


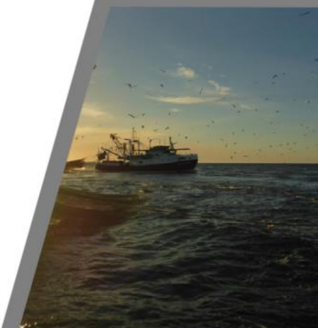


Investigating Potential for Fishing Gear, Technology and Management Measures to Reduce Sawfish and Sea Snake Interactions in Australia's Northern Prawn Fishery (NPF)

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1. Acknowledgements

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Thanks also to Gary Fry and Emma Lawrence, CSIRO for the considerable amount of work undertaken in reviewing the relevant NPF databases and undertaking the Generalised Linear Model (GLM) analyses of both sawfish and sea snake interactions in the NPF. (Appendix 1 - *Analyses of sawfish and sea snake interactions rates (2010 – 2022) in Australia's Northern Prawn Fishery (NPF*).

A special thanks goes to NPF skippers and fleet masters for their time and contributions of information which enabled the development of the NPF Sawfish, Sea Snake and Fishing Gear database. Their ongoing support for the NPF Bycatch Strategy and research projects aimed at identifying and mitigating interactions with bycatch and Endangered, Threatened and Protected species (ETPs) is greatly appreciated.

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NPFI expresses particular appreciation to the Marine Stewardship Council (MSC) for supporting and funding this project through the MSC Ocean Stewardship Fund.

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4. Project Summary

This project seeks to a) assist the fishery to identify low-cost solutions to reduce sawfish interactions in the NPF *and* b) identify and quantify the impacts (including any percentage reductions) of the adoption of the Tom's Fisheye Bycatch Reduction Device (BRD) on sea snake interactions in the NPF.

The project has:

- collected and collated information on fishing gear/mesh types in use in the NPF
- undertaken a desktop analysis of NPF commercial catch data, Crew Member Observer data (CMO), AFMA Scientific Observer (SO) data and relevant reports to identify differences in sawfish interaction rates between individual vessels, fishing grounds and fishing times/seasons
- investigated the availability of alternative technology (eg underwater lights) that may potentially reduce sawfish interactions for trialling in the NPF in 2023/24

The project delivered comprehensive baselines data on:

- differences in sawfish interaction rates between individual fishing vessels, discrete fishing areas and fishing seasons in the NPF
- differences in sawfish interaction rates between various trawl gear/mesh types in use in the fishery
- sea snake interaction rates pre and post the adoption of the Tom's Fisheye BRD at both individual operator and fleet level

The project delivered comprehensive and scientifically robust designs for at-sea gear/technology trials aimed at identifying potential mitigation options. The trial designs included the scope, fishing methods, and data collection, collation and analysis methodology for the sea trials undertaken in 2023 and 2024 as part of a separately funded project.

The project identified and quantified the impact of the Tom's Fisheye BRD on sea snake interactions, including percentage reductions in sea snake interactions between fishing seasons/years since the fleet-wide adoption of the Toms Fisheye in the NPF in 2020. Available results from trials/projects in other prawn fisheries are also referenced in this report.

The outputs from this project - coupled with the results of sea trials undertaken as part of the separately funded project – will inform potential mitigation measures to reduce sawfish interactions in the NPF and will contribute to addressing the 2022 NPF ADCR condition relating to ETP Outcome 1 (sawfish) and the NPF's current EPBC Act WTO conditions relating to sawfish and sea snakes.

Project outputs will also have relevance to other MSC certified Australian tropical prawn trawl fisheries (eg Exmouth Gulf, Shark Bay), and non-certified Australian and international tropical prawn trawl fisheries where sawfish and/or sea snake interactions occur.

5. Introduction

The Northern Prawn Fishery (NPF) - Australia's largest and most valuable prawn fishery - was Australia's first tropical prawn fishery to be MSC certified (2012). As a tropical multi-species trawl fishery, the fishery interactions with a broad range of bycatch species. The NPF has been pro- active in addressing the impacts of fishing on the marine eco-system, including bycatch. The NPF operates under a co-management framework underpinned by strong collaboration between industry, fishery managers and researchers.

Interactions with sawfish and sea snakes ETP species are of particular concern in the NPF. Identifying mitigation measures to reduce interactions with these species is an extremely high priority for the fishery as sawfishes are currently one of the most globally endangered marine groups of animals and northern Australia is one of their last habitats where populations still occur. There are four species of sawfishes occurring in northern Australia with all four species being protected under the EPBC Act. Three of these species are listed as vulnerable and the fourth as migratory. The NPF interacts with various numbers of sawfish each year, primarily Narrow sawfish (*Anoxypristis cuspidata*). The impacts of fishing on sawfish populations is largely unknown, however sawfish are known to have a poor ability to escape mesh nets due to their rostrums being snagged on the meshing of trawl gears. Since bycatch reduction devices (BRDs) currently used in trawl fisheries are not effective at reducing sawfish catches, new methods to minimise sawfish bycatch are needed.

Anecdotal reports from NPF operators indicate that there is potential to reduce sawfish interactions through modifications to fishing gear however there is currently no robust scientifically validated data available to support this. Funding will support activities aimed at filling current data gaps, developing a robust design for sea trials of potential gear/technology mitigation solutions to reduce sawfish interactions, provide data to inform future management decisions and research investment on sawfish and meet MSC condition 1.

Sea snakes are ETP species found throughout the NPF – the fishery experiences high levels of sea snake interactions each year. Whilst there are currently no NPF MSC conditions relating to sea snakes, EPBC WTO conditions are in place for the fishery which must be met by 2024. Anecdotal evidence indicates the fishery-wide adoption of the Tom's Fisheye BRD in 2020 has significantly reduced sea snake interactions, however no analysis of the available data has been undertaken to support this claim. Funding will enable analysis of the available data and quantification of the impacts of the Toms Fisheye BRD on sea snake interactions to inform future management decisions and/or research investment on sea snakes.

6. Aims and Objectives

The overall aims of the project are to assist industry members operating in the MSC-certified Northern Prawn Fishery to identify potential practical, low-cost measures to reduce sawfish interactions and to quantify the impacts of the Tom's Fisheye BRD on sea snake interactions in NPF fishing operations.

A key objective of the project is to ensure that the condition in the current draft ACDR relating to ETP Outcome PI (sawfish) can be met within the next MSC certification period ie

Condition 1: *By the fourth annual audit demonstrate that direct effects of the UoAs are highly likely to not hinder recovery of sawfish species*. A related objective is to respond to the NPF's current EPBC WTO conditions pertaining to sawfish and sea snakes.

7. Components and Methods

The project is divided into 5 components to support the overall aims and objectives of the project as follows:

Component 1: Gain a baseline understanding of the various trawl gear/mesh types currently being used by individual fishing vessels in the Northern Prawn Fishery

Component 2: Gain a baseline understanding of the differences in sawfish interaction rates in the Northern Prawn Fishery between individual vessels, discrete fishing areas and fishing seasons

Component 3: Identify and purchase equipment/ technology (eg underwater lights) suitable for use in NPF operational conditions that has potential to reduce sawfish interactions between sawfish

Component 4: Identify and quantify the impact of the Tom's Fisheye BRD on sea snake interactions (including any percentage reductions) between fishing seasons/years since the adoption of the Tom's Fisheye in 2020

Component 5: Develop a robust trial design including scope, fishing methods, and data collection, collation and analysis methodology to be applied to sea trials aimed at testing various trawl gears and other equipment/technology (eg underwater lights) with potential to reduce sawfish interactions (Note: funding for the sea trials was not being sought from MSC)

The following methods were employed to deliver each component:

Component 1

1. Conduct interviews with NPF operators and review existing records to obtain information/data on gear/mesh types in use in the NPF and gear/mesh types are currently being voluntarily trialled as a sawfish mitigation measure

2. Collate and analyse the data to identify differences in sawfish interaction rates by individual vessels and gear/mesh types

3. Based on the outputs of the data analysis, provide advice to NPFI and the project team on the scope of gear/mesh types which should form the basis of the proposed sea trials to be undertaken in 2023/24

Component 2:

1. Collate available data from NPF fishery-dependant logbooks, the NPF Crew Member Observer Program and the NPF Scientific Observer program for the period from 2012 to 2022 inclusive.

2. Conduct an analysis of the collated data for the period 2012 to 2022 inclusive to determine differences in sawfish interaction rates by individual vessel, by fishing areas and by fishing years/seasons

3. Compile the results in report for dissemination to NPFI members and AFMA management, ensuring that the report complies with AFMA's confidentiality policy and protects the identify of individual vessels and individual fishing companies.

Component 3:

1. Undertake a desk top study of available equipment/technology (eg underwater lights) with potential to reduce sawfish interactions

2. Identify and interview relevant supplies who invest/develop and/or sell technological equipment that has the potential to reduce sawfish interactions to identify the appropriate equipment for trial

3. Provide the scope of equipment/technology options (based on likelihood of success) that could be trialled at sea to NPFI and the Project Team for consideration/agreement
4. Purchase the equipment as agreed by NPFI and make available for the 2023/24 sea trials

Component 4:

1. Collate available data of sea snake interactions in NPF commercial fishing operations for the period from 2015 to 2022 inclusive

2. Separate the data into the years 'pre and post adoption' (ie from 2015 – 2019 inclusive and 2020 to 2022 inclusive)

3. Conduct an analysis of the data to identify the impact of the Tom's Fisheye BRD on sea snake interactions of individual vessels and between fishing seasons/years

4. Quantify any percentage reductions of individual vessels and between fishing seasons/years since the adoption of the Tom's Fisheye in 2020

5. Undertake a literature review of available data on the effectiveness of BRDs to reduce sea snake interactions in other Australian prawn trawl fisheries and compare those results with the results pertaining to the Tom's Fisheye BRD

6. Compile the results of these analyses in a report for dissemination to NPFI members and AFMA management, ensuring that the report complies with AFMA's confidentiality policy and protects the identify of individual vessels and individual fishing companies

Component 5:

1. Liaise with NPFI, AFMA and CSIRO to identify the required components/methodologies to inform the design plan for testing various trawl gear/mesh types and other

equipment/technology (eg underwater lights) with potential to reduce sawfish interactions in a scientifically robust way

2. Develop and document the scope, methods and protocols for fishing activities and data collection, collation and analysis from the trials

3. Seek approval from NPFI, AFMA and CSIRO for the design plan

4. Liaise with NPFI on the appropriate timing and process to be conducted to identify suitable NPF vessels to conduct the trials

8. Activities and Results

The activities and results for each component are reported as follows:

8.1 Component 1: Gain a baseline understanding of the various trawl gear/mesh types currently being used by individual fishing vessels in the Northern Prawn Fishery

NPFI conducted interviews with NPF operators and reviewed existing records and anecdotal information information/data on gear/mesh types used in the NPF and gear/mesh types that are currently being voluntarily trialled as a sawfish mitigation measure.

The output from this activity was a baseline of the suite of trawl gear/net and mesh types being used by individual fishing vessels in the Northern Prawn Fishery **(Table 1**).

Table 1: Industry timeline of grey mesh TED flap adoption. Note: - all vessels were using quad gear

company	year	description	comments
A	2020	Vessels in this fleet were operating one net with grey mesh TED flaps and 3 nets with black ruby material TED mesh flaps (season 2).	Years 2020-2021: it was difficult to know exactly what vessels were using what net mesh type as no accurate records were kept.
A	2021	Vessels in this fleet started using 2 nets grey mesh TED flaps and 2 nets with black ruby mesh TED flaps. In the 2021 tiger prawn season (season 2), all vessels had transitioned to using 2 nets with grey mesh TED flats on one side and 2 nets with black mesh TED flaps on the other side	
A	2022-23	All vessels in this fleet using grey mesh ted flaps on all nets, except for two vessels which were undertaking formal sea trials as part of a separate research project. The two trial vessels used 2 grey mesh TED flaps and 2 black mesh TED flaps)	
B	2018-19	In either 2018 or 2019 all vessels in this fleet started using grey meshes on the TED flaps	
C	2021-2022	Vessel using black mesh TED flaps	Used black until 2022 season 1
C	2022	Swapped the black mesh TED flaps on all nets to grey mesh TED flaps on all nets	Changed to grey mesh in 2022 season 2

NPFI collated and developed a database of all NPF industry logbook data from 2010 to 2022. The NPF Sawfish, Sea Snake and Fishing Gear database amalgamates information on various fishing net materials, innovative Bycatch Reduction Devices (BRDs) and Turtle Excluder Device (TED) orientations employed in the fishery (where data is available).

A desktop analysis of the different types of net mesh being used in the NPF was undertaken to investigate quantifiable differences in sawfish interaction rates following the adoption of new gear types within the fishery. Recent feedback from skippers and fishing companies has highlighted a potential reduction in sawfish entanglements with the use of grey Magna mesh, a sturdier material employed in the TED flaps (**Figure 1**). To assess any differences, the introduction of grey magna mesh into the fishery was systematically categorised and incorporated into the NPF Sawfish, Sea Snake and Fishing Gear database to provide for comparison with vessels using the original black mesh TED flaps. The database also amalgamated individual vessel TED orientations and Bycatch Reduction Devices (BRD) used throughout fishing years and seasons.

Figure 1: Left photo: rigid and sturdy grey Magna (3.8 mm) mesh material; right photo: traditional black sapphire mesh (2.6 mm) material.

Vessel swept area and catch per unit effort (CPUE) were also calculated. Due to the way information is collected in NPF logbooks, catch per unit effort was calculated as individuals per km^2 trawled area in a fishing day, not to the level of each trawl during the fishing day. This was determined using the number of nets a vessel was towing, headrope length (*m*) of each net multiplied by 0.667 (estimated effective fishing width of a net being towed), average trawl speed in knots (converted to *m* by multiplying by 1852) of a vessel, and duration of trawling (hrs) in a fishing day as follows:

Swept Width (m) = number of nets * headrope length (m) * 0.667

Swept Length (m) = trawl speed (knots) * 1852 * trawl duration (hrs)

$$\textbf{Swept Area per fishing day (km}^2\textbf{)} = \frac{\textbf{Swept Width (m) * Swept Length (m)}}{\textbf{1,000,000}}$$

CPUE data from the NPF Sawfish, Sea Snake and Fishing Gear database was used to explore differences in interaction rates between vessels using grey and black mesh TED flaps (**Appendix 1**). Five vessels introduced the material in the 2019 fishing season, followed by an additional fifteen vessels between 2020 and 2022. The headrope lengths for vessels using the grey mesh ted flaps with quad gear varied between 14.2m to 14.44m.

8.1.1 Results of NPFI Desktop Analysis: Comparison of Grey and Black TED Mesh Flaps on Vessels Towing 14 – 15 metre Headrope Length

The desktop analysis firstly examined differences in CPUE for sawfish interactions between vessels using similar gear sizes and headrope lengths ranging from 14 to 15 metres, comparing grey and black mesh TED flap materials introduced in 2019. From 2019 to 2021, vessels using the grey mesh material had a higher CPUE; however, the CPUE for 2022 is almost identical to that of the black mesh, coinciding with the greater adoption of all-grey TED flaps among vessels (**Figure 2**).

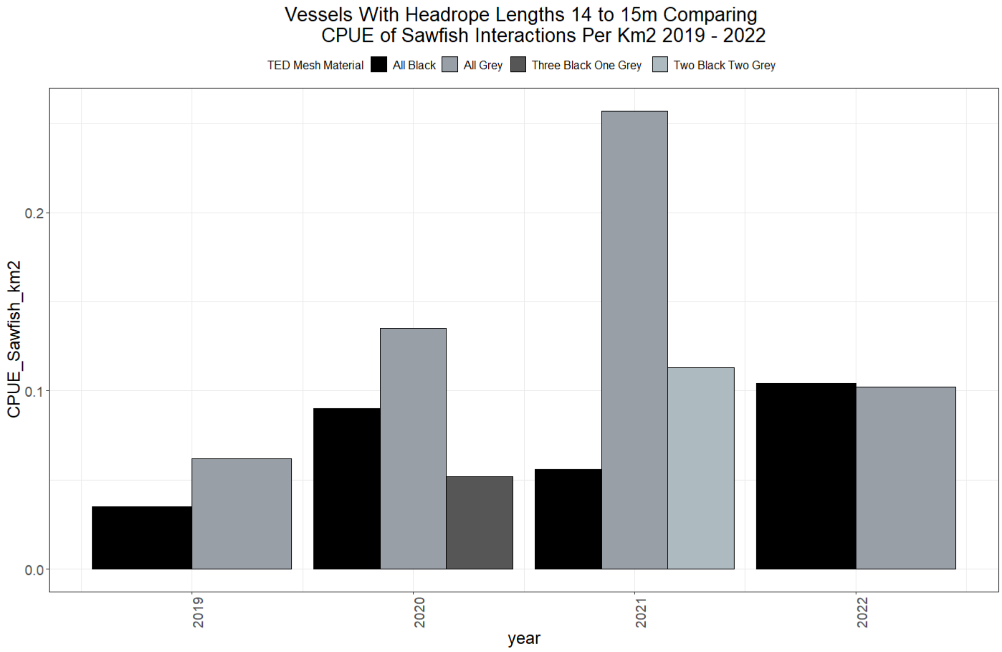


Figure 2: CPUE of sawfish interactions per km2 by vessels with headrope lengths of 14 to 15m using the different TED mesh material from 2019 to 2022 (Source: NPF Sawfish, Sea Snake and Fishing Gear database).

The project scope also identified the importance of analysing the data by different fishing zones within the same year, as sawfish interactions differ significantly both spatially and annually. The 2022 year was selected for analysis due to this being the year of the highest adoption of grey TED mesh flap material. When examining the CPUE for 2022 by zone and TED mesh material, eight zones exhibited a higher CPUE with vessels using black mesh TED flap material, while six zones showed higher CPUE with grey mesh (see **Figure 3**). Note: The Keerweer zone was not included as the sample size was too low.

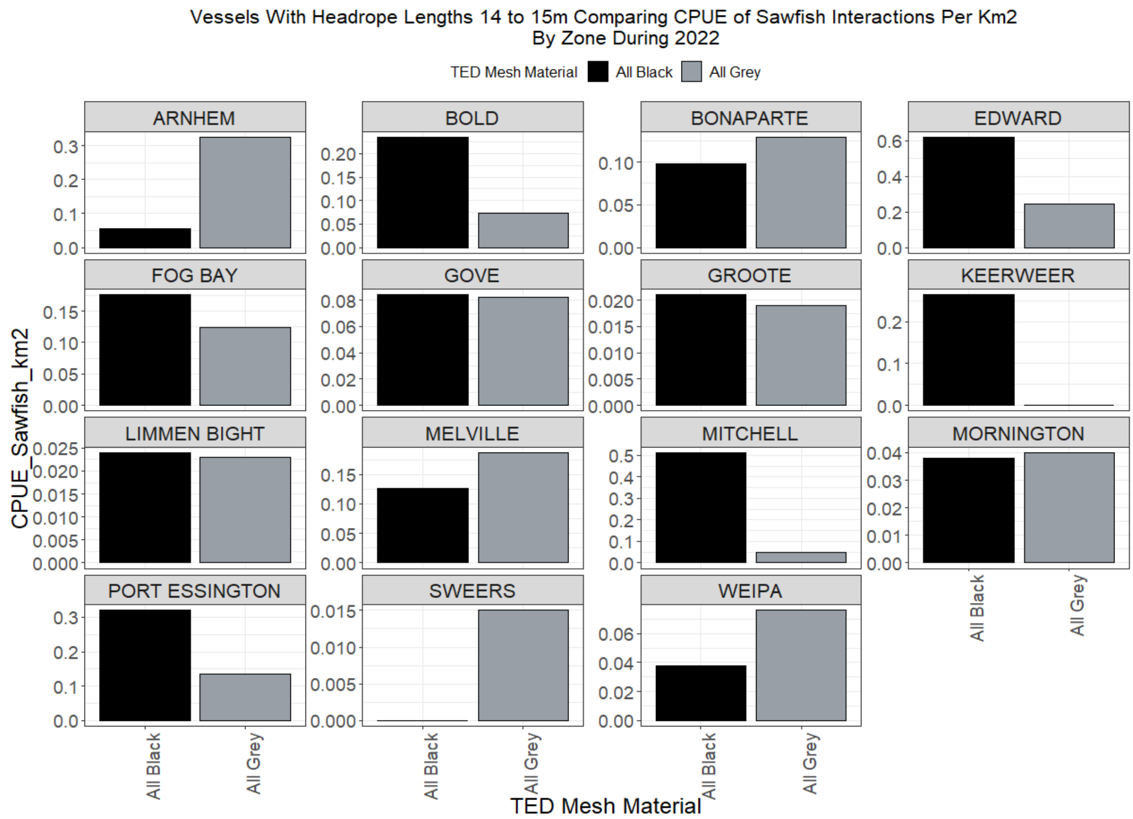


Figure 3: CPUE of sawfish interactions per km2 by vessels with headrope lengths of 14 to 15m using the different TED mesh material by Zone in 2022 (Source: NPF Sawfish, Sea Snake and Fishing Gear database).

In the analysis of the data, difficulty arose from the sporadic interactions with sawfish as sawfish are a rare incidental catch, being absent on many more fishing days than present. This resulted in many zero values in the database, posing two key challenges. Firstly, detecting changes becomes challenging due to the need for substantial data volumes to reliably determine any differences. Secondly, accounting for regional variations as well as annual variations is complex as fishing effort fluctuates and vessels do not consistently encounter sawfish during their operations across the fishery.

To address these challenges, CSIRO was contracted to conduct a Generalised Linear Model (GLM) analysis of the NPF sawfish interactions data. The objective was to determine whether accounting for variations in vessel, year, season, zone, and gear could reveal any significant differences between vessels using grey mesh TED flats and vessels using black mesh TED flaps and their interactions with sawfish. The full CSIRO report "*Analyses of sawfish and sea snake* *interactions rates (2010 – 2022) in Australia's Northern Prawn Fishery (NPF)*" of the GLM analysis is provided at **Appendix 1**.

8.1.2 Summary of CSIRO GLM analysis of the differences in sawfish interaction rates in the Northern Prawn Fishery between individual vessels, discrete fishing areas and fishing seasons using different gear/mesh types from 2010 to 2022. (Lawrence and Fry, 2024 – Appendix 1)

The raw data was firstly analysed to assess the history of sawfish interactions within the NPF. Most fishing days within the NPF have zero interactions with sawfish. When sawfish interactions occur, they mostly involve one or two sawfish, rarely higher. Years 2020 to 2022 represented the three highest mean interaction-rate years in the database. When analysing the raw data, grouping the years 2017 to 2019 and 2020 to 2022 showed that 85% of vessels reported more interactions within the 2020 to 2022 period, irrespective of TED mesh material used.

The results indicate that increased sawfish interaction rates with vessels using grey mesh TED flap material are consistent over time. It is important to note that the sample size (n) for grey mesh TED flap data points is much lower compared to that for black mesh material. Additionally, the period of higher catches with grey mesh TED flaps (2019-2022) coincided with a strong education program specifically aimed at improving the accuracy of recording ETP species in logbooks, which may have contributed to the apparent increase in reported interactions.

There are many factors that can influence sawfish interactions within the NPF such as effort, year and zone. Therefore, a Generalised Linear Mixed Models (GLMM) were fitted to the data to determine which was the best fit, and whether the TED mesh material had a significant effect on catch rates. Each model had the same basic terms with catch as the response and then an offset for effort, fixed effects for year, zone, season, TED mesh material, TED orientation and a random effect for vessel. All the models were fit using the GLMMTMB package in R. The distributions of the models were different, and the fit and model diagnostics were checked to determine which fit best.

The model with the best fit and lowest AIC was the negative binomial hurdle GLMM. The binomial model, modelling the probability of a zero on any given fishing day/night shows that after accounting for differences in catch rates by year, zone and season (TED orientation was dropped as not significant) there is still a significantly increased chance of interacting with a sawfish for vessels using the grey mesh compared to the vessels using the black mesh ($p<0.001$). Conditional on at least one sawfish being caught, there was no significant difference in the interaction rate on grey mesh ($p = 0.51385$).

It was difficult to estimate the increase in sawfish interaction rates due to the introduction of the grey mesh material as it involves assumptions about the fishing effort distribution and related factors. However, on average across different years, zones, and seasons, vessels using grey mesh TED flaps showed approximately a 37% higher interaction rate compared to those using black mesh. It remains unclear whether this reflects improved reporting accuracy by the fleet, as there was significant industry effort to enhance reporting during this period.

It was also difficult to quantify from the CSIRO GLMM analysis if the different TED mesh flap material or improved reporting resulted in increased reported sawfish interactions between vessels in the years 2020 to 2022. The results of these analyses informed the development of gear mitigation sea trials to be undertaken under a separate project. (Refer S7.5)

8.2 Component 2: Gain a baseline understanding of the differences in sawfish interaction rates in the Northern Prawn Fishery between individual vessels, discrete fishing areas and fishing seasons

The NPF Sawfish, Sea Snake and Fishing Gear database was used to assess sawfish interaction rates by vessels, fishing areas and years/season changes over time.

8.2.1 Results of the Analysis of Sawfish Interaction Rates by Vessels, Fishing Areas and Year/Season

The frequency of sawfish interactions reported in NPF logbooks was relatively constant from 2014 to 2019, with number of interactions ranging between 306 and 607, before showing an increase from 2020 to 2022, with number of reported interactions ranging from 990 to 1337 **(Figure 4**). Likewise, the average reported sawfish interactions per fishing day remained consistent from 2014 to 2019, ranging from 0.04 to 0.08, however increased during the period spanning 2020 to 2022, with the number of reported interactions per fishing day ranging from 0.16 to 0.19 (**Figure 5**).

During the period from 2018 to 2022 inclusive there has been increased focus by NPFI and AFMA on ETP species reporting. This included a targeted industry-wide education program specifically aimed at improving the accuracy of recording Endangered, Threatened or Protected (ETP) species in NPF logbooks. This may have contributed to the apparent increase in reported interactions from 2020 to 2022.

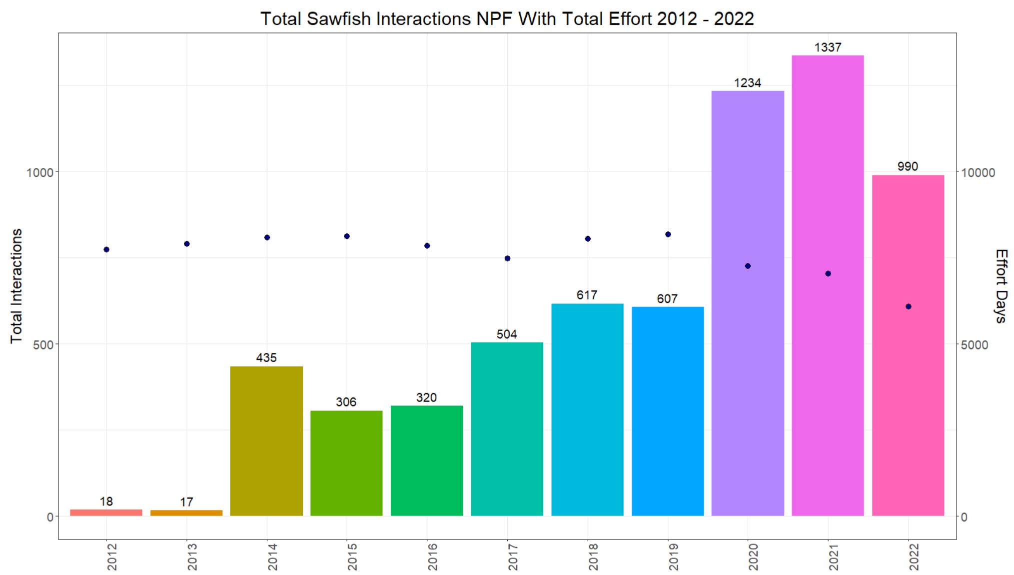


Figure 4: Total sawfish interactions within the NPF with total effort plotted by the blue dots 2012 to 2022 (Source: NPF Sawfish, Sea Snake and Fishing Gear database).

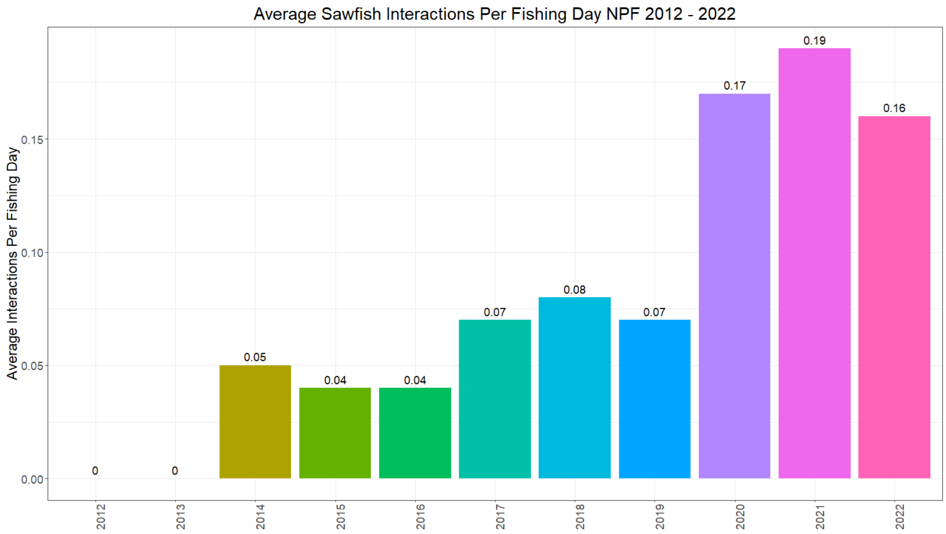


Figure 5: Average sawfish interactions within the NPF per fishing day 2012 to 2022 (Source: NPF Sawfish, Sea Snake and Fishing Gear database).

Various factors, including year, season, and geographical location, can also influence sawfish interactions. The NPF fishing grounds are broken up into 15 statistical areas for catch reporting purposes in the annual NPF data summary. Therefore, it's important to separate the data into the 15 statistical areas that define the spatial boundaries of the NPF fishing grounds, which will be referred to as zones in the following text (**Figure 6**). This approach allows for a comprehensive examination of areas with varying levels of sawfish interactions.

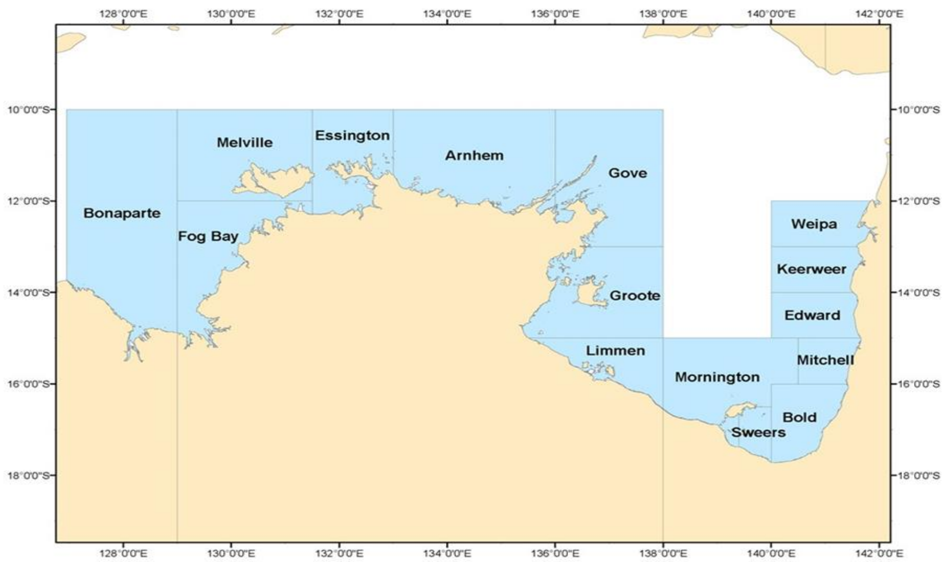


Figure 6: Statistical areas of the NPF.

When accounting for fishing effort, the Bonaparte, Melville and Port Essington zones had higher average sawfish interactions per fishing day compared to other regions (**Figure 7 and Figure 8**). There were more sawfish interactions in total numbers during the tiger prawn season compared to the banana prawn season. This is typically attributed to higher fishing effort during the tiger prawn season (**Figure 9**). However, when accounting for effort, the interactions of sawfish per fishing day were predominately higher in the banana prawn season compared to the tiger prawn season (**Figure 10**). When analysing CPUE per km2 trawled of sawfish interactions, interactions in the banana prawn season were always higher than in the tiger prawn season. Sawfish interaction CPUE per km2 rates ranged from 0.03 to 0.28 during the banana brawn season and 0.02 to 0.05 during the tiger prawn season (**Figure 11**). This is primarily because the vessels perform shorter tows when targeting schools of banana prawns. Furthermore, over the last three-year period (2020-2022) when sawfish reporting in logbooks improved, there was a drop in sawfish reductions in total numbers and CPUE, consistent with the introduction of the Grey mesh TED flaps. However, this could also be associated with the shorter season/reduced effort in the Tiger Prawn season in 2022. (Ref: **Appendix 1.** "Investigating potential for fishing gear, technology and management measures to reduce sawfish and sea snake interactions in Australia's Northern Prawn Fishery (NPF)")

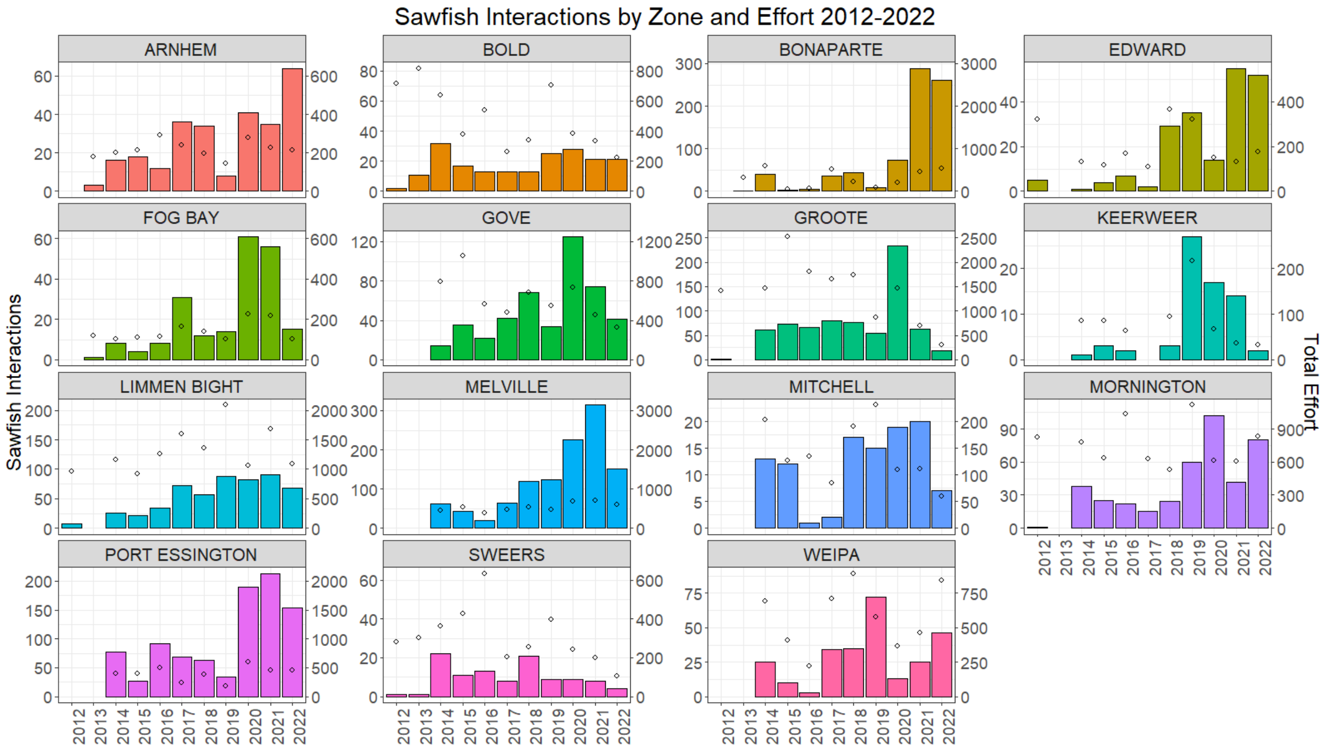


Figure 7: Total sawfish interactions by NPF zones and effort plotted by circles from 2012 to 2022 (Source: NPF Sawfish, Sea Snake and Fishing Gear database).

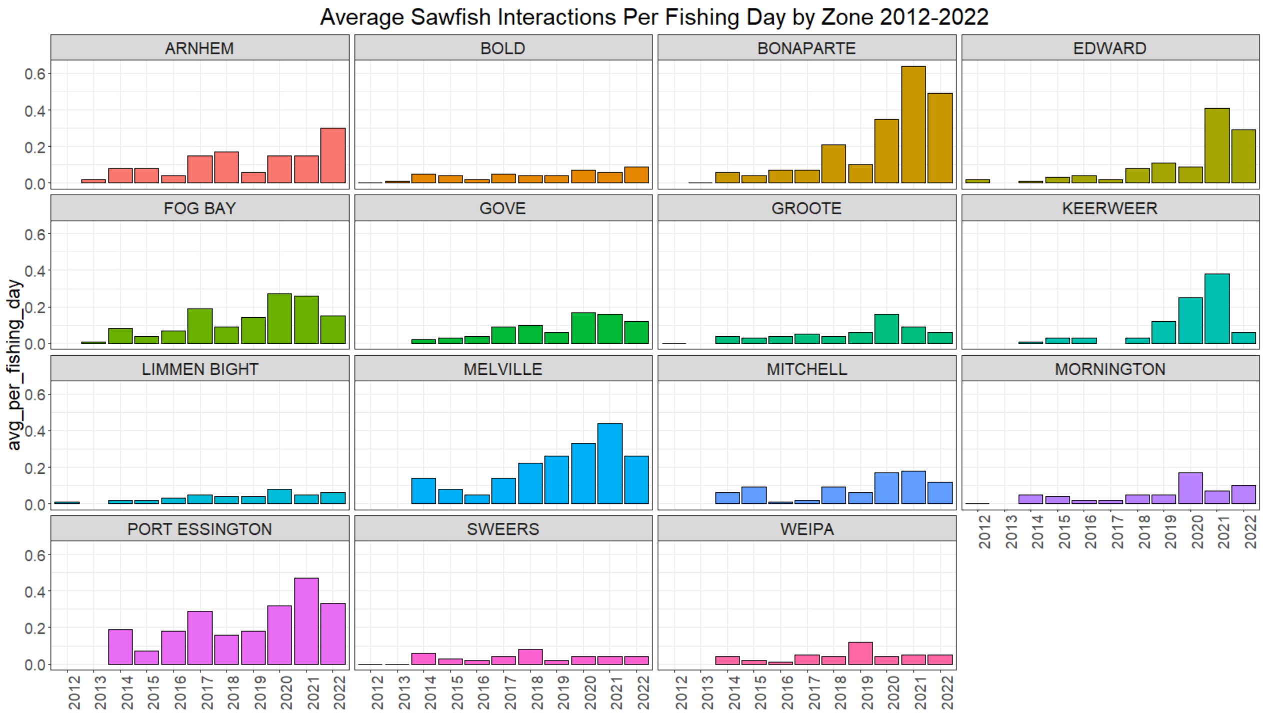


Figure 8: Average sawfish interactions per fishing day in each NPF zone from 2012 to 2022 (Source: NPF Sawfish, Sea Snake and Fishing Gear database).

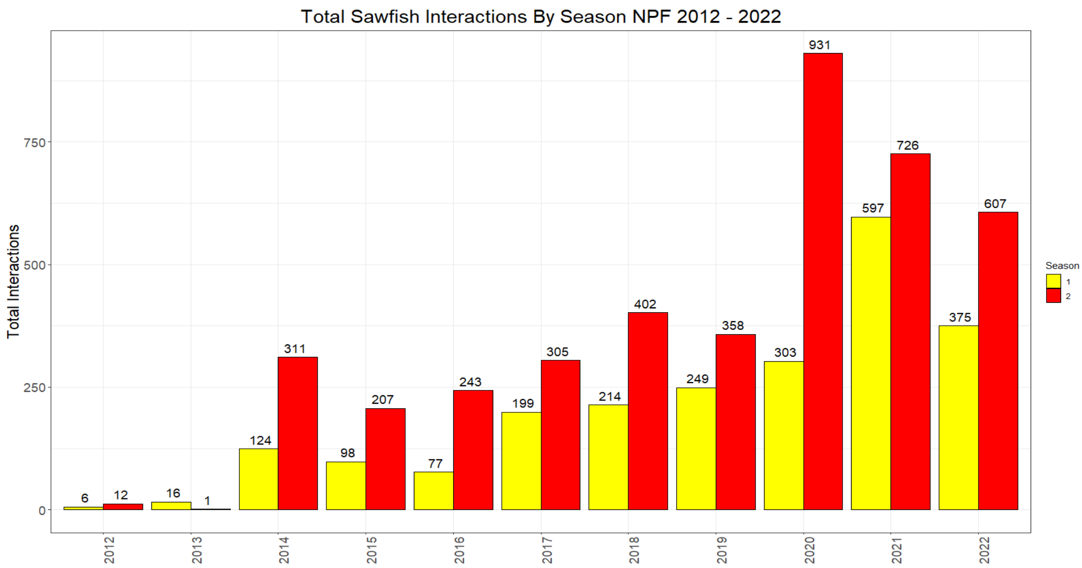


Figure 9: Total sawfish interactions by season from 2012 to 2022 (Source: NPF Sawfish, Sea Snake and Fishing Gear database).

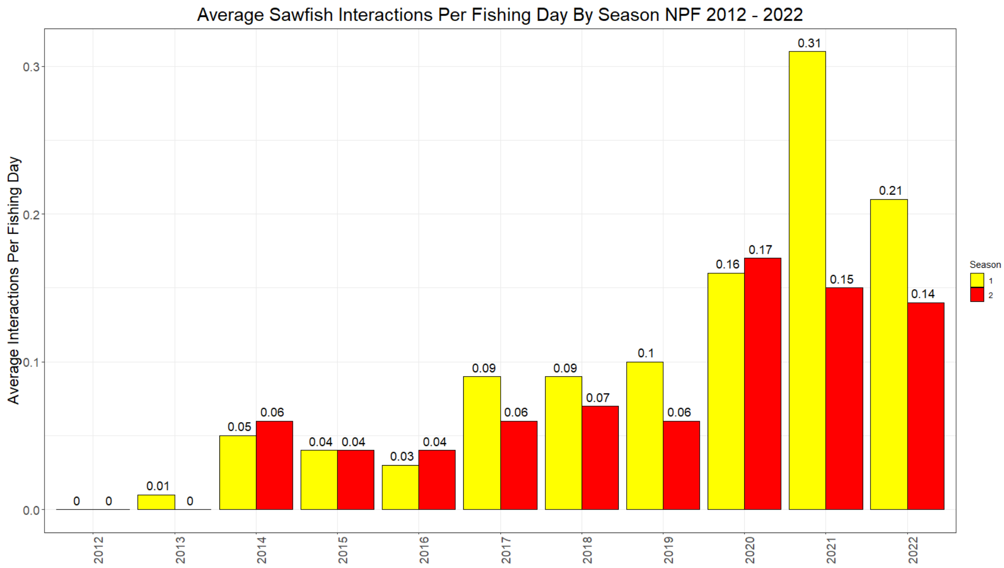


Figure 10: Average sawfish interactions per fishing day by season from 2012 to 2022 (Source*:* NPF Sawfish, Sea Snake and Fishing Gear database).

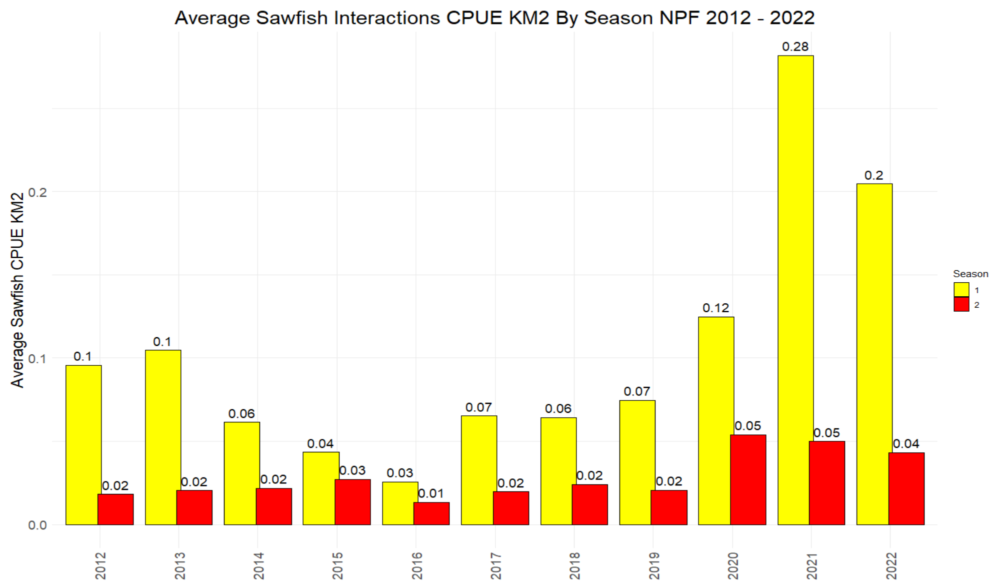


Figure 11: Average sawfish CPUE km2 by season from 2012 to 2022 (Source: NPF Sawfish, Sea Snake and Fishing Gear database).

Analysis of the *NPF sawfish interactions data* showed that the mean CPUE sawfish interactions per km2 trawled remained relatively constant from 2012 to 2019 and increased in 2020 to 2022 (**Figure 12**).

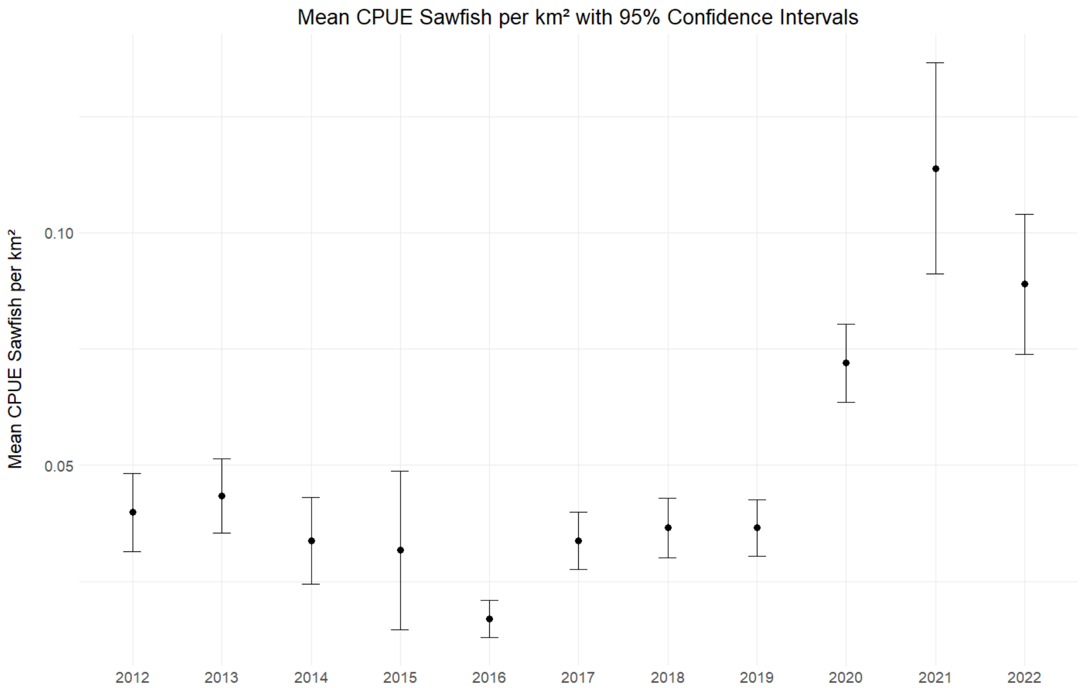
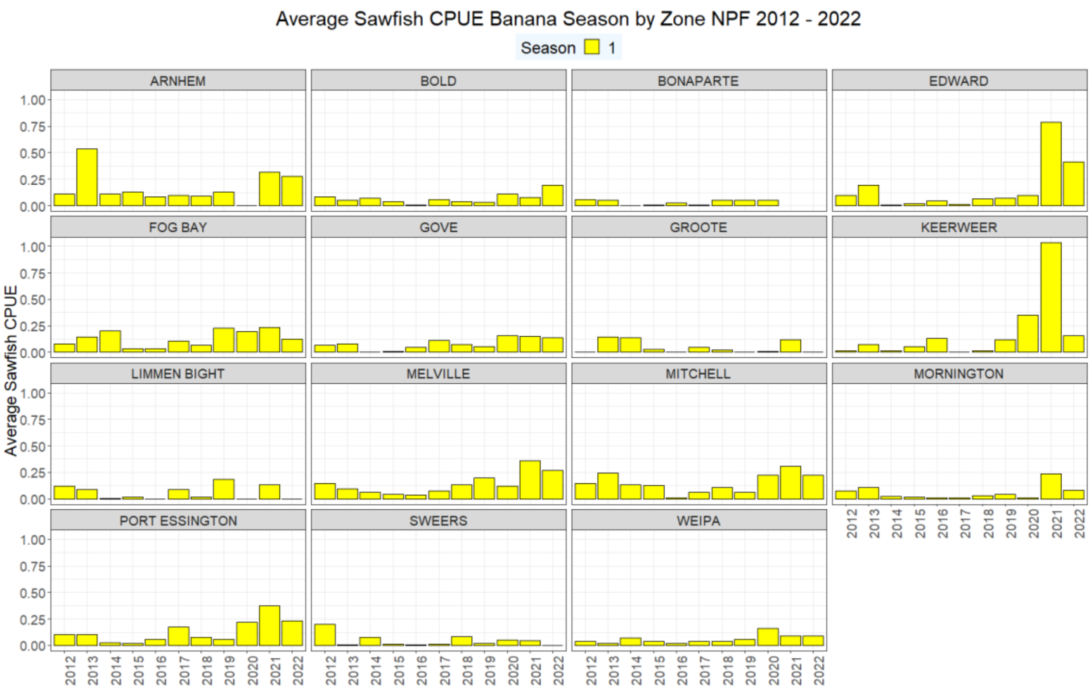


Figure 12: Trends in mean CPUE (numbers per km2) with 95% confidence intervals for sawfish from 2012 to 2022 (Source: NPF Sawfish, Sea Snake and Fishing Gear database).

To further explore the increase in sawfish interactions CPUE per km2 from 2020 to 2022 the data was analysed by NPF zone and season. Notable variations in sawfish interactions emerged in the banana prawn season with the Edward, Keerweer and Port Essington zones exhibiting increased CPUE in 2020 to 2022. Conversely, during the tiger prawn season, Bonaparte and Fog Bay zones exhibited increased CPUE in 2020 to 2022 (see **Figure 13**). These findings suggest that seasonal factors influence the prevalence of sawfish interactions across different zones.



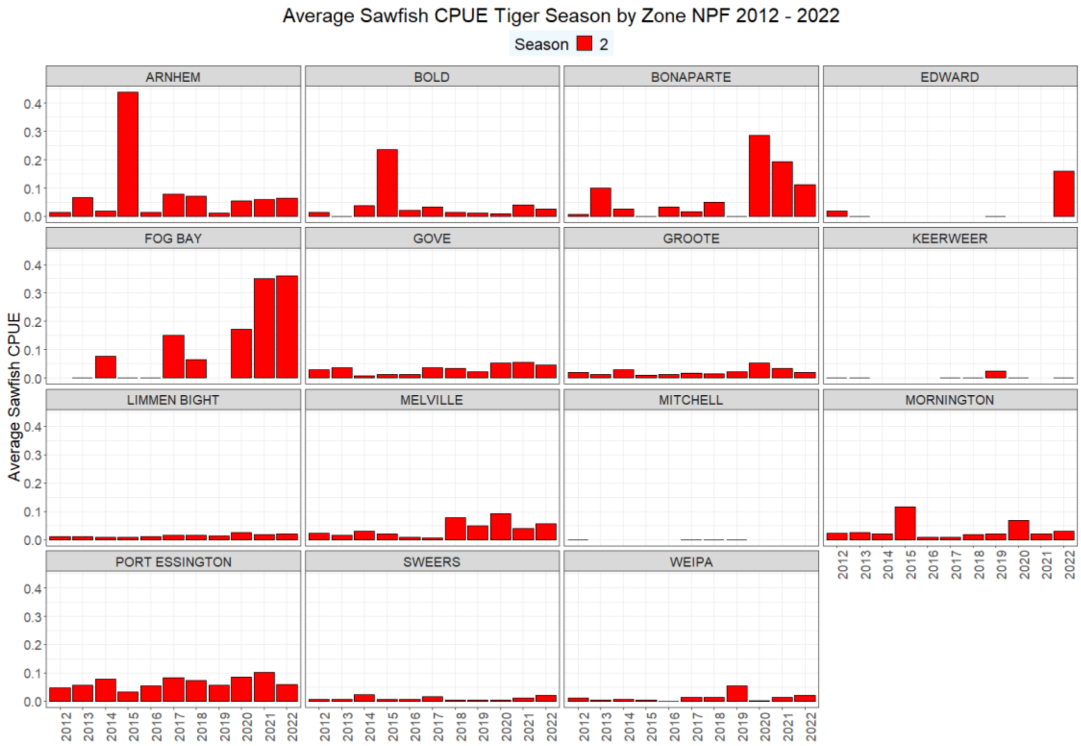


Figure 13: Average sawfish interactions CPUE per km2 in each NPF zone by season (yellow = banana season and red = tiger season) from 2012 to 2022 (Source: NPF Sawfish, Sea Snake and Fishing Gear database.

There are three additional data sets in which sawfish interactions are recorded. These are the Crew Member Observer data, the AFMA Scientific observer data and the NPF prawn population monitoring survey data sets. These data are analysed over time through triennial NPF CSIRO Bycatch Sustainability projects to assess and verify the quality of the crew-member observer data against the AFMA scientific observer and the NPF prawn population monitoring data sets, and to monitor interaction trends over time. CSIRO have conducted the most recent analysis of the data and the results have been provided in ("*Monitoring interactions with bycatch species using crew-member observer data collected in the Northern Prawn Fishery: 2020 – 2022*" Fry et al, 2024).

8.2.2 Raw Catch Data Analysis Results: Crew Member and AFMA Observer Data (CSIRO)

The NPF fishing grounds are broken up into 10 statistical 'Regions' for banana prawns (Dichmont et al, 2001) which have historically been used to monitor catch rate trends across the three additional datasets (CMO, AFMA and Prawn Population Monitoring) (**Figure 14**). Mean catch rates (non-modelled) were plotted separately by 'Region' and by 'Year' for the crew-member observer program and combined AFMA scientific observer program and NPF prawn population monitoring survey 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.

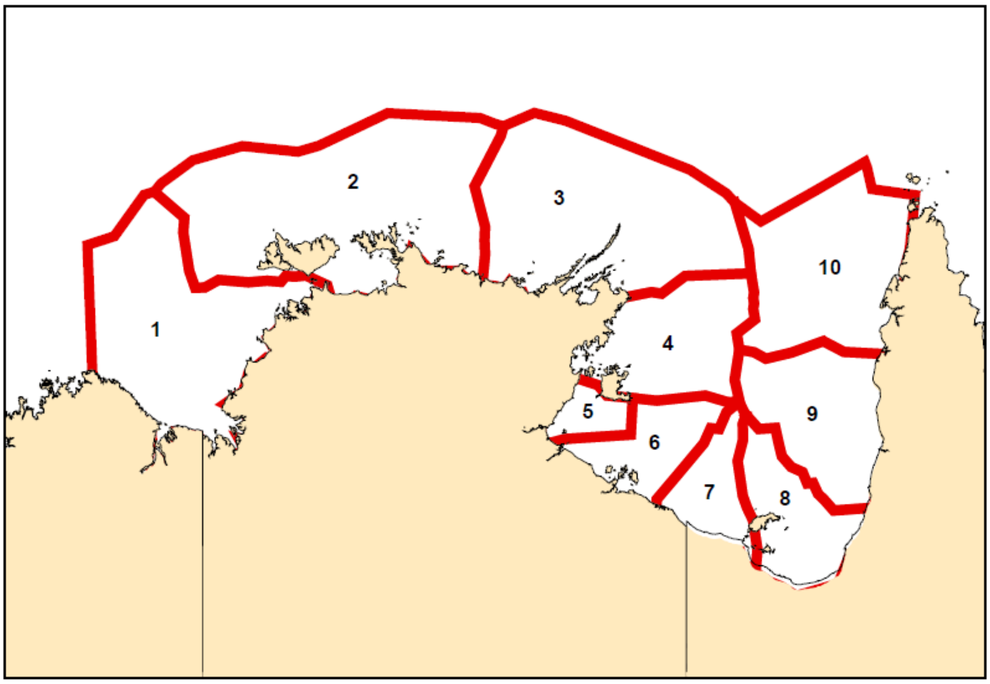


Figure 14: Map of the Northern Prawn Fishery boundary in northern Australia showing the 10 statistical regions for banana prawns (Source: CSIRO NPF bycatch sustainability report).

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 from 2002 to 2022. This was a result of the difference in data recording procedures between the programs. Species identification was carried out by AFMA and CSIRO scientific observers on board vessels during the AFMA scientific observer program and NPF prawn population monitoring surveys respectively, therefore resulting in a higher proportion of individuals identified to species. 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 trained to carry out on-vessel identification. The photographs collected were then later used by CSIRO scientific staff to identify all individuals to species level. 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 sawfishes were a group where the proportion of individuals identified to species level was much lower in the crew-member observer program compared to the AFMA scientific observer and NPF prawn population monitoring surveys. The crew-member observer catches of 'Unidentified Pristidae' were generally higher across all 'Regions' and 'Years'. The Narrow Sawfish (*Anoxypristis cuspidata*) made up about 90% of the catch composition for the sawfish group in the NPF between 2002 and 2022. 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 2022. Mean catch rates of the Green Sawfish (*Pristis zijsron*) were low across all 'Regions' and 'Years' but were generally similar but slightly higher in the crew-member observer data set compared to the combined AFMA scientific observer and NPF prawn population monitoring data set. The Largetooth Sawfish (*Pristis pristis*) appeared to show relatively low but stable catch rates over the recent years from 2016 to 2022 and was core common along the eastern Gulf of Carpentaria (‘Region’ 10). 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*).

Although there were some discrepancies in actual catch rates between the crew-member observer program and combined AFMA scientific observer program and NPF prawn population monitoring surveys, the trends in catch rates across 'Regions' and 'Years' were generally similar for many ETP and 'at risk' species. These data consistencies indicate 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 (**refer Figures 14 – 15 inclusive in Fry et al, 2024**).

8.2.3 CSIRO GAM Modelled Catch Rate Trends

Only one species of sawfish (*Anoxypristis cuspidate – narrow sawfish*) was able to be modelled for catch rate trends from 2003 to 2022 across the three datasets. 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. Furthermore, the NPF prawn population monitoring surveys are only distributed within seven '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, 2 and 3) instead of only the seven 'Regions' when only the NPF prawn population monitoring data was used.

The catch rates for the Narrow Sawfish recorded by the crew-member observer program and combined AFMA scientific observer program and NPF prawn population monitoring surveys showed a very stable trend across the period of 2010 to 2022 (Figure 15). The annual mean catch rates for both the two data sets were quite similar between 2010 and 2022. While there was relatively low variability in catch rates within each year for the crew-member observer program, there was higher within-year variability in catch rates for the combined AFMA scientific observer program and NPF prawn population monitoring survey (Fry et al, 2024).

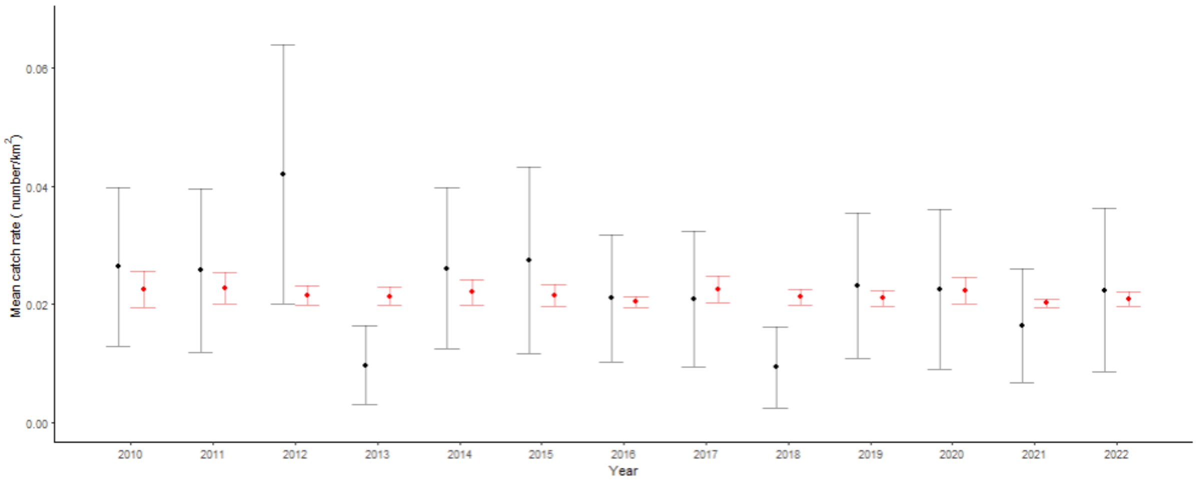


Figure 15: Trends in mean catch rate (numbers per km2) with 95% confidence intervals for the sawfish; *Anoxypristis cuspidata*, based on a depth of 24 m and in 'Region' 6 from the CMO program (red points) and combined AFMA scientific observer program and NPF prawn population monitoring surveys (black points) from 2010 to 2022.

8.2.4 Conclusion from Analyses

Sawfish interaction rates remained consistent from 2010 to 2022 across the Crew Member Observer, AFMA Scientific Observer and NPF prawn population monitoring survey programs (**Figure 15**). These data don't indicate the significant increase in mean interaction rates (number/km2) observed in the most recent years (2020 – 2022). This further strengthens the conclusion that the improved accuracy of reporting sawfish interactions by industry resulting from the NPFI /AFMA education program is likely to be the main contributor to the increased number of interactions recorded in NPF vessel logbooks.

NPFI will continue to monitor sawfish interactions within the fishery to compare interaction rate trends across years and individual fishing zones. Several projects are currently underway to evaluate the effectiveness of different gear mitigation measures in reducing sawfish entanglements and interactions. These include testing sturdier net mesh material that may be less likely to entangle sawfish rostrums in the throat of the net, and modified TED designs to reduce instances of sawfish entering codends.

8.3 Component 3: Identify and purchase equipment/ technology (eg underwater lights) suitable for use in NPF operational conditions that has potential to reduce sawfish interactions between sawfish

There has been limited technology developed for specifically reducing sawfish interactions with trawl gear. Those that have been developed and trialled have currently had minimal success. The aim of this desktop study was to explore recent technological innovations to identify gear mitigation options that have had success removing bycatch in trawl fisheries and that may be practical for reducing sawfish interactions within the NPF. The following technologies were identified and explored:

Underwater Cameras (SNTech, 2023)

There have been considerable new developments in designing compact underwater camera systems that can easily attach to trawl fishing gear to help improve understanding of how fishing gear is interacting with target and non-target species.

New, improved, and compact underwater camera systems such as the CatchCam systems can be easily installed on fishing gear. This allows for strategic filming of specific sections of the net where interactions may occur, providing valuable footage for analysis. The Catchcam system's user-friendly designs enables immediate review of the footage as soon as a haul is complete, allowing for immediate gear modification. This enhances the efficiency and effectiveness of adapting and monitoring trawl fishing gear to reduce bycatch interactions.

The primary concern with using the camera technology in the NPF is the lack of brightness of the camera lights. The NPF's muddy and turbid waters often affect underwater visibility and camera footage quality. As well, the CatchCam's brightest setting is 500 lumens, which reduces battery life to five hours, insufficient for recording a full night of fishing. Frequent battery replacements are onerous and impractical – as well, sawfish interactions are relatively rare. A camera system capable of recording an entire night's fishing activity would be preferable. However, the CatchCam shows promise, and with improved battery life, could be a useful resource for monitoring the effectiveness of gear mitigation options being trialled in the NPF.

Modular Harvesting System (Precision Seafood Harvesting, 2023)

The New Zealand snapper and gurnard fishery developed the Modular Harvesting System, a new fish harvesting technology that replaces the traditional mesh lengthener and cod-end of the trawl net with a unique method of catching fish (Precision Seafood Harvesting, 2023). This material was designed to improve the health of retained fish species and remove unwanted smaller juvenile fish. Additionally, it has increased the survivability of bycatch species by preventing them from being caught or stuck in the net meshes. Austral Fisheries, a stakeholder within the NPF, has been liaising with Precision Seafood Harvesting to explore the potential for designing similar technology for NPF trawl gear, particularly in areas with higher sawfish interactions such as the throat, TED, and TED flap sections. Using a material without a mesh-like structure could significantly reduce sawfish entanglements, allowing the animals to reach the TED and escape through the opening. The material will be trialled in the NPF in the 2024 tiger prawn season as part of a separate gear mitigation project.

Figure 16: Modular Harvesting System in the New Zealand fish trawl (Source: https://precisionseafoodharvesting.co.nz/home/modular-harvesting-system/).

Electric Field (Abrantes et al, 2020)

The study aimed to assess the effectiveness of electric fields in mitigating sawfish bycatch in prawn fisheries. Through tank experiments, researchers tested various electric pulse waveforms to determine their impact on sawfish behaviour. Two largetooth sawfish individuals were observed in holding tanks, and behaviours such as twitching, changes in swimming direction, and reaction distance were recorded.

The findings indicate that sawfish can sense and react to electric fields, displaying behaviours such as turning back or swimming parallel to the electrodes when exposed to the electric pulses. However, none of the tested waveforms were effective in eliciting a fleeing behaviour from a distance sufficient to prevent sawfish from entering trawl nets, with reactions occurring only when the sawfish were within close proximity to the electrodes.

Furthermore, the study suggests that increasing the voltage, frequency, or duration of the electric pulses may potentially improve effectiveness of this technology but could pose challenges and risks such as increased stress to sawfish and other non-target species, potential danger to humans, and increased costs.

Ultimately, the study concluded that current electric pulse technologies are unlikely to be useful in reducing sawfish bycatch in prawn trawl fisheries. The authors recommend revisiting the use of electric fields as sawfish deterrents in the future when technological advancements allow for increased field propagation to elicit fleeing behaviour from greater distances.

Smaller Bar Spacing TED (Garstin and Oxenford, 2018)

This study documents elasmobranch bycatch in the Atlantic seabob trawl fishery and examines the effectiveness of a modified TED (with a reduced bar spacing of 4.45 cm and the addition of a brace bar) in reducing elasmobranch bycatch.

A 40% decline in elasmobranch catch rate was observed when using modified TEDs compared with control TEDs, with the mean bycatch rate dropping from 2.3 to 1.4 individuals per twin—trawl/h. Additionally, the modified TEDs reduced the mean size of rays caught by 6.3% and eliminated three 'Near Threatened' ray species from the bycatch. However, the devices had little effect on the capture of smaller elasmobranch species. The study concluded that modified TEDs effectively reduce the bycatch of vulnerable elasmobranch species, supporting progress towards MSC certification standards.

Eayrs and Fuentevilla (2021) identified the TED is a key area for improvement in shrimp trawls regarding bycatch reduction. They note the lack of new TED designs in recent years, suggesting that existing TEDs may meet legislative requirements however, improvements are necessary to address the poor exclusion of large, endangered, or vulnerable organisms such as sawfish and sponges, and to reduce shrimp loss. (Eayrs & Fuentevilla, 2021).

This study indicates that smaller bar spacing TEDs hold promise for the NPF. Decreasing the bar spacing of currently used TEDs is also a relatively low-cost measure that could potentially reduce interactions with smaller sawfish. Currently, juvenile sawfish can pass through the TED and enter the codends of trawl gear. If modified TEDs can prevent this, it increases the likelihood of these animals escaping through the TED escape opening. The NPF is collaborating with NPF industry to develop and trial modified TEDs and analyse their effectiveness in reducing juvenile sawfish interactions as part of a separate project.

Green LED Lights Gillnet Fishery (Senko et al, 2022)

Senko et al 2022 studied the effects that green LED lights attached to Gillnet fishing nets could have on reducing bycatch species while maintaining target species catches. Green LED lights have been shown to reduce bycatch of elasmobranchs in some gillnet fisheries that operate at night (Senko et al. 2022). In this experiment along Mexico's Baja California peninsula, green LED lights significantly reduced mean rates of total discarded bycatch biomass by 63%. Significant decreases in elasmobranchs (95%), Humboldt squid (81%), and unwanted finfish (48%) were achieved. In contrast, there were no significant differences in target fish catch or value (Senko et al 2022).

This study shows some promise for the NPF given the success of LED lights in deterring elasmobranch species from fishing gear. Additional testing in turbid inshore environments is required to determine whether green LED lights would have the ability to reduce sawfish bycatch and what impact they will have on target prawn species catch. However, it should be noted that the NPF has trialled similar techniques with lights with limited success, including unacceptable prawn loss and *increased* small fish bycatch (see below).

At Sea Testing of a Submerged Light BRD Onboard the FV Ocean Thief for approval In Australia's Northern Prawn Fishery (Maynard and Gaston, 2010)

A trial by Maynard and Gaston, 2010 showed that the inclusion of light in the trawl system significantly changed the catch per unit effort (weight and abundance) of ponyfishes, biddies, non-target prawns, trevallies (family Carangidae), and threadfin salmon (family Polynemidae), whiting (family Sillaganidae) and abundance of cardinalfish (family Apogonidae). The trial was halted after five tows (13.9 trawl hours) due to a commercially unacceptable reduction in the catch rate of the target species. The orientation of the lights (facing downwards, along the headline) caused an overall increase in bycatch weight (51%).

PISCES LED Lights to Reduce Bycatch (SNTech, 2023)

Further investigation into light technologies has revealed innovations by Safety Net Technologies, which has developed robust light devices. The Pisces underwater lights can emit various colours, flashing rates, and brightness settings, with a single charge lasting up to 270 hours depending on the brightness (SNTech, 2023). They infer different colours of light have demonstrated the ability to attract or deter certain species (SNTech, 2023). In the previous NPF trials only a white light was trialled. However, it remains uncertain whether different coloured lights would effectively deter sawfish in the turbid waters of the NPF fishing grounds. As light technologies advance and more research is conducted on sawfish response to light spectrums, the practicality of trailing these lights in the NPF will be assessed by NPF industry.

In conclusion, NPFI took the decision to divert the funding for this component to purchase 2 new 'state of the art' Catchcam underwater cameras from UK company Safety Net Technologies to monitor sawfish ETP interactions with fishing gear. The cameras were fitted to nets on NPF trawlers and collecting video footage to obtain additional information and lead to better understanding of interactions with sawfish (and other ETPs) and prawn trawl fishing gear as part of the NPFI/DCCEEW '*Mitigating sawfish interactions in the Northern Prawn Fishery'* project. The cameras purchased through this project have provided increased capacity to collect underwater footage of ETP interactions during the DCCEEW project. The table below summarises the pros and cons as well as the likelihood of success of each gear/technology product evaluated in the desktop analysis (**Table 2**).

Table 2: Evaluating the pros and cons of each of current gear/technology available and their likelihood of success at reducing sawfish interactions within the NPF.

Equipment/technology	Pros	Cons	Likelihood of success
Safety Net Technologies CatchCam	Robust, compact and easy to manoeuvre, immediate and fast review of footage capacity to make shot by shot adjustments to trawl gear	Expensive, low battery life on high brightness setting, difficult to access camera and battery once installed in the net	Medium
Modular Harvesting System	Innovative approach to remove mesh netting from trawl gear which would reduce sawfish entanglement, improved survivability of catch, relatively cost effective	Challenging to install to existing trawl gear, may result in loss of fishing time/ catch in the initial stages of trials to get the gear fishing correctly and monitor waterflow.	Medium/High (subject to impacts on gear efficiency)
Electric Field	Sawfish did react to the electric pulses in fields	No further development in this technology space to date, current technology unlikely to reduce sawfish interactions	Low/None
Modified TED's	Cost effective, positive results in reducing bar spacing to remove smaller juvenile species, highlighted as a key opportunity to allow easier escapement for small sawfish	Unsure how different TED designs will affect commercial catch, could be costly to trial subject to how much the TEDs impact commercial catch; need a TED that the entire fleet could potentially use if successful therefore size and weight are important considerations,	High
Light Deterring Technology	Green LED lights have had some success in reducing elasmobranch bycatch in gillnet fisheries, development in lights have also made the designs more robust and easier to attach to trawl gear without the need for large batteries	Can be costly and unsure of durability, could increase small fish bycatch substantially, no studies have tested green LED lights on sawfish	Medium/Low

8.4 Component 4: Identify and quantify the impact of the Tom's Fisheye BRD on sea snake interactions (including any percentage reductions) between fishing seasons/years since the adoption of the Tom's Fisheye in 2020

The Northern Prawn Fishery (NPF) interacts with approximately fifteen sea snake species with consistent levels of interactions recorded through the electronic logbooks and monitoring programs. Sea snakes are an increasingly important ETP species given their conservation and sustainability status. Sea snake interactions occur over most of the NPF fishing grounds - reducing the impacts on sea snakes from commercial fishing practices has been highlighted as a research priority in the NPF[1].

The Tom's Fisheye Bycatch Reduction Device (BRD), developed between 2015 and 2017 as an initiative of the Northern Prawn Fishery Industry, aimed to reduce small bycatch in trawls by 30% (**Figure 17**). Scientific trials conducted from 2016 to 2018 demonstrated its efficiency in reducing finfish bycatch from trawl gear by approximately 40% (Laird et al., 2020). Subsequent to a literature review on Bycatch Reduction Device (BRD) effectiveness in reducing sea snake captures, it was anticipated that the Tom's Fisheye BRD may also show a reduction in sea snake interaction rates within the NPF.

Figure 17: The Tom's Fisheye bycatch reduction device (BRD)

The Northern Prawn Fishery Logbook data from 2010 to 2022 was used to compile the NPF Sawfish, Sea Snake and Fishing Gear database, including information on specific fishing gear and BRD types used per vessel. The database included metrics such as swept trawl area and catch per unit effort of sea snake interactions pre and post the implementation of the Tom's fisheye.

A desktop analysis using NPF sea snake interactions raw data was undertaken by NPFI to assist with separating the data into 'pre and post adoption' of the Toms Fisheye BRD. From 2015 to 2022 the number of sea snake interactions recorded in the fleet logbooks have ranged from

[1] NPF 5 Year Strategic Research Plan 2023-2028

7,281 to 13,929 with a mean of 10,460 (**Figure 18**). Overall, the average number of sea snakes caught per fishing day have ranged from 0.9 to 2.03 with a mean of 1.4 (**Figure 19**).

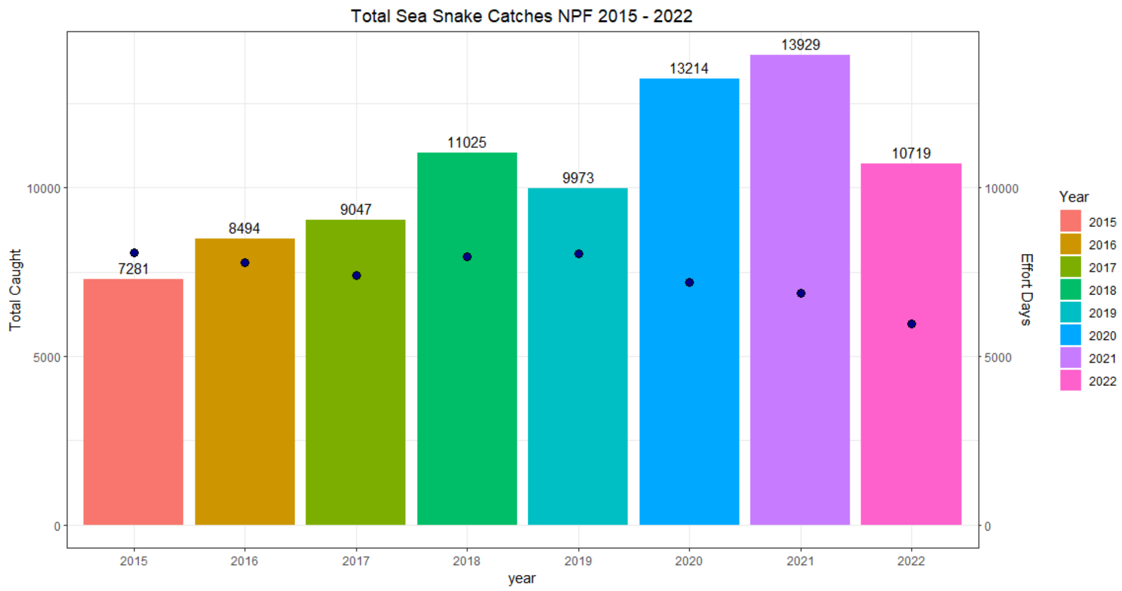


Figure 18: Total interactions of sea snakes in the NPF from 2015 To 2022 with effort plotted by the blue dots (Source: NPF Sawfish, Sea Snake and Fishing Gear database).

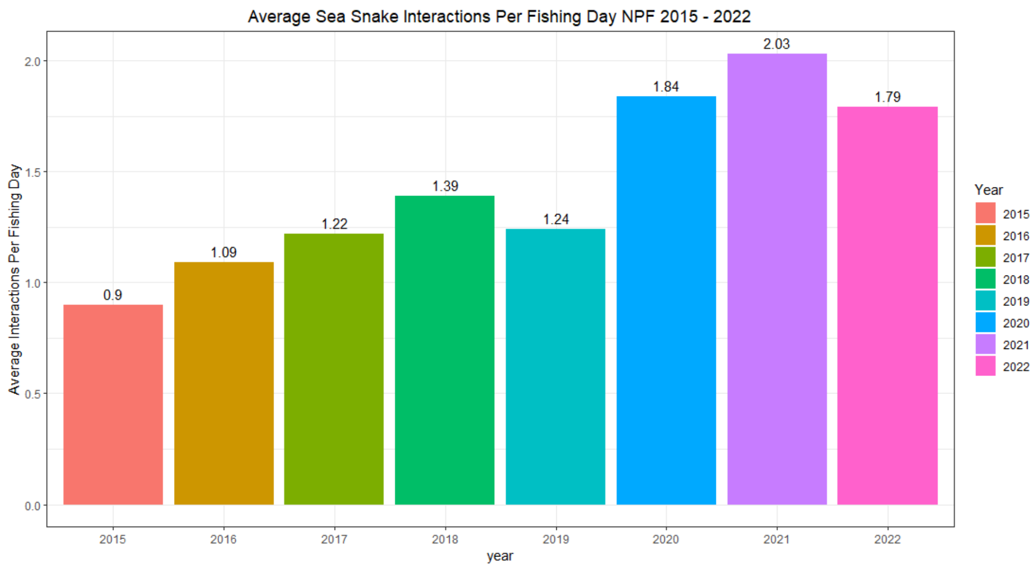


Figure 19: Average interactions of sea snakes per fishing day in the NPF from 2015 to 2022 (Source: NPF Sawfish, Sea Snake and Fishing Gear database).

Sea snake interactions occur over most of the NPF fishing grounds (**Figure 20**). However, it is important to review the spatial data to determine whether there is a difference in interaction rates in different areas in the fishery. Examination of the logbook data indicates that similar levels interactions (15 sea snakes or more per day) have occurred throughout the NPF fishing grounds and highlights their spatial abundance (**Figure 21**).

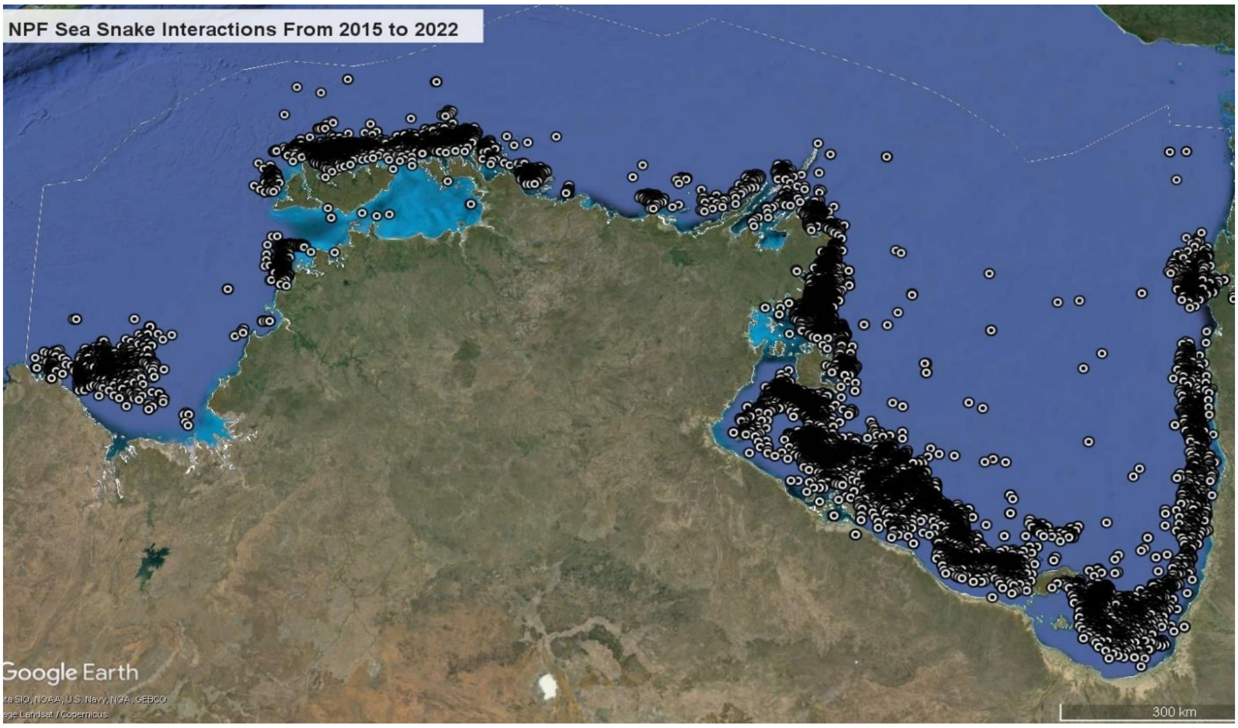


Figure 20: All NPF sea snake interactions recorded from 2015 to 2022 (Source: NPF Logbook data).

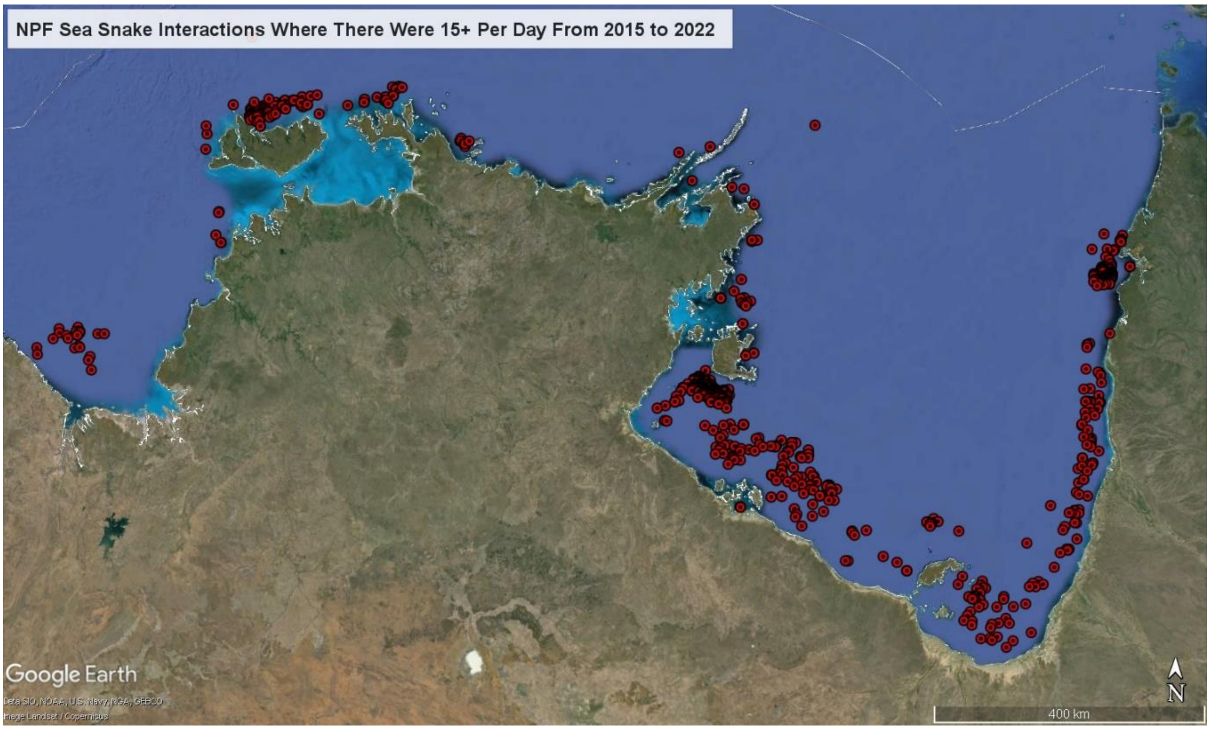


Figure 21: NPF sea snake interactions from 2015 to 2022 where 15 or more individuals were reported per fishing day per vessel (Source: NPF Logbook data).

The Tom's Fisheye BRD became mandatory for use by all vessels in tiger prawn seasons and mandatory for use by vessels targeting tiger prawns in banana prawn seasons from 2020 onwards. Catches of sea snakes were relatively steady in the tiger prawn fishery from 2015 to 2019 ranging from 6184 to 7848, with interactions increasing to just over 10,000 in 2020 then steadily decreasing in the two following years (**Figure 22**).

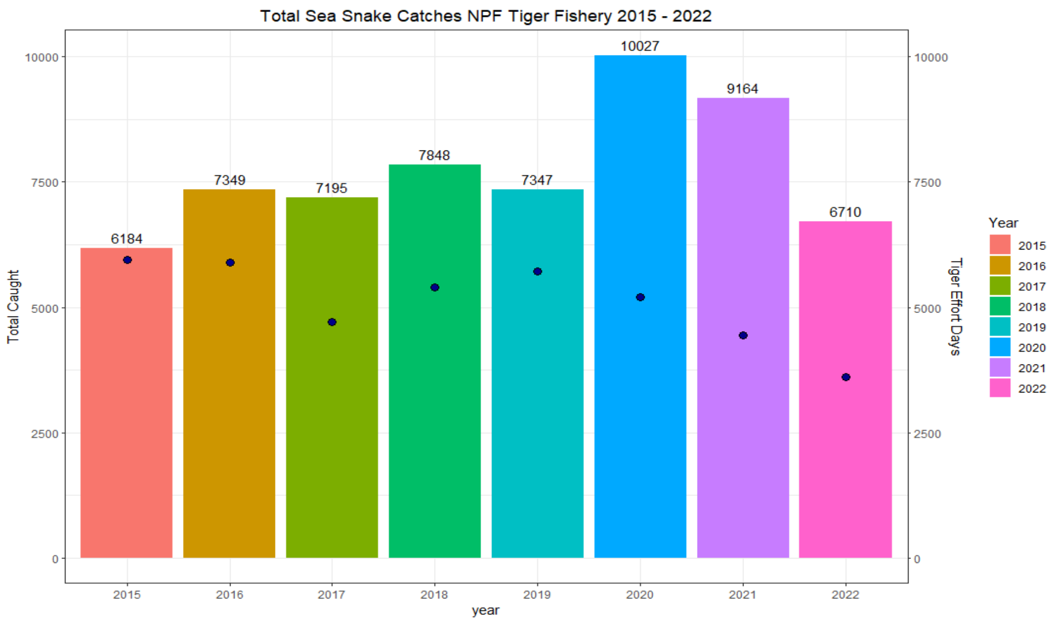


Figure 22: Total interactions of sea snakes from 2015 to 2022 in the tiger prawn fishery with effort plotted by the blue dots. Years 2015 to 2019 are pre-Tom's Fisheye compared with 2020 to 2022 where adoption of Tom's Fisheye is compulsory in the tiger prawn fishery (Source: NPF Sawfish, Sea Snake and Fishing Gear database).

Drawing specific conclusions about the Tom's Fisheye BRD solely through desktop analysis was challenging due to accounting for regional variations being complex given fishing effort fluctuates annually. It also proved difficult to eliminate regional variations year to year. To address these challenges, CSIRO was contracted to conduct a Generalised Linear Model (GLM) analysis on the NPF sea snake interactions database. The objective was to determine whether accounting for variations in vessel, year, season, zone, and gear could still reveal significant differences between the instances of sea snake interactions pre and post the introduction of the Tom's Fisheye.

8.4.1 Summary of CSIRO GLM analysis of the data to identify and quantify the impact of the pre and post Tom's Fisheye BRD implementation (2015-2019 and 2020-2022) on sea snake interactions (including any percentage reductions) between fishing seasons/years since the adoption of the Tom's Fisheye in 2020 (*Lawrence and Fry, 2024 - Appendix 1*)

The NPF raw data was analysed to determine if any sea snake interaction trends pre and post the adoption of the Tom's Fisheye BRD could be inferred. There have been many different combinations of BRDs tested in the fishery to analyse their effectiveness at reducing sea snake interactions however the low sample numbers across most combinations made it difficult to determine effectiveness. Therefore, the BRDs tested were categorised into three groups, Toms Fisheye BRD (TOMS), no Toms Fisheye BRD used (NOT_TOMS) and some combination of Toms Fisheye BRD and another BRD (OTHER) for further analysis as the Tom's Fisheye BRD is currently the most used BRD in the fishery.

While the interaction rates of sea snakes were considerably higher when the Tom's Fisheye BRD was not used, the incidence of sea snake interactions was higher when the Tom's Fisheye was used. Vessels with the Toms Fisheye appeared to interact with sea snakes more often than vessels not using the Toms. This could be a result of significantly more vessels using Tom's Fisheye from 2020 onwards and only during the tiger season when sea snake interactions are much higher than in the banana prawn season. Furthermore, from 2020 onwards when Tom's fisheye was the most used BRD in the fishery, there has been an improvement in catch reporting for ETPs in the NPF logbook. This is likely a result of the industry education program specifically aimed at improving the accuracy of ETP interaction reporting.

To account for factors such as season, year, region, and gear type influencing sea snake interactions, Generalised Linear Mixed Models (GLMM) were fitted to the NPF sea snake interactions data. The analysis aimed to determine whether different BRD types significantly affected sea snake interaction rates. The model with the best fit and lowest AIC was the negative binomial GLMM.

The model indicates significant differences in sea snake interaction rates across years and regions, reflecting annual variations in fishing effort. Interaction rates were significantly lower with the use of Tom's Fisheye. However, estimating the exact reduction in catch rate due to Tom's Fisheye is challenging, as it involves assumptions about fishing effort distribution and associated factors. On average, accounting for year, zone, and TED orientation, catch rates were approximately 17% lower when using Tom's Fisheye compared to not using it.

Averaging across all factors eliminates potential biases when analysing interactions between vessels and sea snakes. The observed 17% reduction in catch rates using Tom's Fisheye reflects expected outcomes if fishing effort were equal across region, season, year, and TED orientation. However, this estimate should be interpreted with caution, as it does not imply a 17% reduction in sea snake catches solely due to Tom's Fisheye - the raw catch rates were actually 40% lower. Additionally, the model results indicate that vessels with a Top Escape TED orientation experienced a 6% reduction in sea snake interactions compared to those with Bottom Escape TED orientations.

8.4.2 Literature Review of Available Data on The Effectiveness of BRDs to Reduce Sea Snake Interactions in Other Australian Prawn Trawl Fisheries

The review undertaken by NPFI indicated that considerable research has focussed on the impact of trawl fisheries on sea snake populations and quantifying fish bycatch reduction when implementing Bycatch Reduction Devices (BRDs). However, the review only identified seven at-sea research trials which directly quantified the effectiveness of BRDs in reducing sea snake interactions with trawl gear and most research dates back over a decade within Australia. The key findings of these seven BRD trials are summarised below:

An assessment of bycatch reduction devices in a tropical Australian prawn trawl fishery (Brewer et al, 1998)

Scientific trials were undertaken on the *RV Southern Surveyor* and displayed promising results concluding the Square Mesh Panel BRD when placed at 50 meshes from the drawstring reduced sea snake captures by 50% (Brewer et al, 1998). However, losses of commercial prawn catch were significant when BRD's were within the 50 meshes (Brewer et al, 1998).

The impact of turtle excluder devices and bycatch reduction devices on diverse tropical marine communities in Australia's northern prawn trawl fishery (Brewer et al, 2006)

In a 2001 trial following Brewer et al 1998 experiment, two BRDs—the Bigeye and Square-mesh panel—were tested with both downward and upward-facing Turtle Excluder Devices (TEDs). These were compared against control nets equipped only with TEDs or BRDs. The results showed an estimated 5% reduction in sea snake interactions with the TED + BRD gear compared to control nets (Brewer et al, 2006). However, the 50% reduction observed in 1998 was not replicated, likely due to differences in the BRD's positioning or configuration to reduce significant losses of commercial prawn species (Brewer et al, 2006).

At Sea Testing of the Popeye Fishbox Bycatch Reduction Device Onboard the FV Adelaide Pearl for Approval in Australia's Northern Prawn Fishery (Raudzens et al, 2007)

The Popeye Fishbox BRD was trialled in the Northern Prawn Fishery (NPF) aboard the FV Adelaide Pearl in 2006 over a 21-day period. The trial compared two nets: one equipped with the Popeye BRD and the other acting as a control without a BRD. Initially tested at 70 meshes, the trial resulted in a notable reduction of sea snake catches, representing an 87% reduction in sea snake bycatch (Raudzens et al, 2007). Subsequent trials were conducted during the 2007 Tiger Prawn Season, with 20 operators receiving Popeye Fishbox BRDs (Burke et al, 2012). However, adoption rates were limited in subsequent seasons due to various factors, including safety concerns during installation, significant prawn loss in the banana prawn fishery, and insufficient ongoing support due to the device not meeting the NPF BRD minimum prawn loss criteria (Burke et al, 2012).

Reducing Impacts of Trawling on Protected Sea Snakes: By-Catch Reduction Devices Improve Escapement and Survival (Milton et al, 2009)

Milton et al, (2009) highlighted subsequent studies investigating BRD performance within the NPF, indicating that no BRD improved sea snake escapement when placed at 120 meshes from the drawstring (Brewer et al, 2006). Further trials in the NPF evaluated the effectiveness of the Yarrow Fisheye, a modified version of the standard Fisheye, demonstrating a mean reduction of 43% in sea snake interactions (Heales et al, 2008). Anecdotal reports indicated that there was limited uptake of the Yarrow Fisheye BRD in the NPF due to the introduction of the Square Mesh Panel BRD

Additionally, an assessment of a Fisheye BRD in 2009 within the NPF, varying distances from the codend, revealed a 43% reduction in sea snake interactions on vessels where the Fisheye BRDs were positioned less than 70 meshes from the codend drawstring (Milton et al, 2009).

The 2009 Milton et al study concluded that positioning BRDs closer to the codend significantly reduces sea snake vulnerability to capture. Additionally, Milton et al. noted there was greater reduction in sea snake interactions when using the Popeye Fishbox BRD compared to the Fisheye BRD's and square mesh panel. However, as mentioned above, further sea trials provided insufficient evidence that this device could meet NPF BRD minimum prawn loss criteria (Burke et al, 2012).

Reducing the Impact of Queensland's Trawl Fisheries on Protected Sea Snakes (Courtney et al, 2010)

In 2010 A Queensland Government vessel *RV Gwendoline May* was charted for an 8-day trawl trial located in the trawling grounds between Cape Upstart and Cairns, Qld (Courtney et al, 2010). The trial examined four treatments (**Figure 23**).

Figure 23: Four BRD 'treatments' compared during the trial. From left to right BRD's were the standard codend with no BRD (control), fisheye BRD, square mesh codend BRD and square mesh panel BRD. The most forward edge of each device was 50 meshes from the drawstring (Source: Courtney et al, 2010).

Throughout this trial, it was observed that the fisheye and square mesh codend configurations significantly reduced sea snake captures compared to the standard codend, with reductions of 63% and 60%, respectively. Furthermore, no statistically significant difference was found between the square mesh codend and the fisheye in terms of sea snake captures (Courtney et al, 2010). It appears that no additional research to further investigate the use and effectiveness in reducing sea snake interactions was undertaken. However, several BRD's are currently mandated for use in the Queensland trawl sector (State of Queensland, 2024).

Industry Gear Innovations Achieves Bycatch Reduction Target in the NPF (Laird et al, 2020).

In 2018, the NPF Industry Pty Ltd (NPFI) initiated efforts to enhance Bycatch Reduction Device (BRD) designs aimed at reducing small fish bycatch in the Northern Prawn Fishery by 30%. During the trial of the Kons Covered Fisheye (KCF), 28 sea snake interactions occurred in nets equipped with the KCF, compared to 49 in nets with the Square Mesh Panel BRD.

The report concluded the ability of sea snakes to escape through these new BRDs was still unknown as only a small number of interactions were recorded during the trials. However, the number of sea snakes recorded during the trials of the KCF indicated these fisheye designs and their placement could enhance sea snake escapement (28 sea snakes in nets with KCF BRD compared to 49 in nets with a Square Mesh Panel BRD).

Additionally, valuable feedback from fishers participating in the trials undertaken during this project indicated a notable reduction in sea snake captures when utilising BRDs, signalling an area warranting further investigation (Laird et al, 2020).

Torres Strait Prawn BRD Trial Summary (Liddell & Wilson., 2021 Pers Comm)

Trials were conducted by the Australian Fisheries Management Authority (AFMA) in the Torres Strait Prawn Fishery, Queensland, Australia from 2019 to 2022 testing the effectiveness of the Tom's fisheye in reducing bycatch. The Tom's BRD was developed as part of the NPF initiative to improve BRD design to reduce small fish bycatch (Laird et al, 2020). The Toms BRD was the most successful in removing overall bycatch from the trawl gear at 40% (Laird et al, 2020).

The results of the Toms Fisheye BRD trials in the Torres Strait prawn fishery showed a 28% decrease in sea snake captures compared with a Fisheye and Small Mesh Window BRD (Liddell & Wilson., 2021 Pers Comm[2]).

These results indicate the importance of analysing sea snake interactions in the NPF by comparing vessels equipped with Tom's Fisheye to vessels using other devices to obtain a better understanding of the effectiveness of the Tom's Fisheye BRD in reducing sea snake interactions in the NPF.

Conclusion: The literature review undertaken as part of this project underscores the critical importance of ongoing monitoring to assess and optimise the effectiveness of BRDs in reducing sea snake interactions. Several BRD studies found positioning of the BRD key to sea snake escapement, with BRD's performing best when placed within 70 meshes from the codend drawstring (Milton et al 2009). NPFI will continue to monitor and quantify the effectiveness of Tom's Fisheye BRD at reducing sea snake interactions in the NPF.

8.5 Component 5: Develop A Robust Trial Design Including Scope, Fishing Methods, And Data Collection, Collation And Analysis Methodology To Be Applied To Sea Trials Aimed At Testing Various Trawl Gears And Other Equipment/Technology With Potential To Reduce Sawfish Interactions

A comprehensive and scientifically robust design for sea trials of fishing gear with potential to reduce sawfish interactions to be undertaken as part of the NPFI/DCCEEW '*Mitigating sawfish interactions in the Northern Prawn Fishery*' project was developed by NPFI in collaboration with CSIRO and AFMA.

The project team agreed that sea trials should be conducted to assess any differences between the new grey Magna mesh TED flap material compared to the standard black sapphire material. The first trial design would require 8 - 10 boats (15 – 20% of the fleet) each using a combination of nets with two different mesh types for the full duration of the 2023

[2] These results have not yet been published however a summary of the trial outputs was provided to NPFI by AFMA.

banana and tiger prawn seasons. This was determined as the best approach to removing potential biases such as vessel, zones, season and year which can influence sawfish interactions as seen from the CSIRO GLMM analysis.

The trial boats will use the original 51mm x 2.6 mm sapphire mesh TED flaps on one side (2 nets) and the new 60 mm x 3.9 mm grey Magna mesh TED flaps on the other side (2 nets). The nets would not be rotated during the trials. The skippers and crews will collect and record sawfish interactions observed in each net from each trawl shot to determine the effectiveness of the mesh types in reducing sawfish interactions. Data will also be collected on where in the net the interaction/s occurred to quantify if the TED mesh flaps are a common area for entanglement. Data collection sheets with instructions on data collection requirements/methods will be provided by NPFI to each boat participating in this component of the trials.

It was agreed that 5 additional NPF vessels would participate in more detailed trials on different gear mitigation options as follows:

1) Trials to be undertaken comparing the industry standard black sapphire mesh (51mm x 2.6mm) TED flaps (control) with Magna grey mesh 3.9mm x 60mm (experimental). This decision was driven by industry feedback that the more sturdy and stronger Magna mesh material has reduced sawfish captures in the TED flap area. Two vessels were scheduled to trial this design during the 2023 tiger prawn season. The aim of this trial is to determine changes in entanglement rates of sawfish by reducing the potential for their rostrums to tangle in the net mesh when encountering the TED. The vessels will:

(i) Replace the current 51mm x 2.6mm Sapphire mesh TED flaps with 60mm x 3.9mm Magna mesh

(ii) Replace the current 51mm x 2.6mm Sapphire mesh TED flaps with 60mm x 3.9mm Ruby mesh

(iii) Replace the current 51mm x 2.6mm Sapphire mesh TED flaps with a more rigid 70mm x 4.1mm Sapphire mesh material

2) A separate trial will be aimed at comparing the previous TED flap mesh materials as well as trialling Magna grey mesh (3.9mm x 60mm) 15 meshes forward of the TED within the throat of the net. This has been identified by industry and scientists as a frequent area of sawfish entanglement. One vessel was scheduled to undertake this trial during the 2023 NPF tiger prawn season.

The trials on all three vessels would be conducted over a consecutive 14-day period with one AFMA scientific observer on board each vessel for the duration of the trials.

Two additional vessels would trial a new TED design known as the Sawfish Turtle Excluder Device (STED) over a 14-day period during the NPF 2023 tiger season. The trial design required the catch from each net for every trawl shot to be separated, sorted and weighed to determine the impact of the STED on prawn catches and general bycatch. Data on sawfish and other ETP interactions is be recorded by individual net and net position from each shot to provide catch rate data. The gear trials on these two vessels are aimed at determining the effectiveness of the STED to improve sawfish escapement.

The scope and protocols for underwater video footage analysis and reporting by CSIRO was developed under this activity. This involved CSIRO building the custom underwater camera and lighting system suitable for within-trawl video recording, tailored to the conditions and vessel operations in the NPF. Underwater cameras will be attached to all four nets on each of the 5 vessels participating in the trials to record bycatch activity/interactions with the TED flaps/net. At sea observers will install the camera and lighting systems on the trial vessels prior to the start of each trial. Using data gathered from previous trials of underwater cameras in the NPF, the cameras will be installed in areas of the trawl nets where sawfish are most commonly entangled to capture video footage of sawfish entanglement and escapement rates eg behind the TED.

The independent observers on each commercial vessel will operate the camera systems during times of trawling activities. At the end of each night the observers will rotate the cameras, recharge the batteries and transfer the video data to hard drives. CSIRO will retrieve the camera systems and recorded video data from the vessels at the end of each trial. The original video data will be provided to the respective company owners and NPFI. CSIRO will hold a copy of the video data under a confidentiality project licence agreement to facilitate future data analysis.

The output from this activity is a scientifically robust design for commercial, at-sea trials of gear and technology mitigation measures to reduce sawfish interactions including scope, fishing methods, timing and data collection, collation and analysis methodology, approved by NPFI, AFMA and CSIRO.

The project has delivered a comprehensive and scientifically robust design for at-sea gear/technology trials aimed at identifying potential mitigation options. The trial design included the scope, fishing methods, and data collection, collation and analysis methodology for the sea trials undertaken in 2023 and 2024 as part of a separately funded project.

The outputs of this project - coupled with the outcome of sea trials to be undertaken as part of the separately funded project – will inform potential mitigation measures to reduce sawfish interactions in the NPF and will contribute to addressing the 2022 NPF ADCR condition relating to ETP Outcome 1 (sawfish) and the NPF's current EPBC Act WTO conditions relating to sawfish and sea snakes.

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APPENDIX 1.

Australia's National
Science Agency

Analyses of sawfish and sea snake interactions rates (2010 – 2022) in Australia's Northern Prawn Fishery (NPF)

June 2024

Emma Lawrence and Gary Fry, CSIRO

Contents

Background

Interactions with sawfish and sea snakes Endangered Threatened and Protected (ETP) species are of particular concern in the NPF. Identifying mitigation measures to reduce interactions with these species is an extremely high priority for the fishery. The impacts of fishing on sawfish populations are largely unquantified, however sawfish are known to have a poor ability to escape mesh nets due to their rostrums being snagged on the meshing of trawl gears. Since bycatch reduction devices (BRDs) currently used in trawl fisheries are not effective at reducing sawfish catches, new methods to minimise sawfish bycatch are needed.

Sea Snakes are ETP species found throughout the NPF – the fishery experiences high levels of sea snake interactions each year. Whilst there are currently no NPF Marine Stewardship Council conditions relating to sea snakes, Environment Protection Biodiversity Conservation Act Wildlife Trade Operations conditions are in place for the fishery which must be met by 2024. Anecdotal evidence suggests the fishery-wide adoption of the Tom's Fisheye BRD in 2020 has significantly reduced sea snake interactions, however no analysis of the available data has been undertaken to support this claim.

CSIRO was contracted to:

- conduct a Generalised Linear Model (GLM) analysis of NPF sawfish interactions data (20102022). The objective was to determine whether accounting for variations in vessel, year, season, zone, and gear could reveal any significant differences between vessels using grey mesh TED flaps and vessels using black mesh TED flaps and their interactions with sawfish *and*
- conduct a Generalised Linear Model analysis of NPF sea snake interactions data (2015-2019 and 2020-2022). The objective was to determine whether accounting for variations in vessel, year, season, zone, and gear could still reveal significant differences between the instances of sea snake interactions pre and post the introduction of the Tom's Fisheye.

The aims of this desktop project were to assist industry members operating in the MSC-certified Northern Prawn Fishery to identify potential low-cost measures to reduce sawfish interactions and to quantify the impacts of the Tom's Fisheye BRD on sea snake interactions in NPF fishing operations.

1 Analysis of the differences in sawfish interaction rates in the Northern Prawn Fishery between individual vessels, discrete fishing areas and fishing seasons using different gear/mesh types from 2010 to 2022

1.1 Results

Preliminary analysis of the raw sawfish data interaction rates (*Anoxypristis cuspidata*, *Pristis zijsron, Pristis clavata, Pristis pristis*), (per vessel fishing day/night) showed that grouping the years from 2017 to 2019 and from 2020 to 2022 showed that 85% of vessels reported more interactions within the 2020 to 2022 period, irrespective of TED mesh material used. The total numbers of sawfish caught per vessel per fishing day/night varied over the years with a few high interactionrate days such as in 2020 and 2021 (Figure 1). However, the maximum number of sawfish interactions per km^2 trawled area was relatively stable between vessels per day/night with around 5 to 10 sawfish (Figure 2). The histogram of the distribution of the number of sawfish interactions per year shows that in most of the fishing effort days, interactions were zero (Figure 3). Figure 4 shows the distribution when at least one sawfish interaction occurred and demonstrates that the number was almost always one or two, rarely higher. Interaction rates were consistently low from 2010 to 2019 with between 0.0170 to 0.0476 sawfish interactions per km^2 trawled area (Table 1). However, during 2020 to 2022, interaction rates were considerably higher, ranging from 0.0720 to 0.114 sawfish per km^2 trawled area (Table 1).

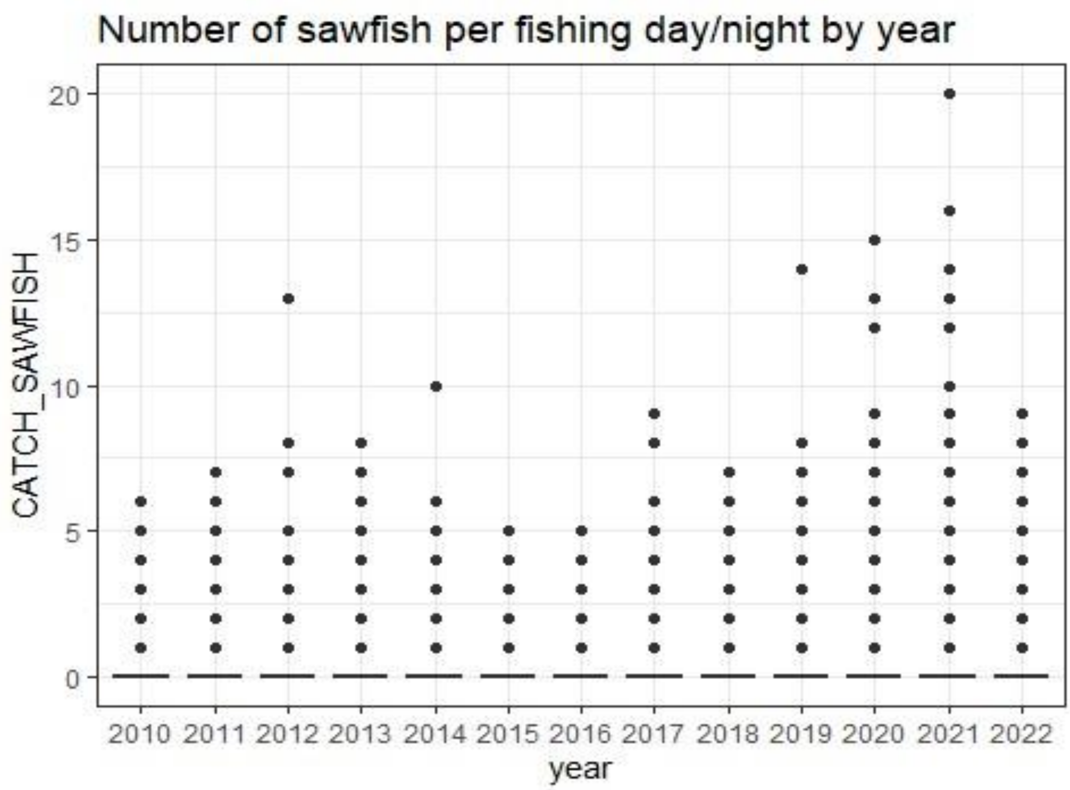

Figure 1: Boxplot of number of sawfish interactions per fishing day by year and vessel.

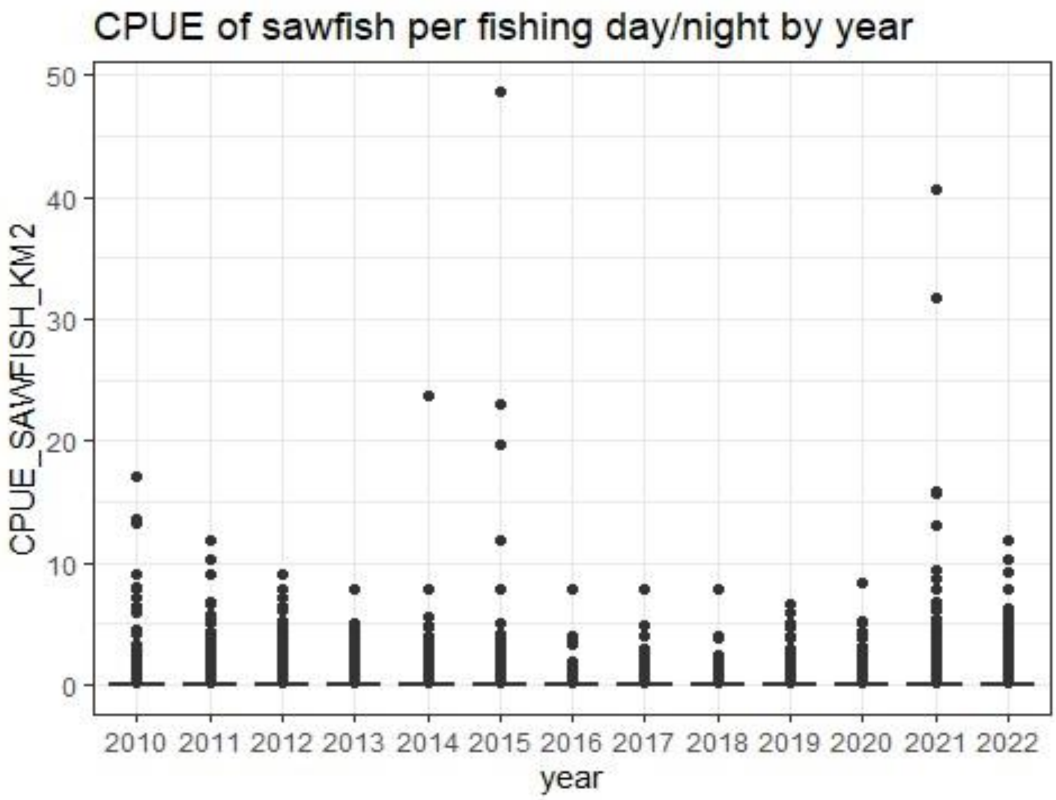

Figure 2: Boxplot of number of sawfish (CPUE) per Km[2] sawfish interactions per fishing day by year and vessel.

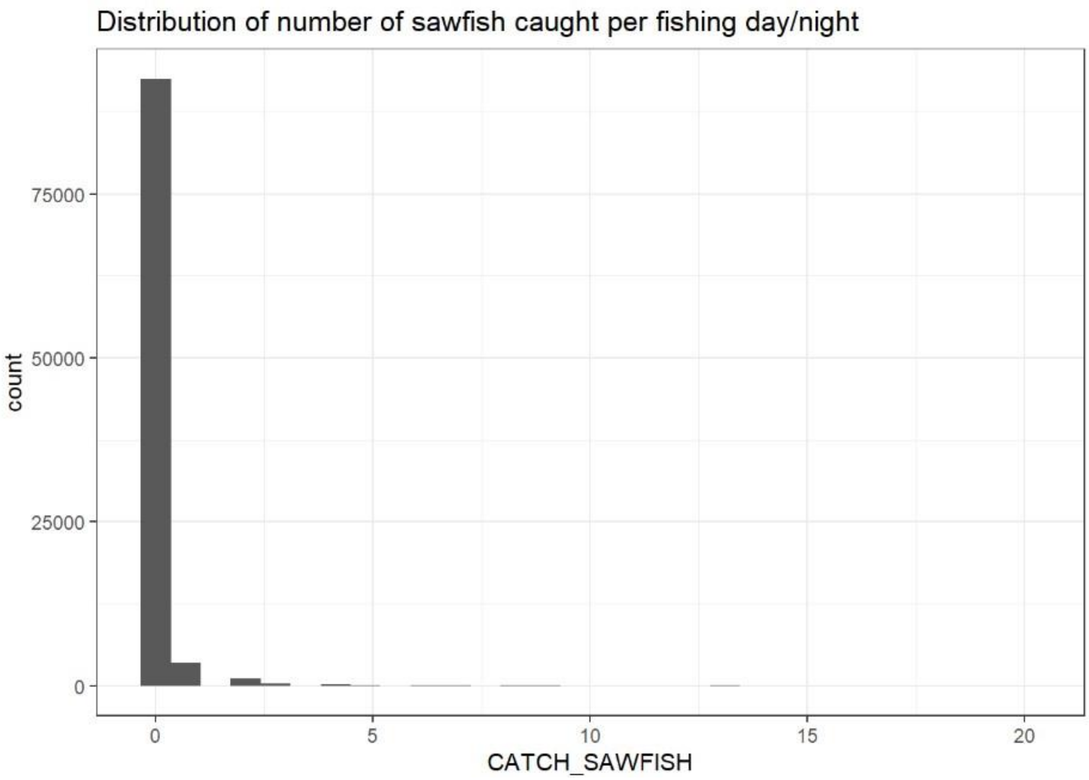

Figure 3: Frequency histogram of number of sawfish interactions per fishing day/night per vessel.

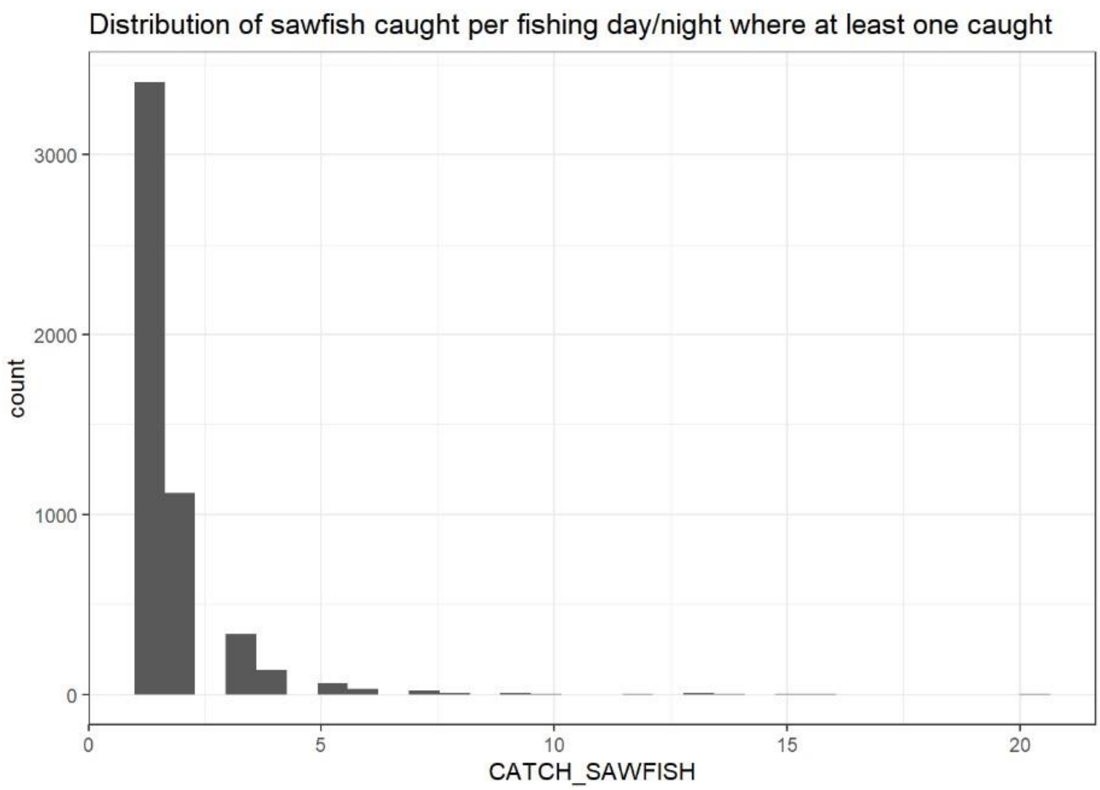

Figure 4: Frequency histogram of number of sawfish interactions per fishing day per vessel where there was one or more interactions.

Table 1: Mean CPUE of sawfish interactions per km^2 by year.

	2010 (N=7929)	2011 (N=7277)	2012 (N=7525)	2013 (N=7767)	2014 (N=8022)	2015 (N=7919)	2016 (N=7768)	2017 (N=7375)	2018 (N=7919)	2019 (N=8054)	2020 (N=7202)	2021 (N=6892)	2022 (N=6050)	Overall (N=97699)
Mean (SD)	0.0384 (0.422)	0.0476 (0.396)	0.0398 (0.325)	0.0434 (0.315)	0.0337 (0.376)	0.0317 (0.683)	0.0170 (0.158)	0.0337 (0.237)	0.0366 (0.256)	0.0365 (0.244)	0.0720 (0.322)	0.114 (0.848)	0.0890 (0.525)	0.0472 (0.429)
Median [Min, Max]	0 [0, 17.0]	0 [0, 11.9]	0 [0, 9.07]	0 [0, 7.92]	0 [0, 23.7]	0 [0, 48.7]	0 [0, 7.92]	0 [0, 7.92]	0 [0, 7.92]	0 [0, 6.61]	0 [0, 8.43]	0 [0, 40.6]	0 [0, 11.9]	0 [0, 48.7]

When comparing interaction rate means by year and TED mesh material type, the highest interaction rates occurred using the All-Grey mesh material, although interaction rates for the Two Black Two Grey combination were similar. The All-Black mesh material and Three Black One Grey mesh material showed considerably lower interaction rates of sawfish (Table 2). The variability (SD) associated with all the measurements is very high relative to the mean.

Table 2: Mean CPUE of sawfish interactions per km^2 by TED mesh type.

	All Black (N=89650)	All Grey (N=4557)	Three Black One Grey (N=1504)	Two Black Two Grey (N=1988)	Overall (N=97699)
Mean (SD)	0.0418 (0.410)	0.123 (0.522)	0.0517 (0.159)	0.114 (0.888)	0.0472 (0.429)
Median [Min, Max]	0 [0, 48.7]	0 [0, 15.6]	0 [0, 1.98]	0 [0, 31.7]	0 [0, 48.7]

Due to the skewed data with most fishing days having zero sawfish interactions, the proportion of fishing day/nights with at least one sawfish interaction by year and BRD material was analysed separately. These results showed that increased interaction rates of sawfish when using trawl nets with Grey Mesh TED flaps is consistent through time. During the period 2020 to 2022, around twice as many trawls interacted with at least one sawfish compared to the period from 2010 to 2019 (Table 3). The frequency in sawfish interactions when trawls had the Grey Mesh TED flaps were also more than twice that of trawls with Black Mesh TED flaps (Table 4 and 5).

Table 3: Proportion of fishing days with at least one sawfish interaction by year.

	2010 (N=7929)	2011 (N=7277)	2012 (N=7525)	2013 (N=7767)	2014 (N=8022)	2015 (N=7919)	2016 (N=7768)	2017 (N=7375)	2018 (N=7919)	2019 (N=8054)	2020 (N=7202)	2021 (N=6892)	2022 (N=6050)	Overall (N=97699)
Mean (SD)	0.0288 (0.167)	0.0416 (0.200)	0.0409 (0.198)	0.0438 (0.205)	0.0364 (0.187)	0.0290 (0.168)	0.0281 (0.165)	0.0438 (0.205)	0.0525 (0.223)	0.0489 (0.216)	0.105 (0.307)	0.104 (0.306)	0.100 (0.301)	0.0526 (0.223)
Median [Min, Max]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]

Table 4: Proportion of fishing days with at least one sawfish interaction by TED Mesh Material from 2010 to 2022.

	All Black (N=89650)	All Grey (N=4557)	Three Black One Grey (N=1504)	Two Black Two Grey (N=1988)	Overall (N=97699)
Prop_sawfish					
Mean (SD)	0.0450 (0.207)	0.152 (0.359)	0.122 (0.328)	0.116 (0.321)	0.0526 (0.223)
Median [Min, Max]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]

Table 5: CPUE per km^2 sawfish interactions by mesh type for years 2019 to 2022.

	2019		2020			2021			2022		overall			
	All Black (N=7271)	All Grey (N=783)	All Black (N=4962)	All Grey (N=736)	Three Black One Grey (N=1504)	All Black (N=4252)	All Grey (N=652)	Two Black Two Grey (N=1988)	All Black (N=3664)	All Grey (N=2386)	All Black (N=20149)	All Grey (N=4557)	Three Black One Grey (N=1504)	Two Black Two Grey (N=1988)
Mean (SD)	0.0338 (0.229)	0.0620 (0.358)	0.0687 (0.339)	0.135 (0.430)	0.0517 (0.159)	0.0920 (0.822)	0.257 (0.873)	0.114 (0.888)	0.0800 (0.566)	0.103 (0.455)	0.0631 (0.499)	0.123 (0.522)	0.0517 (0.159)	0.114 (0.888)
Median [Min, Max]	0 [0, 6.61]	0 [0, 5.86]	0 [0, 8.43]	0 [0, 5.21]	0 [0, 1.98]	0 [0, 40.6]	0 [0, 15.6]	0 [0, 31.7]	0 [0, 11.9]	0 [0, 11.9]	0 [0, 40.6]	0 [0, 15.6]	0 [0, 1.98]	0 [0, 31.7]

Generalised Linear Mixed Models (GLMM) were fitted to the Sawfish interaction data to determine which was the best fit, and whether the TED mesh material had a significant effect on catch rates. Fitting GLMMs to the data is important because it helps to standardise the data for differences in the fishing effort by factors like year and zone. Each model had the same basic terms with catch as the response and then an offset for effort, fixed effects for year, zone, season, TED Mesh Material, TED orientation and a random effect for vessel. All the models were fit using the GLMMTMB package in R. The distributions of the models were different, and the fit and model diagnostics were checked to determine which fit best. The models tested were:

1. Poisson GLMM
2. A Poisson hurdle GLMM (the number of sawfish caught is modelled conditional on the probability of encountering a zero-observation allowing for separate processes between the two model components).
3. A negative binomial hurdle GLMM (as above but with a Negative binomial distribution rather than Poisson for the count component).

The model with the best fit and lowest AIC was the negative binomial hurdle GLMM (the BRD type was later dropped as it caused model fitting problems and would have little effect on sawfish catches anyway).

```
##   Family: truncated_nbinom2   (
log ) ## Formula:
##  CATCH_SAWFISH  ~  offset(log(Swept_Area_km2))  +  year  +
zone_name  +    ##         season  +  TED_Mesh_Material  +  (1  |
vessel_name) ## Zero  inflation:                  ~.
```

```
## Data: SS_data[SS_data$TED_Mesh_Material %in% c("All Black", "All Grey"),
] ##
##      AIC      BIC   logLik deviance df.resid
##   42662.3   43238.9  -21270.1   42540.3
94146  ##
## Random effects:
##
## Conditional model:
##  Groups      Name        Variance Std.Dev.
##  vessel_name (Intercept) 0.3419   0.5847
##   Number   of   obs:   94207,   groups:
vessel_name, 69 ##
## Zero-inflation model:
##  Groups      Name        Variance Std.Dev.
##  vessel_name (Intercept) 0.8641   0.9295
## Number of obs: 94207, groups:  vessel_name, 69
##
## Dispersion parameter for truncated_nbinom2 family ():
0.43  ##
## Conditional model:
##                                Estimate Std. Error z value
Pr(>|z|)
## (Intercept)                   -0.728900   0.237093  -3.074
0.002110 **
## year2011                      -0.124666   0.181244  -0.688
0.491558
## year2012                      -0.259428   0.179506  -1.445
0.148393    ## year2013                    -0.347498   0.182315
-1.906 0.056646 .
## year2014                      -0.414529   0.189194  -2.191
0.028450 *
## year2015                 -0.833664   0.208541  -3.998 6.40e-
05 ***
## year2016                 -0.829088   0.207610  -3.993 6.51e-
05 ***
## year2017                      -0.460853   0.183926  -2.506
0.012223 *
## year2018                      -0.652929   0.176212  -3.705
0.000211 ***
## year2019                      -0.475426   0.176380  -2.695
0.007029 **
## year2020                      -0.483671   0.167249  -2.892
0.003829 **
## year2021                      -0.174217   0.174419  -0.999
0.317872
## year2022                      -0.568875   0.179282  -3.173
0.001508 **
## zone_nameBOLD                 -0.412430   0.203344  -2.028
0.042535 *
## zone_nameBONAPARTE           -0.356414   0.166888  -2.136
0.032708 *
## zone_nameEDWARD                0.107351   0.216698   0.495
0.620323
## zone_nameFOG BAY               0.040896   0.215238   0.190
0.849306
## zone_nameGOVE                 -0.518580   0.176985  -2.930
0.003389 **
```

```
## zone_nameGROOTE              -0.408846    0.169094   -2.418
0.015612 *
## zone_nameKEERWEER            -0.878738    0.372787   -2.357
0.018413 *
## zone_nameLIMMEN BIGHT     -1.023701   0.184363  -5.553 2.81e-
08 ***
## zone_nameMELVILLE            -0.184784    0.154596   -1.195
0.231982
## zone_nameMITCHELL            -0.002747    0.248142   -0.011
0.991169
## zone_nameMORNINGTON          -0.391262    0.176568   -2.216
0.026696 *
## zone_namePORT ESSINGTON     -0.173643    0.158217   -1.097
0.272424
## zone_nameSWEERS              -0.708555    0.259693   -2.728
0.006364 **
## zone_nameWEIPA               -0.502958    0.203194   -2.475
0.013314 *
## season2                   -1.004955   0.082799 -12.137  < 2e-
16 *** ## TED_Mesh_MaterialAll Grey -0.094888   0.145343  -0.653
0.513851    ## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' '
1
```

```
## Zero-inflation model:
##                                  Estimate Std. Error z value
Pr(>|z|)
## (Intercept)              3.44208    0.15641  22.007  < 2e-
16 ***
## year2011                     -0.34511     0.09138   -3.777
0.000159 ***
## year2012                     -0.33700     0.09106   -3.701
0.000215 ***
## year2013                 -0.41273    0.08943  -4.615 3.93e-
06 *** ## year2014               -0.15334    0.09215  -1.664
0.096117 .
## year2015                      0.06580     0.09731    0.676
0.498958
## year2016                      0.06650     0.09864    0.674
0.500183
## year2017                 -0.37383    0.09074  -4.120 3.79e-
05 ***
## year2018                 -0.54028    0.08666  -6.234 4.54e-
10 ***
## year2019                 -0.47490    0.08847  -5.368 7.96e-
08 ***
## year2020                 -1.14536    0.08521 -13.441  < 2e-
16 ***
## year2021                 -1.15089    0.08821 -13.047  < 2e-
16 ***
## year2022                 -0.89612    0.09185  -9.757  < 2e-
16 ***
## zone_nameBOLD             0.79261    0.10475   7.567 3.83e-
14 ***
```

```
## zone_nameBONAPARTE          -0.10436      0.09429   -1.107
0.268390
## zone_nameEDWARD              0.17463      0.11875    1.471
0.141391      ## zone_nameFOG BAY          0.20944    0.11971
1.750 0.080189 .
## zone_nameGOVE             0.41362    0.09197    4.497 6.89e-
06 ***
## zone_nameGROOTE           0.85619    0.08921    9.598  < 2e-
16 ***
## zone_nameKEERWEER            0.27289      0.16673    1.637
0.101678
## zone_nameLIMMEN BIGHT      1.15268    0.09131  12.624  < 2e-
16 ***
## zone_nameMELVILLE            0.02711      0.08776    0.309
0.757354
## zone_nameMITCHELL            0.17133      0.12907    1.327
0.184370
## zone_nameMORNINGTON       0.67903    0.09380    7.239 4.52e-
13 *** ## zone_namePORT ESSINGTON   -0.16941    0.08941  -1.895
0.058120 .
## zone_nameSWEERS           1.10719    0.12752    8.683  < 2e-
16 ***
## zone_nameWEIPA            0.81434    0.10339    7.877 3.36e-
15 ***
## season2                      -0.09375     0.04224   -2.220
0.026448 *    ## TED_Mesh_MaterialAll Grey -0.37511    0.07157
-5.241 1.60e-07 *** ## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '
' 1
```

1.2 Conclusion

The binomial model which models the probability of a zero catch on any given fishing day/night, showed that after accounting for differences in interaction rates by year, zone and season, vessels using the grey mesh had a significantly greater change of interacting with a sawfish compared to vessels using the black mesh. However when at least one sawfish was recorded in a trawl, there was no significant difference in the interaction rate between the grey mesh and black mesh. This is not surprising given only one or two sawfish interactions occur per fishing day.

It wasn't straight-forward to estimate the increase in interaction rate due to the introduction of grey mesh material as it requires making assumptions about the distribution of fishing effort and the factors associated with that effort. However, averaging the results over year, zone and season, the sawfish interaction rates on vessels using grey mesh was approximately 37% higher than vessels using black mesh. It is important to interpret this estimate with care as it does not mean that 37% more sawfish interactions occurred via the introduction of grey mesh. Rather it provides an estimate of the relative difference between the grey mesh and black mesh used across the fishery.

2 Analysis of the data on sea snake interactions collected during the 2018 Tom's Fisheye at-sea trial and identify and quantify the impact of the pre and post Tom's Fisheye BRD implementation (2015-2019 and 2020-2022) on sea snake interactions (including any percentage reductions) between fishing seasons/years since the adoption of the Tom's Fisheye in 2020

2.1 Results

The total numbers of sea snake interactions per vessel per fishing day/night was generally less than 20 from 2010 to 2016 and up to 30 from 2017 to 2022 (Figure 5). However, when looking at the number of sea snake interactions per km2 trawled area, years 2014, 2015 and 2016 showed higher interaction rates compared to other years, especially in 2015 with more than 500 sea snakes estimated in a km2 trawled area (Table 6, Figure 6). These high interaction rates were a result of catching 6 – 8 sea snakes in trawls of very short duration (2 minutes) in the banana prawn season. Most prawn trawls interacted with no sea snakes between 2010 and 2022 (Figure 7). However, when sea snake interactions occurred, most trawls interacted with two individuals (Figure 8).

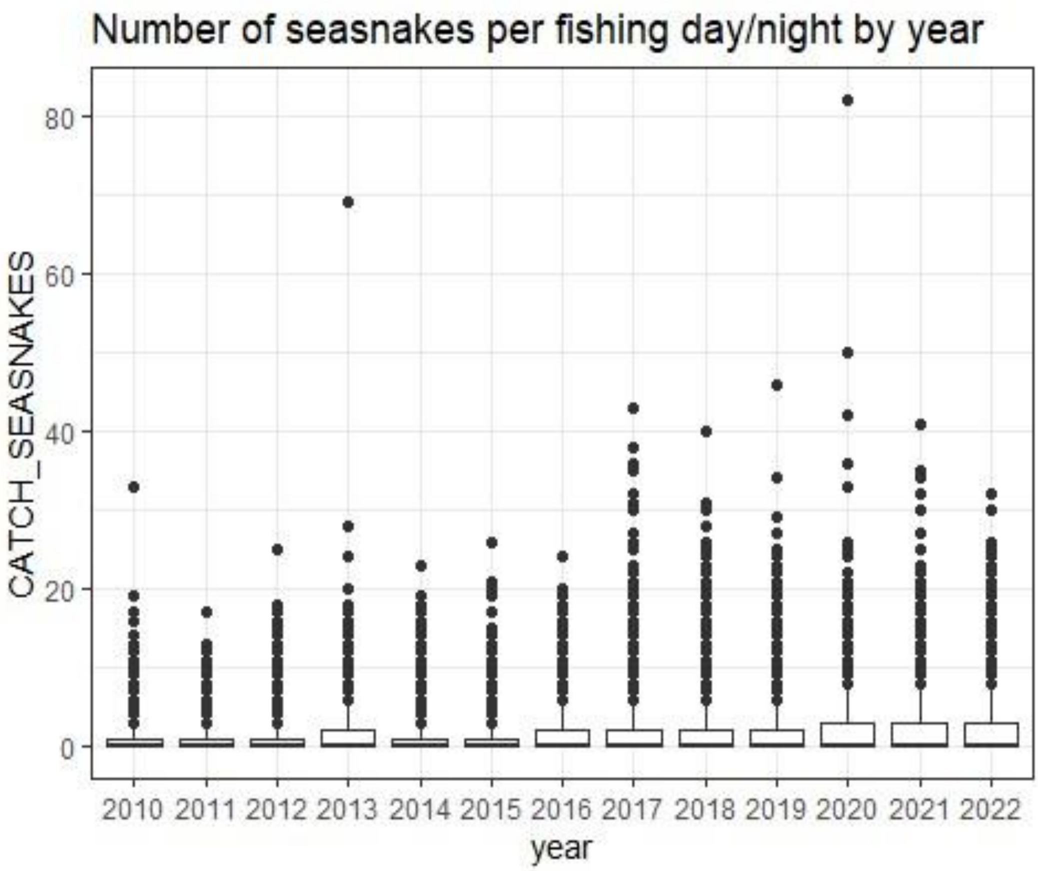

Figure 5: Boxplot of sea snake interactions per fishing day/night per vessel by year (*Source: NPFI MSC grant dataset, CSIRO*).

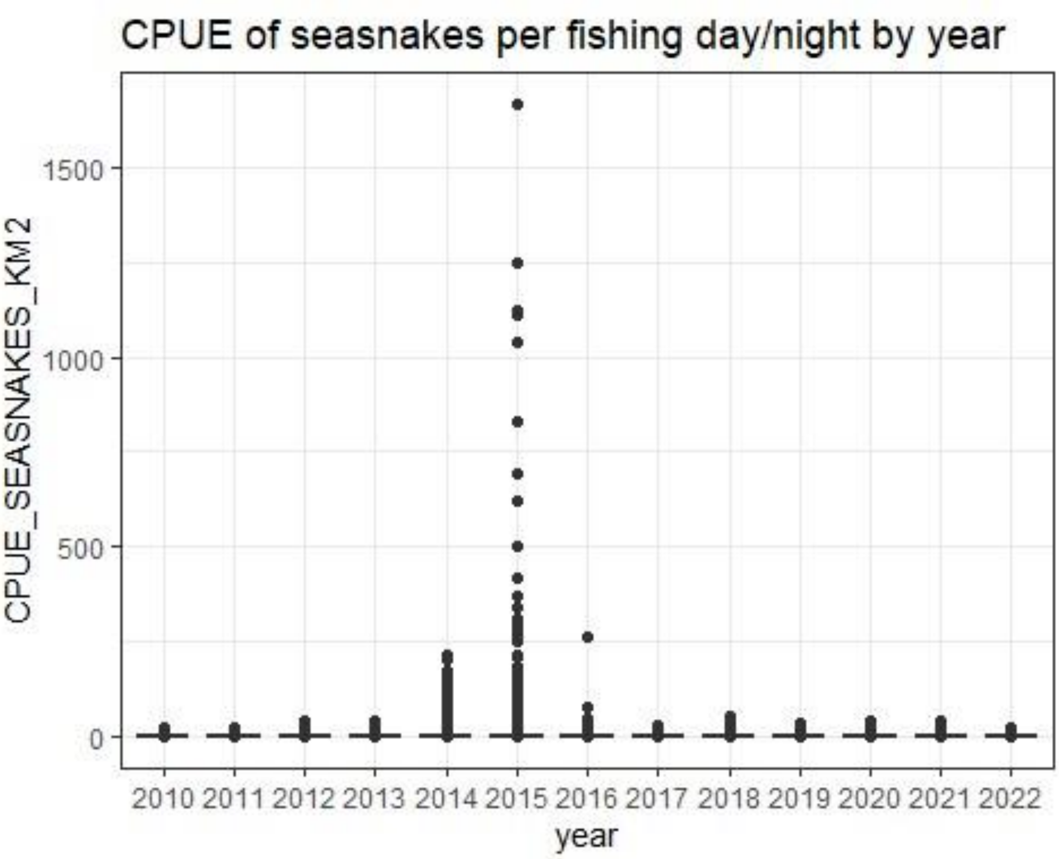

Figure 6: Boxplot of sea snake Catch Per Unit Effort (CPUE_SEASNAKES_KM2) fishing day/night per vessel by year (*Source: NPFI MSC grant dataset, CSIRO*).

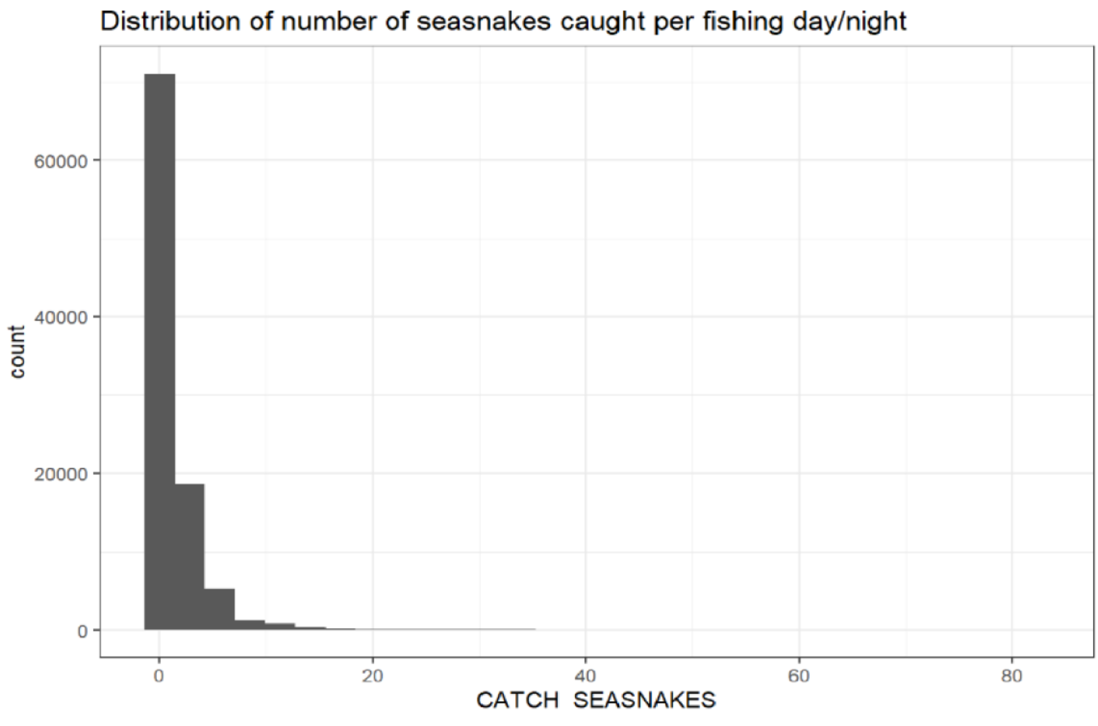

Figure 7: Frequency histogram of catch numbers of sea snake per fishing day/night per vessel from 2010 to 2022 (*Source: NPFI MSC grant dataset, CSIRO*).

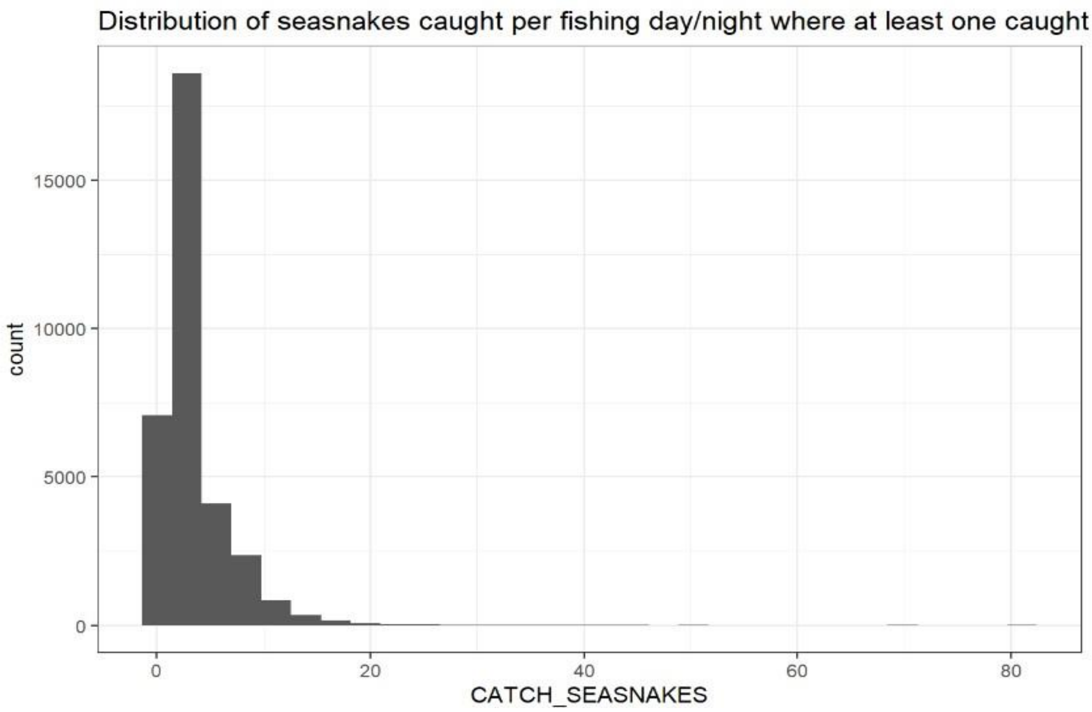

Figure 8: Frequency histogram of catch numbers of sea snake per fishing day/night per vessel from 2010 to 2022 where at least one sea snake was caught (*Source: NPFI MSC grant dataset, CSIRO*).

The highest mean interactions of sea snakes was seen in 2015 with nearly five snakes per km^2 trawled area, followed by 2014 where mean interactions were around 1.3 snakes per km^2 trawled area (Table 6). Interaction rates were also high in the period of 2020 to 2022, ranging from 0.770 to 0.887 sea snakes per km^2 trawled area. When comparing BRD performance in mean interactions of sea snakes, the Yarrow Fisheye showed the highest interaction rates (1.48 se snakes per km^2 trawled area) followed by the most commonly used BRD; Square mesh Panel

(SMP), with 1.23 sea snakes per km^2 trawled area. The combination of Fisheye and FishEX70 and the Kons Covered Fisheyes (KCF) showed no interactions of sea snakes and interactions were also low with the combination of Kons Covered Fisheyes (KCF) and Tom's Fisheye; interaction rates of 0.091 sea snakes per km^2 trawled area. However, there were low sample numbers across most gear combinations making it difficult to determine any clear outcomes. Therefore, the BRDs were categorised into only three groups, Tom's Fisheye (TOMS), no Tom's Fisheye used (NOT_TOMS) and some combination of Tom's Fisheye and another BRD (OTHER) for further analysis as Tom's Fisheye is currently the most commonly used BRD in the fishery.

The proportion of fishing day/nights where sea snake interactions occurred is similar across years (30 – 40%). There is a slight increase from 2020 to 2022 with 40 – 50% of fishing days/nights interacting with sea snakes (Table 7).

Table 6: Catch Per Unit Effort (sea snake per km2 trawl area) of sea snakes from 2010 to 2022 and across BRD Type (*Source: NPFI MSC grant dataset, CSIRO*).

	2010 (N=7929)	**2011 (N=7277)**	**2012 (N=7525**	**2013 (N=7767**	**2014 (N=8022**	**2015 (N=7919)**	**2016 (N=7768)**	**2017 (N=7375**	**2018 (N=7919**	**2019 (N=8054**	**2020 (N=7202**	**2021 (N=6892**	**2022 (N=6050)**	**Overall (N=97699**
Mean (SD)	0.543 (1.38)	0.425 (1.23)	0.542 (1.60)	0.522 (1.54)	1.32 (9.82)	4.96 (43.6)	0.475 (3.38)	0.496 (1.26)	0.670 (1.97)	0.566 (1.52)	0.770 (1.80)	0.887 (1.92)	0.760 (1.50)	1.01 (12.9)

Median [Min, Max]	0 [0, 25.6]	0 [0, 23.8]	0 [0, 39.2]	0 [0, 42.9]	0 [0, 216]	0 [0, 1670]	0 [0, 265]	0 [0, 28.7]	0 [0, 52.6]	0 [0, 37.9]	0 [0, 41.6]	0 [0, 39.6]	0 [0, 23.8]	0 [0, 1670]

	Fisheye (N=6454)	**Fisheye/FishEX70 (N=109**	**Fisheye/Toms Fisheye (N=334)**	**KCF (N=95)**	**KCF/Toms Fisheye (N=110)**	**SMP (N=66276)**	**SMP&SKCFx2/KCFx2 (N=104)**	**SMP/FishEX70 (N=3930)**	**SMP/KCF (N=409)**	**SMP/Toms Fisheye (N=3757)**	**SMPx2/KCFx1/Toms Fisheyex1 (N=335)**	**Toms Fisheye (N=15125)**	**Yarrow Fisheye (N=222)**	**Yarrow/FishEX70 (N=439)**	**Overall (N=97699)**
Mean (SD)	0.445 (1.78)	0 (0)	0.569 (0.981)	0 (0)	0.0911 (0.274)	1.23 (15.6)	1.12 (1.26)	0.508 (0.896)	0.629 (1.14)	0.465 (0.896)	0.418 (0.696)	0.637 (1.03)	1.48 (3.60)	0.228 (0.413)	1.01 (12.9)
Median [Min, Max]	0 [0, 48.7]	0 [0, 0]	0 [0, 5.12]	0 [0, 0]	0 [0, 1.15]	0 [0, 1670]	0.703 [0, 6.32]	0 [0, 10.6]	0 [0, 9.23]	0 [0, 10.4]	0 [0, 2.96]	0 [0, 19.5]	0 [0, 27.4]	0 [0, 1.76]	0 [0, 1670]

Table 7: Proportion of fishing day/nights with any sea snake catch by year and BRD type from 2010 to 2022 (*Source: NPFI MSC grant dataset, CSIRO*).

	2010 (N=7929)	**2011 (N=7277)**	**2012 (N=7525)**	**2013 (N=7767)**	**2014 (N=8022)**	**2015 (N=7919)**	**2016 (N=7768)**	**2017 (N=7375)**	**2018 (N=7919)**	**2019 (N=8054)**	**2020 (N=7202)**	**2021 (N=6892)**	**2022 (N=6050)**	**Overall (N=97699)**
Mean (SD)	0.344 (0.475)	0.282 (0.450)	0.326 (0.469)	0.337 (0.473)	0.281 (0.449)	0.289 (0.453)	0.323 (0.468)	0.312 (0.463)	0.353 (0.478)	0.319 (0.466)	0.432 (0.495)	0.471 (0.499)	0.458 (0.498)	0.345 (0.475)
Median [Min, Max]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]

	Fisheye (N=6454)	**Fisheye/FishEX70 (N=109)**	**Fisheye/Toms Fisheye (N=334)**	**KCF (N=95)**	**KCF/Toms Fisheye (N=110)**	**SMP (N=6627 6)**	**SMP&SKCFx2/KCFx2 (N=104)**	**SMP/FishEX70 (N=3930)**	**SMP/KCF (N=409)**	**SMP/Toms Fisheye (N=3757)**	**SMPx2/KCFx1/Toms Fisheyex1 (N=335)**	**Toms Fisheye (N=15125)**	**Yarrow Fisheye (N=222)**	**Yarrow/Fi shEX70 (N=439)**	**Overall (N=97699)**
Mean (SD)	0.246 (0.431)	0 (0)	0.377 (0.485)	0 (0)	0.109 (0.313)	0.316 (0.465)	0.769 (0.423)	0.419 (0.493)	0.423 (0.495)	0.375 (0.484)	0.331 (0.471)	0.490 (0.500)	0.324 (0.469)	0.308 (0.462)	0.345 (0.475)
Median [Min, Max]	0 [0, 1.00]	0 [0, 0]	0 [0, 1.00]	0 [0, 0]	0 [0, 1.00]	0 [0, 1.00]	1.00 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]

While the interaction rates were considerably higher when the Tom's Fisheye was not used (NOT_TOMS) (Table 8), the incidence of any sea snake interaction was higher when the Tom's Fisheye was used (Table 9). Vessels with the Tom's Fisheye appeared to interact with sea snakes more often than vessels not using Tom's Fisheye. This could be a result of significantly more vessels using Tom's Fisheye from 2020 onwards and only during the Tiger Prawn season where sea snake interactions were probably much higher than in the Banana Prawn season. Furthermore, from 2020 onwards when Toms Fisheye was the most commonly used BRD in the fishery, there has been an improvement in catch reporting for TEPs in logbook. The data was then analysed using a GLMM to account for other factors that might affect interaction rates of sea snakes.

Table 8: Catch Per Unit Effort of sea snakes from 2019 to 2022 by the three BRD categories (*Source: NPFI MSC grant dataset, CSIRO*).

	NOT_TOMS (N=8537)	OTHER (N=4536)	TOMS (N=15125)	Overall (N=28198)
Mean (SD)	1.07 (2.67)	0.460 (0.882)	0.637 (1.03)	0.738 (1.70)
Median [Min, Max]	0 [0, 41.6]	0 [0, 10.4]	0 [0, 19.5]	0 [0, 41.6]

Table 9: Proportion of fishing day/nights with any sea snake catch from 2019 to 2022 by each of the three BRD categories (*Source: NPFI MSC grant dataset, CSIRO*).

	NOT_TOMS (N=8537)	OTHER (N=4536)	TOMS (N=15125)	Overall (N=28198)
Mean (SD)	0.309 (0.462)	0.365 (0.482)	0.490 (0.500)	0.415 (0.493)
Median [Min, Max]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]	0 [0, 1.00]

Generalised Linear Mixed Models (GLMM) were fitted to the sea snake interaction data to determine which was the best fit to determine whether the different BRD types had a significant effect on interaction rates of sea snakes. Each model had the same basic terms with catch as the response and then an offset for effort, fixed effects for year, zone, season, TED orientation and BRD type and a random effect for vessel. All the models were fit using the GLMMTMB package in R. The distributions of the models were different and the fit and model diagnostics were checked to determine which fit best. The models tested were:

1. A Poisson GLMM
2. A Negative binomial GLMM

Having season in the model resulted in some strange results, this is because Tom's Fisheye was not used frequently in the Banana Prawn season as it is only a requirement to use when vessels are targeting tiger prawns, so the season term was dropped. The model with the best fit and lowest AIC was the negative binomial GLMM.

```
Family: nbinom2  ( log )
Formula:          CATCH_SEASNAKES ~ offset(log(Swept_Area_km2)) + 0 +
year + zone_name +      TED_orientation + Toms + (1 | vessel_name) Data:
SS_data[SS_data$Toms %in% c("TOMS", "NOT_TOMS"), ]


      AIC       BIC    logLik  deviance  df.resid
 243723.4  244016.1 -121830.7  243661.4     93132

Random effects:


Conditional model:
Groups      Name        Variance Std.Dev.
vessel_name (Intercept) 1.711    1.308
Number of obs: 93163, groups:  vessel_name,
69
Dispersion parameter for nbinom2 family (): 0.376


Conditional model:
```

```
                              Estimate Std. Error z value Pr(>|z|)
year2010                        -1.11716    0.16944  -6.593 4.30e-11
*** year2011                       -1.46697    0.16957  -8.651  < 2e-
16 *** year2012                           -1.28110     0.16933  -7.566
3.86e-14 *** year2013                           -1.27535     0.16909  -
7.542 4.61e-14 *** year2014                          -1.25783    0.16938
-7.426 1.12e-13 *** year2015                         -1.11151    0.16938
-6.562 5.30e-11 *** year2016                         -1.27325    0.16883
-7.542 4.64e-14 *** year2017                         -1.24435    0.16682
-7.459 8.70e-14 *** year2018                         -1.24842    0.16672
-7.488 6.98e-14 *** year2019                         -1.23418    0.17004
-7.258 3.92e-13 *** year2020                         -0.87213    0.16855
-5.174 2.29e-07 *** year2021                         -0.60224    0.16877
-3.568 0.000359 *** year2022                         -0.64349    0.16902
-3.807 0.000141 *** zone_nameBOLD                     0.75665    0.05254
14.401  < 2e-16 *** zone_nameBONAPARTE               -0.30683    0.05510
-5.568 2.57e-08 *** zone_nameEDWARD                   1.02733    0.06351
16.175  < 2e-16 *** zone_nameFOG BAY                  0.25004    0.06886
3.631 0.000282 *** zone_nameGOVE                     -0.56620    0.05133
-11.031  < 2e-16 *** zone_nameGROOTE                  0.25063    0.04696
5.337 9.46e-08 *** zone_nameKEERWEER                  1.13503    0.08604
13.192  < 2e-16 *** zone_nameLIMMEN BIGHT            -0.23413    0.04777
-4.902 9.50e-07 *** zone_nameMELVILLE                 0.23043    0.05065
4.549 5.38e-06 *** zone_nameMITCHELL                  1.14194    0.06806
16.779  < 2e-16 *** zone_nameMORNINGTON              -0.29967    0.05094
-5.882 4.04e-09 *** zone_namePORT ESSINGTON          -0.03749    0.05307
-0.706 0.479897     zone_nameSWEERS                   0.26924    0.05633
4.779 1.76e-06 *** zone_nameWEIPA                     0.74720    0.05219
14.318  < 2e-16 *** TED_orientationTop Escape -0.05433    0.02876
-1.889 0.058885 .
TomsTOMS                      -0.17982    0.03342  -5.380 7.44e-08 ***
```

2.2 Conclusion

The model output shows the parameter estimates and P-values for the catch of sea snakes based on the negative binomial model. The model indicates significant differences between years and regions. The catch rates of sea snakes were significantly lower when using Tom’s Fisheye. (*Source: NPF Sawfish, Sea Snake and Fishing Gear Database*).

The model indicates significant differences between years and regions, which is not surprising given fishing effort changes from year to year. The interaction rates of sea snakes were significantly lower when using Tom’s Fisheye. It isn’t straight-forward to estimate the decrease in interaction rate due to the introduction of Tom’s Fisheye as it requires making assumptions about the distribution of fishing effort and the factors associated with that effort. However, averaging the results over the levels of year, zone_name and TED_orientation, the interaction rates when using Tom’s Fisheye was approximately 17% lower than when not using Tom’s Fisheye. By averaging across all these factors, we eliminate any potential biases when analysing interactions between vessels and sea snakes. Therefore, the observed 17% reduction in interaction rates reflects what could be expected using Toms’ Fisheye if all conditions were equal at any given moment, such as if the fishery had equal effort across region, season and year and vessels fishing with different TED orientation. It is important to interpret this estimate with care as it does not mean that 17% less sea snakes interactions occurred via the introduction of Tom’s Fisheye, in fact the raw interaction rates were 40% lower. It does show that the development and introduction of new innovations in trawl gear design can reduce interactions with ETP species in the NPF.

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