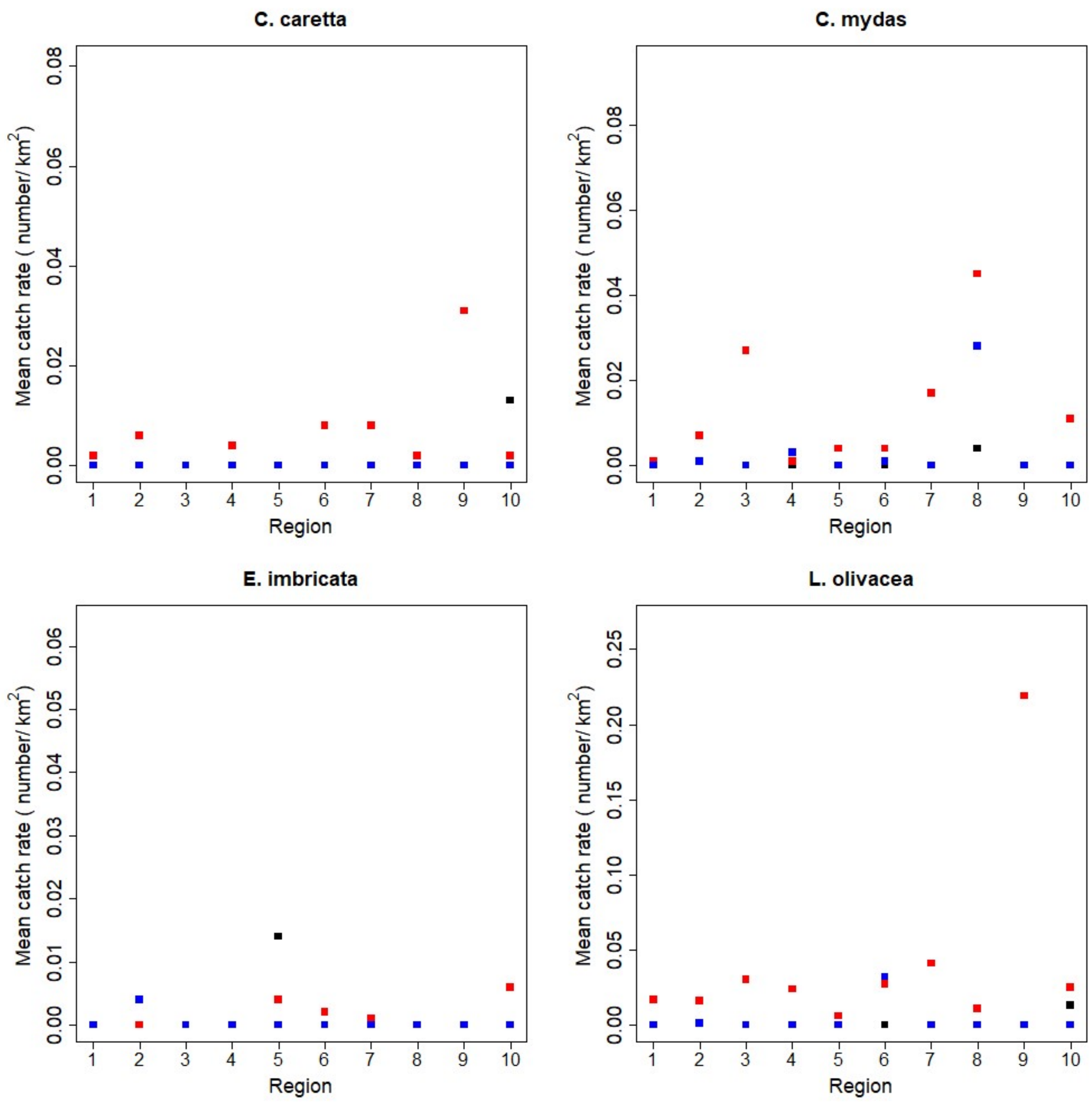


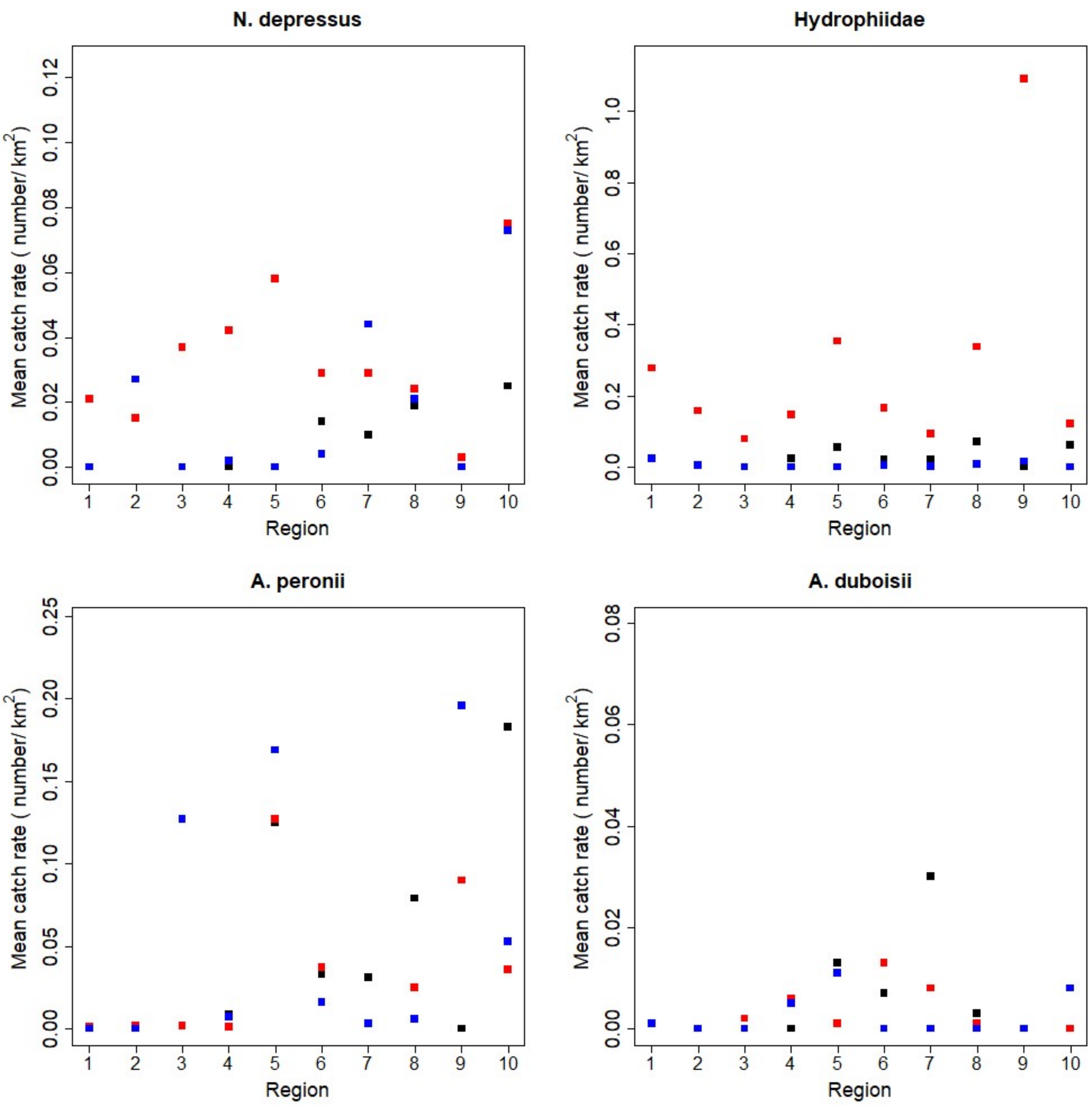
Syngnathidae
H. histrix
T. bicoarctata
H. taeniophorus
Mean catch rate (number/ km2)
Region

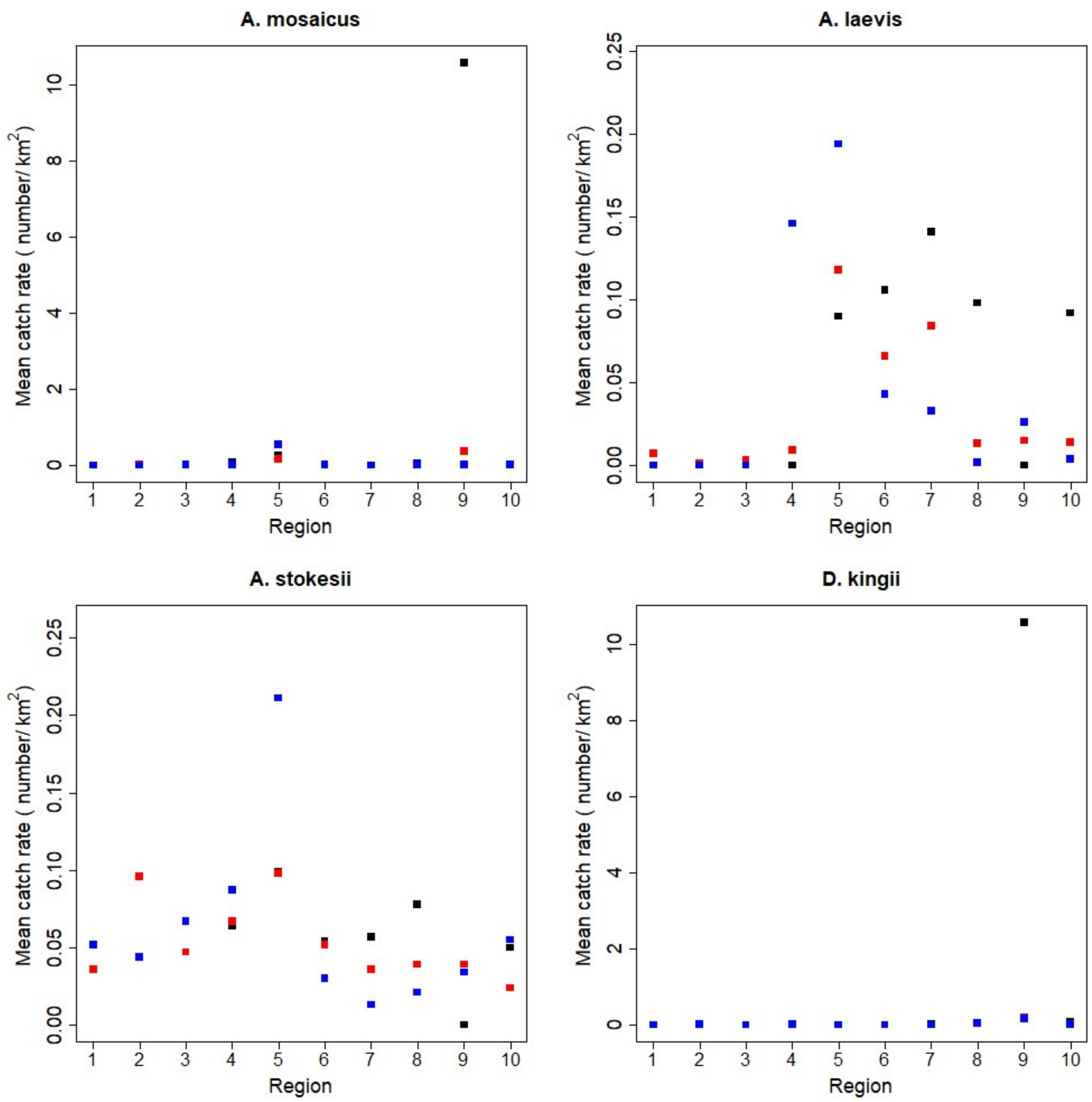

H. grayi
H. kuda
C. brachysoma
F. scalaris
Mean catch rate (number/ km2)
Region
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.10
0.15
1
2
3
4
5
6
7
8
9
10

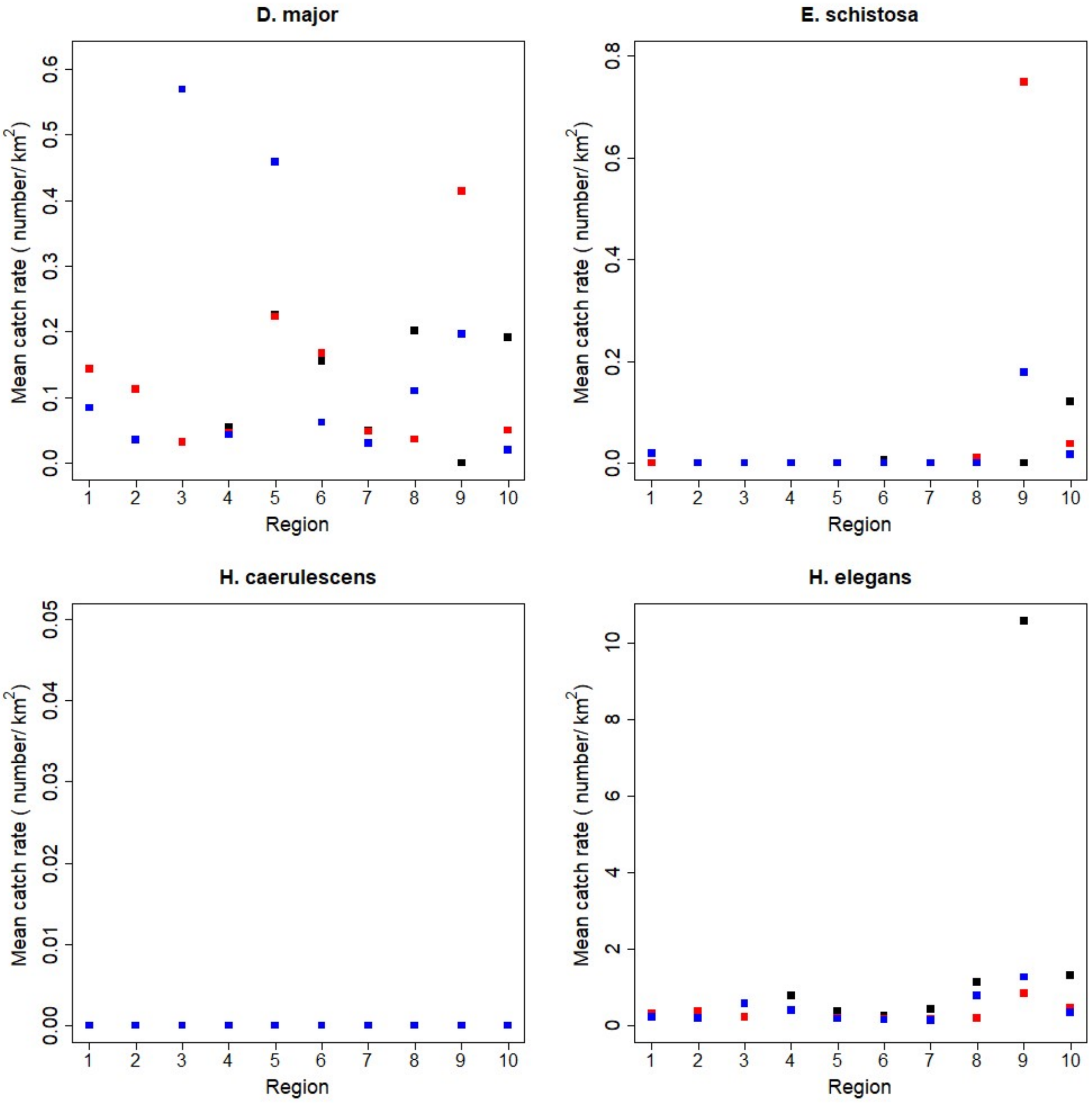

F. tigris
H. zebra
S. biaculeatus
T. longirostris
Mean catch rate (number/ km^2)
Region
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.01
0.02
0.03
0.04
0.0
0.1
0.2
0.3
0.4
0.5
1
2
3
4
5
6
7
8
9
10

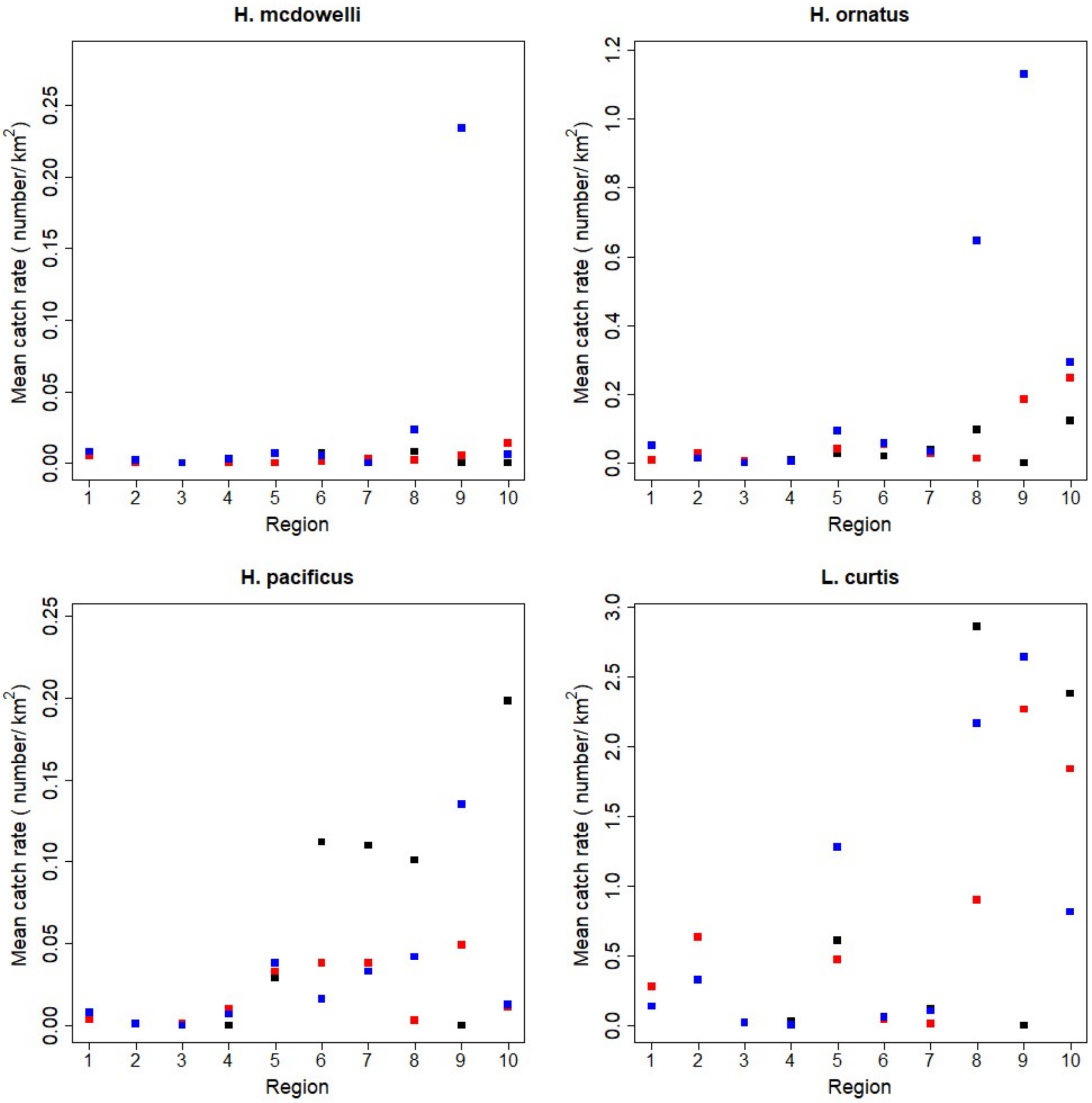

H. queenslandicus
Trachyrhamphus sp A
Trachyrhamphus sp short-tailed
Cheloniidae
Mean catch rate (number/ km2)
Region


C. caretta
C. mydas
E. imbricata
L. olivacea
Mean catch rate (number/ km^2)
Region
1 2 3 4 5 6 7 8 9 10
0.00 0.02 0.04 0.06 0.08
0.00 0.01 0.02 0.03 0.04 0.05 0.06
0.00 0.05 0.10 0.15 0.20 0.25


N. depressus
Hydrophiidae
A. peronii
A. duboisii
Mean catch rate (number/ km2)
Region
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.0
0.2
0.4
0.6
0.8
1.0
0.05
0.15
0.20
0.25
1
2
3
4
5
6
7
8
9
10


A. mosaicus
Mean catch rate (number/ km^2)
Region
A. laevis
Mean catch rate (number/ km^2)
Region
A. stokesii
Mean catch rate (number/ km^2)
Region
D. kingii
Mean catch rate (number/ km^2)
Region


D. major
E. schistosa
H. caerulescens
H. elegans
Mean catch rate (number/ km^2)
Region



H. mcdowelli
H. ornatus
H. pacificus
L. curtis
Mean catch rate (number/ km^2)
Region

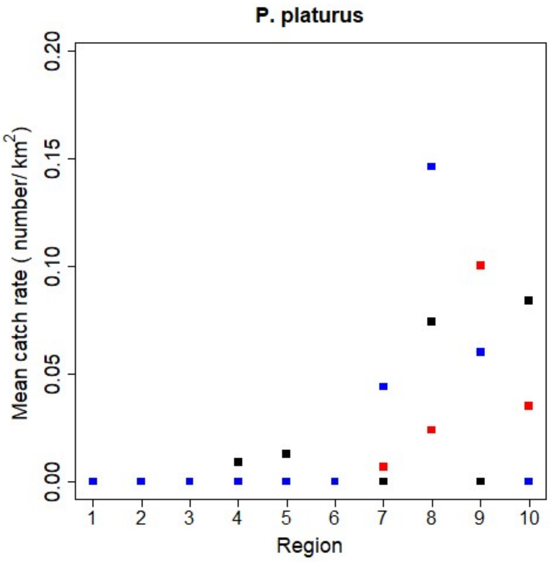
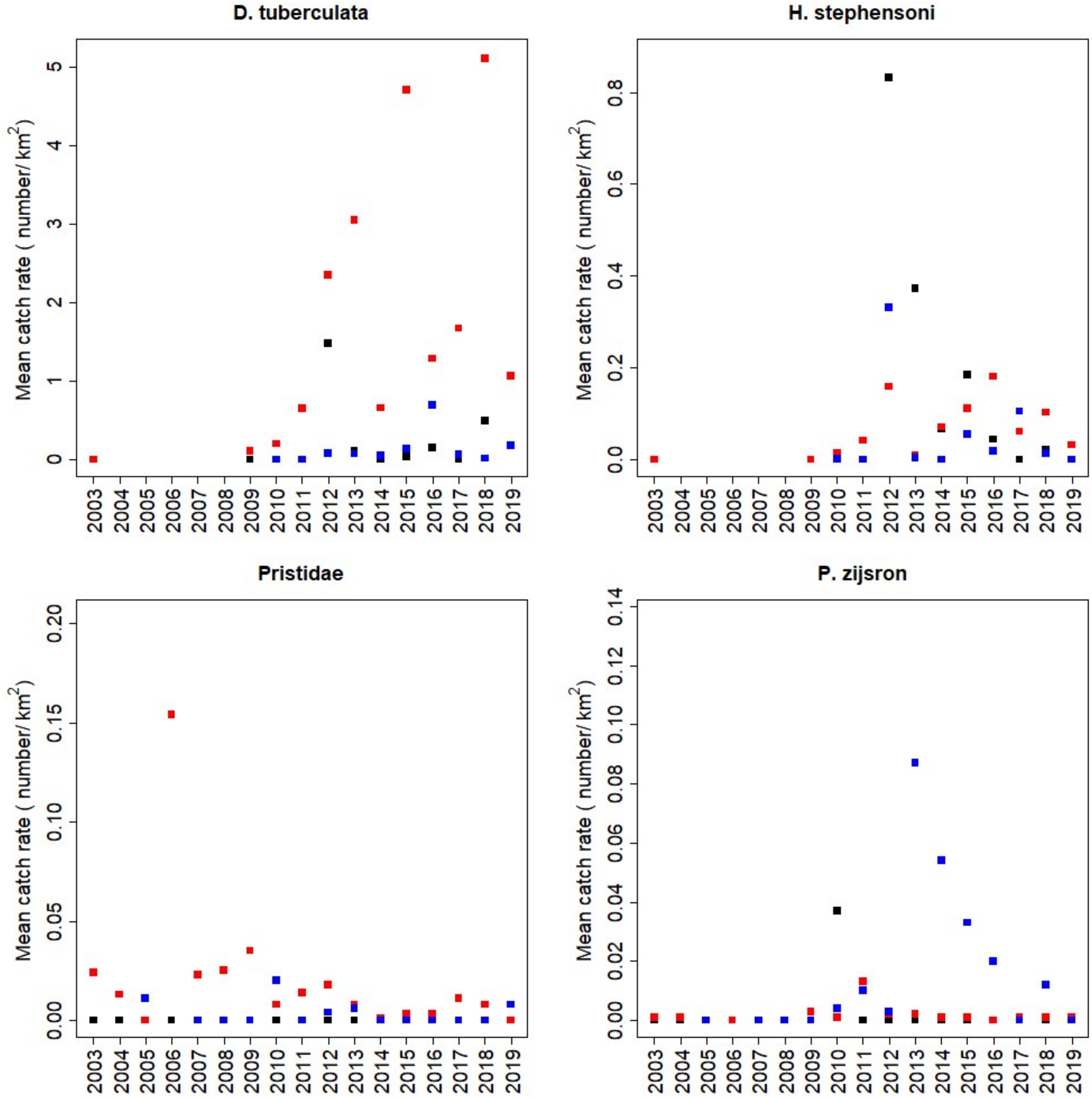
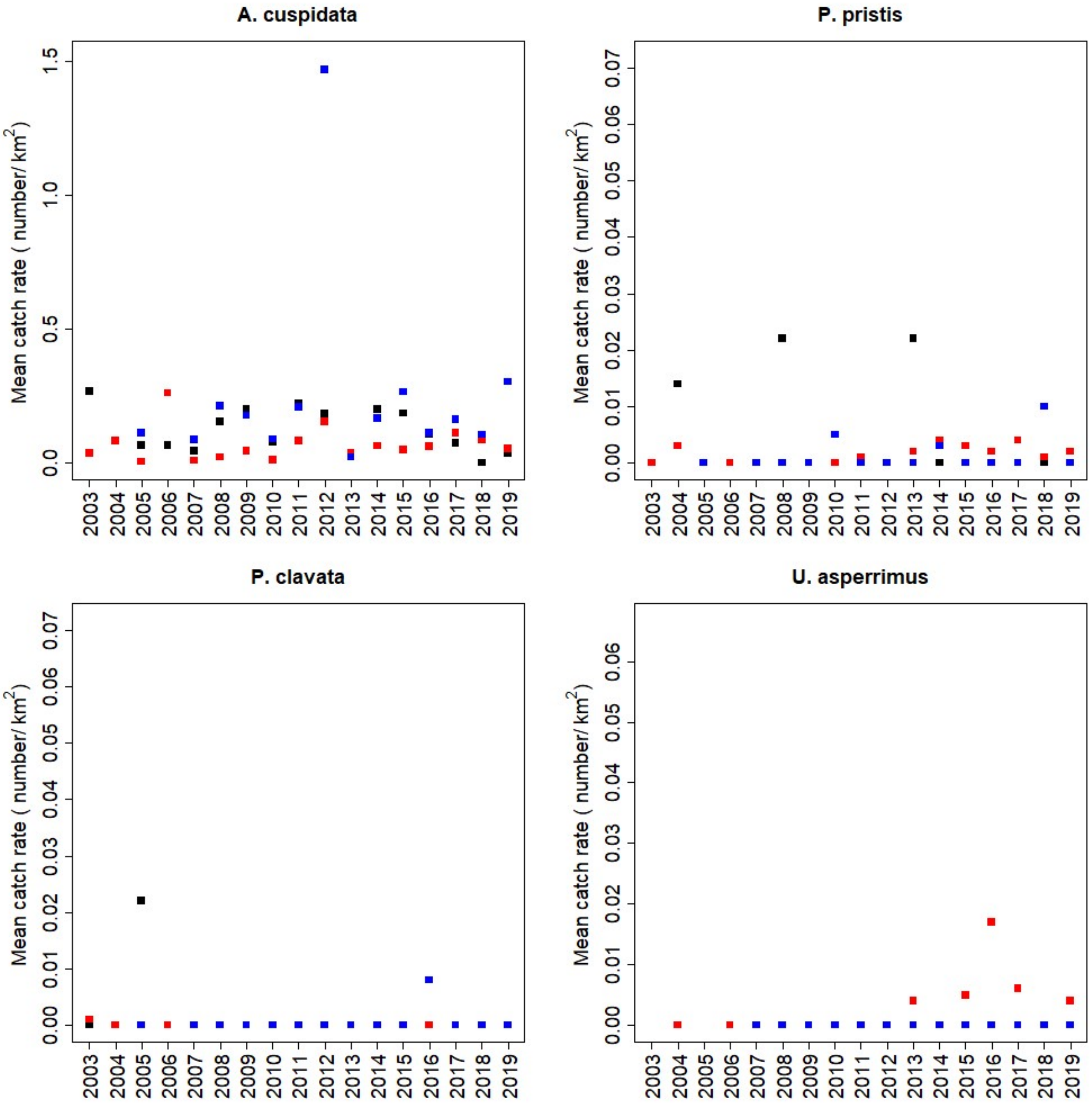
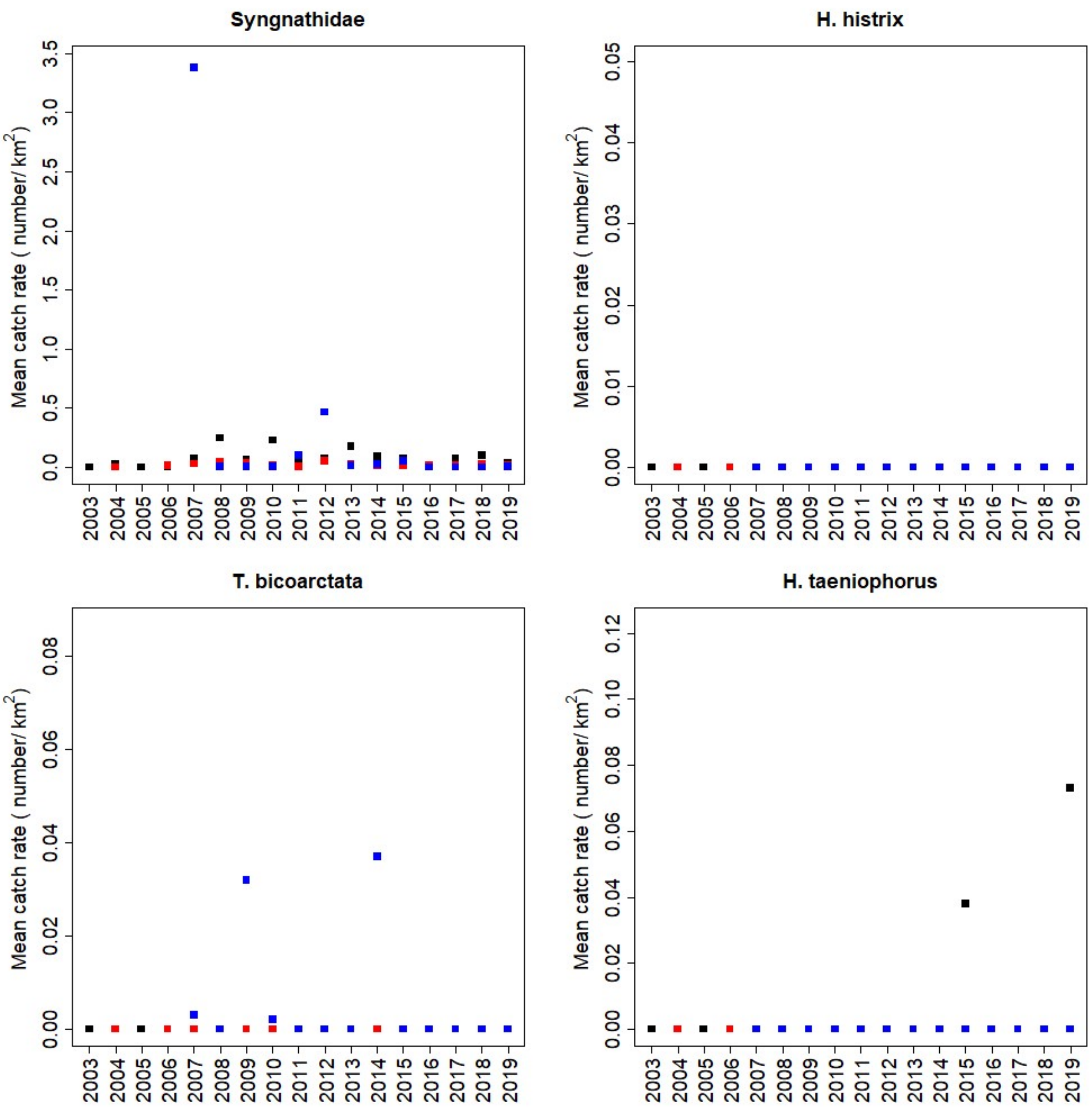

P. platurus
Mean catch rate (number/ km^2)
0.00
0.05
0.10
0.15
0.20
1
2
3
4
5
6
7
8
9
10
Region

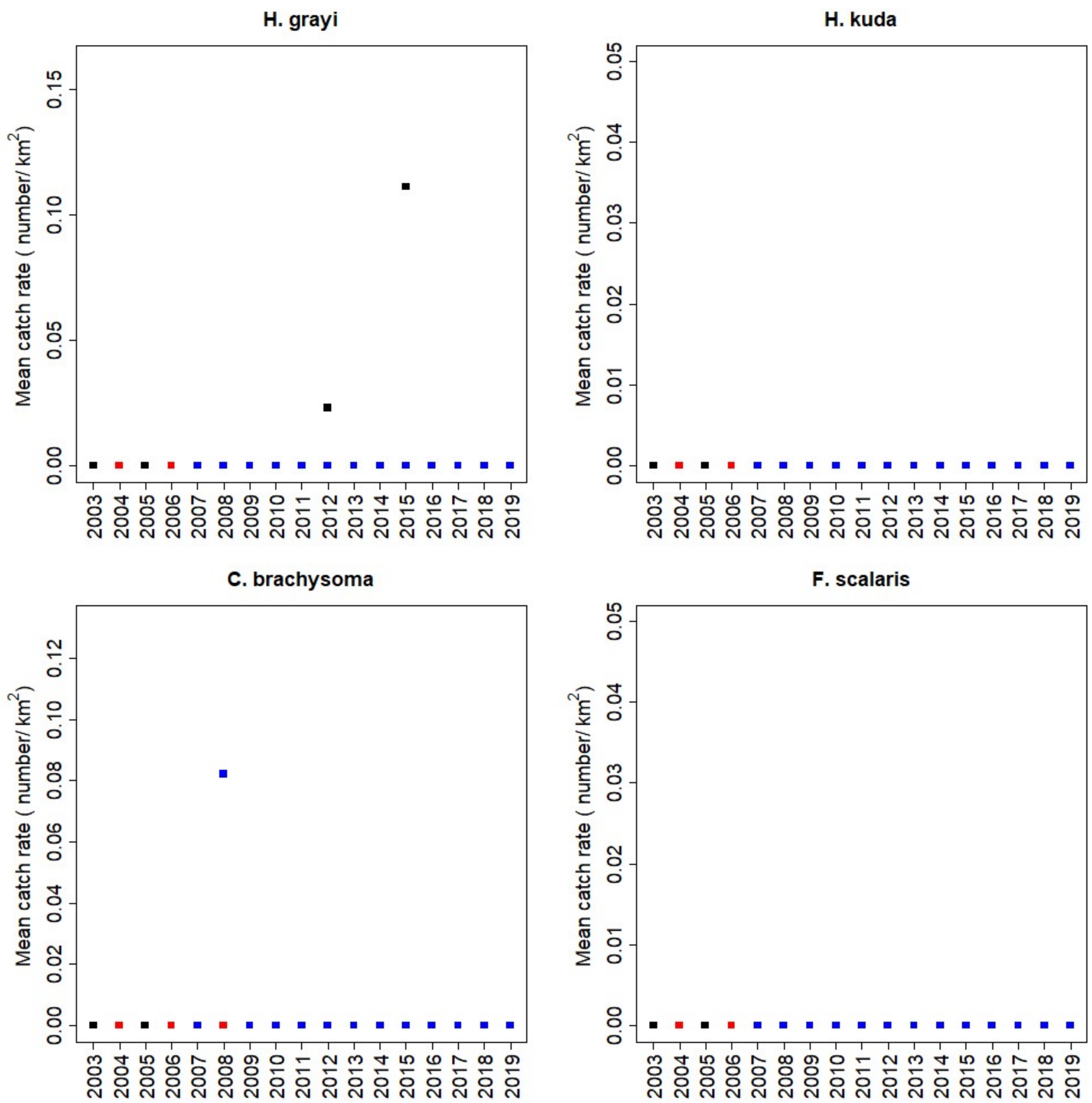
Figure 17: Mean catch rates (numbers per km²) of the TEP and 'at risk' bycatch species from the (a) crew-member observer program (red points), (b) AFMA scientific observer program (blue points) and (c) NPF prawn population monitoring surveys (black points) by 'Year' for 'Regions' 4, 5, 6, 7, 8 and 10.

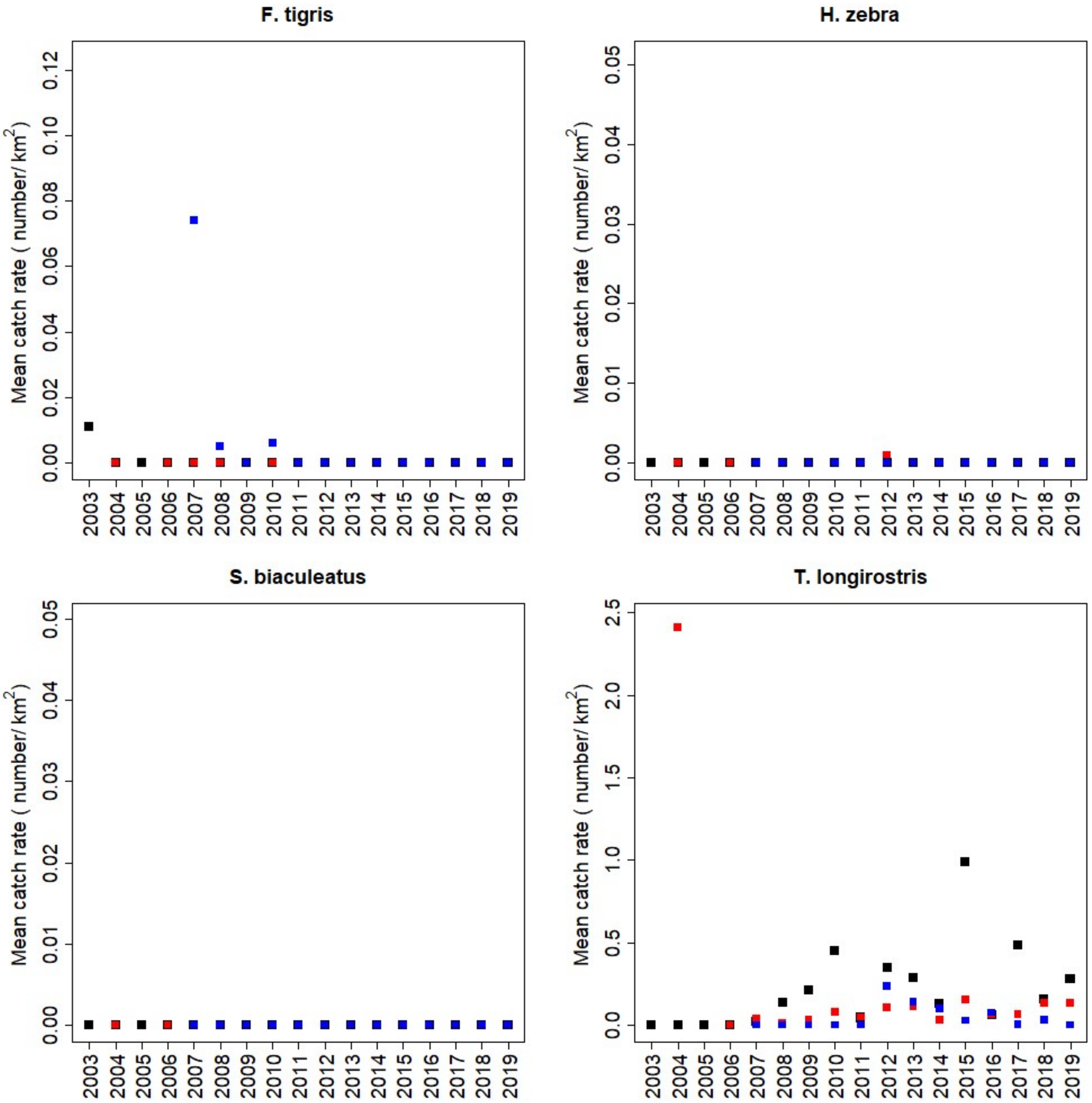


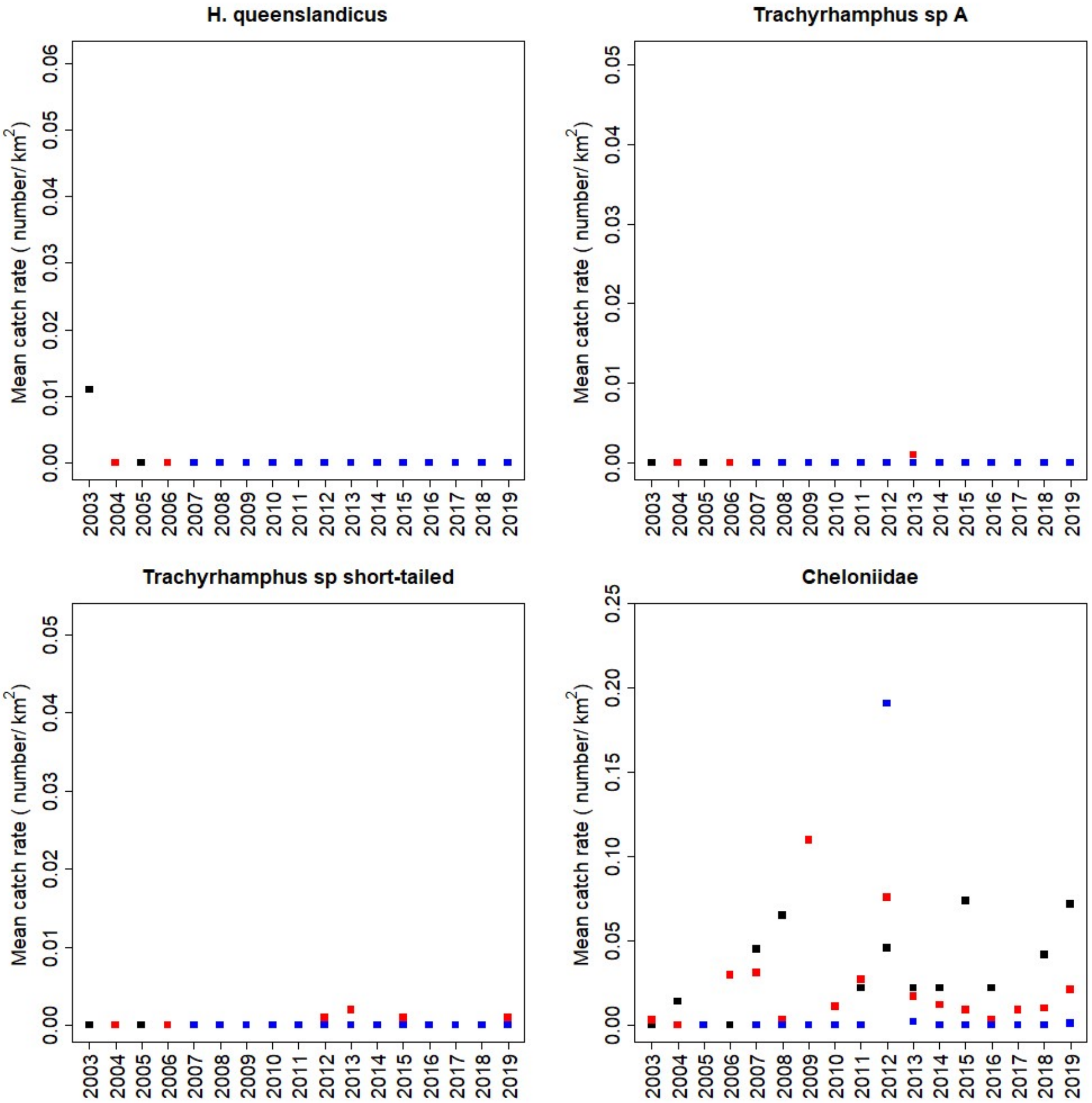

A. cuspidata
P. pristis
P. clavata
U. asperrimus
Mean catch rate (number/ km2)
2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019



Syngnathidae
H. histrix
T. bicoarctata
H. taeniophorus
Mean catch rate (number/ km^2)
2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019


H. grayi
H. kuda
C. brachysoma
F. scalaris
Mean catch rate (number/ km2)
0.00
0.05
0.10
0.15
0.01
0.02
0.03
0.04
0.06
0.08
0.12
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019


F. tigris
H. zebra
S. biaculeatus
T. longirostris
Mean catch rate (number/ km2)
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019


H. queenslandicus
Trachyrhamphus sp A
Trachyrhamphus sp short-tailed
Cheloniidae
Mean catch rate (number/ km^2)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.05
0.10
0.15
0.20
0.25
2003
2004
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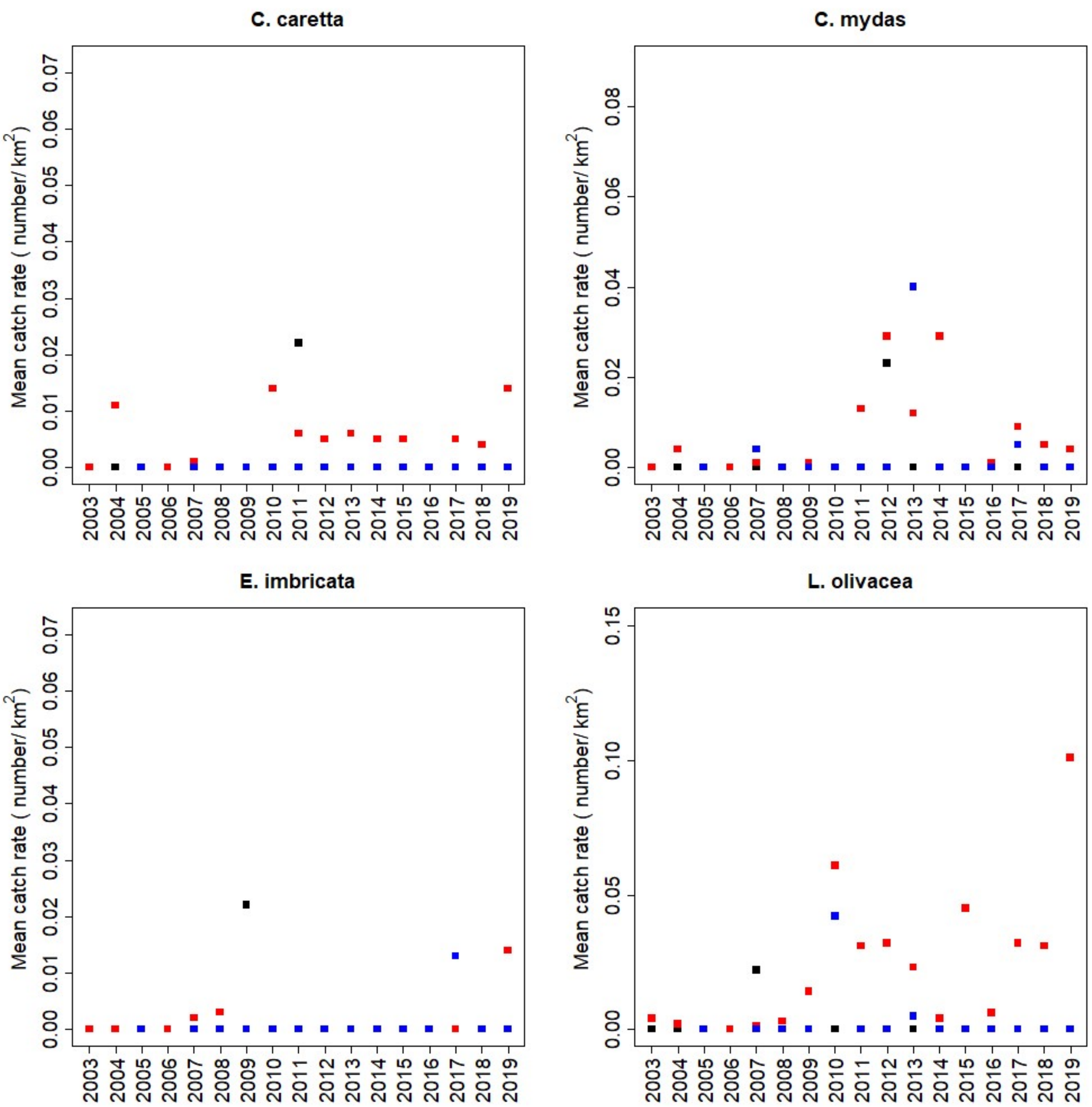
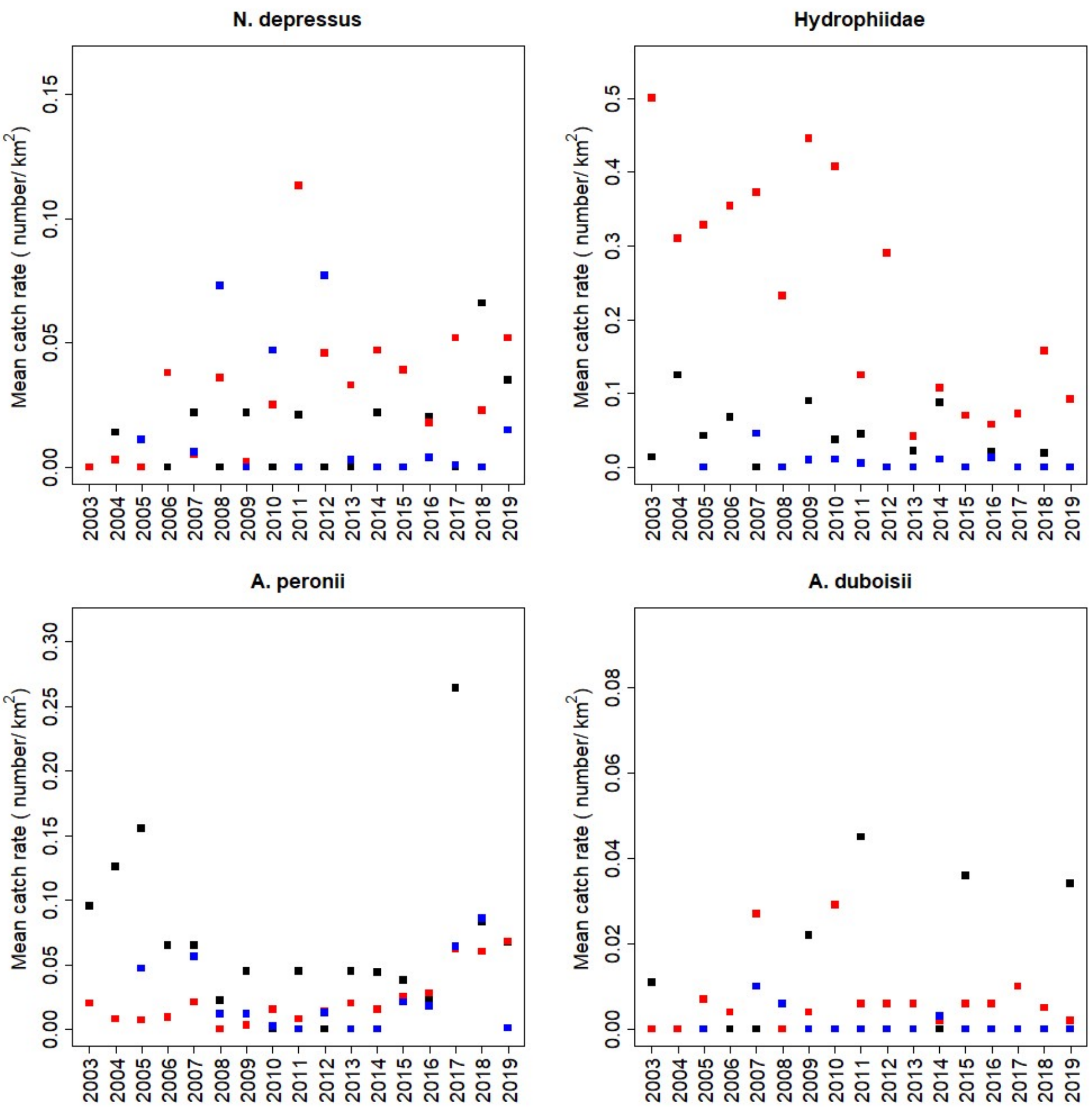
2016
2017
2018
2019


C. caretta
C. mydas
E. imbricata
L. olivacea
Mean catch rate (number/ km^2)


N. depressus
Hydrophiidae
A. peronii
A. duboisii
Mean catch rate (number/ km2)
0.00
0.05
0.10
0.15
0.0
0.1
0.2
0.3
0.4
0.5
0.20
0.25
0.30
0.02
0.04
0.06
0.08
2003
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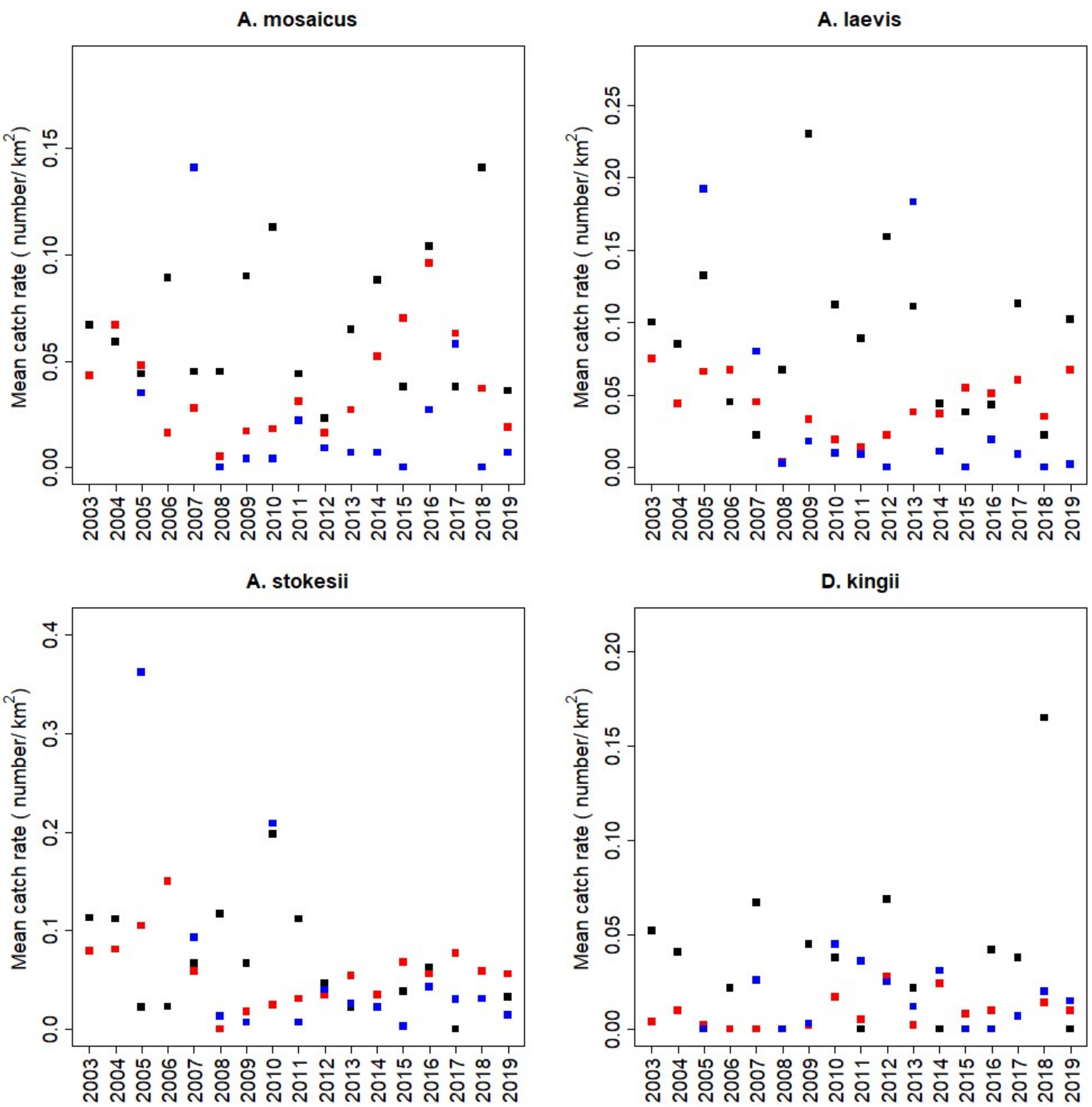
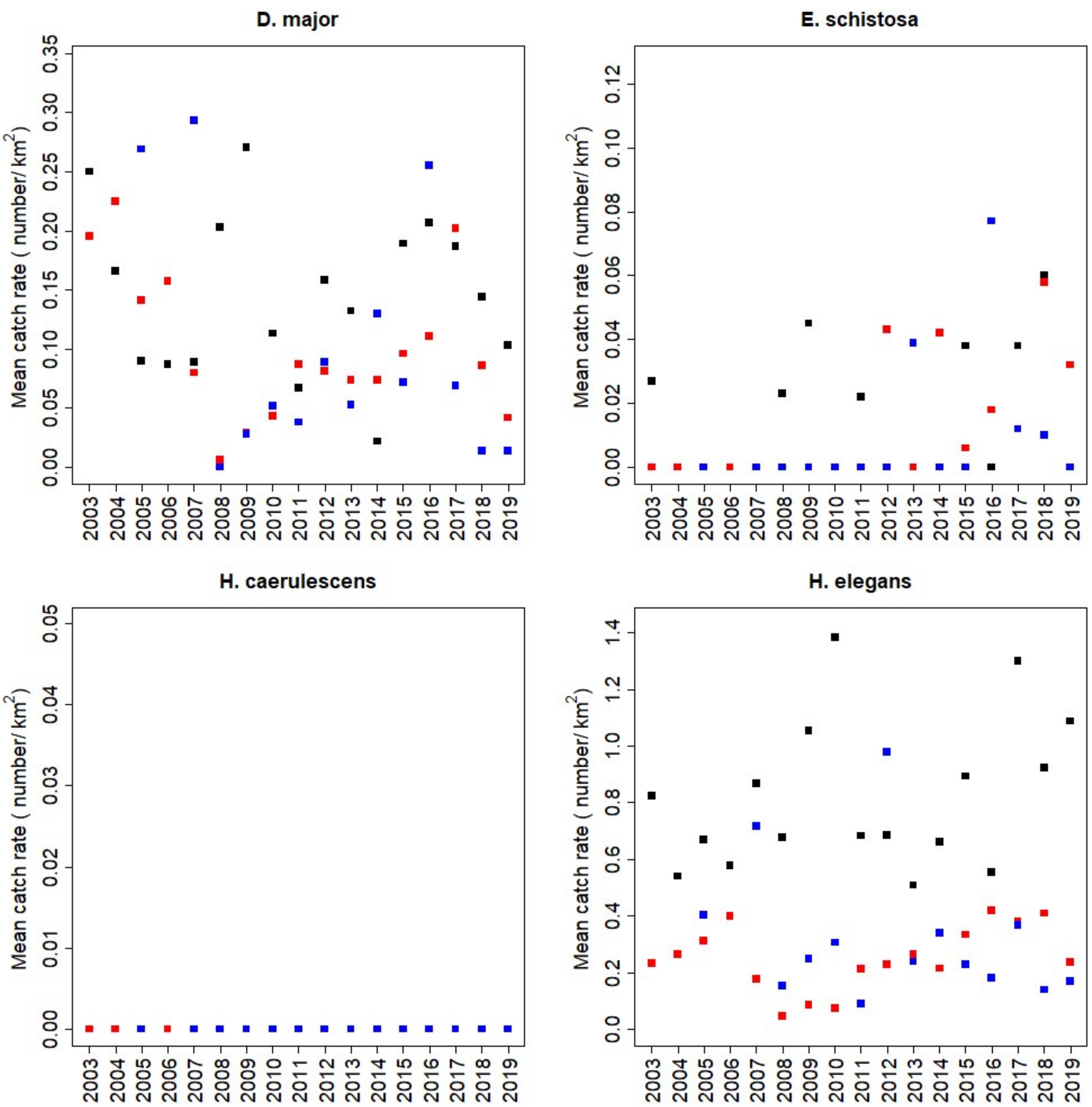
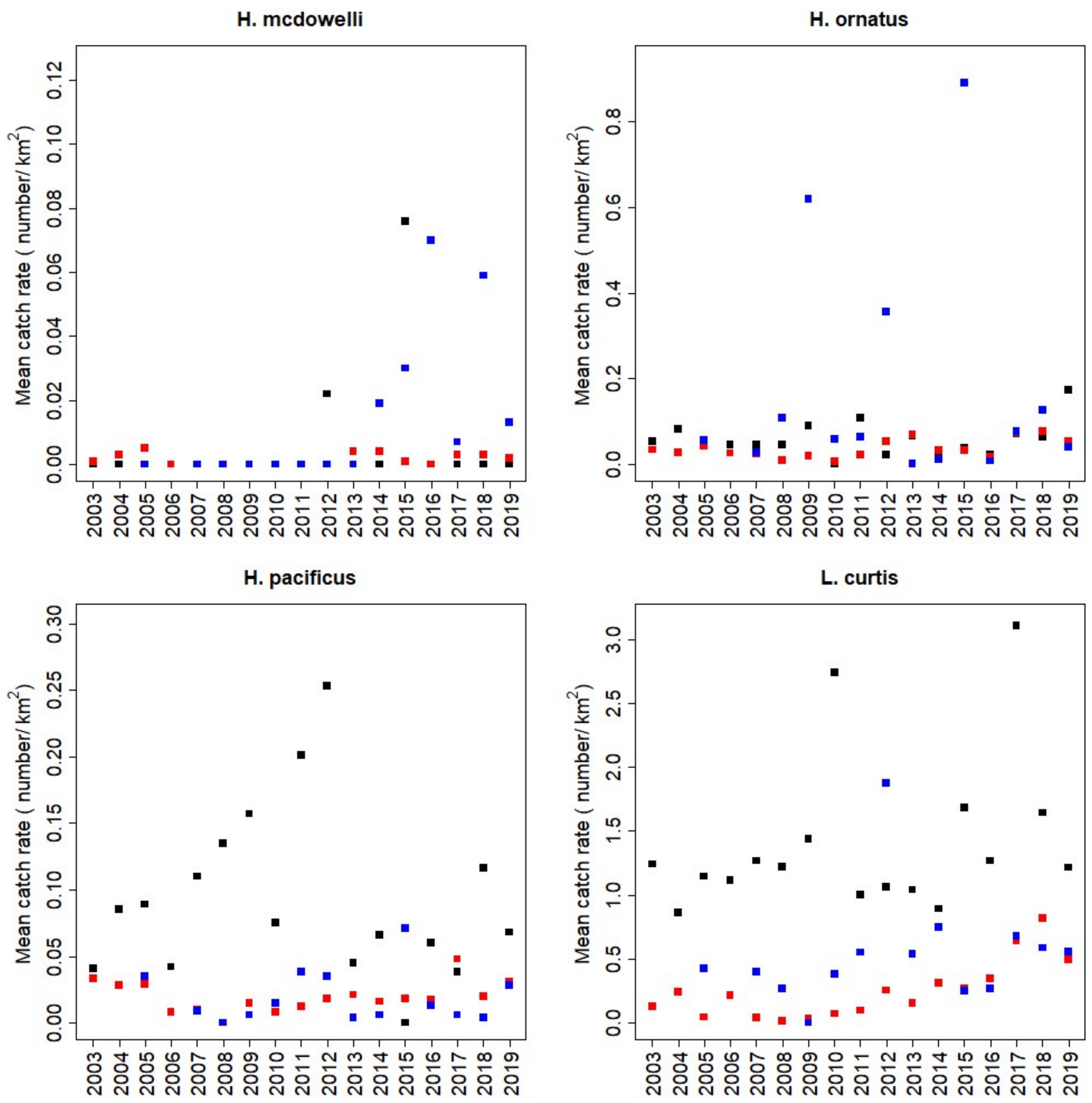
2018
2019


A. mosaicus
A. laevis
A. stokesii
D. kingii
Mean catch rate (number/ km2)
2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019


D. major
E. schistosa
H. caerulescens
H. elegans
Mean catch rate (number/ km²)
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019


H. mcdowelli
H. ornatus
H. pacificus
L. curtis
Mean catch rate (number/ km2)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.0
0.2
0.4
0.6
0.8
0.05
0.15
0.20
0.25
0.30
0.5
1.0
1.5
2.0
2.5
3.0
2003
2004
2005
2006
2007
2008
2009
2010
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2015
2016
2017
2018
2019

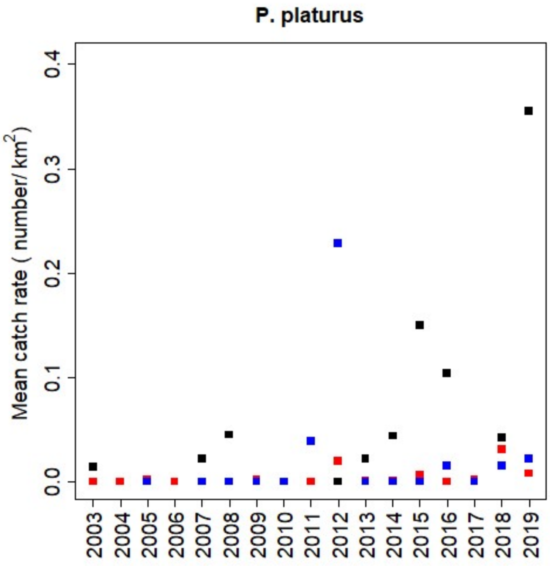

P. platurus
Mean catch rate (number/ km2)
0.0
0.1
0.2
0.3
0.4
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

Figure 18: Trends in mean catch rate (numbers per km^2) with 95% confidence intervals for the marine turtle; *Natator depressus*, based on a depth of 24 m and in 'Region' 6 from the crew-member observer program (red points) from 2003 to 2019.

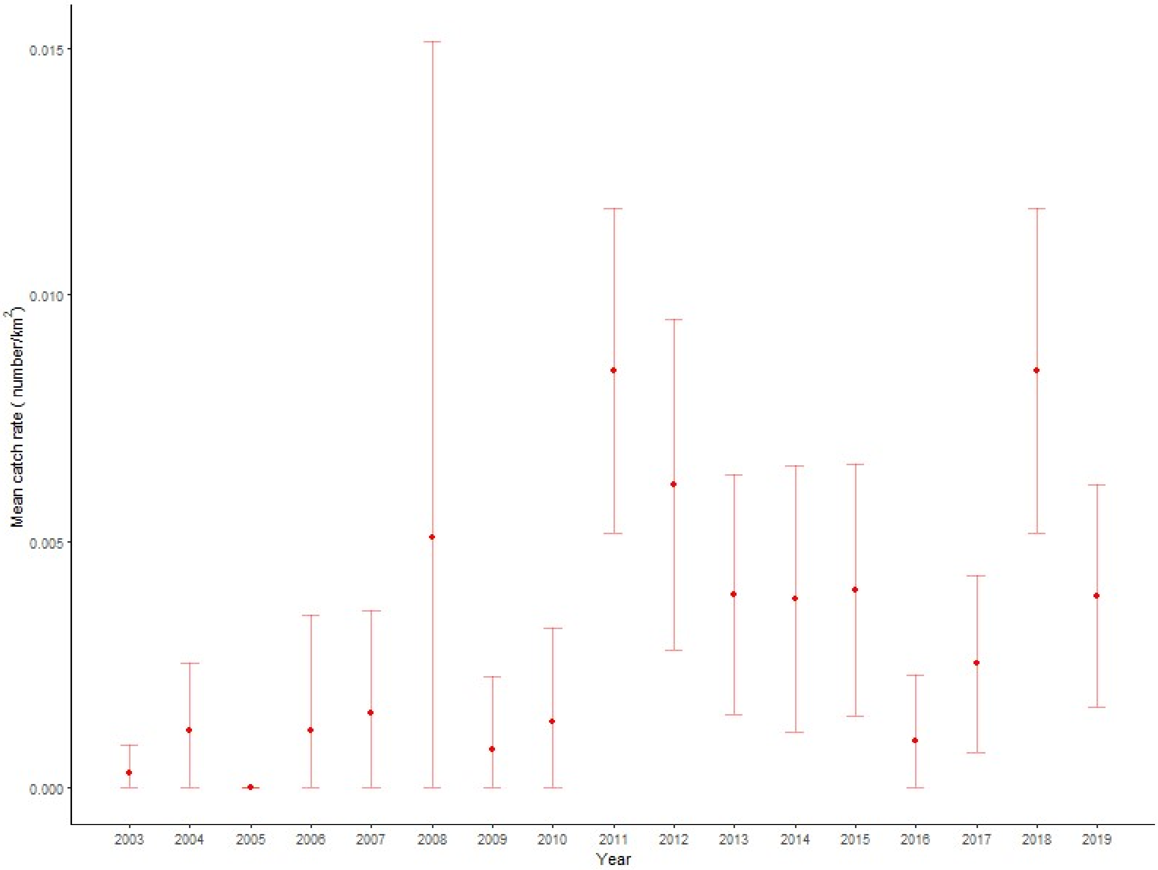


Figure 19: Trends in mean catch rate (numbers per km²) with 95% confidence intervals for the sea snake; *Acalyptophis peronii*, based on a depth of 24 m and in 'Region' 6 from the crew-member observer program (red points) from 2003 to 2019.

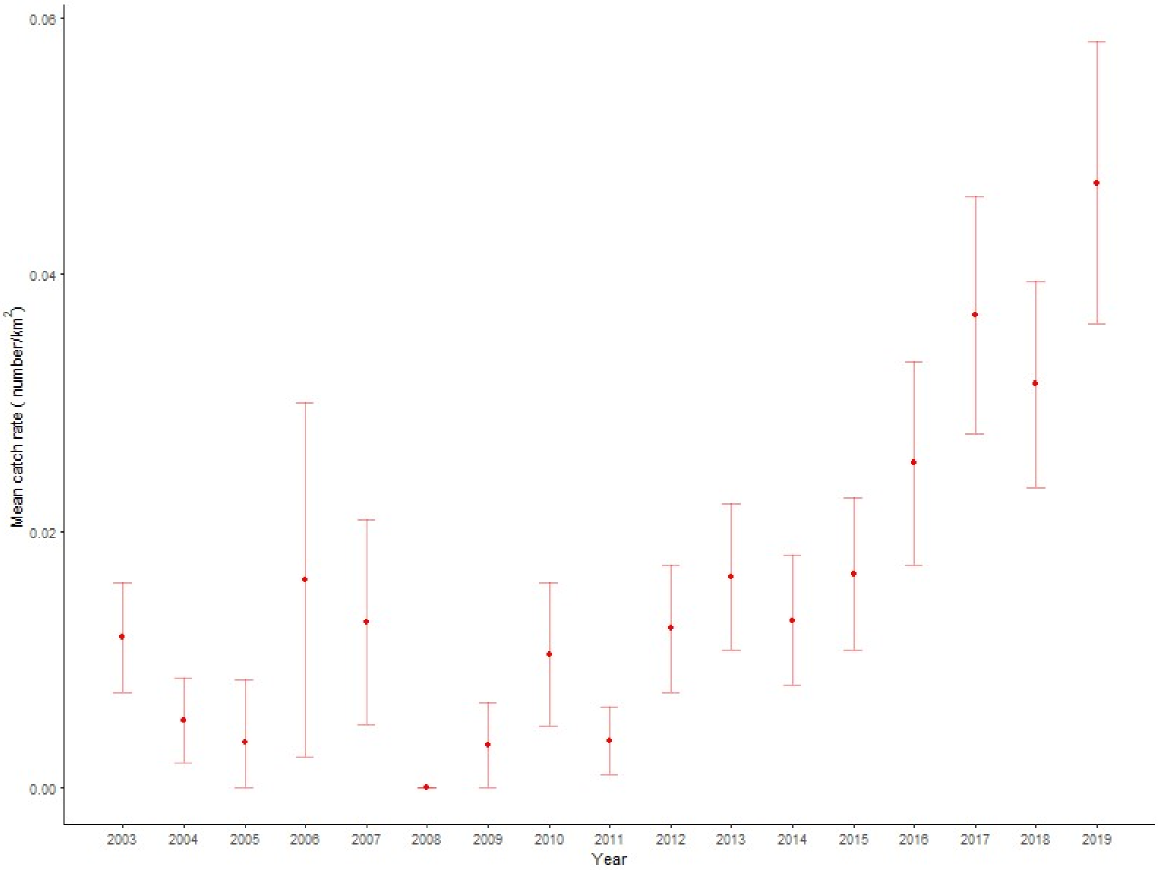


Figure 20: Trends in mean catch rate (numbers per km^2) with 95% confidence intervals for the sea snake; *Aipysurus duboisii*, based on a depth of 24 m and in 'Region' 6 from the crew-member observer program (red points) from 2003 to 2019.

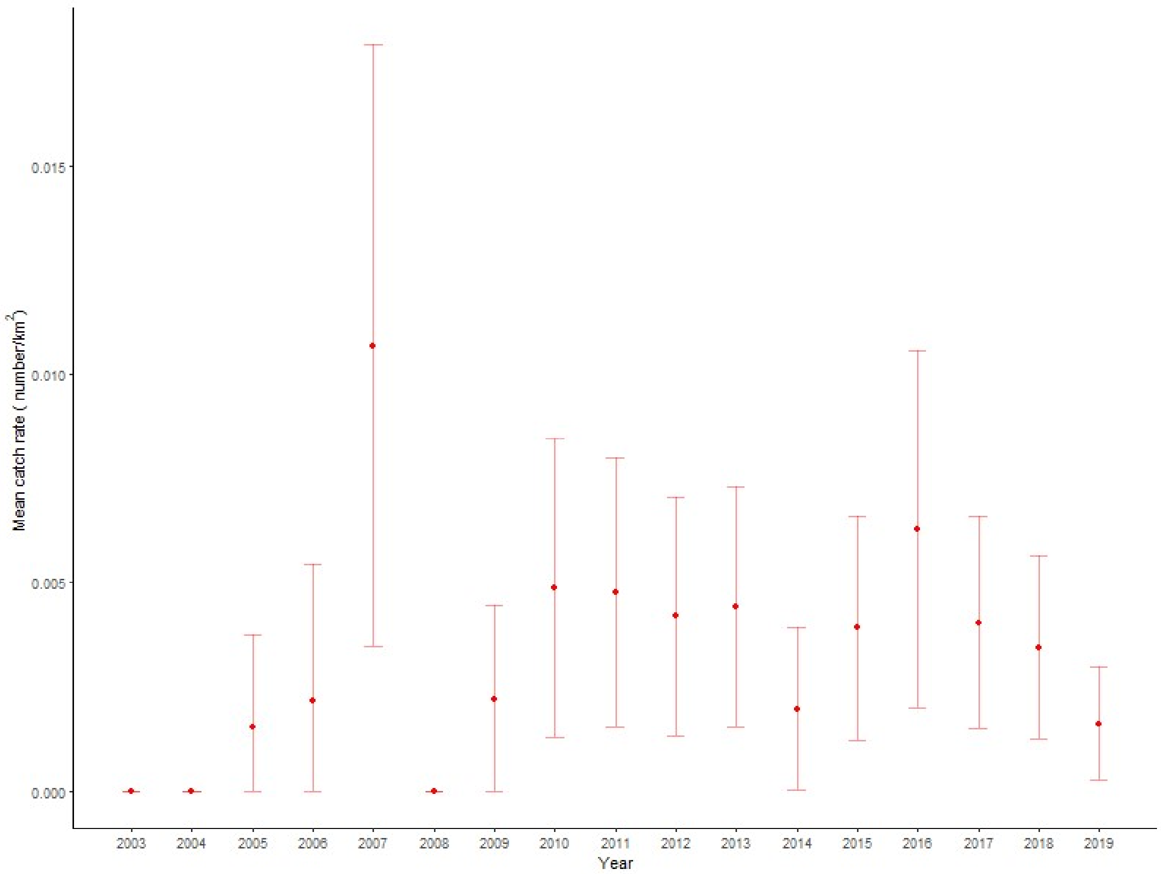


Figure 21: Trends in mean catch rate (numbers per km^2) with 95% confidence intervals for the sea snake; *Aipysurus mosaicus*, based on a depth of 24 m and in 'Region' 6 from the crew-member observer program (red points) from 2003 to 2019.

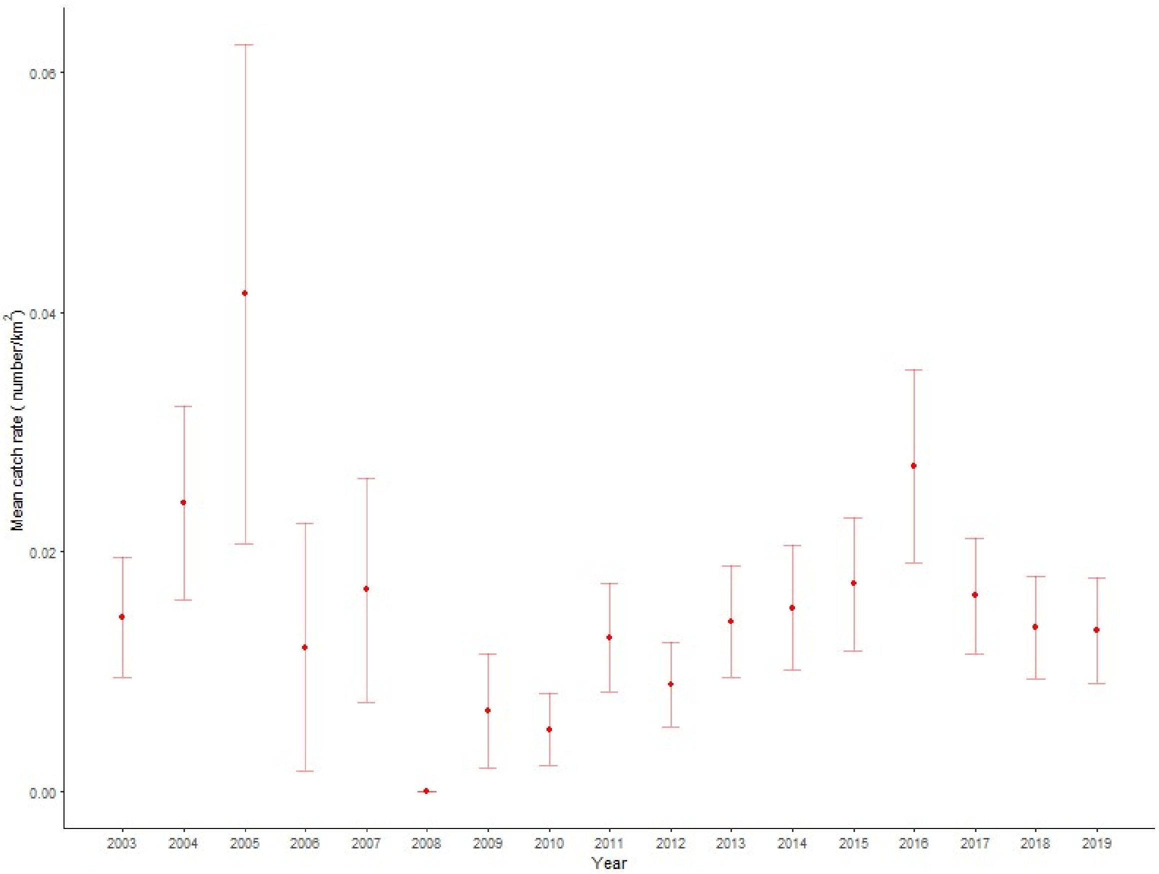


Figure 22: Trends in mean catch rate (numbers per km^2) with 95% confidence intervals for the sea snake; *Aipysurus laevis*, based on a depth of 24 m and in 'Region' 6 from the crew-member observer program (red points) from 2003 to 2019.

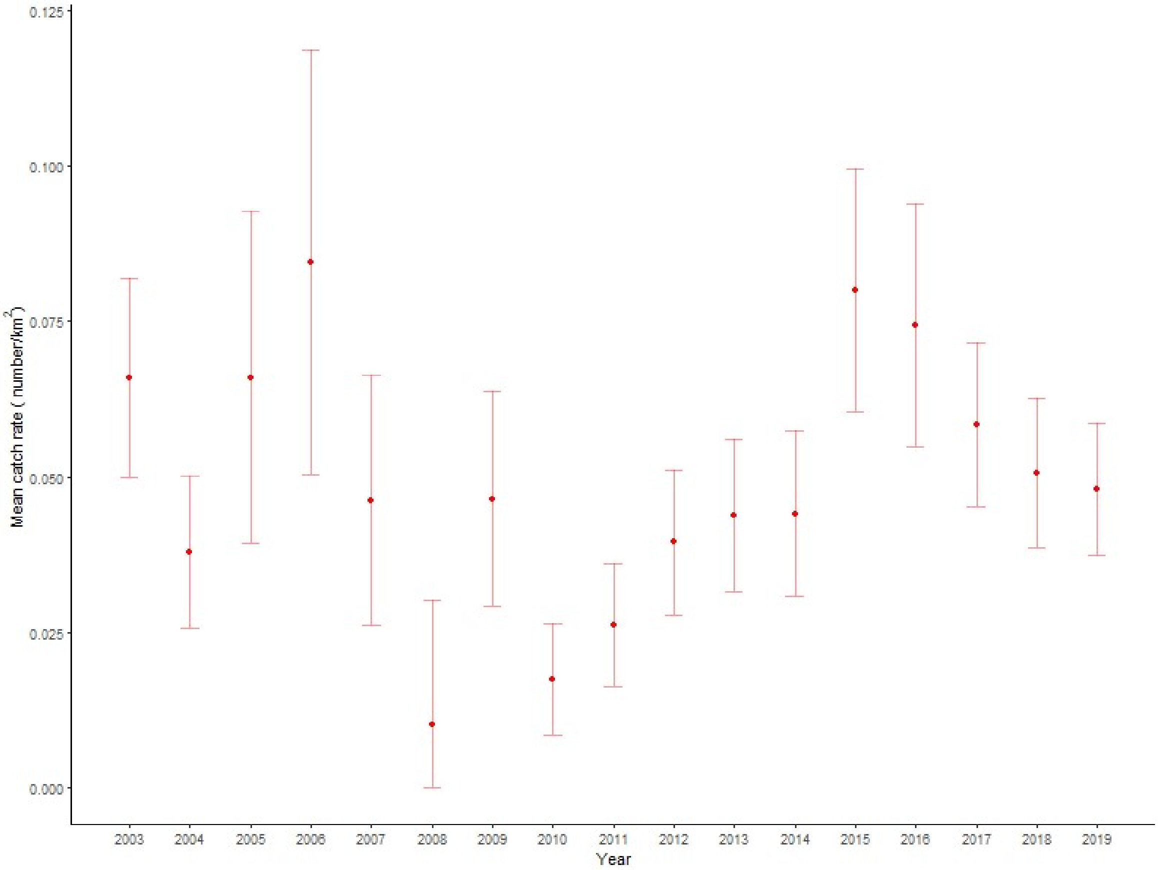


Figure 23: Trends in mean catch rate (numbers per km²) with 95% confidence intervals for the sea snake; *Astrotia stokesii*, based on a depth of 24 m and in 'Region' 6 from the crew-member observer program (red points) and the combined AFMA scientific observer program and NPF prawn population monitoring surveys (black points) from 2003 to 2019.

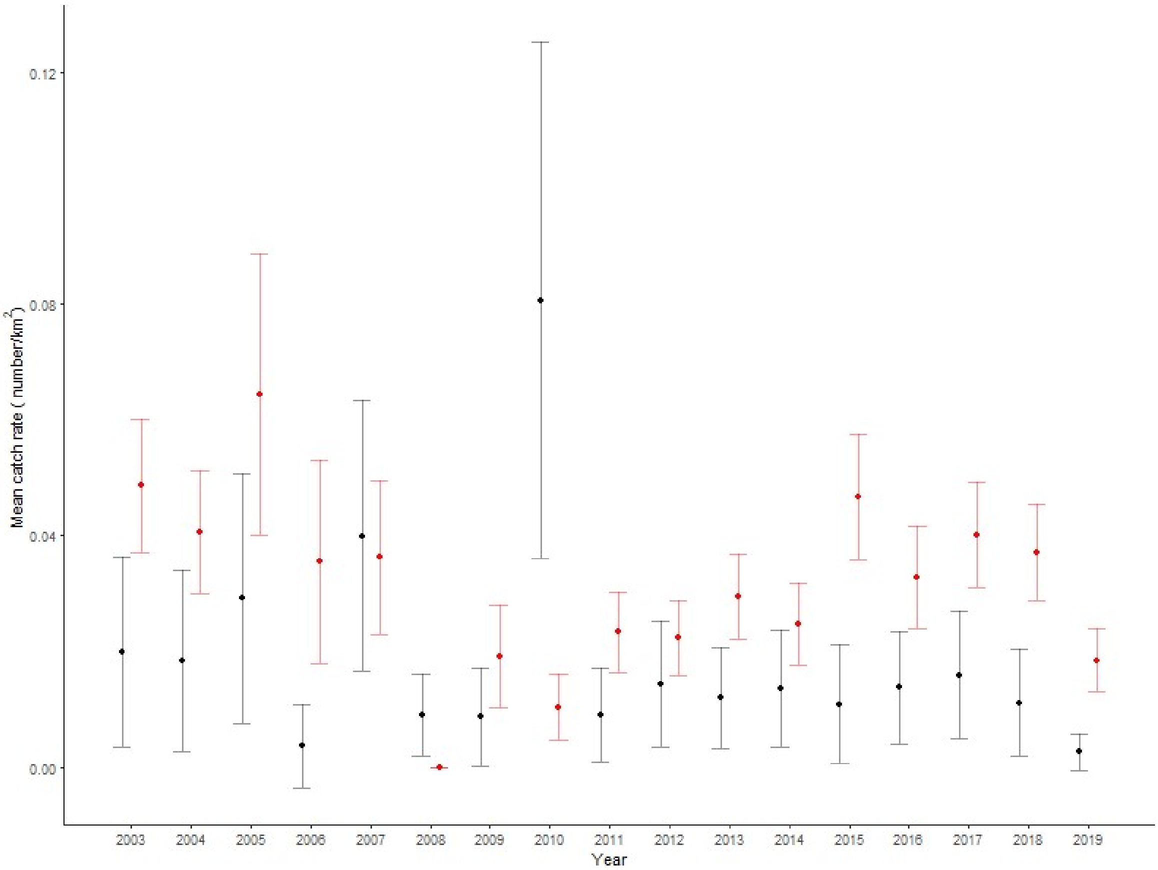


Figure 24: Trends in mean catch rate (numbers per km^2) with 95% confidence intervals for the sea snake; *Disteira major*, based on a depth of 24 m and in 'Region' 6 from the crew-member observer program (red points) and the combined AFMA scientific observer program and NPF prawn population monitoring surveys (black points) from 2003 to 2019.

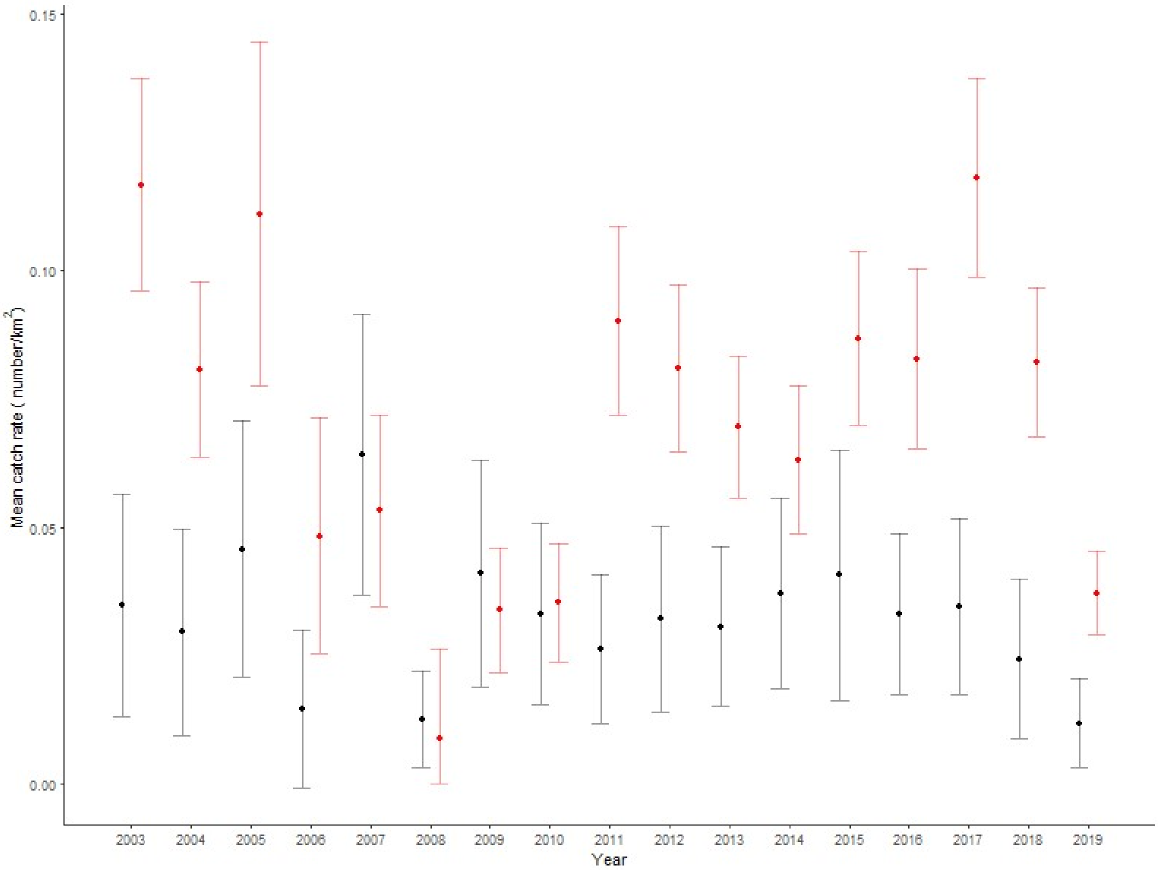


Figure 25: Trends in mean catch rate (numbers per km²) with 95% confidence intervals for the sea snake; *Hydrophis elegans*, based on a depth of 24 m and in 'Region' 6 from the crew-member observer program (red points) and the combined AFMA scientific observer program and NPF prawn population monitoring surveys (black points) from 2003 to 2019.

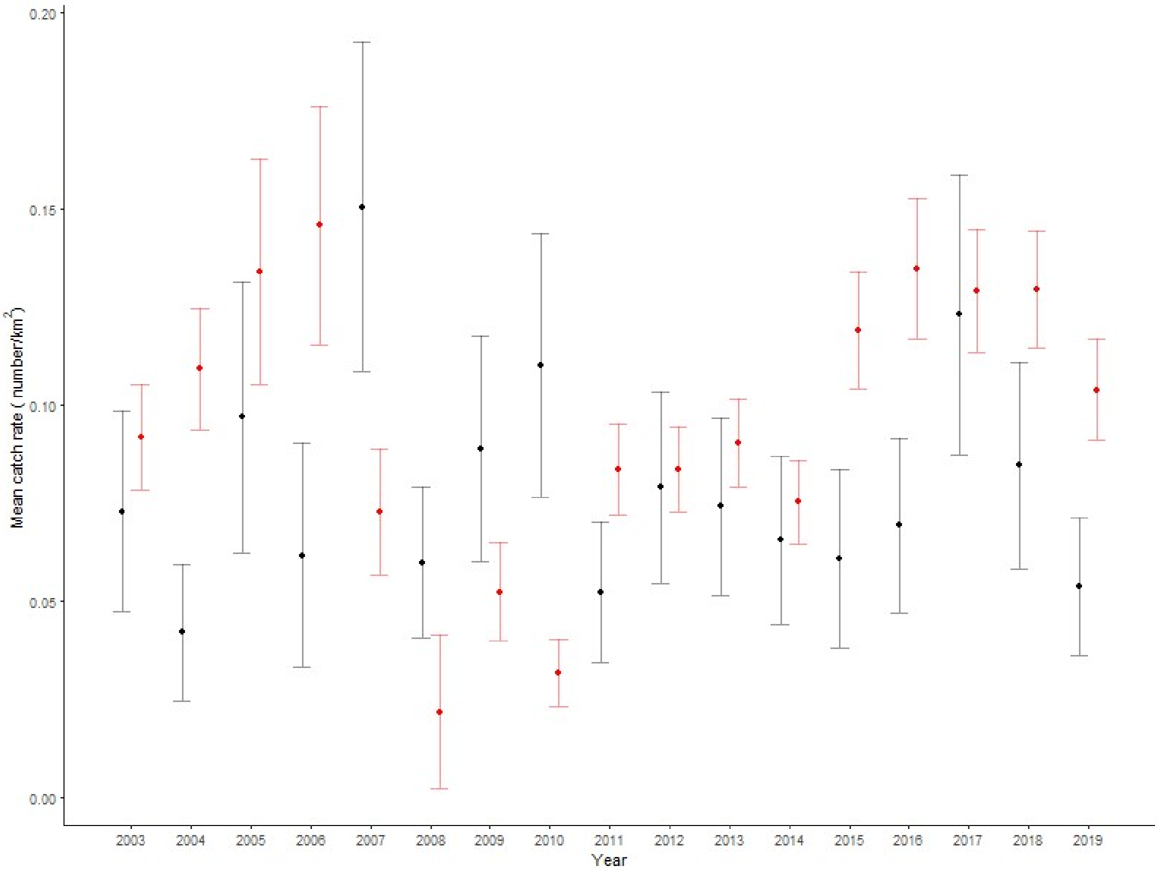


Figure 26: Trends in mean catch rate (numbers per km²) with 95% confidence intervals for the sea snake; *Hydrophis ornatus*, based on a depth of 24 m and in 'Region' 6 from the crew-member observer program (red points) and the combined AFMA scientific observer program and NPF prawn population monitoring surveys (black points) from 2003 to 2019.

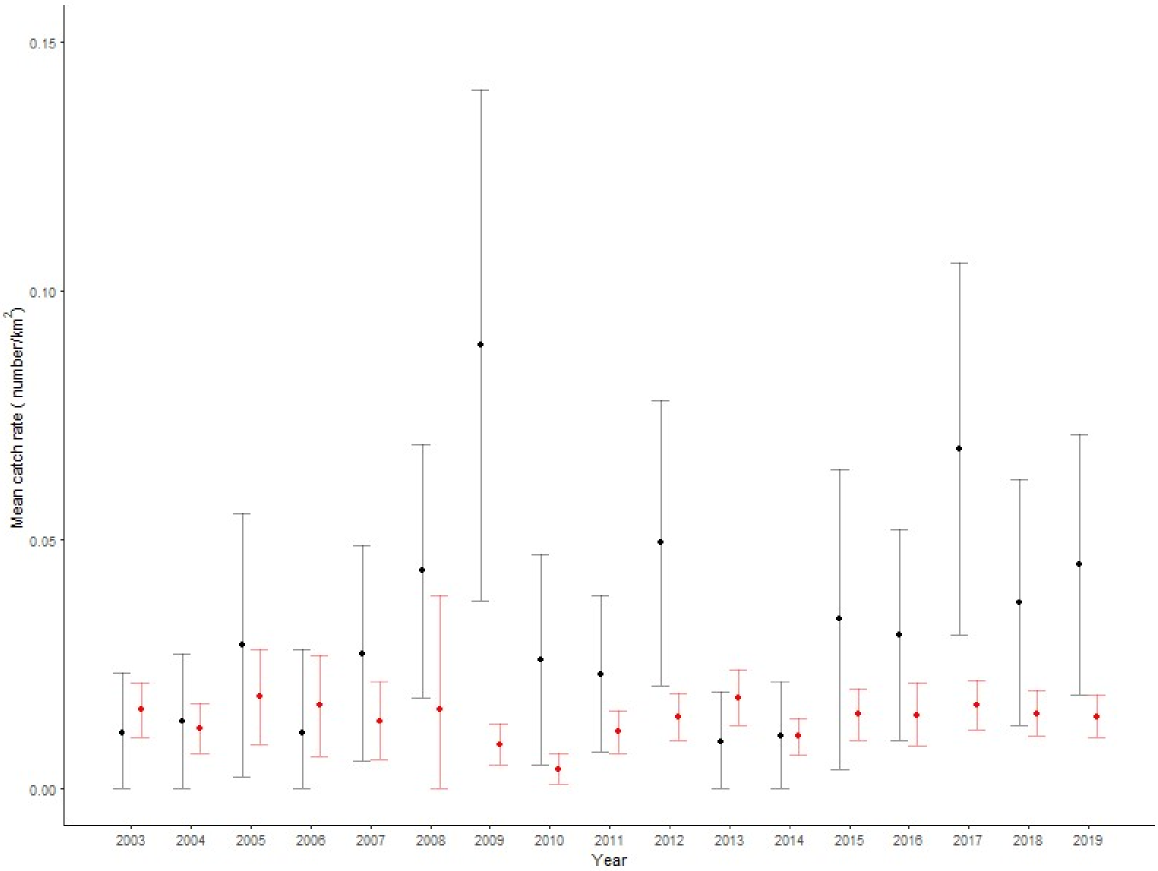


Figure 27: Trends in mean catch rate (numbers per km^2) with 95% confidence intervals for the sea snake; *Hydrophis pacificus*, based on a depth of 24 m and in 'Region' 6 from the crew-member observer program (red points) from 2003 to 2019.

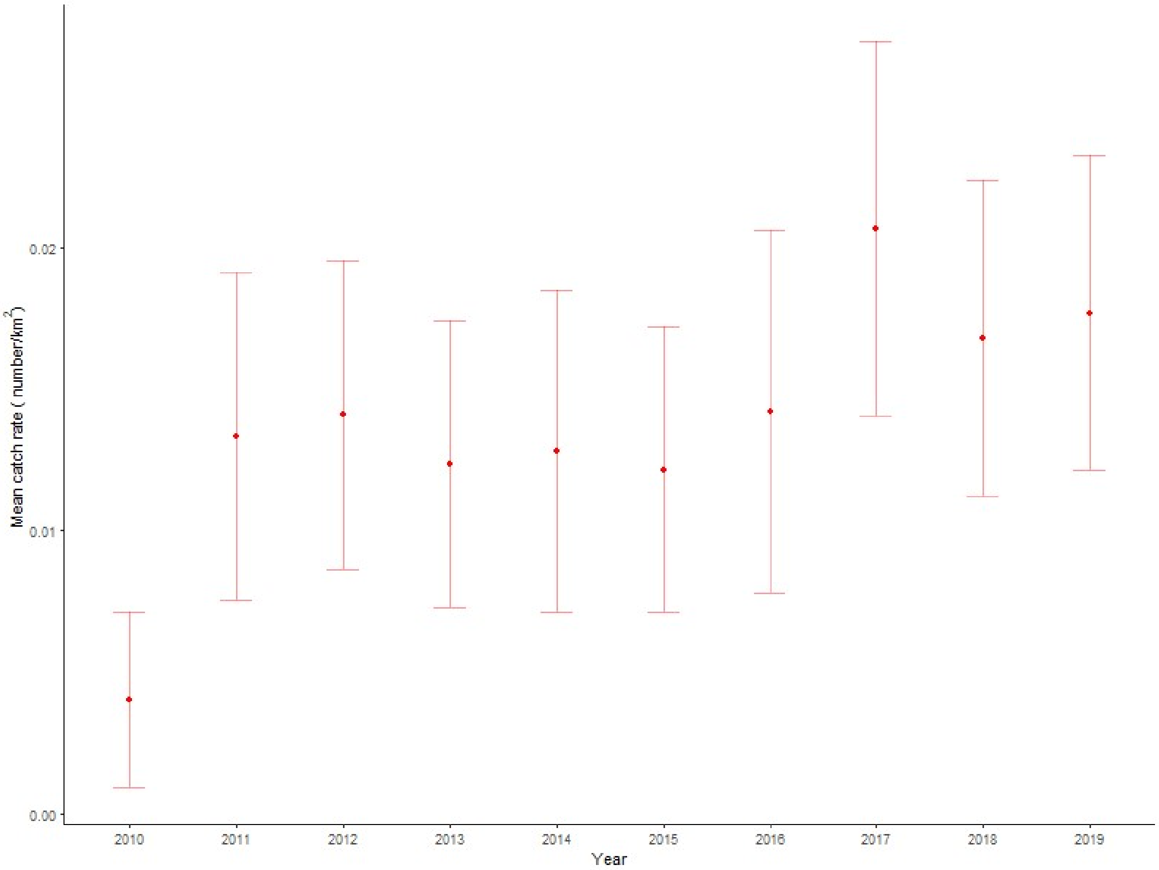


Figure 28: Trends in mean catch rate (numbers per km²) with 95% confidence intervals for the sea snake; *Lapemis curtis*, based on a depth of 24 m and in 'Region' 6 from the crew-member observer program (red points) and the combined AFMA scientific observer program and NPF prawn population monitoring surveys (black points) from 2003 to 2019.

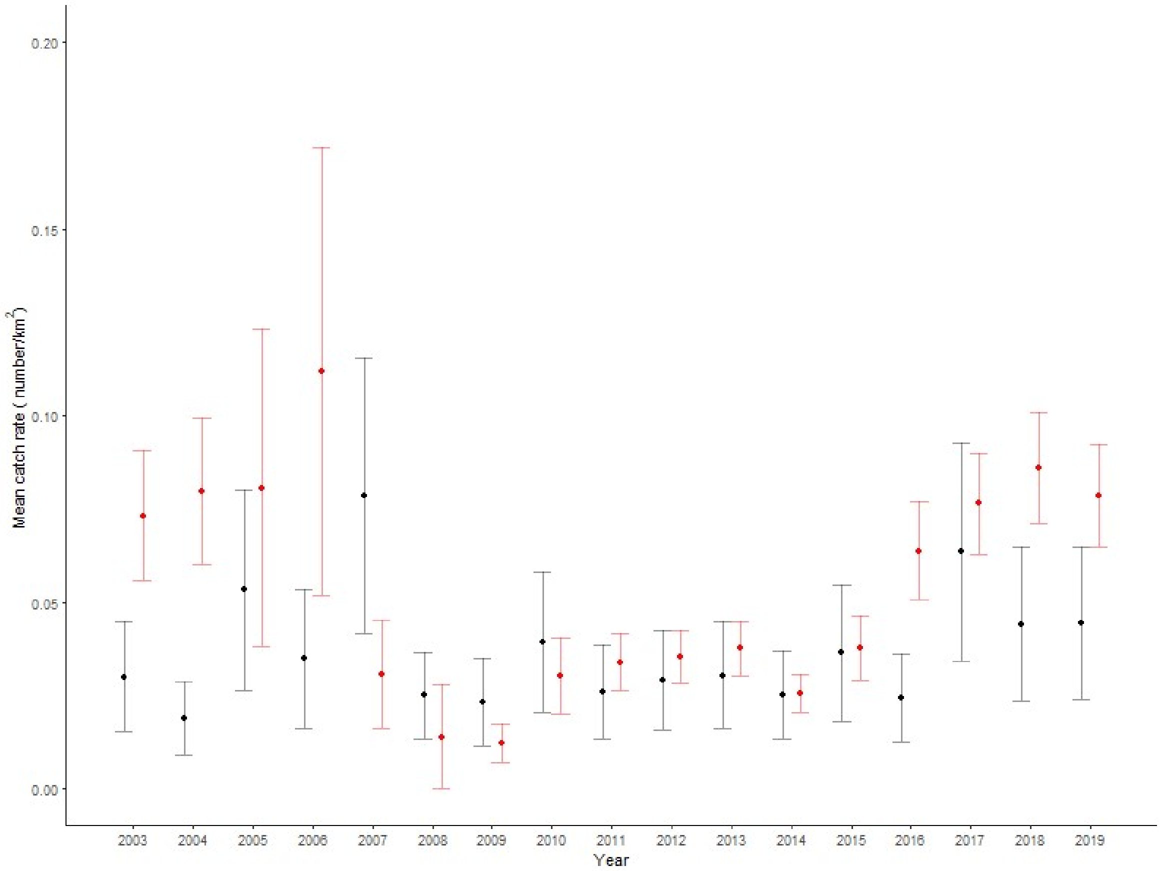


Figure 29: Trends in mean catch rate (numbers per km²) with 95% confidence intervals for the Straightstick Pipefish; *Trachyrhamphus longirostris*, based on a depth of 24 m and in 'Region' 6 from the crew-member observer program (red points) and the combined AFMA scientific observer program and NPF prawn population monitoring surveys (black points) from 2010 to 2019.

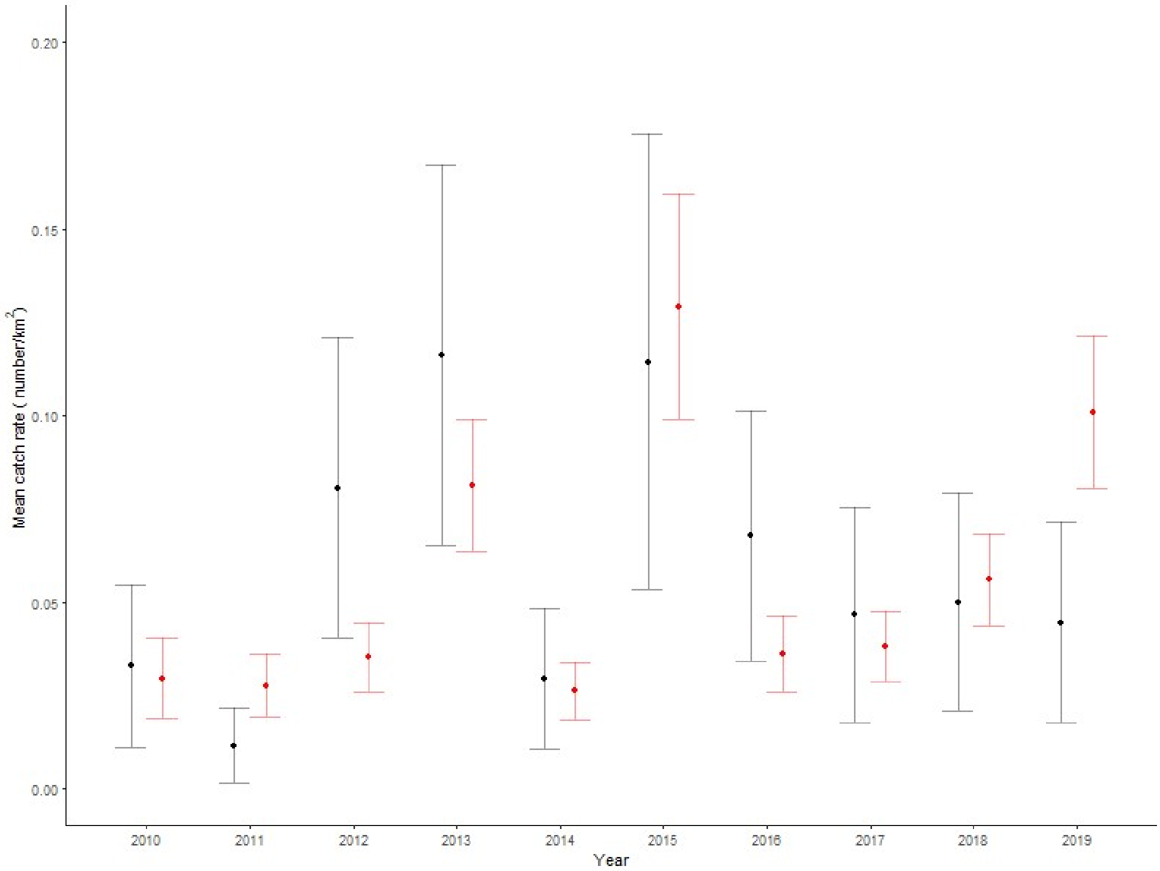


Figure 30: Trends in mean catch rate (numbers per km^2) with 95% confidence intervals for the sawfish; *Anoxypristis cuspidata*, based on a depth of 24 m and in 'Region' 6 from the crew-member observer program (red points) from 2010 to 2019.

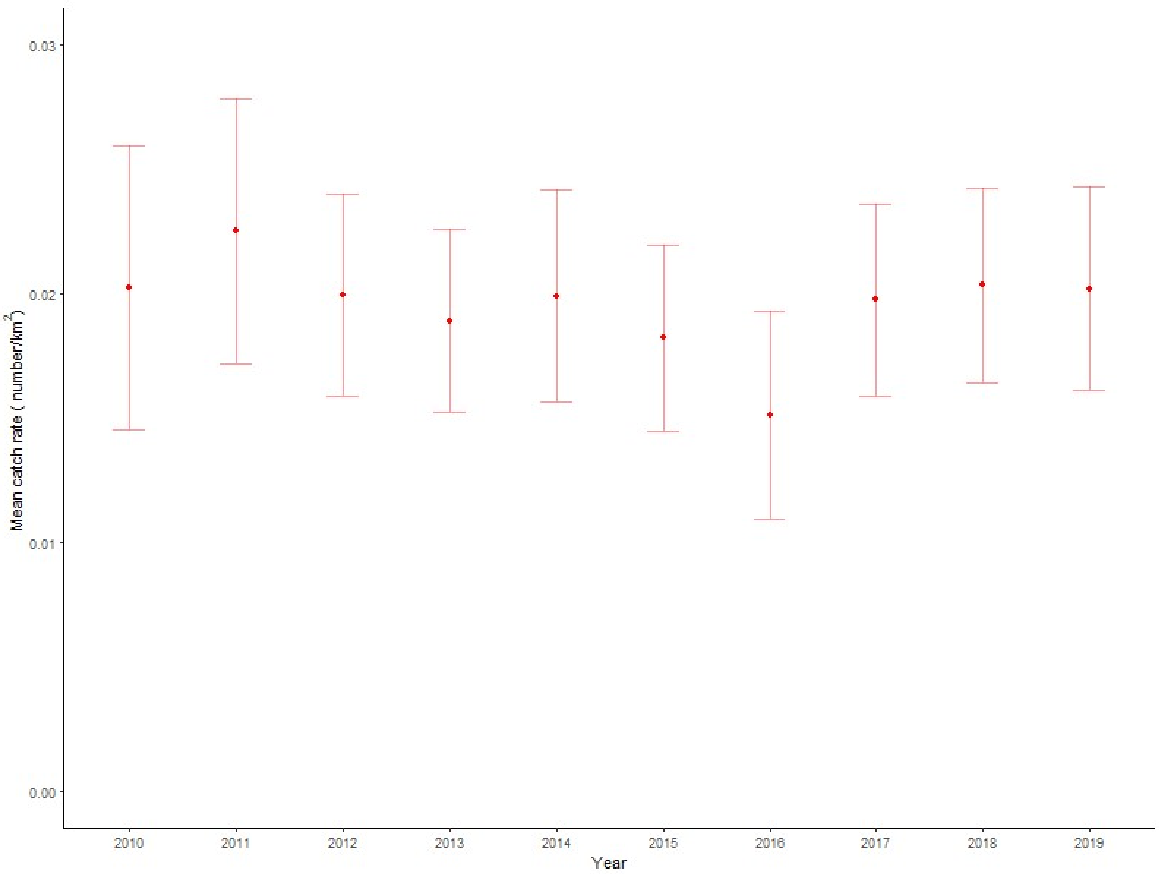
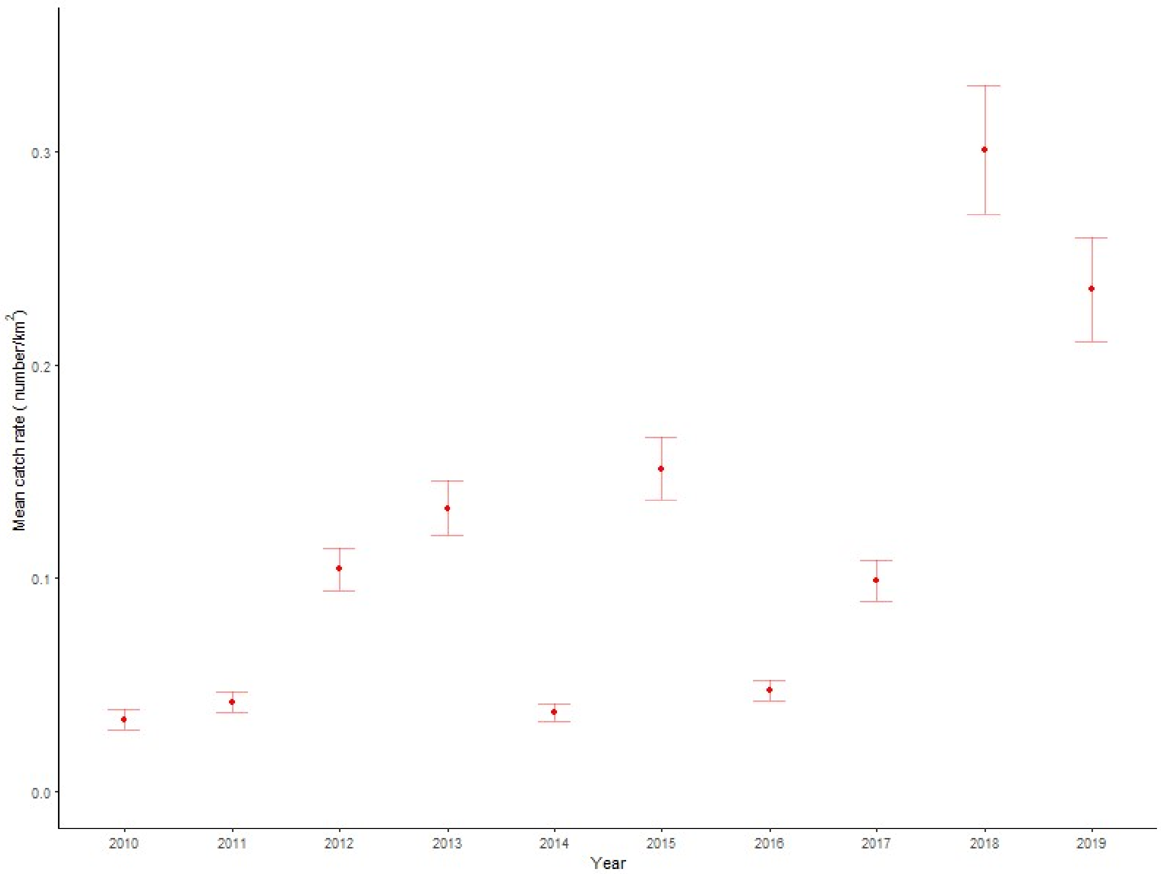


Figure 31: Trends in mean catch rate (numbers per km²) with 95% confidence intervals for the Brown-striped Mantis Shrimp; *Dictyosquilla tuberculata*, based on a depth of 24 m and in 'Region' 6 from the crew-member observer program (red points) from 2010 to 2019.



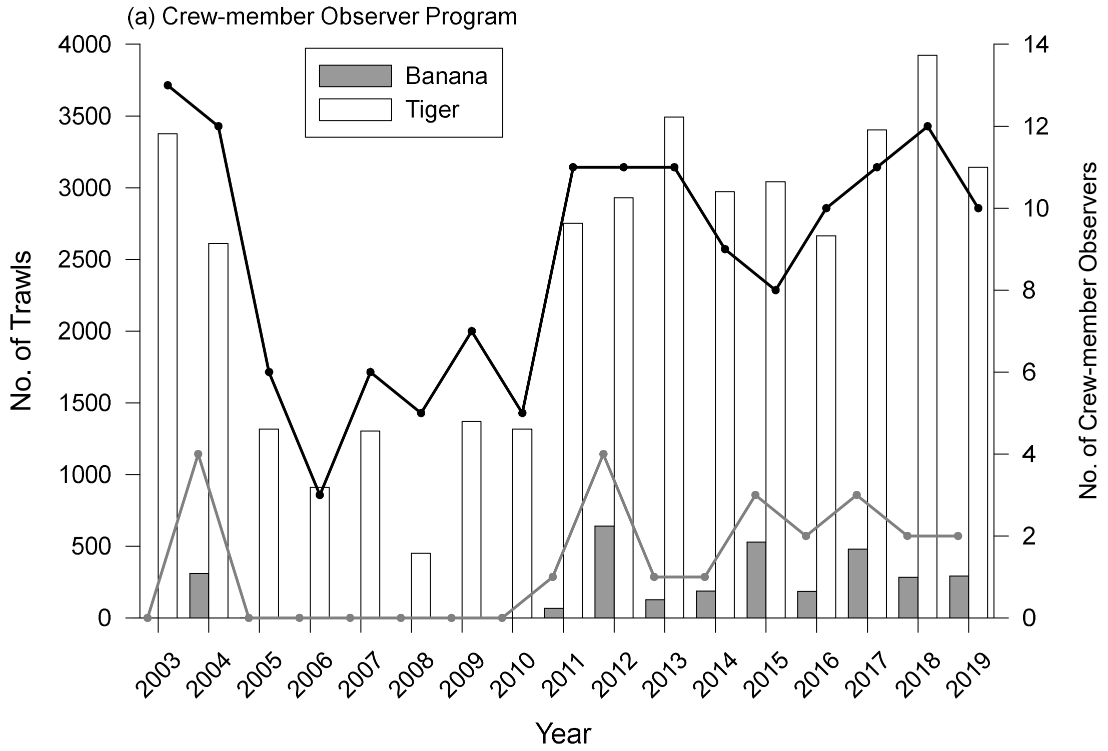
6.8 Crew-member and AFMA observer coverage levels

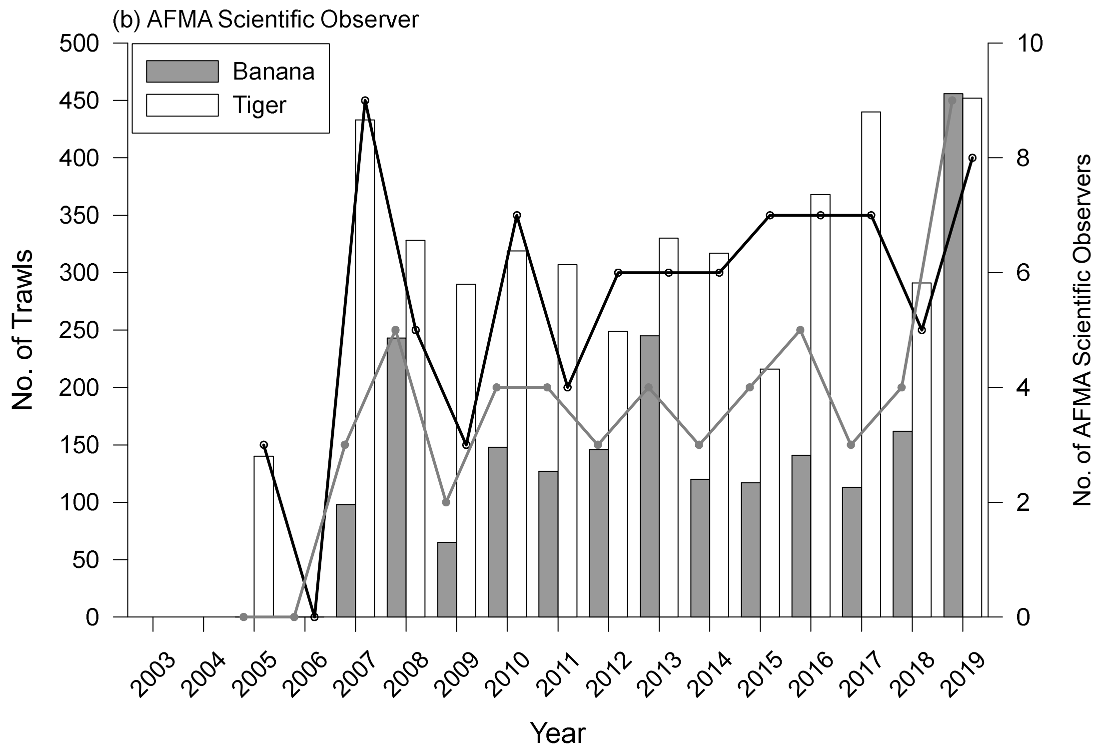
The number of NPF crew participating in the crew-member observer program has significantly increased since 2010 (Table 2; Figure 32 a). From a low of between three to seven observers per year during the 2006 to 2010 tiger prawn season surveying 500 to 1,300 trawls per year, the participation rate for the tiger prawn seasons has increased from eight to 12 crew-member observers annually over the last nine years. This has also led to an increase in the total number of trawls surveyed by crew-member observers in the tiger prawn seasons, from about 1,400 in 2009 and in 2010, around 2,900 in 2011 and in 2012, nearly 3,500 in 2013, around 3,000 in 2014 and in 2015, 2,700 in 2016, 3,400 in 2017, nearly 4,000 in 2018 and 3,100 in 2019.

The majority of crew-member observer coverage in the NPF has been during tiger prawn seasons. In 2004 there were four crew-member observers recording catches of TEP and 'at risk' bycatch species during the banana prawn season from about 310 trawls (Figure 32 a). Not until 2011 was there a greater level of coverage of the banana prawn season. From 2011 to 2013, between one and four crew-member observers have recorded data from a total of approximately 800 trawls surveyed during the banana prawn seasons. Over the last six years, 2014 to 2019, there have been between one and three crew-member observers recording catch data from around 200 to 500 trawls per year during the banana prawn seasons. This consistent level of coverage across both the banana prawn and tiger prawn seasons has met or exceeded the recommended crew-member observer coverage required to successfully assess the sustainability of bycatch species in the NPF (Brewer et al. 2007).

The AFMA scientific observers have recorded catches of TEP and 'at risk' bycatch species from 2005 to 2019. Although the spatial and temporal coverage by the AFMA scientific observers were much lower overall compared to the crew-member observers, there was a more even spread of trawls recorded between the banana and tiger prawn seasons (Table 2; Figure 32 b). For each of the banana prawn seasons from 2007 to 2019, there were between two and nine vessels with AFMA scientific observers onboard resulting in 65 to 456 trawls per year surveyed for TEP and 'at risk' bycatch species. For each of the tiger prawn seasons from 2005 to 2019, there were between three and nine vessels with AFMA scientific observers onboard resulting in 140 to 452 trawls surveyed annually by AFMA scientific observers. This level of coverage has also met or exceeded the recommended scientific observer coverage required to successfully assess the sustainability of bycatch species in the NPF (Brewer et al. 2007).

Figure 32: Plot of (a) number of crew-member observers (line) that participated in the crew-member observer program and the total number of prawn trawls (bar) that were recorded by the crew-member observers from 2003 to 2019 and (b) number of vessels AFMA scientific observers boarded (line) and total number of prawn trawls (bar) that were recorded by AFMA scientific observers for both the banana and tiger prawn seasons.





7 Discussion

7.1 Data Collection

Brewer et al. (2007) estimated from analytical power calculations that a minimum of ten crew-member observers and one AFMA scientific observer were required to collect catch data from at least 2,350 trawls each year to detect declines in the TEP and ‘at risk’ bycatch species. Between 2005 and 2008, the crew-member observer program had a participation level of no more than about half this level; three to six observers and 450 to 1,320 individual trawl records in any given year (Table 2). This level of catch sampling fell considerably short of the minimum level of coverage that is required for the crew-member observer program to detect significant catch rate changes in the TEP and ‘at risk’ bycatch species. Furthermore, a high proportion of the catch records in these years could not be identified to species level, making the data of limited use. Data quality issues had to be taken into account for the catch rate trend analyses of TEP and ‘at risk’ bycatch species for the first 2009 Bycatch Sustainability Assessment (Fry et al. 2009).

One of the main issues was the apparent inconsistency between the crew-member observer data set and the AFMA scientific observer and NPF prawn population monitoring data sets. Partly, differences in the proportion of individuals that were identified to species caused disparities in the data sets at a species level. For example, nearly 100% of all sea snakes and 100% of the sawfishes were identified to species from the AFMA scientific observer program and NPF prawn population monitoring surveys in the years 2003 to 2008 (see Table 13). However, in some years of the crew-member observer program, only 30 – 55% of sea snakes and 30 – 60% of sawfishes were identified to species as there was a lack of photographs matched to the catch data. During laboratory verification, scientific staff could not identify these catch interactions to species.

Participation levels for both the crew-member observer and AFMA scientific observer programs improved during the 2009 to 2013 period for the second (2015) Bycatch Sustainability Assessment (Fry et al. 2015). Furthermore, the previous data quality issues had been addressed through more rigorous training at the annual crew-member observer workshops. These improvements led to more robust catch data being collected through the crew-member observer program. For example, the proportions of sea snakes and sawfishes being successfully identified to species rose to 80 – 95% and 85 – 90%, respectively, for the crew-member observer program. The number of crew-member observers increased to at least 12 per year and collected catch data from between 2,900 and 3,600 trawls per year. Consequently, a larger number of TEP and ‘at risk’ bycatch species were analysed for catch rate trends by 2015. In the 2009 assessment, there were only two sea snake species (*Hydrophis elegans* and *Lapemis curtis*) and one sawfish species (*Anoxypristis cuspidata* including the unidentified sawfishes) that had enough detections to allow modelling of catch rate trends. In the 2015 assessment, there were 11 species modelled; seven sea snakes (*Aipysurus mosaicus*, *Aipysurus laevis*, *Astrotia stokesii*, *Disteira major*, *Hydrophis elegans*, *Hydrophis ornatus* and *Lapemis curtis*), one syngnathid (*Trachyrhamphus longirostris*), one sawfish (*Anoxypristis cuspidata* including the unidentified sawfishes) and two invertebrates (*Dictyosquilla tuberculata* and *Solenocera australiana*) and the 'Unidentified Hydrophiidae' group.

The last bycatch sustainability assessment in 2018 analysed the crew-member observer data and combined AFMA scientific observer and NPF prawn population monitoring survey data up to 2016. With this additional data collected from the 2014 to 2016 banana prawn and tiger prawn seasons, it was possible to model catch rate trends for eight sea snake species, the same seven species, plus *Hydrophis pacificus*, one syngnathid (*Trachyrhamphus longirostris*), one sawfish (*Anoxypristis cuspidata*) and one invertebrate species (*Dictyosquilla tuberculata*). Despite the numbers of species modelled being the same, the 2018 list is an improvement on the 2015 assessment, as one of the original 11 species was no longer considered ‘at risk’ and removed from the assessment and replaced by an additional sea snake species for which robust data was available.

Over the three years between 2017 and 2019, the crew-member observer program has continued to improve in performance with consistent reliable data collection methods and maintained levels of coverage for the banana prawn and tiger prawn seasons. The number of trawls monitored and the proportions of TEP and ‘at risk’ bycatch species able to be identified to species has increased. Combined with the AFMA scientific observer program, this resulted in meeting or exceeding the recommended levels of annual fishery coverage required to successfully assess the sustainability of bycatch species in the NPF. The interaction data available for the current bycatch sustainability assessment has led to a greater number of species being modelled for catch rate trends. This list now includes one marine turtle species (*Natator depressus*), ten sea snake species (*Acalyptophis peronii*, *Aipysurus duboisii*, *Aipysurus mosaicus*, *Aipysurus laevis*, *Astrotia stokesii*, *Disteira major*, *Hydrophis elegans*, *Hydrophis ornatus*, *Hydrophis pacificus* and *Lapemis curtis*), one syngnathid species (*Trachyrhamphus longirostris*), one sawfish (*Anoxypristis cuspidata*) and one invertebrate species (*Dictyosquilla tuberculata*).

Importantly, there are still some TEP and 'at risk' bycatch species that were not able to be modelled in the current 2021 Bycatch Sustainability Assessment. This is because the number of catch data records for many of these species remains low, even for species that have been recorded since the start of the crew-member observer program. Some groups (turtles, sawfishes and sea snakes) have been recorded by crew-member observers in the NPF since the programs' introduction in 2003. These species have also been regularly monitored during the AFMA scientific observer program from 2005 and the NPF prawn population monitoring surveys from 2002. However, for the syngnathids (TEP), elasmobranch, small teleost and invertebrate ‘at risk’ bycatch species, catches have only been monitored by crew-member observers, CSIRO and AFMA scientific observers since 2006 (syngnathids and elasmobranchs), 2009 (invertebrates) or 2011 (teleosts). For the catch trend models to fit the catch data for these species, numbers of interactions over the data collection period needs to reach a minimum threshold. If the crew-member observer and AFMA scientific observer programs continue in collecting robust catch data, the next three years of data collection should see additional species being added to this growing list.

7.2 Sustainability of bycatch species in the NPF

As the NPF has been operating for more than 50 years, there is no true baseline for catch rates for any of these species. Scientific surveys of marine taxa within the NPF footprint were not undertaken for the first decade or more of fishery exploitation. In addition, trends in catch rates of TEP and ‘at risk’ bycatch species over time are confounded by the continuous changes that have occurred over the fishery’s lifetime, such as changes in fishing power, gears, timing of the fishing seasons, size of the fleet and commercial effort distribution. A clear example in 2000 and 2001 was the mandatory introduction of TEDs and BRDs that caused a major reduction in catches of some large TEP species (marine turtles and elasmobranchs) and small bycatch species in the prawn trawl nets (Brewer et al. 2004; Brewer et al. 2006) with consequent reductions in the mortality of many species thereafter. Some species are also impacted by other activities in northern Australia that are less easily quantified. For example, marine turtles or their eggs are a traditional food source for Indigenous people in northern Australia and SE Asia; and increasing coastal developments can potentially impact turtle nesting sites along the Australian coasts (https://www.awe.gov.au/environment/marine/publications/recovery-plan-marine-turtles-australia-2017). Sawfish species are impacted by the Queensland N3 and N9 gillnet fisheries that operate in the coastal waters of north Queensland (Peverell 2005) and the development of coastal mining operations in the far north may have an impact on sawfish populations and their nursery habitats.

Detecting changes in the catch rates, and therefore abundance, of those rare bycatch species has proven to be difficult in multispecies tropical trawl fisheries where the bycatch component of catches is usually very species diverse (Heales et al. 2003). Several previous studies have used quantitative approaches to assess the risk to trawling for a range of species caught as bycatch in the NPF (Brewer et al. 2007; Zhou and Griffiths 2008; Zhou et al. 2009a). From a power analysis of trawl data, Brewer et al. (2007) estimated the levels of fishery-dependent trawl-catch sampling effort required to detect declines in catch rates of prawn trawl bycatch. They suggested that between 15,536 and 24,933 trawls were required to be able to detect a 20% drop in catches over a year for rare bycatch species (< 0.1 individuals/ha^{-1} or < 10 individuals/km^2) with a power of 90% and a level of significance of 5%. They concluded that the power to detect even quite large declines in catch rates of the rarely caught species would only be possible after some years (e.g. five to ten years) of modest-sized annual surveys.

In the early years of the crew-member observer program (2003 – 2004), the number of trawls surveys each year was comparable to the annual estimated level required to detect declines in bycatch species, around 3,000 each year. However, there was a significant drop in crew-member participation between 2005 and 2010 with trawls surveyed only reaching about 450 to 1,300 trawls each year. Over the next three-year period from 2011 to 2013, the total number of trawls surveyed annually by the crew-member observer program reached between 2,800 and 3,600 trawls. This effort was continued over the 2014 to 2016 period with similar crew-member observer participation reaching between 2,800 to 3,600 trawls surveyed annually. This level of coverage has now been exceeded over the three years of this bycatch assessment period (2017 – 2019) with more than 11,500 trawls surveyed in that period. The total number of trawls surveyed within the data collection period for the crew-member observer program (2003 to 2019) is now more than 44,000 trawls.

The improvement in trawl coverage has led to an increase in the number of the more common TEP and 'at risk' bycatch species being quantitatively assessed for changes in catch rate trends. In addition, the continued improvements in training of the crew-member observers has resulted in more robust data collection and recording, such as higher proportions of catch interactions being photographed for later species identifications. This is also evident from the improved catch interactions for bycatch groups that are generally difficult to separate out of large catches of trawl bycatch such as the syngnathids and ‘at risk’ invertebrates. The catch rates of these groups are now consistent between the crew-member observer data and the combined AFMA scientific observer and NPF prawn population monitoring data.

The estimated trawl sample-size required to compile a data set that can provide statistically robust detection of a change in population of TEP species was large (~15,000 – 25,000 trawls) (Brewer et al. 2007). Over the last nine years of consistent crew-member observer participation, this level has been exceeded with 31,103 trawls in that period resulting in a data set that quantitatively models change in population levels of 14 species. Hence, the crew-member observer program has been effective at accurately recording interactions of these TEP and ‘at risk’ bycatch species, some of which are difficult to detect in trawl catches due to their small size and cryptic nature.

The initial analysis of the AFMA scientific observer and NPF prawn population monitoring data together with the historical NPF bycatch assessment data found that these data sets were consistent in catch rate trend with the crew-member observer data collected recently. There is little evidence of under-reporting of the species by the crew-member observer program. Furthermore, the modelled catch rate trends using only the crew-member observer data for five more commonly caught species of sea snakes (*Astrotia stokesii*, *Disteira major*, *Hydrophis elegans*, *Hydrophis ornatus* and *Lapemis curtis*) and one species of syngnathid (*Trachyrhamphus longirostris*) were generally similar to the modelled catch rate trends when the AFMA scientific observer and NPF prawn population monitoring data sets were combined and compared. For these six species at least, the crew-member observer data can be demonstrated to be statistically similar to the fishery-independent scientific data (AFMA scientific observer and NPF prawn population monitoring) and of sufficient quality to be used in scientific catch rate trend analysis.

7.2.1 Marine turtles

There were five species of marine turtles recorded within the NPF region. Most turtle species are known to be highly migratory and widely distributed, occurring in most tropical waters of the Indo-Pacific region (https://www.environment.gov.au/marine/marine-species/marine-turtles). However, there is one species endemic to northern Australia, *Natator depressus*, the most common species recorded in the NPF.

It is difficult to quantify the effect of trawling on turtle populations with other impacts such as Indigenous hunting for food, egg collecting and disruptions to turtle nesting sites caused by coastal infrastructure placement, and other impacts such as pollution and ghost-fishing. However, since the introduction of TEDs in the NPF in 2000, catches of turtles have declined significantly (Brewer et al. 2006). The mortality of turtles from commercial trawling has also been significantly reduced due to the effectiveness of TEDs at quickly releasing these animals from the prawn trawl net once they enter the net opening and travel down the net throat.

Brewer et al. (2006) showed that TEDs were very effective at reducing the catches of turtles; excluding 99 – 100% of turtles from prawn nets with TEDs installed. Brewer et al. (2004) reported that all the types of TEDs assessed for turtle exclusion rates were very effective at significantly reducing catches of this group, both in a range of different regions and under a variety of weather conditions. A similar study by Robins et al. (2003) found that the most common species caught in the NPF was *Natator depressus* (60%) and *Lepidochelys olivacea* (29%) and reported a reduction of more than 95% in turtle catches when TEDs were installed in prawn nets. It has been estimated that since the introduction of TEDs in the NPF, turtle catches have decreased from about 5,000 – 6,000 per year (Poiner and Harris 1996; Robins et al. 2003) to less than 30 (Brewer et al. 2004). Furthermore, prior to the introduction of TEDs in the NPF, Poiner and Harris (1996) reported about 10 – 18% of turtles caught drowned and another 50% were damaged by prawn trawl nets. Similarly, Robins et al. (2003) estimated about 22% of turtles caught in nets without TEDs die. With the introduction of TEDs, this level of undesirable impact has been reduced to less than 0.5% of the turtles previously caught and prawn trawling is now a negligible source of turtle mortality (Brewer et al. 2004).

The results of our analyses showed that the marine turtles have a widespread distribution across northern Australia and mean catch rates were relatively variable across 'Regions' and 'Years' in each of the three data sets. Catch rates were generally low due to the use of TEDs and no decline in the catch rate trend was seen for the Flatback Turtle (*Natator depressus*) from 2003 to 2019. There appeared to be no general decline in catches for any of the other four turtle species from the crew-member observer, AFMA scientific observer and NPF prawn population monitoring data. Furthermore, about 40% of the marine turtles were recorded in the try net gear which is checked roughly half-hourly during tiger prawn fishing operations. Hence, most marine turtles recorded by the crew-member observer, AFMA scientific observer and NPF prawn population monitoring surveys were released alive and in a healthy condition (95%).

As this group is listed as protected species in the EPBC Act 1999, any interactions with fishing activities in the NPF needs to be recorded. Therefore, continued monitoring by fishery-dependent and fishery-independent programs is required. However, due to the effectiveness of TEDs in the fishery, it is unlikely that sufficient catch data will be recorded in future to carry out a robust catch rate trend assessment on these species. Brewer et al. (2007) concluded that between 24,000 and 124,000,000 trawls were needed to detect an annual decline in catches of turtles in the NPF when

TEDs were used. The data from this project indicate that there is already strong evidence that current commercial prawn trawling practices of using TEDs has minimal impact on their populations.

7.2.2 Sea snakes

There are approximately 30 species of sea snakes occurring in northern Australia, about half of which are endemic to this region (Stobutzki et al. 2000). Of the 20 species of sea snakes reported within the NPF region, 14 of these were recorded by the crew-member observer program, AFMA scientific observer program or NPF prawn population monitoring surveys. A number of survival studies have shown that sea snake mortality, both within-trawl and post-trawl deaths, from commercial prawn trawling is about 48 – 60% of all snakes caught (Wassenberg et al. 1994; Ward 1996; Stobutzki et al. 2000; Wassenberg et al. 2001). The survival of sea snakes depended on a number of factors; when the snake enters the net, weight of the total catch, how snakes are treated post-capture, the species and its morphology and most importantly, duration of trawl (Stobutzki et al. 2000). They reported that trawls over three hours duration resulted in sea snake mortality rates of up to 75%. Furthermore, a study on life-history traits of sea snakes showed that this group may be highly susceptible to trawling (Fry et al. 2001). They found that trawl catches were comprised of a significantly greater proportion of females to males for most species. However, most of the sea snakes caught were mature; 67% for males and 89% for females, and that few juvenile snakes were recorded within commercial prawn trawl grounds. Sea snakes are live-bearers and produce few offspring every year; between three and 20 young per clutch. The females of most species, with the exception of *Aipysurus mosaicus*, give birth in the months of February to March, which does not overlap with the current prawn trawling seasons.

It has been shown that TEDs and BRDs that are currently used in the commercial fleet, and their placement within nets, have very little effect (< 5% reduction) on the catches of sea snakes (Brewer et al. 2004; Brewer et al. 2006; Milton et al. 2008). In the 2004 to 2006 tiger prawn seasons, Milton et al. (2009a) assessed the performance of currently used BRDs by asking commercial fishers to change the positioning of these devices closer to the codend. They found that a reduction in sea snake catches of at least 43% was achievable when the Fisheye BRD was set at 66 meshes compared to 120 meshes from the codend drawstring. Furthermore, trials of a different BRD (the Popeye Fishbox) by AFMA scientific observers on commercial vessels showed this device reduced catches of sea snakes by 85% when set at 70 meshes from the drawstring. Recently, the fishery adopted a number of new BRDs for use in the NPF. Along with the Popeyes Fishbox at 70 meshes, three new devices were approved for use in the tiger prawn seasons; Kon's Covered Fisheyes at 55 and 78 meshes, FishEX 70 at 65 meshes or Tom's Fisheye at 60 meshes. The potential effect of sea snake escapement rates for these new devices has not been assessed yet. However, the implementation of more effective BRD's, at a position closer to the drawstring is likely to be an effective measure in further reducing catches of sea snakes by commercial prawn trawlers in the NPF.

A number of studies, including this NPF bycatch assessment, have shown that the distributions and catch rates of each sea snake species are spatially and temporally patchy within the NPF (Heatwole 1975; Redfield et al. 1978; Wassenberg et al. 1994; Ward 1996; Stobutzki et al. 2000; Fry et al. 2001; Milton et al. 2008, Fry et al. 2015). Research trawling in the Gulf of Carpentaria showed that catch rates for *Hydrophis elegans* slightly declined between 1989 and 1998, along with three other species; *Disteira kingii*, *Disteira major* and *Hydrophis mcdowelli* (Stobutzki et al. 2000). These species also appeared to prefer open habitats with flat bottom, typical of prawn trawl grounds. However, catch rates for the more reef-associated species; *Aipysurus* and *Astrotia* species, remained relatively stable over the same period (Stobutzki et al. 2000). They did show that there were some regional differences in sea snake catch rate trends over time. Within most regions there was little change in the overall mean catch rates except for Weipa where catches halved from the 1989 to the 1996-98 period. The continued stability of sea snake populations is supported by this bycatch sustainability assessment. Though research trawls suggest that the species compositions at Groote, Mornington and Weipa regions had changed over the period 1989 – 1998, there were no marked changes in the distribution and catch rates of the sea snakes from this bycatch sustainability assessment to the previous 2018 assessment (Fry et al. 2018). There was also little change in the fishery effort distribution for the crew-member observer program over the reporting period of 2014 – 2016 to 2017 – 2019.

There have also been several studies investigating the susceptibility of sea snakes to trawling using risk assessment analysis. Milton (2001) used a ranking matrix of susceptibility to trawling and capacity of populations to recover from impact to assess the sea snake species in the NPF. He identified two species to be at higher risk to trawling; *Disteira kingii* and *Hydrophis pacificus*. Although *Disteira kingii* populations showed a higher capacity to recover than most species, it was the second most susceptible species to trawling due to its restricted distribution (Milton 2001). *Hydrophis pacificus* showed a restricted distribution within the Gulf of Carpentaria and nearby regions and favoured potential trawl ground habitats (Milton 2001). In a subsequent NPF study, Milton et al. (2008) used a quantitative risk assessment to quantify the impacts of trawling on populations of sea snakes. Using research and commercial trawl catch data from 1976 to 2007, they showed that the abundances of most species of sea snakes in the NPF have been relatively stable over the last 30 years. The two species that had localised catch distributions in the NPF, *Disteira kingii* and *Hydrophis pacificus* (Milton 2001), showed evidence of recent declines in abundance on commercial prawn trawling grounds (Milton et al. 2008). However, these fishing grounds only accounted for an estimated 16% of their available habitat within the NPF managed area.

The crew-member observer program, AFMA scientific observer program and NPF prawn population monitoring surveys have collected a considerable amount of catch data since the Milton et al. (2001 and 2008) studies to continue sustainability studies for the sea snake species. This distribution and catch data have shown that both of these two species occupy a relatively broad distribution through the NPF with abundances concentrated in the coastal regions within the high commercial effort areas of the fishery. For *Disteira kingii*, catch rates are varied from 2003 to 2019 and between the three data collection programs with no clear upward or downward trend evident. The catch rates over time for *Hydrophis pacificus* have been relatively steady over the last few years in the crew-member observer program.

Milton et al. (2008) also estimated an index of fishing mortality for each species of sea snake and compared these to a conservative sustainable trawl impact reference point of half their natural mortality rate. They concluded that trawl mortalities for most species were low (less than 2.6% per year), and below the reference points for each species. *Hydrophis pacificus* had the highest estimated mean fishing mortality but this was less than half the sustainable trawl impact reference point. Therefore, they concluded that no sea snake species appeared to be at risk at current levels of fishing effort in the commercial fishery (Milton et al. 2008). Their result is supported by data from our current bycatch sustainability assessment, where no sea snake species appeared to show any significant decline in catch rates over the period of data collection.

A recent study by Zhou et al. (2009b) developed an integrated approach to investigate the fishing impact on population sustainability of rare sea snake species. This approach involved developing a quantitative sustainability assessment coupled with population trend modelling. The sustainability assessment component used simple detection-nondetection data for population estimation and linked sustainability to simple life-history traits. They applied the approach to assess the sustainability of 14 species of sea snakes incidentally caught in the NPF. Their results indicated that the risks to population sustainability and extinction for each sea snake species from fishing was mitigated by the distribution of individuals in unfished areas, their low catch rate, and some post-trawl survival (Zhou et al. 2009b). The estimated mean fishing mortality rate was low for all species in that study, but there was also high uncertainty. They concluded that none of the 14 sea snake species in the NPF were found to be unsustainable at current fishing intensity levels. However, they did recommend periodical reviews of sea snake sustainability if fishing intensity and effort distribution patterns change (Zhou et al. 2009b). Given that the commercial fishing effort distribution has not changed markedly over the last few years (see Figure 6 and Figure 7), it is likely that there has been no change to the susceptibility of the sea snake species in the NPF.

These studies appear to support our results on the susceptibility of sea snakes to trawling in the NPF. This current assessment did not identify any sea snake species that are likely to be adversely impacted by trawling in the NPF. There was a general trend in the crew-member observer data of lower catch rates across the 2007 to 2010 period for many species. This coincided with high catch rates during the same period for the 'Unidentified Hydrophiidae' group, which can be explained by the poorer quality of data provided by the crew-member observers from 2007 to 2010. However, since 2011 there has been a noticeable decline in recordings of the ‘Unidentified Hydrophiidae’ group to only slightly higher than seen in the AFMA scientific observer program or NPF prawn population monitoring surveys. The improvement in identification of snakes indicates that the crew-member observer program is collecting robust and reliable data on the sea snakes for the NPF bycatch sustainability assessment.

From the crew-member observer data collected between 2017 and 2019, some of the species showed a slight decline in catch rates but these declines were not to a level lower than those seen in previous years; *Aipysurus duboisii*, *Aipysurus mosaicus*, *Aipysurus laevis*, *Astrotia stokesii*, *Disteira major* and *Hydrophis elegans*. The distribution of these species is widespread across the NPF and not restricted within the current inshore commercial fishing effort distribution. Thus, these sea snakes would survive outside locations that are fished where mortality would be lower. Catch rates appeared to slightly increase for many species such as *Acalyptophis peronii*, *Hydrophis pacificus* and *Lapemis curtis*.

Although there was insufficient data to undertake robust catch rate trend analysis for all of the sea snake species recorded in the NPF, the observed catch distributions and mean catch rates recorded suggested that catches for most species were relatively stable or increasing over the time period of 2002 to 2019. Brewer et al. (2007) reported that to detect declines of 50% over five years for the nine most common sea snake species would require using ten crew-member observers and one AFMA scientific observer (2,350 trawls). To detect changes for the 11 most common species of sea snakes would require at least 15 crew-member observers and three AFMA scientific observers and more than 8,400 trawls. These recommended levels of coverage have been met by the crew-member observer and AFMA scientific observer programs for the last nine years and have provided robust and reliable data to assess ten sea snake species in this assessment with none of these species shown to have significantly declining catch trends.

As the sea snake group is also listed as protected species under the EPBC Act 1999, any interactions with fishing activities in the NPF needs to be recorded. Therefore, continued monitoring by fishery-dependent and fishery-independent programs is required to obtain sufficient catch data to undertake a robust catch rate trend analysis for each of the species.

7.2.3 Syngnathids

At least 14 species of syngnathids were recorded within the NPF region. Some of the species have only been recorded from historical CSIRO scientific research and observer surveys. However, 11 species were recorded during the crew-member observer program, AFMA scientific observer program and NPF prawn population monitoring surveys within the NPF region. There were very low numbers of catch records available for all but the most common species; *Trachyrhamphus longirostris*. The low catch rates for most of the syngnathid species was due to the difficulty in identifying individuals to species and the requirement to release the individual quickly once captured (all Syngnathidae species are listed as protected under the EPBC Act 1999).

Most of the syngnathid individuals caught during the earlier CSIRO scientific research and observer surveys where fresh specimens that could be identified on board. In contrast, the method used to record species of syngnathids caught during the crew-member observer program, AFMA scientific observer program and NPF prawn population monitoring surveys was to photograph each individual and identify the image later in the laboratory. Photographing specimens is not a reliable method of species identification for this group as there is considerable variation in colour and morphology within most species of syngnathids. This led to a high proportion of syngnathid catches being recorded only to 'Unidentified Syngnathidae' and under-reporting of individuals at a species level. For the most common species where catch rate trend analysis was possible;*Trachyrhamphus longirostris*, the catch rates from the data recorded by the crew-member observers and the combined AFMA scientific observers and NPF prawn population monitoring survey data was comparable over the data collection period.

Brewer et al. (2007) did not assess the number of trawls needed to detect declines in catches of the syngnathids in the NPF. However, they did suggest that due to their rarity, small size and difficulty in finding them amongst the small bycatch, a large number of trawls would be required to be sampled to adequately assess their sustainability to prawn trawling. Furthermore, syngnathids are cryptic and generally associated with benthic structures, and due to their body shape are poor swimmers so unlikely to be capable of swimming upwards into the codend to escape through any top-mounted BRD, making them vulnerable to trawling.

As the Syngnathidae group is listed as protected species under the EPBC Act 1999 and catch rate trend analysis was only possible for one syngnathid species, it is necessary to continue monitoring these species in the future. Both fishery-dependent and fishery-independent sampling is required to obtain sufficient catch data to undertake a robust catch rate trend analysis on the rarer species.

7.2.4 Sawfishes

There were four species of sawfishes recorded within the NPF region. Due to their life-history characteristics, the sawfishes are regarded as highly vulnerable to any reductions in their population level (Simpfendorfer 2000). This group has become nationally and internationally recognised as being at risk to fishing activities with populations already being severely impacted by fishing in a number of countries (Dulvy et al. 2016, Kyne et al. 2021). Sawfishes are likely to take several decades to recover from significant reductions in populations (Brewer et al. 2004). They are caught as bycatch by several trawl and gillnet fisheries in northern Australia and generally have high fishing mortalities associated with being caught (Stobutzki et al. 2000, Peverell 2005, Kyne et al. 2021, Yan et al. 2021).

The sawfishes have been identified as at risk to trawling from a previous risk assessment of the bycatch species in the NPF using ranking criteria for the susceptibility of species to capture and mortality and capacity to recover once the population is depleted (Stobutzki et al. 2000; Stobutzki et al. 2002; Zhou and Griffiths 2008). They reported that three of the four sawfish species previously recorded in the NPF region were least likely to be sustainable from prawn trawl fishing due to their benthic or demersal habits and having restricted depth ranges; the Green Sawfish (*Pristis zijsron*), Largetooth Sawfish (*Pristis pristis*) and Dwarf Sawfish (*Pristis clavata*). Furthermore, their life-history characteristics such as having low survival rates, producing small numbers of young, likely small population size and restricted distribution ranges mostly within the trawl grounds of the NPF (from catch records and low catch rates as shown in this bycatch sustainability assessment) and specific juvenile habitats and recruitment conditions (Lear et al. 2019; Morgan et al 2021) means that these species' populations have a low capacity to recover from trawl impacts (Stobutzki et al. 2000).

Zhou and Griffiths (2008) used a quantitative ecological risk assessment approach – Sustainability Assessment for Fishing Effects (SAFE) – to estimate fishing impacts and compare the impacts to sustainability reference points based on life-history parameters of these species. They concluded that potentially the most vulnerable sawfish species to current commercial trawling in the NPF was *Pristis pristis*. This species had an estimated fishing mortality close to its estimated minimum unsustainable fishing mortality.

The first Bycatch Sustainability Assessment (Fry et al. 2009) showed little change in catches of sawfishes as a result of the introduction of TEDs into the commercial fleet. Brewer et al. (2004) noted that these species often become entangled in trawl nets, especially in front of the TED, due to the numerous teeth along their rostrum. A recent study on entanglement rates of sawfishes in trawl nets of the NPF showed that most sawfishes were recorded as being caught just in front of the TED or hanging out of the TED opening with their rostrum tangled in the mesh flaps of the TED opening (Laird et al. 2019). Similarly, Griffiths et al. (2006a) found only a slight increase in the capacity to recover from trawl impacts for this sawfish species as a result of the installation of TEDs.

As with the previous three Bycatch Sustainability Assessments (Fry et al. 2009; Fry et al. 2015, Fry et al. 2018), there was insufficient catch data available for three of the four species of sawfish to carry out catch trend analysis. The ability to detect population declines for the most common species in the NPF, the Narrow Sawfish (*Anoxypristis cuspidata*) would require at least ten crew-member observers and one AFMA observer collecting data from 2,350 trawls every year (Brewer et al. 2007). The continued success of the crew-member observer program over the last nine years provided sufficient fishery coverage and robust catch data to enable this species to be assessed, which showed a stable catch rate over the last decade. However, to detect declines in the other rarer sawfish species would require more crew-member observer and AFMA scientific observer coverage of a much larger number of trawls per year.

The modelled trend analysis of the crew-member observer data for *Anoxypristis cuspidata* showed no significant impact on the catches in the NPF between 2010 and 2019, although there was considerable variability in catches within years. As no catch rate trend analysis was possible for three of the four sawfish species and these three species of sawfish are listed as protected species under the EPBC Act 1999, it is necessary to continue monitoring all of the sawfish species in the future, using both fishery-dependent and fishery-independent sampling. A program objective is to obtain sufficient catch data to undertake a robust trend analysis of catch rates for each of the three less-common species.

7.2.5 Elasmobranchs

The Sustainability Assessment for Fishing Effects (SAFE) study for the elasmobranchs (Zhou and Griffiths 2008) in 2006 highlighted eight shark and ray species that were caught in very low numbers and only within commercially fished areas of the NPF. A number of these species also had higher estimated fishing-induced mortalities than their minimum unsustainable fishing mortalities; *Carcharhinus albimarginatus*, *Orectolobus ornatus*, *Squatina* sp. A, *Taeniura meyeni* and *Urogymnus asperrimus* (Zhou and Griffiths 2008). Two of these species, *Carcharhinus albimarginatus* and *Squatina* sp. A, were immediately removed from the 'at risk' list as a result of gathering further distribution and biological information and consultation with scientific experts (see Appendix A). The Banded Wobbegong (*Orectolobus ornatus*) was subsequently removed from the list in 2009 due to expert opinion and its primary distribution outside the current fishing effort distribution. The Blotched Fantail Ray (*Taeniura meyeni*) was removed in 2011 due to its estimated fishing mortality lower than its maximum sustainable mortality and its known distribution mostly outside the current fishing area.

The remaining species, the Porcupine Ray (*Urogymnus asperrimus*) has only been recorded nine times within the NPF during the historical CSIRO scientific research and observer surveys, and seven times during the crew-member observer program (one interaction in each of 2013, 2015, 2017 and 2019 and three interactions in 2016). However, this species is also reported to occur widely across the Indo-Pacific region, including most of the northern Australian coast (Last and Stevens 2009; Fishbase 2014), and is more of a reef-associated species (Fishbase 2014) therefore most of the population is unlikely to be caught in prawn trawls.

With the introduction of TEDs in 2000, it is also likely that this large ray is effectively removed from the catch if it is encountered. The TEDs used in the current commercial fleet have led to a significant reduction in the overall catches of rays; >31% (Brewer et al. 2006). There were also high exclusion rates for large rays from nets with TEDs installed, more than 94% (Brewer et al. 2006). However, they concluded that the numbers of *Urogymnus asperrimus* caught were too low to make any TED-effect comparison. This species occurs at large sizes in the NPF, so we expect that they may have similar exclusion rates in TED-installed nets to the results seen for the *Dasyatis* (30 – 40% reduction), *Himantura* (42 – 100% reduction) and the *Pastinachus* species (98% reduction) when compared to nets without TEDs. The contention that TEDs allow this large ray to escape is supported by the results from this bycatch sustainability assessment with the only seven records of *Urogymnus asperrimus* caught during the crew-member observer program from 2003 to 2019. Importantly, the rays that were caught were landed in the try-net gear which do not have TEDs installed so they could not escape (in each case they were released alive).

Brewer et al. (2007) estimated from power calculations that the ability to detect a decline in large rays was highly dependent on crew-member observer effort levels. Annual effort levels required varied from 4,150 trawls (10 crew-member observers and one AFMA scientific observer) to detect a 50% decline in *Urogymnus asperrimus* over ten years to 15,644 trawls to detect a 25% decline in five years (Brewer et al. 2007). Since the start of their monitoring in 2006, there was insufficient catch data for this elasmobranch species to carry out a modelled catch rate trend analysis.

In summary, *Urogymnus asperrimus* has only been found seven times during the crew-member observer program, AFMA scientific observer program and NPF prawn population monitoring surveys from 2006 to 2019 and it would most likely be excluded by TEDs. We conclude that it is unlikely that this species is at risk from trawling by the NPF and *Urogymnus asperrimus* should be removed from the list of bycatch species being monitored.

7.2.6 Teleosts

Similar to the elasmobranchs, the 2006 Sustainability Assessment for Fishing Effects study for the teleosts (Zhou et al. 2009a) highlighted a number of species that were caught in very low numbers and only within commercially fished areas. Two of these species had estimated fishing mortality rates exceeding their maximum sustainable yield; *Dendrochirus brachypterus* and *Scorpaenopsis venosa*. These two species, along with *Hemirhamphus robustus, Lutjanus rufolineatus* and *Parascolopsis tosensis* also had their upper confidence interval (95%) of estimated mean fishing mortality rate exceed their minimum unsustainable fishing mortality rate (Zhou et al. 2009a). As a result of consensus at the February 2009 Bycatch subcommittee meeting, four other species were also included in the ‘at risk’ list; *Onigocia spinosa*, *Benthosema pterotum*, *Scomberoides commersonnianus* and *Sphyraena jello* (Zhou et al. 2009a; see Appendix A). Subsequently, all of these species, except for *Dendrochirus brachypterus* and *Scorpaenopsis venosa*, were removed from the ‘at risk’ list as a result of gathering further distribution information – most fish distributions were primarily outside the NPF region – and consultation with scientific experts (see Appendix A). The two remaining species were removed from the 'at risk' priority list at the end of 2011 due to the 2010 SAFE study that showed both had estimated fishing mortality lower than their maximum sustainable mortality.

In the same 2010 SAFE re-run, two more species were identified as 'at risk' and added to the priority list; *Lepidotrigla spinosa* and *Lepidotrigla* sp A. These two species have only been recorded during the historical CSIRO scientific research and observer surveys and appeared to have restricted distributions across the NPF. There is very limited data on these two species. They appear to be quite rare with little information on distribution within the NPF. They are difficulty to identify and there is a lack of suitable descriptive information available to assist in species identification onboard vessels. For these reasons, these two species have only been monitored during the NPF prawn population monitoring surveys since 2011.

Brewer et al. (2007) estimated from power calculations that the ability to detect a decline in these small bycatch species was highly dependent on crew-member observer effort levels. A 25% decline in these teleost species would only be detectable with at least 15 crew-member observers and five AFMA scientific observers collecting annual data. However, to detect a 50% decline over five or ten years, then only ten crew-member observers and one AFMA scientific observer was needed (Brewer et al. 2007).

To date, neither of these two species has been recorded during the three survey programs. It is recommended that they continue to be monitored by the NPF prawn population monitoring surveys until there is more distribution and catch information collected.

7.2.7 Invertebrates

There were six species of invertebrates that were included in the ‘at risk’ bycatch list in 2009; two squid, one cuttlefish, one prawn and two mantis shrimp species (see Appendix A). These were included as a result of consensus at the February 2009 Bycatch subcommittee meeting. Subsequently, most of these species, except for the prawn; *Solenocera australiana*, and two mantis shrimp species; *Dictyosquilla tuberculata* and *Harpiosquilla stephensoni*, were removed from the ‘at risk’ list as a result of gathering further distribution information – either distributions were primarily outside the NPF region or the species were not likely to be caught or retained in prawn trawls – and consultation with scientific experts (see Appendix A).

In 2012, the Marine Stewardship Council (MSC) certification process for the NPF acknowledged that *Solenocera australiana* has a widespread distribution across northern Australia, including in offshore areas, where no NPF trawling is likely to occur (Tonks et al. 2008; Fry et al. 2009). Although this prawn species is consistently caught in the NPF, it has shown a steady increase in crew-member observer catches from 2010 to 2013, it was concluded that it is not adversely susceptible to impacts from NPF trawling and was removed from the ‘at risk’ priority list in 2013 (MRAG 2012).

In contrast, there were no catch records available for either of the two mantis shrimp species from past CSIRO scientific research and observer surveys in the NPF from 1976 to 2005 (Fry et al. 2009). It was concluded that these two species were rare within the NPF. However, once the crew-member observer program, AFMA scientific observer program and NPF prawn population monitoring surveys began monitoring these two species in 2009, they were recorded quite regularly, occurring within many of the 10 'Regions' and across the 'Years' from 2009 to 2019. The consistent increases in crew-member observer, AFMA scientific observer and NPF prawn population monitoring survey catches for *Dictyosquilla tuberculata* from 2009 to 2019 indicate that this species is relatively common in the NPF. There has been a drop in catch rates in 2014, 2016 and 2017 from the crew-member observer program. However, highest catches of any year were seen in the following two years (2018 and 2019). Although the available catch records from the three survey programs indicate a species distribution mostly within the current commercial fishery effort distribution, its distribution is likely to be more widespread and our data suggest that this species is unlikely to be adversely impacted by trawling in the NPF. *Dictyosquilla tuberculata* should be removed from the list of bycatch species being monitored.

While similar increases in catch rates were seen for *Harpiosquilla stephensoni* during the crew-member observer program from 2009 to 2012, there was a marked drop in catch in 2013 which was also evident from the AFMA scientific observer and NPF prawn population monitoring data. Catch rates showed a steady increase in the crew-member observer program from 2014 to 2016 to the highest catch rates seen in any year. However, over the last three years catch rates for all three of the monitoring programs have declined to lowest levels seen in the last ten years. It is therefore recommended that *Harpiosquilla stephensoni* continue to be monitored, at least for the next three years, using both fishery-dependent and fishery-independent sampling, until further distribution and catch data is available to undertake a robust catch rate trend analysis.

7.3 Conclusion

In 2009, the first Bycatch Sustainability Assessment identified major performance and data quality issues in the crew-member observer program leading to the program being assessed as ineffective in providing reliable and accurate data for catch rate trend analysis of TEP and 'at risk' bycatch species. The data scope compromised the usefulness of the time-series data up to that point. As a consequence, the 2009 Bycatch Sustainability Assessment succeeded in assessing the catch rate trends of only three TEP and 'at risk' bycatch species. The crew-member observer data collected for the 2009 and 2010 banana and tiger prawn seasons continued to fail in its obligation to meet the minimum level of crew-member observer participation needed to detect a significant change in the catches of rare trawl bycatch of the NPF.

Since then, there has been a significant improvement in crew-member observer participation and data collection quality. The improvement coincided with the implementation of a payment scheme for crew-member observers given the extra workload needed to complete their additional tasks on board the vessels. This scheme rewarded those observers that fulfilled a requirement for the minimum proportion of trawls (or more) being surveyed by the end of the tiger prawn season. The coverage levels of the crew-member observer program over the last nine years have now exceeded the minimum requirements. The quality of catch data has also improved with greater than 80% of all TEP and 'at risk' bycatch species (excluding marine turtles) currently being photographed for species identifications by scientific staff.

The requirement for a minimum of one AFMA scientific observer for both the banana and tiger prawn seasons has been met. This data, along with the value-adding NPF prawn population monitoring surveys, were successfully used to validate crew-member observer data across eight of the ten NPF 'Regions'. This improvement has now led to the current Bycatch Sustainability Assessment providing statistical analysis of the catch rate trends for TEP and ‘at risk’ bycatch 14 species. It is anticipated that with continued crew-member participation and reliable data collection into the future, that this number of species can be further increased to detect significant changes in catch rates for many of the rarer TEP and 'at risk' bycatch species of the NPF. However, it is probable that for some of the rarest TEP and ‘at risk’ bycatch species, there will never be sufficient catch records collected to successfully carry out a robust analytical assessment of their sustainability to prawn trawling in the NPF region.

There are a number of scientific studies that show the marine turtles are already effectively removed from trawl nets by the installation of TEDs. There is evidence that these devices also significantly reduce catches of large elasmobranchs, such as the ‘at risk’ elasmobranch species. However, there is still progress to be made on the types and positions of BRDs in the codend. For example, the Popeye Fishbox BRD and Fisheye BRD, when set at about 70 meshes from the codend drawstring, can effectively remove sea snakes. This net configuration has shown to reduce up to 85% of sea snakes from the codend and increase their survival rates of being trawled. A range of new BRDs and at net positions closer to the codend drawstring were independently tested in the NPF (see

Lawrence and Fry 2016). Results were promising and if validated and adopted by the NPF fleet, improved escapement of sea snake could result.

The sparse data series for three sawfish species, their particular vulnerability to fishing net entanglement and their life history and critical ontogenetic habitat requirements renders them particularly at risk of severe population decline. As a consequence, any sawfish mortality as fishery bycatch will be crucial for their population sustainability. Avoiding sawfish bycatch within the NPF is critical. Hence, future innovation in net and configuration that reduces the entanglement of their rostrum should be a priority. Further changes to net design, such as a semi-rigid throat section just in front of the TED or smaller sized mesh in front of the TED including the TED flaps, might increase sawfish escapement through the TED by reducing the chance of their rostrums getting tangled in the meshes of the net. Currently, there is work focused on investigating within trawl behaviour of sawfishes and trawl gear modifications that may increase sawfish escapement from prawn trawls nets. However, these mitigation measures are not likely to produce significant declines in the catches for the other 'at risk' bycatch groups; the syngnathids, teleosts or invertebrates. Because these species are generally small in size and are benthic or at least benthic-associated species, their ability to escape through TEDs or top-mounted BRDs is limited.

Information from other published sources indicate that the 'at risk' elasmobranch and invertebrate species have wide-ranging distributions with much of their distribution outside of the current commercial trawl effort distribution (Fishbase 2014, http://ala.org.au). New information about species distributions has led to some 'at risk' bycatch species being removed from the priority monitoring list. Other species are being recorded in increasing numbers by the crew-member observer program, suggesting that initial abundance estimates have been underestimated and it is unlikely that these species are at risk from current trawling practices in the NPF. In 2018, the SAFE method was re-run for all elasmobranch, teleost and invertebrate species occurring within the NPF and the results reported here assisted in determining the risk to these species of being adversely impacted by trawling in the NPF. As a result of that risk assessment analysis, none of the elasmobranch, teleost and invertebrate species being monitored in the crew-member observer program were determined to be at risk to trawling in the NPF.

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9 Appendices

9.1 Appendix A: Summary of the risk assessment results following the outcomes of the highest level of assessment

Taxonomic Group	Scientific Name	Common Name	Role in Fishery	Highest Level of Assessment	Risk Score	Justifications for removal from the list	Source	Current Action (provided by Dave Brewer)	Comments	Priority species as at 2013
Chondrichthyan	*Orectolobus ornatus*	Banded wobbegong	DI	SAFE	Extreme High Risk	Distribution across eastern Australian coast, reef associated. Experts agreed species was not at risk as it did not occur in area of the fishery.	Bycatch Subcommittee 27th January 2009	Remove from list.	Expert opinion provided by Chondrichthyan Technical Working Group; May 2009. See Last and Stevens (2009) and Fishbase (2014)	✗
	Taeniura meyeni	Blotched Fantail Ray	DI	SAFE 2011	Low Risk	Results from Zhou (2011) SAFE 2011 deemed this species low risk to current NPF fishing.	Bycatch Subcommittee 27th January 2009.	Remove from list.		✗
	Urogymnus asperrimus	Porcupine Ray	DI	SAFE 2011	Precautionary medium risk	To remain on list and continue to be addressed as part of the current monitoring program.	Bycatch Subcommittee 27th January 2009.	To remain on list.	To be re-assessed in future CSIRO project – by December 2014.	✓
	Carcharhinus albimarginatus	Silvertip shark	DI	SAFE	Extreme High Risk	Widely distributed outside of NPF; species has extensive distribution across tropical Indo-Pacific coastal waters; including Indonesian waters. Caught once in the fishery.	Bycatch Subcommittee 27th January 2009.	Remove from list.	See Last and Stevens (2009) and Fishbase (2014).	✗
	Squatina albipunctata (Squatina sp. A)	Eastern angel shark	DI	SAFE	Extreme High Risk	Species only occurs along the east coast of QLD, and south to Lakes Entrance, Victoria.	Bycatch Subcommittee 27th January 2009.	Remove from list.	See Last and Stevens (2009).	✗
Teleost	*Dendrochirus brachypterus*	Dwarf Lionfish	DI	SAFE 2011	Low Risk	Results from Zhou (2011) SAFE 2011 deemed this species low risk to current NPF fishing.	Bycatch Subcommittee 27th January 2009.	Remove from list.		✗
	Scorpaenopsis venosa	Raggy Scorpion fish	DI	SAFE 2011	Low Risk	Results from Zhou (2011) SAFE 2011 deemed this species low risk to current NPF fishing.	Bycatch Subcommittee 27th January 2009.	Remove from list.		✗

Taxonomic Group	Scientific Name	Common Name	Role in Fishery	Highest Level of Assessment	Risk Score	Justifications for removal from the list	Source	Current Action (provided by Dave Brewer)	Comments	Priority species as at 2013
	Parascolopsis tosensis	Tosa dwarf monocle bream	DI	SAFE	Precautionary Extreme High Risk	Distribution primarily outside the NPF; Western Pacific: Indonesia, Japan, Malaysia, Philippines, Taiwan, China and East Timor. Considered not at risk	Bycatch Subcommittee 27th January 2009.	Remove from list.	See Fishbase (2014) and Russell (1990).	✘
	Hemiramphus robustus	Three-by-two garfish	DI	SAFE	Precautionary Extreme High Risk	Species primarily occupies coastal regions and estuaries. Pelagic species and slender body morphology result in extremely low selectivity by trawls. Highly unlikely to be at risk by NPF	Bycatch Subcommittee 27th January 2009.	Remove from list.	Expert opinion provided by Shane Griffiths; July 2009.	✘
	Lutjanus rufolineatus	Yellowlined snapper	DI	SAFE	Precautionary Extreme High Risk	Reef associated, distribution primarily outside the NPF; Indo-West Pacific: Maldives, Japan to Indonesia and northern Australia east to Samoa and Tonga – but populations within the Gulf may be at risk	Bycatch Subcommittee 27th January 2009.	Remove from list.	See Fishbase (2014) and Allen (1995)	✘
	Onigocia spinosa	Midget flathead	DI	SAFE	Precautionary high	Distribution primarily outside the NPF; Western Pacific: Japan, South China Sea, Philippines, northwest shelf of Australia through Timor and Arafura Sea – but populations within the Gulf may be at risk	Bycatch Subcommittee 27th January 2009.	Remove from list.	See Fishbase (2014) and Sainsbury et al. (1985).	✘

Taxonomic Group	Scientific Name	Common Name	Role in Fishery	Highest Level of Assessment	Risk Score	Justifications for removal from the list	Source	Current Action (provided by Dave Brewer)	Comments	Priority species as at 2013
	Benthosema pterotum	Skinnycheek lanternfish	DI	SAFE	Precautionary high	Deepwater species; 10-300m, Bathypelagic species and small body morphology result in extremely low selectivity by trawls. Highly unlikely to be at risk by NPF. Extensive distribution primarily outside the NPF; Indo-west Pacific: Arabian Sea to West Pacific, southeast Atlantic, possibly northwest Pacific and eastern Indian Ocean – but populations within the Gulf may be at risk	Bycatch Subcommittee 27th January 2009.	Remove from list.	See Fishbase (2014) and Hulley (1986).	✗
	Scomberoides commersonnianus	Talang queenfish	DI	SAFE	Precautionary high	Species has wide distribution outside the Gulf of Carpentaria, occupying coastal regions and estuaries across southern hemisphere tropical waters (very common species). Members confident that species is not at high risk. Pelagic distribution result in extremely low selectivity by trawls. Highly unlikely to be at risk by NPF	Bycatch Subcommittee 27th January 2009.	Remove from list.	Expert opinion provided by Shane Griffiths; July 2009. See Griffiths et al. (2006b).	✗
	Sphyraena jello	Giant seapike	DI	SAFE	Precautionary High	Pelagic species with a wide distribution outside NPF. Most common around reefs. Extremely low selectivity by trawls, rarely caught in the fishery. Highly unlikely to be at risk by NPF	Bycatch Subcommittee 27th January 2009.	Remove from list.	Expert opinion provided by Shane Griffiths; July 2009.	✗

Taxonomic Group	Scientific Name	Common Name	Role in Fishery	Highest Level of Assessment	Risk Score	Justifications for removal from the list	Source	Current Action (provided by Dave Brewer)	Comments	Priority species as at 2013
	Ariosoma anago	Silvery Conger	DI	SAFE 2011	Precautionary medium risk	Distribution widespread in the Indo-West Pacific: Australia, China, India, Indonesia, Japan, Korea, Malaysia, New Caledonia, Philippines, Sri Lanka, Taiwan, Vietnam. In Australia likely to occur along the north, east and west coasts. Primarily outside the NPF. Habitat: coastal sandy and muddy bottoms. Considered not at risk.	SAFE 2011: Zhou (2011)	Remove from list.	See: www.Fishbase.org (2014) Rees (1999) CSIRO Data Map (2011)	✘
	Conger cinereus	Longfin African Conger	DI	SAFE 2011	Precautionary medium risk	Distribution widespread in Indo-Pacific region: Red Sea and East Africa to the Marquesan and Easter islands, north to southern Japan and the Ogasawara Islands, south to northern Australia and Lord Howe Island. Primarily outside the NPF. Habitat: common on reef flats and seagrass beds of shallow lagoons but ranges to depths of 80 m on outer reef slopes. Trawl mortality considered to be low. Considered not at risk.	SAFE 2011: Zhou (2011)	Remove from list.	See: www.Fishbase.org (2014) Myers (1991) Fricke (1999) CSIRO Data Map (2011)	✘

Taxonomic Group	Scientific Name	Common Name	Role in Fishery	Highest Level of Assessment	Risk Score	Justifications for removal from the list	Source	Current Action (provided by Dave Brewer)	Comments	Priority species as at 2013
	Epinephelus malabaricus	Malabar Grouper	DI	SAFE 2011	Precautionary medium risk	Distribution Indo-Pacific: Red Sea and East Africa to Tonga, north to Japan, south to Australia. Primarily outside the NPF. Habitat: coral and rocky reefs, tide pools, estuaries, mangrove swamps and sandy or mud bottom from shore to depths of 150m. Considered not at risk.	SAFE 2011: Zhou (2011)	Remove from list.	See: www.Fishbase.org (2014) Heemstra and Randall (1993) CSIRO Data Map (2011)	✘
	Lepidotrigla sp.	Triglidae : Gurnards	DI	SAFE 2011	Precautionary medium risk	Distribution: wide ranging in Pacific, Indian Oceans, species dependent	SAFE 2011: Zhou (2011)	N/A	See: www.Fishbase.org (2014) CSIRO Data Map (2011)	N/A
	Pterygotrigla hemisticta	Blackspotted Gurnard	DI	SAFE 2011	Precautionary medium risk	Distribution: western Pacific, wide distribution from Japan to Australia.	SAFE 2011: Zhou (2011)	Remove from list.	See: www.Fishbase.org (2014) CSIRO Data Map (2011)	✘
	Lepidotrigla sp C	Gurnard	DI	SAFE 2011	Precautionary medium risk	Distribution: includes outside of current NPF fishing region, wide ranging in Gulf of Carpentaria	SAFE 2011: Zhou (2011)	Remove from list.	See: CSIRO Data Map (2011)	✘
	Lepidotrigla spiloptera	Spotwing Gurnard	DI	SAFE 2011	Precautionary medium risk	Distribution: Indo-West Pacific – Red Sea, Somalia, Zanzibar, Bay of Bengal, Arafura Sea, Philippines, including outside of current NPF fishing region, wide ranging in Gulf of Carpentaria	SAFE 2011: Zhou (2011)	Remove from list.	See: www.Fishbase.org (2014) CSIRO Data Map (2011)	✘
	Lepidotrigla kishinoyi	Gurnard	DI	SAFE 2011	Precautionary medium risk	Distribution: Northwest Pacific – southern Japan, east China Sea, occurs mostly offshore of current NPF fishing region	SAFE 2011: Zhou (2011)	Remove from list.	See: www.Fishbase.org (2014) CSIRO Data Map (2011)	✘

Taxonomic Group	Scientific Name	Common Name	Role in Fishery	Highest Level of Assessment	Risk Score	Justifications for removal from the list	Source	Current Action (provided by Dave Brewer)	Comments	Priority species as at 2013
	Lepidotrigla sp 2	Gurnard	DI	SAFE 2011	Precautionary medium risk	Distribution: including outside of current NPF fishing region, wide ranging in Gulf of Carpentaria	SAFE 2011: Zhou (2011)	Remove from list.	See: CSIRO Data Map (2011)	✗
	Lepidotrigla spinosa	Shortfin Gurnard	DI	SAFE 2011	Precautionary medium risk	Distribution: eastern Indian Ocean – Australia; data poor	SAFE 2011: Zhou (2011)	To remain on list.	See: www.Fishbase.org (2014) CSIRO Data Map (2011)	✓
	Lepidotrigla argus	Long-finned Gurnard	DI	SAFE 2011	Precautionary medium risk	Distribution: Indo-West Pacific – northwestern Australia, Papua New Guinea, occurs mostly offshore of current NPF fishing region	SAFE 2011: Zhou (2011)	Remove from list.	See: www.Fishbase.org (2014) CSIRO Data Map (2011)	✗
	Lepidotrigla sp A	Gurnard	DI	SAFE 2011	Precautionary medium risk	No data available	SAFE 2011: Zhou (2011)	To remain on list.	See: CSIRO Data Map (2011)	✓
	Leptojulis cyanopleura	Shoulder-spot Wrasse	DI	SAFE 2011	Precautionary medium risk	Distribution Indo-West Pacific: Gulf of Oman to the Philippines and Australia. Primarily outside the NPF. Habitat: clear coastal slopes to outer reef lagoons on open rubble patches or rocky bottom, reef associated. Considered not at risk.	SAFE 2011: Zhou (2011)	Remove from list.	See: www.Fishbase.org (2014) Randall et al. (1990) Kuiter and Tonozuka (2001) CSIRO Data Map (2011)	✗

Taxonomic Group	Scientific Name	Common Name	Role in Fishery	Highest Level of Assessment	Risk Score	Justifications for removal from the list	Source	Current Action (provided by Dave Brewer)	Comments	Priority species as at 2013
	Sphyraena qenie	Blackfin Barracuda	DI	SAFE 2011	Precautionary medium risk	Distribution Indo-Pacific: Red Sea and East Africa to the central Indian Ocean and French Polynesia. Eastern Pacific: Mexico and Panama. Primarily outside the NPF. Habitat: Reef associated, near current-swept lagoon and seaward reefs, probably disperses at night to feed. Fast pelagic species and slender body morphology result in extremely low selectivity by trawls. Highly unlikely to be at risk by NPF.	SAFE 2011: Zhou (2011)	Remove from list.	See: www.Fishbase.org (2014) Senou (2001) Lieske and Myers (1994) Myers (1991) CSIRO Data Map (2011)	✗
Invertebrate	*Euprymna hoylei*	Bobtail Squid	Discard	Level 2 PSA	High	Extremely rare in trawl catches. David Milton examined family level assessment and they were never caught. Reported around the Philippines and northwestern Australia (max 3-4 cm ML). Unlikely to be retained in prawn trawl nets.	Bycatch Subcommittee 27th January 2009.	Remove from list.	Expert opinion provided by Malcolm Dunning and David Milton; May 2009.	✗
	Metasepia pfefferi	Flamboyant cuttlefish	Discard	Level 2 PSA	High	Widespread but nowhere abundant in trawl catches throughout northern Australian waters to at least Moreton Bay, on the east coast. Occurs from shallow coral and rocky reefal areas to mid shelf depths. This is a small species (max ~10 cm ML) that probably only lives for a few months.	Bycatch Subcommittee 27th January 2009.	Remove from list.	Expert opinion provided by Malcolm Dunning; May 2009.	✗

Taxonomic Group	Scientific Name	Common Name	Role in Fishery	Highest Level of Assessment	Risk Score	Justifications for removal from the list	Source	Current Action (provided by Dave Brewer)	Comments	Priority species as at 2013
	Solenocera australiana	Coral Prawn	BP	Level 2 PSA	High	Widespread distribution across all of NPF and outside.	Bycatch Subcommittee 27th January 2009; MSC Certification Process (2012)	Remove from list.	Expert opinion provided by Fry et al. 2009.	✗
	Photololigo sp. 3 and sp 4 of Yeatman (1993)	broad squid and slender squid	BP	Level 2 PSA	High	Major squid species in trawl byproduct. Species are wide spread across northern Australia (central NSW to Shark Bay WA); catchability in prawn trawls lower at night when squid move up into the water column. However, egg clusters and adults highly susceptible to trawling in spawning grounds (Dunning et al. (2000). Current catch at acceptable biological catch limit; see Milton et al. 2009b: Byproduct Assessment (FRDC 2006/008).	Bycatch Subcommittee 27th January 2009.	Remove from list.	Expert opinion provided by Malcolm Dunning; May 2009. Expert opinion provided by Milton. See Byproduct Assessment (FRDC 2006/008). See Dunning et al. (2000).	✗
	Dictyosquilla tuberculata	mantis shrimp	BP	Level 2 PSA	High	To remain on list and continue to be addressed as part of the current monitoring program.	Bycatch Subcommittee 27th January 2009.	No new information. To remain on list.	To be re-assessed in current CSIRO project – by December 2009.	✓
	Harpiosquilla stephensoni	mantis shrimp	BP	Level 2 PSA	High	To remain on list and continue to be addressed as part of the current monitoring program.	Bycatch Subcommittee 27th January 2009.	No new information. To remain on list.	To be re-assessed in current CSIRO project – by December 2009.	✓
Marine Reptile	*Hydrophis belcheri*	a sea snake	TEP	Level 2 PSA	High	One individual found in northern Papua New Guinea and not found in Australia.	Bycatch Subcommittee 27th January 2009.	Remove from list.	Expert opinion provided by David Milton; May 2009. See Cogger (1992).	✗

Taxonomic Group	Scientific Name	Common Name	Role in Fishery	Highest Level of Assessment	Risk Score	Justifications for removal from the list	Source	Current Action (provided by Dave Brewer)	Comments	Priority species as at 2013
	Parahydrophis mertoni	Northern mangrove sea snake	TEP	Level 2 PSA	High (Tiger only)	Found in Mudflats and mangroves and not in depth zone of NPF.	Bycatch Subcommittee 27th January 2009.	Remove from list.	Expert opinion provided by David Milton; May 2009. See Cogger (1992)	✘
	Hydrophis ornatus	sea snake	TEP	SAFE	Fished less than maximum sustainable mortality (MSM)	Trawl mortality was below reference points. Remove from list as per Milton (2001) sea snake assessment (FRDC 2005/051).	As per Milton sea snake assessment (FRDC 2005/051)	Remove from list.	Expert opinion provided by David Milton; May 2009. Milton (2001) see Sea Snake Assessment (FRDC 2005/051).	✘
	Hydrophis pacificus	Large-headed sea snake	TEP	SAFE	Fished less than maximum sustainable mortality (MSM)	Trawl mortality was below reference points. Remove from list as per Milton Sea Snake Assessment (FRDC 2005/051).	As per Milton sea snake assessment (FRDC 2005/051)	Remove from list.	Expert opinion provided by David Milton; May 2009. See Sea snake Assessment (FRDC 2005/051).	✘
	Hydrophis vorisi	A sea snake	TEP	Level 2 PSA	High (Banana only)	Found in eastern Torres Strait only and not in NPF.	Bycatch Subcommittee 27th January 2009.	Remove from list.	Expert opinion provided by David Milton; May 2009. See Cogger (1992).	✘
	Ephalophis greyi	North-western Mangrove sea snake	TEP	Level 2 PSA	High	Found in mudflats and mangroves along WA coast and not in depth zone or distributed within NPF.	Bycatch Subcommittee 27th January 2009.	Remove from list.	Expert opinion provided by David Milton; May 2009. See Cogger (1992).	✘
	Hydrophis coggeri	Slender-necked sea snake	TEP	Level 2 PSA	High	Distribution outside NPF.	Bycatch Subcommittee 27th January 2009.	Remove from list.	Expert opinion provided by David Milton; May 2009. See Cogger (1992).	✘

* In cases where species have known widespread distributions primarily outside the NPF, the species is deemed not at risk. However, potential existence of sub-population/genetically distinct local populations, and how to manage this issue will need to be discussed by the bycatch subcommittee.

9.2 Appendix B: First CSIRO data analysis workshop

Bycatch sustainability project 2008 – First internal workshop to assess methods for analysing bycatch data.

23-10-08

1. David Brewer (CMAR; Project Principal Investigator)
2. Dr. Bill Venables (CMIS; Senior Scientist)
3. Dr. You-Gan Wang (CMIS; Senior Scientist)
4. Min Zhu (CMIS; Project Scientist)
5. Dr. Trevor Hutton (CMAR; Fisheries Analyst)

Workshop objective: To present the available data to key CMAR and CMIS staff and to discuss possible approaches to analyse the data and potential problems that may arise.

Brief background

Fishery objective under EPBC – Demonstrate sustainability for all species impacted

Project objectives

1. To develop effective and acceptable methods for assessing annual sustainability by NPF bycatch, in partnership with the AFMA ERA/ERM process, using risk assessment techniques and other innovative analytical techniques.
2. To deliver an annual sustainability assessment report for selected NPF bycatch species
3. To recommend and justify crew-member and scientific observer coverage levels to AFMA and NORMAC for subsequent data collection years

(Assess whether the observer program is capable of delivering on it's management objectives)

Two approaches for informing management decisions

1. Periodic risk assessments
    a. To focus monitoring program
    b. Still needs guidelines for assessing trends in catches – e.g. limit reference points
2. Develop an assessment using monitoring data (and past, patchy catch data)
3. Other options – use alternative management strategies

Issues

1. Data for many species is sparse
2. No baselines
3. Little known about viable population sizes
4. Some species impacted by other activities

E.g. sawfishes also caught in the coastal gill net fisheries and Indonesian fisheries

Project approach

1. Assess value of crew-member observer data
    a. Validation against scientific observer data
    b. Assess value of observer programs and current effort levels
2. Develop an acceptable method for assessing sustainability
    a. May involve developing reference points (1st time for bycatch)
3. Deliver the first annual sustainability assessment for bycatch species

Broader management goal – to implement this approach in other Australian fisheries (SEF, GAB)

Workshop outcomes

1. The data looks 'disturbing' due to low no's for many species as well as other anomalies
2. There may be issues in fishing power over time that may need to be taken into account

Data preparation and analyses ideas

1. Need to look at the disaggregated data to see where and when species occur, using reliable data sets, so we can set up 'expected' catch rate scenarios
2. Include mapping in space and time (a baysian prior)
3. Build a Poisson model using this data as a 'hidden predictor'
4. Part of the analyses will be to look at how systematic differences between crew-member observers and scientific observers might be
5. Trend analyses may involve looking at comparing (parallel) curves, on a log scale.

Actions

1. Talk to Ross Darnell: RE accessing some of Bill's, You-Gan's and/or Min's time (Dave B)
2. Get missing scientific observer and crew-member observer data from AFMA (Gary/Margaret)

9.3 Appendix C: Second CSIRO data analysis workshop

Bycatch sustainability project 2008 – Second internal workshop to assess methods for analysing bycatch data.

20th May 2009: 1000 – 1230

1. David Brewer (CMAR; Project Principal Investigator)
2. Gary Fry (CMAR; Project Co-investigator)
3. Dr. Bill Venables (CMIS; Senior Scientist)
4. Dr. Ross Darnell (CMIS; Senior Scientist)
5. Dr. Emma Lawrence (CMIS; Project Scientist)

Workshop objective: To assess and agree upon the best approach towards a sustainability assessment given the available data from crew-member observer, scientific observer programs and fishery-independent surveys.

Workshop Agenda and Outcomes

1. ***CMAR and CMIS attendance***
   a. Two key CMAR staff attended the workshop to provide project information on project background, desired project outcomes and data set issues.
   b. Three CMIS staff attended the workshop to provide expert advice on the most appropriate data analysis for each of the animal groups. This included one CMIS staff from Acton (ACT), who is responsible for the data analysis.

2. ***Status of current data sets***
   a. All catch and biological data currently available were provided to CMIS staff prior to the workshop.
   b. The data set is not yet complete. CSIRO is waiting on the following before data analysis can be started:
      i. Crew-member observer data for the 2006 tiger prawn season to be provided by AFMA.
      ii. All animals photographed by crew-member observers during the 2006, 2007 and 2008 tiger prawn seasons require species identifications.

3. ***Data sets available and data issues***
   a. *NPF Prawn Population Monitoring Data Set*
      i. Most robust data set; time series from 2002 to 2009; standardised with gear, time, location, accurate species identifications.
      ii. Collected 'out of season'.
      iii. Does not include all species listed as 'at risk' (see Table 2).
      iv. Will be used to match to the crew-member observer data sets on a spatial and temporal scale (on the NPF banana prawn stock regional level) and then used to validate the crew-member observer data sets with respect to catch rates and species identifications.

   b. *NPF Crew-member Observer Data Set:*
      i. Collected within commercial season.
      ii. Possibly unbalanced in its spatial coverage of NPF; the data set will be compared to the entire NPF commercial effort distribution to determine level of effective coverage.

   iii. Only limited number of crew-member observer participation and declining annually.
   iv. All TEP and 'at risk' species recorded; however not all groups were recorded throughout full time series (2003-2009).
   v. Possible inaccuracies in species identifications and data recording.

c. *AFMA scientific observer data set:*
   i. Limited coverage on spatial and temporal scale in the NPF.
   ii. Has direct validation of crew-member observer data sets where AFMA scientific and crew-member observers overlap.
   iii. Only subset of TEP and 'at risk' animal groups recorded.

d. *CSIRO scientific research and observer data set:*
   i. Accurate species identifications of all TEP and 'at risk' animal groups recorded.
   ii. Collected 'out of season' and generally not spatially comparable with current NPF commercial fishery effort distribution.
   iii. Majority of data collected before crew-member observers and NPF prawn population monitoring time.

4. ***Appropriate methods of data analysis:***
   a. Issue of scarcity of data records for most species.
   b. Issue of available data differs in collection methodology, fishing gear used, time and space, initial analyses will need to be performed to determine the potential use of each of the data sets, rather than immediately pooling the data and analysing it as a whole.
   c. Where sufficient data is available for each animal group, a Poisson log-linear generalized linear model will be initially applied to the NPF fishery-independent monitoring survey and crew-member observer data sets separately.
   d. Comparisons on catch rates between these two data sets will be made to check for consistency. If the NPF monitoring and crew-member observer data is not demonstrably inconsistent the two data sets, including all the crew-member observer data, the data sets will be combined to produce more spatially comprehensive analyses.
   e. This data set matching on spatial and temporal scales procedure and comparisons with the NPF prawn population monitoring data sets will also be carried out on the AFMA scientific observer and CSIRO scientific research and observer data sets to check for compatibility and possible inclusions for the final analysis.
   f. For the rarest species, above analysis procedures will not be suitable; therefore the quantitative risk assessment (Zhou and Griffiths 2008) may be used to assess their current risk to trawling given the changes in NPF commercial effort; contractions in fleet size and spatial fishing distributions.

5. ***Action Items:***
   a. Gary F. to send Emma L. the complete NPF prawn population monitoring data set to begin preliminary analysis.
   b. Gary F. to follow up request with AFMA for outstanding crew-member observer data and species identifications.
   c. Following this, Gary F. to send the complete crew-member observer, AFMA scientific observer and CSIRO scientific research and observer data sets to Emma L. for matching and comparison analysis for possible data pooling before final analysis.

Meeting closed: 1230