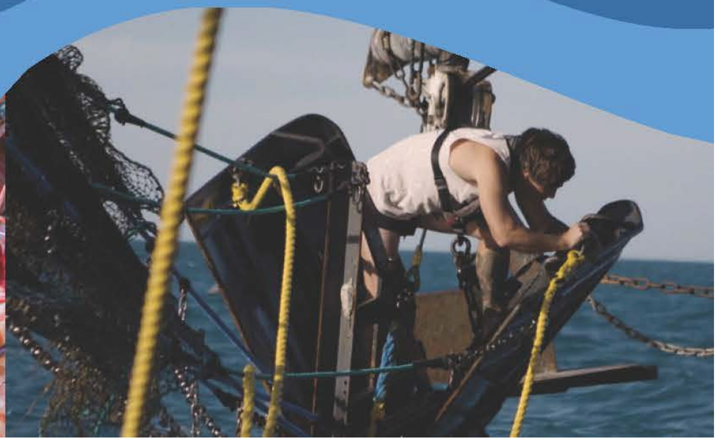
NPF Tiger Prawn Fishery Adaptation Strategy Workshop Report

23rd - 24th February 2023
Brisbane

FRDC FISHERIES RESEARCH AND DEVELOPMENT CORPORATION

Australian Government
Australian Fisheries Management Authority

NPF



NPF TIGER PRAWN FISHERY ADAPTATION STRATEGY WORKSHOP REPORT

NPF Tiger Prawn Fishery Adaptation Strategy workshop
[2022-096] [2023]

This publication (and any information sourced from it) should be attributed to Annie Jarrett, Dr. Ian Knuckey, Dr. Kevin Stokes, Brandon Meteyard, Brodie Macdonald, Jeremy Smith, Darci Wallis, Sarah Kirkcaldie & Cate Coddington. 2023. *NPF Tiger Prawn Fishery Adaptation Strategy Workshop Report*, Final Report to FRDC, Canberra, October 2023, CC BY 3.0

Researcher Contact Details		FRDC Contact Details	
Name:	Ms Annie Jarrett	Address:	25 Geils Court Deakin ACT 2600
Address:	NPF Industry Pty Ltd PO Box 756 Caloundra Qld 4551	Phone:	02 6285 0400
Phone:	+ 61 411426469	Fax:	02 6285 0499
Email:	ceo@npfindustry.com.au	Email:	frdc@frdc.com.au
		Web:	www.frdc.com.au

Cover photos provided by: NPF Industry Pty Ltd

Acknowledgements

The Traditional Owners of the land, sea and waters across Australia are respectfully acknowledged, including the Yuggera and the Turrbal People on whose land the workshop was held. We acknowledge the continuing connection that First Nations Peoples have to their culture and pay our respects to Elders past and present and emerging.

The Authors would like to acknowledge all those who contributed to shaping this report including all workshop participants, some of whom came on their own time (including Dwane Klinkhamer, Ben Croft, Stuart Nisbet, Dr. Cathy Dichmont and Dr. Thor Saunders). This workshop wouldn't have been as successful but for all of the work undertaken by CSIRO and others beforehand to ensure that the information needed was provided to participants in the form of factsheets, these include those at the workshop (see participant list) but also those behind the scenes including: Laura Blamey, Anthea Donovan, Gary Fry, Rob Kenyon, Yeming Lei, Margaret Miller, Chris Moeseneder, Kinam Salee, Mark Tonks, Judy Upston and Tonya van der Velde, André Punt, Roy Deng, Trevor Hutton, Sean Pascoe, Éva Plagányi, Shijie Zhou, and Trevor Hutton.

Executive Summary

The Northern Prawn Fishery operates over a considerable expanse off Australia's northern coast. The fishery has been managed with a combination of voluntary buybacks, internal industry restructuring, and compulsory acquisition programs, resulting in a significant reduction in the number of licenses from 302 in 1985 to 52 in 2007.

The Northern Prawn Fishery targets two main prawn species: banana prawns and tiger prawns. The tiger prawn fishery is particularly important, and its management relies on a sophisticated stock assessment model that uses a weekly time series of data to predict optimal effort and catch trajectories required to achieve long-term maximum economic yield for the fishery.

A workshop was held to improve the biological and economic performance of the Northern Prawn Fishery by identifying concerns and trends regarding the productivity of the tiger prawn fishery, deficiencies in the tiger prawn stock assessment model/s and data collection framework that impede the Northern Prawn Fishery meeting management objectives including legislative requirements and Marine Stewardship Council certification, and key projects that will address the deficiencies above to improve the tiger prawn stock assessment model/s.

The outputs and outcomes from this project will assist the Northern Prawn Fishery Resource Assessment Group and Management Advisory Committee to respond to the Australian Fisheries Management Authority Commission's request that climate change impacts are considered at future by all Australian Fisheries Management Authority resource assessment groups and management advisory committees.

Keywords: Northern Prawn Fishery; maximum economic yield; stock assessment; climate change

Contents

Background

The Northern Prawn Fishery (NPF) occupies an area of 780 000 square kilometres off Australia's northern coast. It extends from the low water mark to the outer edge of the Australian Fishing Zone (AFZ) along approximately 6 000 kilometres of coastline between Cape York in Queensland and Cape Londonderry in Western Australia.

While the NPF covers a wide area, only around 11% of the total NPF area is fished with the major trawl grounds of the NPF being in the Gulf of Carpentaria and the area to the north and south-west of Darwin. Through a combination of voluntary buybacks, internal industry restructuring/adjustments and compulsory acquisition programs, the number of licences in the fishery has been reduced from 302 in 1985, to 132 by 2000 to the current number of 52 by 2007. Catch and effort in the fishery has varied considerably as the number of boats operating in the fishery has changed over time. There are two major sub-fisheries in the NPF: first season targeting Banana Prawns, whose highly variable stock abundance and catches are largely driven by monsoonal rainfall; the second season targeting the less variable stocks of tiger prawns. The workshop was focused on the second season tiger prawn fishery.

The stock assessment model used for the NPF Tiger prawn fishery is critical to providing robust science-based advice on the status of the key target species (grooved and brown tiger prawns) and the major byproduct species (blue and red endeavour prawns) to support management of the fishery. The Tiger prawn stock assessment model comprises four (4) separate models including tiger prawns, endeavour prawns, stock recruitment and E_{mey} level determination models. Several stock assessment methods for the tiger prawn fishery have been developed over time – a delay difference model, Bayesian hierarchical biomass dynamic model and a size-based model. The models can be used in any combination for the different species but the key assessment model, developed over 15 years ago, is an innovative size-structured bio-economic model that uses a weekly time series of data to predict optimal effort and catch trajectories required to achieve long-term maximum economic yield (MEY) for the fishery.

Why a workshop was held

Because of its importance to the fishery in meeting both Commonwealth Harvest Strategy Policy (HSP) requirements and underpinning the Marine Stewardship Council (MSC) assessment, the NPF Resource Assessment Group (NPRAG) regularly reviews different inputs and components of the tiger prawn assessment. Although fundamentally unchanged, it has been incrementally improved over time through ongoing research and development projects. More recently, the NPRAG has noted some concerns and issues facing the fishery that might influence the design of the stock assessment into the future, specifically the: potential impacts of climate change on the fishery; current and future volatility in fishery economics; and indications of spatial variability and localised depletion in tiger prawn abundance in some regions. The NPRAG and the NPF Management Advisory Committee (NORMAC) supported running a workshop to ensure a strategic approach for the future management of the tiger prawn fishery and that the design of the underlying tiger prawn model remains fit-for-purpose over the next decade.

The outputs and outcomes from this project will assist the Northern Prawn Fishery Resource Assessment Group (NPRAG) and NORMAC to respond to the Australian Fisheries Management Authority (AFMA) Commission's request that climate change impacts are considered at future by all AFMA's resource assessment groups and management advisory committees.

Objectives

The objective of the workshop was to improve the biological and economic performance of the NPF by identifying:

- concerns and trends regarding the productivity of the tiger prawn fishery;
- deficiencies in the tiger prawn stock assessment model/s[1] and data collection framework that impede the NPF meeting management objectives including legislative requirements and MSC certification; and
- key projects that will address the deficiencies above to improve the tiger prawn stock assessment model/s[2].

Methods

The following methods were adopted to facilitate effective implementation and delivery of the NPF Tiger Prawn Workshop:

- An independent facilitator, Dr. Kevin Stokes was engaged to chair and moderate the workshop, with assistance from Dr. Ian Knuckey (NPRAG Chair).
- 'Fact sheets' and background briefing papers on key topics were developed by Commonwealth Scientific and Industrial Research Organisation (CSIRO) and distributed to all attendees in advance of the workshop (**Appendix C**).
- A pre-workshop on-line survey aimed at key NPF stakeholders was developed and distributed in advance of the workshop (**Appendix B1**).
- A mix of plenary and working group sessions was used to engage participants in discussions. Plenary session presentations on key topics were provided by CSIRO on Day 1.
- Workshop participants were each allocated to one of five (5) working groups comprised of a mix of industry, government and research members. Each working group allocated a Leader and Rapporteur responsible for recording and reporting working group outcomes to plenary sessions. The reports of all working group discussions were provided to workshop organisers to assist in development of this report. A summary of the working group discussions is provided at **Appendix E**.
- The results of the first online survey were presented by Dr. Knuckey on Day 1 (**Appendix B2**).
- A second online survey was conducted during Day 2, with live results provided at the workshop (**Appendix D**).

[1] The Tiger prawn stock assessment model comprises 4 separate models including tiger prawns, endeavour prawns, stock recruitment and E_{mey} level determination models.
[2] the cost benefits and value for money associated with key projects should be an important consideration at the workshop and determining research priorities following the workshop.

Workshop Proceedings

Workshop Opening

Dr. Kevin Stokes, Workshop Facilitator, opened the workshop with an Acknowledgement of Country and welcomed all participants. The workshop opening included remarks outlining the purpose and objectives of the workshop, workshop format and structure, and acknowledgement of Fisheries Research and Development Corporation (FRDC) funding for the workshop.

Participants

Dr Kevin Stokes, Workshop Chair	Mr Scott Spencer, AFMA Commissioner
Dr Ian Knuckey, NPRAG Chair / NORMAC	Mr Ron Earle, NPFI[3] Chair
Dr John Glaister, NORMAC Chair	Ms Annie Jarrett, NPFI CEO
Dr David Brewer, NPRAG	Mr Brandon Meteyard, NPFI Projects Manager
Dr Rik Buckworth, NPRAG	Mr Bryan van Wyk, Austral / NPRAG
Prof. Tom Kompas, NPRAG	Mr David Carter, Austral / NORMAC
Dr Éva Plagányi, NPRAG/CSIRO	Mr Dwayne Klinkhamer, Austral
Prof. André Punt, CSIRO	Mr Stuart Nisbet, Austral
Dr Trevor Hutton, CSIRO	Mr Andy Prendergast, Austral
Dr Sean Pascoe, CSIRO	Mr Ian Boot, Austfish / NPRAG / NORMAC
Mr Roy Deng, CSIRO	Mr Phil Robson, Raptis / NPRAG
Dr Shijie Zhou, CSIRO	Mr Beau Anderson, Raptis
Dr Denham Parker, CSIRO	Mr Ben Croft, Raptis
Mr Brodie Macdonald, AFMA Senior Manager Northern Fisheries / NORMAC	Mr Norm Peovitis, WA Seafoods
Mr Jeremy Smith, AFMA A/g NPF Manager / NPRAG	Mr John Palmer, WA Seafoods
Ms Cate Coddington, AFMA	Mr Crispian Ashby, FRDC
Ms Sarah Kirkcaldie, AFMA	Dr Cathy Dichmont, Cathy Dichmont Consulting
Ms Anna Willock, AFMA Deputy CEO	Dr Thor Saunders, NSW DPI[4]
Ms Alice McDonald, AFMA Climate Adaptation Senior Program Manager	

Presentation of Pre-workshop Survey Results

Dr Ian Knuckey presented the results from the pre-workshop on-line survey (**Appendix B**), as follows:

- There were 37 survey respondents:
  - Survey respondents included a good cross section of fishery stakeholders, although there were no Non-government organisation (NGO) respondents.
  - The responses highlighted an aging group within the industry. This reinforced the need to ensure processes are in place to consider the next stage of this fishery and setting a new legacy for the next decade.
  - There were, however, also a few younger participants, but most with over 10 years' experience.
- Respondents considered the management of the fishery – focusing on the triple bottom line:

[3] NPFI – Northern Prawn Fishery Industry
[4] NSW DPI – New South Wales Department of Primary Industries

    - It is essential to pay heed to recreational and indigenous interests, with social issues building in importance.
    - The fishery is well placed with regard to sustainability and economic objectives, with further work required to strive towards social objectives.
    - Most of the management tools were seen as important overall to achieve sustainability outcomes, with catch rate triggers the most important for economic outcomes (followed by Total Allowable Effort (TAEs), seasonal closures and closure areas). Respondents saw the management tools as not designed for social outcomes as this hasn't been the strongest driver in the fishery to date.
- There was reasonable confidence overall that the fishery has the right fishery management approach.
    - Reflects the co-management and the way the fishery has been developing and innovating for decades.
    - Overall agreement that all management tools (closed areas, seasonal closures, catch rate trigger, TAEs, gear restrictions, bycatch reduction devices) should be retained, with the current package of management tools pretty close to the mark.
    - Some potential changes identified for potential further consideration were the season length, season start dates and fleet size.
- Stock assessment – most respondents have at least some understanding of the stock assessment.
    - While there was general support of the current assessment over the last decade, there was less confidence that it will be sufficient to look after the fishery for the next decade.
- The importance of the various data inputs was highlighted, with catch and effort ranked the highest and the economic survey ranked lower. However, all data inputs were seen as important, with at least 60% of responses ranking all inputs as either medium/high or high importance.
- Issues highlighted as risks over the next decade were (noting the workshop is focused on the assessment, not management):
    - Cost of fishing considered the highest risk, then climate change, social licence, impact on threatened species and prawn markets. These were followed by localised depletion, stock sustainability and biosecurity.
    - The lowest risks identified were overcapitalisation, poor management and overfishing.
    - The biggest risk from a social licence perspective are Protected species (specifically sawfish). It was also noted that there are significant public concerns regarding trawling, although the habitat is highly dynamic, and the spatial footprint is small.
- Monitoring and research were considered to be the most important overall matters when considering the future risks to the fishery, followed by the harvest strategy. The importance of the stock assessment is equivalent to the other processes for some issues but drops off for some of the issues.
    - It was noted that many of the future risks are not part of the workshop as its purpose is primarily to improve the stock assessment.
- The responsibilities for dealing with the future risks falls across various agencies, with many of the future risks being the responsibility of the NPFI, followed by AFMA management, though noting that many will require AFMA and industry working jointly together towards a solution:
    - NPFI – ongoing work across everything
    - AFMA – focus on stock sustainability, overfishing, climate change, localised depletion
    - Industry – prawn markets
    - Diseases, biosecurity – other government agencies.

The results from the survey are provided at **Appendix B1**.

Fact Sheets and Workshop Presentations

Prior to the meeting, workshop participants were provided with fact sheets on a range of issues pertaining to the tiger prawn assessment (Table 1 below).

Table 1: Summary of fact sheets

Number	Title	Summary
1	Summary of key issues for discussion at NPF tiger prawn strategic workshop	This overview document outlines the key components of the Tiger prawn stock assessment and provide preliminary comments and issues that have been identified with the difference components.
2	Technical description of the NPF stock assessment method and bio-economic TAE setting method	This technical document provides a detailed summary of the Tiger Prawn Stock assessment including the: • Size structured model • Bioeconomic model • Biomass dynamic model.
3	NPF Tiger Prawn Stock Assessment Process flow chart	This overview document includes a flow chart outlining the stock assessment process showing the flow of data into different NPF models and the relevant model outputs.
4	Integrated Monitoring of the Northern Prawn Fishery 2002-2022; gulf-wide and regional indices of abundance	This technical document details historical abundance indices across the NPF monitoring program. The document includes comparisons between indices of relative abundance including catch per unit effort (CPUE), recruit and spawning surveys. The document also contains site specific abundance results.
5	Review of the NPF fishing power analyses	A review of the NPF fishing power methodology has led to four key questions covered by this paper: 1. Should we explore direct use of vessel and gear information instead of the swept area tiger prawn index (SATIG)? 2. Should we estimate species-specific annual fishing power? 3. Should we fit the offset variables in the model? 4. Should we be developing a standardised CPUE index?
6	Preliminary Update of the NPF Species Split Project	This paper includes a preliminary update to the species split models using additional data from the NPF monitoring surveys since 2005 and the commercial sampling conducted during 2019–2021.
7	Thoughts on spatial models for the NPF	A summary of the considerations to inform whether or not, and how, to move to a spatial NPF model.

Number	Title	Summary
8	Summary of endeavour prawn project	A summary of the red endeavour prawn project including three major components: 1. Modelling growth with historical survey data 2. CPUE standardization (blue and red endeavours) 3. development of stock assessment methods for red endeavour prawn and improving the blue endeavour assessment model.
9	Summary of spatial representation of NPF prawns in a tropical Models of Intermediate Complexity for Ecosystem (MICE)	The MICE models the population dynamics of prawn species using a weekly time step from 1970 to current, and as either local populations in each spatial region or connected via a shared spawning biomass as well as regional combined influences of river flow.
10	Environmental variables summary to inform strategic planning under climate change for the tiger prawn fishery	A summary of data for a variety of environmental across the Gulf of Carpentaria including river flow, sea level, sea surface temperature (SST), air temperature, solar exposure, the Southern Oscillation Index (SOI) and a Cyclone Index.
11	Annual effort threshold issues and solutions in the tiger prawn bio-economic model	Examines issues with the current base case model that sets a minimum effort level at 2 777 (nominal) boat days for each of the two tiger prawn fishing strategies (half of the 2007 fishing effort multiplied by 108%), introduced to ensure that the pathway to an MEY trajectory did not include very low effort levels that were not feasible or practical for the fishery.
12	What is an appropriate threshold	The aim of this factsheet is to explain where the threshold values used in the model came from, and what might be a more appropriate value for future modelling work.
13	Data Factsheet summary of inputs and timeline for the NPF stock assessment analyses	An overview of the different data sources, their use and timing, as well as a historical timeline of changes in data availability through the history of the fishery.

Summary of Key Issues

Workshop participants noted that overall, the various models and data inputs to the assessment need to be improved and there are key issues that prevent optimal management of the fishery including:

- The tiger prawn stock assessment model is somewhat dated with many factors having changed since it was developed.
- The fishing power analysis for key species needs to be reviewed.
- Endeavour prawn CPUE is being standardised and will be included in the tiger prawn model.

- Spatial models are becoming increasingly adopted globally. Consideration needs to be given to the advantages and disadvantages of moving to a spatial assessment model (or other means of evaluating spatial effects) rather than a whole of fishery model.
- Environmental / climate factors affecting tiger prawns and possible implications for the stock assessment and bio-economic models need to be addressed.

Bio-economic model

- The objective basis for the minimum effort threshold needs to be reviewed as it has not been restraining effort in the fishery in recent years.
- Consideration needs to be given to modifying the settings in the model to address the current anomalous volatile economic situation.
- Banana prawn fishery economics will also impact the bioeconomic of the tiger prawn fishery. Approaches and motivation for integrating banana prawn fishing costs into the tiger prawn fishery model should be considered.

Data

- Many of the biological parameters of tiger prawn (e.g., temporal availability, growth, and fecundity) having not been updated since the 1980s and early 1990s. This could have an impact on assessment outcomes given the potential scale and/or range of changes, both spatially and temporally.

Industry perspectives

Industry participants were invited to provide their perspectives on the tiger prawn fishery and provided the following feedback:

- It has been a difficult few years with increased operating costs and volatile fuel prices with many companies relying on other sources of income. Industry questioned whether the fluctuating seasons were caused by environmental conditions or overfishing. There was general consensus from participants that fluctuating catch rates were caused by environmental factors.
- Concerns were also expressed over the cost of research - participants noted that the fishery has to be profitable to be able to invest in future research and agreed research needs to be more targeted to get tangible outcomes. It was suggested that data already collected could be analysed to assess if there are any trends in the good years.
- Industry expressed concerns regarding climate change and the need to ensure that there are ways that the sector can help to reduce emissions. Industry noted that environmental changes are hard to predict and there needs to be in-season flexibility.
- Concerns were expressed by some industry participants around industry continuity, aging participants and potential loss of industry/fishery knowledge, given that 80% of the current participants will be retiring in the next 10 years. The need for succession planning, new entrants and new investment in the fishery was flagged.
- Concerns that the model has continually overestimated the effort that can be put into the fishery were raised, noting that there aren't enough boats, fishing days and capacity to increase net sizes in order to operationalise the available effort.
- It was generally agreed that the fishery has all the right management tools available to it, with some adjustments required to improve the overall management.

- While there is some appetite to look at spatial effects in the fishery, caution is needed, particularly as spatial management/assessments can be very costly.
- Concerns were expressed about reliance on models when prawn productivity fluctuations could be the result of environmental change.
- Environmental considerations need to be included in the model. Most industry members believe that the downturn in the tiger prawn fishery is not due to overfishing and that environmental factors are a big driver.

Working Group Discussions

Day 1

The working groups were requested to respond to four (4) questions arising from the results of the pre-workshop survey (**Appendix B2**) as follows:

1. Which survey outputs and industry comments are most relevant to the workshop objectives?
2. Do the majority of responses to the survey on these topics align with your views?
3. If no, where do your views differ?
4. Are there other issues pertaining to the workshop objectives that have not been picked up by the survey responses?

Different approaches were followed by working groups in responding to the questions, but some common themes were observed across all working groups (see **Appendix E** for a summary of working group discussions). Working groups focused primarily on Questions 1 (priorities identified in the survey relevant to the tiger prawn stock assessment) and 4 (other priorities the survey did not identify). The following is a summary of working group discussions and key issues identified for further discussion/consideration:

Climate and environmental impacts and drivers for key target stocks

- All the working groups recognised that understanding the environmental drivers for tiger prawn stocks, including impacts of climate change, is a priority for the NPF. This could include:
  - Understanding and prioritising which environmental parameters are the most reliable indicators. Industry understanding of environmental drivers and what is being seen on the water might provide useful insights
  - Understanding what if any impacts environmental factors have on fisher behaviour
  - Consideration given to how best to collect these data to be effectively used in the stock assessment or harvest settings for the fishery, noting environmental data should be as up-to-date as possible
  - Leveraging third parties (Bureau of Meteorology (BoM), CSIRO etc.) to collect data where possible
- Several working groups and subsequent plenary discussions questioned whether there is scope to undertake retrospective evaluation of environmental data to determine what the key drivers are for the tiger prawn stocks[5].

---

[5] It was later observed during the workshop discussion that this may not be possible

Fishing Power

- All working groups observed that it would be beneficial to review the fishing power model and/or better understand the drivers of the model. Some working groups also expressed a desire to better understand the influence of the fishing power model on the tiger prawn sock assessment outputs. For example, does an overestimate of fishing power indicate the tiger prawn stocks are more depleted than actual levels.
- Industry participants feel the fishing power model does not reflect their observations of what is happening on the water. In particularly, industry participants questioned the high level of effort creep predicted by the model since 2010.
- There were also questions about whether the model is capable of considering nuances across the fleet (e.g., skipper expertise).

Stock assessment inputs and sustainability

- There was unilateral agreement that the species split model needs to be updated to better understand catch composition between brown and grooved tiger prawns, noting the species split project is due for completion in 2023.
- Most working groups considered that updating stock assessment inputs should be a priority. However, consideration needs to be given to the costs and benefits of updating the various inputs, given that some research is very expensive (e.g., tagging programs) and may not result in different estimates from the current inputs. Questions were asked whether other data could inform inputs (e.g., length frequency estimates, tag recapture, growth estimates).
- Several working groups discussed scope to adjust weighting of inputs (e.g., more emphasis on survey data) and using averages of recent years rather than estimates from previous seasons.
- Questions were raised about whether there is a link between stock size and recruitment and can this be used to model/predict stock dynamics and harvest levels.
- Several groups raised the issue of linkages between effort for tiger prawns and banana prawns (both common and redleg banana prawns) and how this is accounted for [or not] in the tiger prawn stock assessment. Questions related to the impacts of tiger prawn fishing during the first (banana) prawn season in terms of removing recruits from the tiger prawn fishery, and effort distribution between the redleg banana prawn fishery and the tiger prawn fishery in terms of the economics of the NPF overall.
- There is a feeling that localised depletion can occur and that individual fishing grounds can be fished down.
- Several working groups discussed the spatial aspects of key stocks including variation in recruitment, impacts of line fishing, importance of spatially explicit fishing grounds, noting the various fishing grounds produce differently at different times[6].

Economics and cost of fishing, use of Maximum Economic Yield in the fishery

- There was unanimous agreement that the minimum effort threshold needs to be reviewed noting the issues it has created for setting the 2022 TAE. It was agreed that the threshold is an important component of the fishery and should be retained. It was noted that setting the effort threshold based on

[6] While the workshop generally agreed stocks parameters and fishing operations are spatially distinct across the NPF, later discussions agreed that the addition of spatial parameters into the model may not be worthwhile from a cost-benefit perspective.

previous levels of fishing effort (i.e., the previous level which was based on effort levels from 2007[7] may not be relevant to the current economics of the fishery). There was a discussion as to whether a dynamic threshold could be applied to the fishery.

- A question was asked as to whether, given the current size of the fleet size resulting from the historical reductions in effort, the economic approach to managing stock and harvest levels is appropriate, or should the assessment be more focused on stock sustainability.

Flexibility in fishery (season start/finish, triggers)

- The ability to adjust fishing seasons (for good and bad years) was raised a number times by different groups. Suggestions including adjusting the season length[8] (longer or shorter depending on conditions) and timing of season commencement.
- However, it was noted that ad hoc adjustments to variable season openings creates challenges for industry from a business planning perspective.

Other issues

- A number of working groups noted the potential impacts of changes in abundance of prawn predator species (Barramundi, sharks etc) which result in trophic impacts on the abundance of prawn species.
- Costs of fishing have increased significantly in recent years and economic factors are impacting on the NPF in various ways, including the ability to attract and retain crew.
- Historical spatial closures should be reviewed to determine whether they still meet their original objectives and whether they are still needed given other changes in the fishery.
- Consideration should be given to tapping into other potential sources of non-scientific knowledge (e.g., industry or other anecdotal information available).

Day 2

A brief overview of Day 1 proceedings and discussions was provided in the opening plenary session on Day 2. Participants were reminded of the aims and objectives of the workshop. The working groups were then asked to consider the following issues (identified from Day 1) in terms of priority, taking into account their potential cost, feasibility and value:

Issues	Details
Monitoring	• Fishing power inputs • Biological parameters change over time • Data that is available but not used • Physical data oceanography, river flows, climate change etc.
Biological	• Ecosystems (habitats/food/predators)

[7] In 2008, there was agreement to take an 8% increase in effort due to the reduction in boat numbers since 2006 and that this should apply to half the tiger prawn effort (assuming that effort was split 50/50 to brown and grooved tiger prawns). The 2007 level of nominal effort was 5 142 days, when divided by 2 and increased by 8% gives the minimum effort constraint of 2 777 days for brown tiger prawns; if it had been based on the last stock assessment at the time it would have been 1 280.

[8] The Tiger Prawn Harvest Strategy currently includes a 350 kg/boat/day catch trigger which applies to catches in weeks 12 and 13 of the tiger prawn season

Issues	Details
Assessment	• Fishing power model • Economics modification • Inclusion of climate change, SOI • Inclusion of spatial indicators • Feasibility of spatially based assessment • Catchability.
Decision rules	• Effort threshold • Effort controls other than TAE (seasons/closures).

In discussing these issues, working groups were requested to consider the following questions:

1. Which, if any, of the identified priority issues (approaches (monitoring/assessment/decision rules) are most likely to achieve the objectives of the workshop?
2. Are there others that haven't been considered?
3. Identify how these will achieve workshop objectives e.g., through more data/science, management measures (closures etc).
4. If cost (of research, to fishing operations etc) is an issue, please rank the top three priorities to be addressed in the next 3 years.

Priority Issues

As occurred in Day 1, different approaches were adopted by individual working groups in responding to questions. However, common themes were again observed across all working groups (see **Appendix E** for a summary of working group discussions). Plenary discussion of the working group reports led to the identification of the following priority issues/actions:

Fishing power and catchability

- Integrate influence analysis of the different inputs into the fishing power model and review the Prawn Trawl Performance Model input data.

Environmental drivers/ climate change impacts

- Examine and prioritise the environmental parameters influencing tiger prawn populations.
- Consider how environmental factors/climate change can be incorporated into the model (e.g. MICE).
- Consider ways to implement cost-effective monitoring of environmental factors where there is confidence in the relationship between environmental parameters and stock dynamics. Monitoring should leverage efforts already being undertaken by other organisations.
- Consider the capacity/feasibility of looking at environmental data and stock levels retrospectively to identify relationships between tiger prawn stocks and environmental drivers.[9]

[9] Discussions later identified limitations with looking at the stock assessment retrospectively

Economics and minimum effort threshold (low cost and feasible)

- The economic components of the stock assessment should be re-examined including whether they remain relevant to the current model as well as whether an economic assessment is the best approach for the fishery.
- Review effort threshold, including the potential for a dynamic threshold that accounts for changes in the fishery.
- Review the need for/relevance of 'forecasting' approach in MEY model[10].

Biological data

- Finalise the Species Split project as a high priority; incorporate results into the assessment.
- Review biological inputs to the model according to the age of and confidence in the data, the cost of updating, likelihood of parameter changes and influence on the stock assessment outputs.

Online Survey Day 2

Following the working group and plenary deliberations, a second on-line survey of all participants was conducted to obtain *individual participant* feedback and prioritisation on each of the components of the following topics:

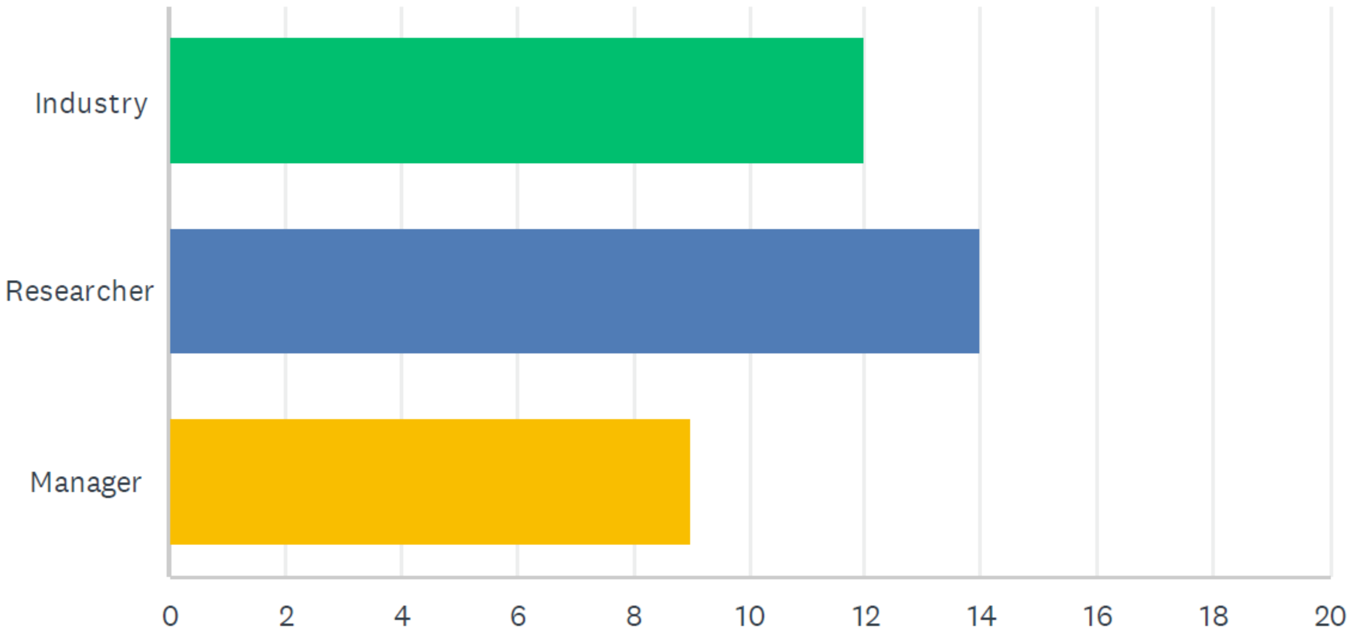
Issues	Details
Data Collection and Monitoring	• Fishing power inputs • Biological parameters change over time • Physical data oceanography, river flows, climate, etc • Biological: ecosystems (habitats / food /predators).
Assessment	• Fishing power model • Inclusion of climate change, SOI etc. • Catchability • Economic modification • Feasibility of spatially based assessment • Inclusion of spatial indicators.
Decision rules	• Effort threshold • Effort controls other than TAE (seasons/closures).

The during-workshop survey and results of this survey are included at **Appendix D1** and **Appendix D2** respectively.

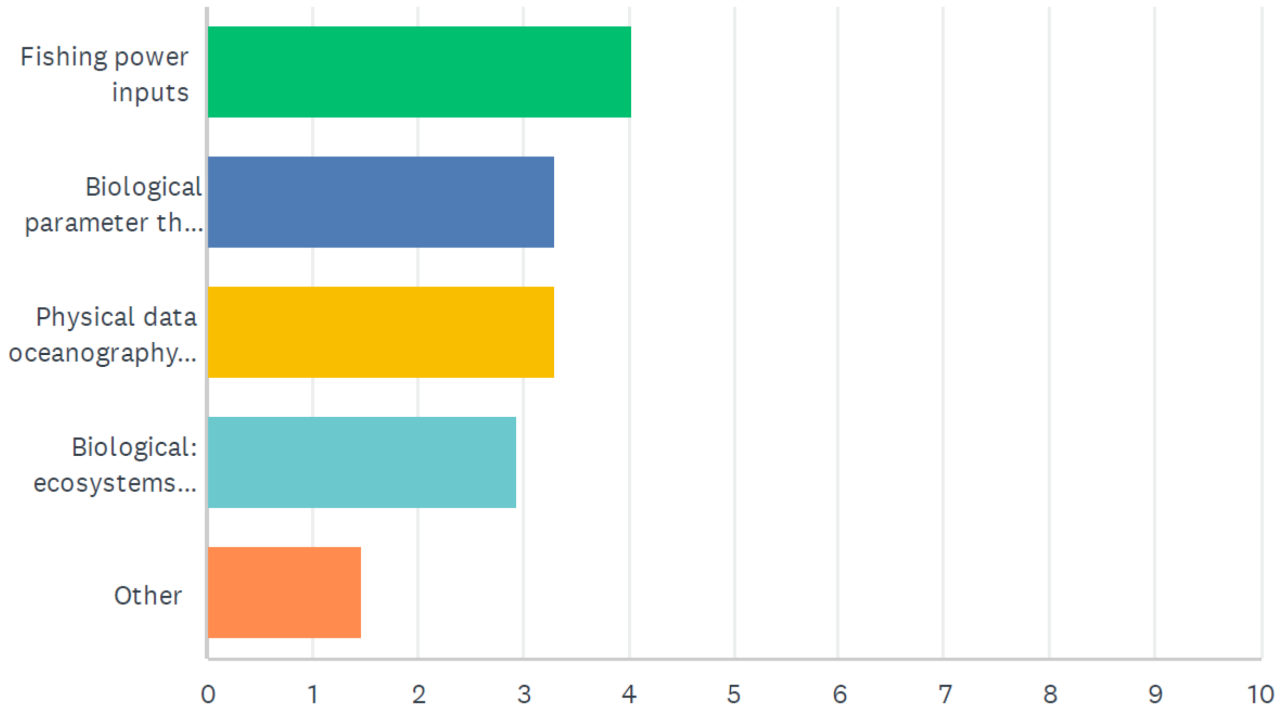
[10] As proposed by Prof. Tom Kompas

The results of the Day 2 on-line survey are reported as follows:

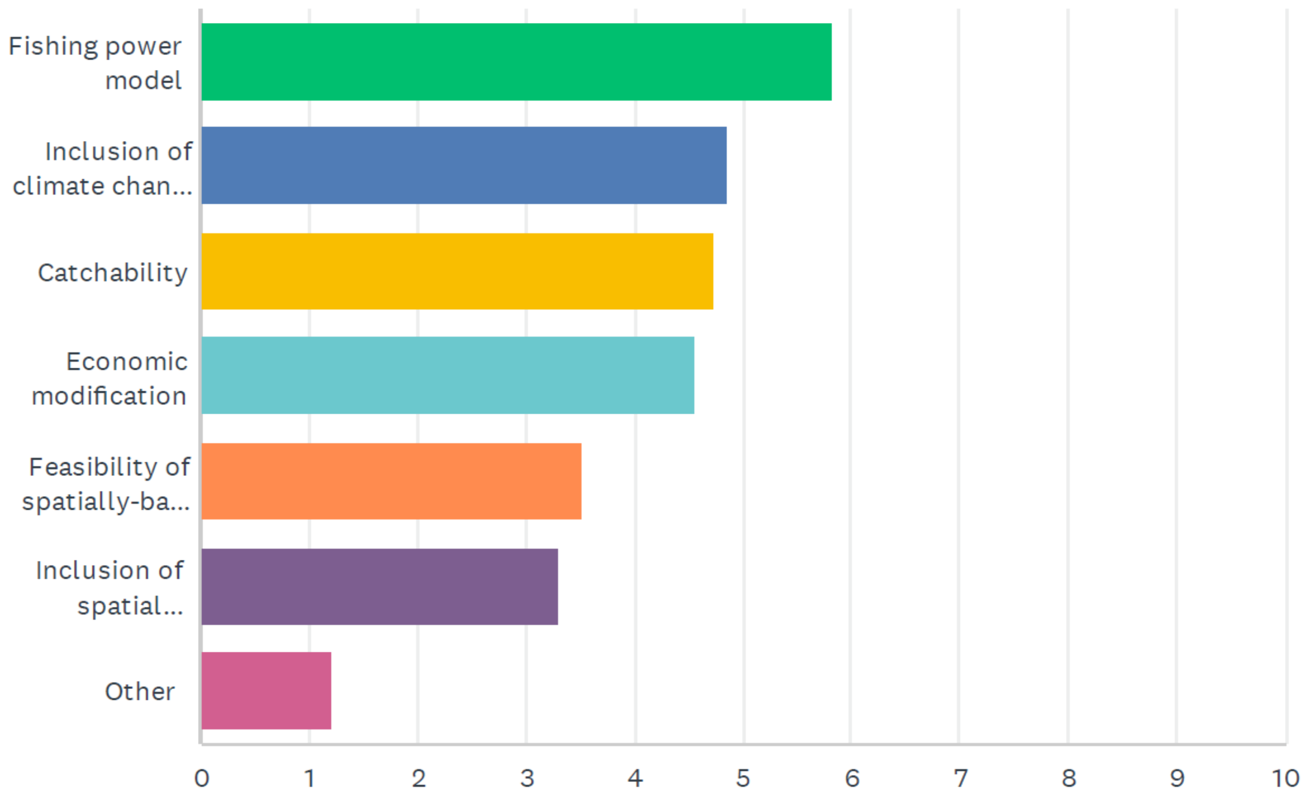
Make up of participants



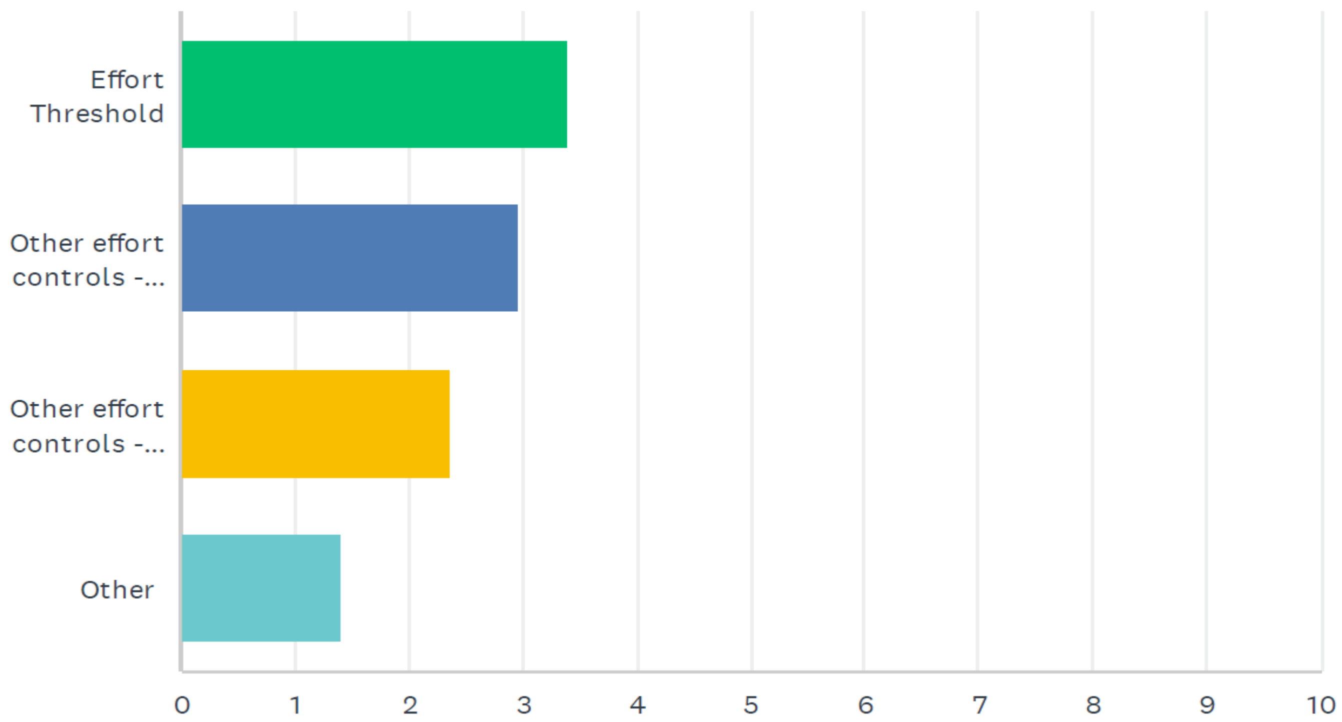
Data Collection and Monitoring Priorities



Stock Assessment Priorities



Decision Rules Priorities



Additional comments provided by respondents across these priorities included:

- Finding more efficient and cost-effective ways of data collection and monitoring
- Consider prioritisation of key data through modelling, along with finding other ways to use existing data sets
- The review of the fishing power component of the model is a very high priority before other changes are considered in the current model
- Improving our understanding of environmental drivers is essential
- Consideration of how the economic components of the model can be improved is required
- Exploration of the weightings within the model (including down-weighting CPUE and increasing the weighting of the fishery independent survey (FIS))
- Review of use of triggers within the assessment including their uses for different purposes (e.g., catch rate triggers)

Overall participants provided very positive feedback of the content and process of the workshop (97% were very satisfied or satisfied).

Appendix A: Workshop agenda

NPF Tiger Prawn Fishery Adaption Strategy Workshop Agenda
23rd & 24th February 2023

Venue: View Hotel, Cnr Kingsford Smith Drive & Hunt Street,
Hamilton, Brisbane

Workshop Objectives

To improve the biological and economic performance of the Northern Prawn Fishery (NPF) by identifying:

- concerns and trends regarding the productivity of the tiger prawn fishery
- deficiencies in the tiger prawn stock assessment model/s[1] and data collection framework that impede the NPF meeting management objectives including legislative requirements and Marine Stewardship Council (MSC) certification
- key projects that will address the deficiencies above to improve the tiger prawn stock assessment model/s[2]

Day 1 Looking back and what's available (Thursday 23 February 2023)			
Time	**Topic**	**Purpose**	**Responsibility**
8.30am	Arrival Tea & Coffee		
9:00am	1. Welcome Day 1	Welcome attendees and open the workshop with an Acknowledgement of Country; outline the objectives and structure of the workshop AFMA Perspective	Dr. Kevin Stokes, Chair Brodie Macdonald
9:15am	2. The current tiger prawn assessment	Provide information about the current model including: Underpinning science • Biology • Spatial components of the fishery • Environmental factors (e.g., temperature / rainfall) • fishing power • species composition and species split algorithm Data used in the assessment • Biological (including new endeavour prawn work) • Effort (including new endeavour prawn work) • Fleet • Catch (including new species split results) • Economics - fuel costs / prawn prices / operational costs How the current stock assessment brings it all together	CSIRO
10.15	Morning Tea		
10.35	The current tiger prawn assessment cont.	As above	CSIRO

[1] The Tiger prawn stock assessment model comprises 4 separate models including Tiger prawns, Endeavour prawns, stock recruitment and E_{mey} level determination models
[2] the cost benefits and value for money associated with key projects should be an important consideration at the workshop and determining research priorities following the workshop.

NPF Tiger Prawn Fishery Adaption Strategy Workshop Agenda
23rd & 24th February 2023

Venue: View Hotel, Cnr Kingsford Smith Drive & Hunt Street, Hamilton, Brisbane

Workshop Objectives

To improve the biological and economic performance of the Northern Prawn Fishery (NPF) by identifying:

- concerns and trends regarding the productivity of the tiger prawn fishery
- deficiencies in the tiger prawn stock assessment model/s[1] and data collection framework that impede the NPF meeting management objectives including legislative requirements and Marine Stewardship Council (MSC) certification
- key projects that will address the deficiencies above to improve the tiger prawn stock assessment model/s[2]

Day 1 Looking back and what's available (Thursday 23 February 2023)			
Time	**Topic**	**Purpose**	**Responsibility**
8.30am	**Arrival Tea & Coffee**		
9:00am	**1. Welcome Day 1**	Welcome attendees and open the workshop with an Acknowledgement of Country; outline the objectives and structure of the workshop AFMA Perspective	Dr. Kevin Stokes, Chair Brodie Macdonald
9:15am	**2. The current tiger prawn assessment**	Provide information about the current model including: Underpinning science • Biology • Spatial components of the fishery • Environmental factors (e.g., temperature / rainfall) • fishing power • species composition and species split algorithm Data used in the assessment • Biological (including new endeavour prawn work) • Effort (including new endeavour prawn work) • Fleet • Catch (including new species split results) • Economics - fuel costs / prawn prices / operational costs How the current stock assessment brings it all together	CSIRO
10.15	**Morning Tea**		
10.35	**The current tiger prawn assessment cont.**	As above	CSIRO

[1] The Tiger prawn stock assessment model comprises 4 separate models including Tiger prawns, Endeavour prawns, stock recruitment and E_{mey} level determination models

[2] the cost benefits and value for money associated with key projects should be an important consideration at the workshop and determining research priorities following the workshop.

Time	Topic	Purpose	Responsibility
11.35am	3. The good, the bad and the ugly	Present pre-workshop survey results Q & A session	Dr. Ian Knuckey Plenary
12:30pm	Lunch		
1.15	The good, the bad, the ugly cont.	Present individual perspectives on the current state of the fishery	Industry participants/ Plenary (Chair)
2.00		Discuss perspectives/outputs of survey to identify common areas of concern/priorities to be addressed	Working Groups
3.00		Reports from Working Groups	WG Rapporteurs
3.30	Afternoon Tea		
3: 50	4. Existing research / gaps in knowledge/ new research	Outline available information that can be incorporated into the assessment and/or knowledge gaps that need to be filled (e.g. Environmental /climate change considerations) • Environmental and physical data for the GoC • Downscaled regional climate projections for GoC and SOI • MICE model • Opportunities to improve the model using relevant banana prawn information (e.g. real time economics) • Supply chains resilience	CSIRO
4.50pm	5. Implications of what we've heard so far	Summarise Day 1 discussions including: • key outputs & priorities from WGs • available research/data • research/ data gaps Q & A	Chair/ Plenary
5.05pm	6. Chair Summary	Outline objectives for Day 2/Close Day 1	
5:15pm	Close Day 1		
6.30pm	**WORKSHOP DINNER – VIEW HOTEL**		

Australian Government
Australian Fisheries Management Authority

NPF

FRDC
FISHERIES RESEARCH AND DEVELOPMENT CORPORATION

NPF Tiger Prawn Fishery Adaption Strategy Workshop

23-24 February 2023

Agenda

Day 2 Where to from here (Friday 24 February 2023)

Time	Topic	Purpose	Responsibility
8.30am	**Arrival tea & Coffee**		
9:00am	**Welcome Day 2**	Open Day 2 with an Acknowledgement of Country and a Re-cap of Day 1 discussions	Dr. Kevin Stokes, Chair
9.15am	**7. Over the horizon**	Present pre-workshop survey results Round 2 Identify, discuss and agree future risks and opportunities in the NPF over the next 10 years (eg climate change; fuel; markets)	Dr. Ian Knuckey/ Plenary
10.30	**Morning Tea**		
10:50am	**8. Moving forward - what's needed?**	Discuss and identify priorities on what could/should be considered in future assessments and/or management approaches/strategies • Spatial considerations • Impact of environmental conditions/monitoring (environment report card) • Evaluation of effort thresholds • Dynamic B_0 • Other (e.g. line fishing, optimisation of multispecies assessment approach)	Working Groups
12.15 noon		Report from Working Groups	WG Rapporteurs
12.45pm	**Lunch**		
1:30pm	**9. Setting Priorities**	Agree priorities (stock assessment/ management) for further consideration based on WG outputs	Plenary Session (Chair)
2:15pm	**10. Next steps**	Agree process/allocate responsibilities to support and achieve workshop outcomes	Plenary Session (Chair)
2:45pm	**11. Chair summary**	Summarise the discussions/outputs from Days 1 and 2 Close workshop	Chair
3:00pm	**Workshop close**		

Australian Government
Australian Fisheries Management Authority

NPF

FRDC
FISHERIES RESEARCH AND DEVELOPMENT CORPORATION

Appendix B: Pre-workshop survey

1. Pre-workshop survey

NPF Tiger Prawn Fishery Workshop

Background

This survey is designed to support the upcoming Northern Prawn Tiger Fishery Strategic Planning Workshop to be held on 23-24th February 2023. . More detailed information is provided below, but generally, this survey is designed to start you thinking about the issues being presented at the workshop and for the organisers to understand your views on the management and assessment of the fishery so we can focus discussions.

You can remain anonymous if you prefer, by avoiding the initial "About You" questions. You can also put your name and email at the end of the survey if you like.

It requires about 15 minutes of you time.

Please complete this survey by 18th February 2023

The NPF occupies an area of 780 000 square kilometres off Australia's northern coast (Figure 1). It extends from the low water mark to the outer edge of the Australian Fishing Zone (AFZ) along approximately 6 000 kilometres of coastline between Cape York in Queensland and Cape Londonderry in Western Australia.

While the NPF covers a wide area, only around 11% of the total NPF area is fished with the major trawl grounds of the NPF being in the Gulf of Carpentaria and the area to the north and south-west of Darwin.

Through a combination of voluntary buybacks, internal industry restructuring/adjustments and compulsory acquisition programs, the number of licences in the fishery has been reduced from 302 in 1985, to 132 by 2000 to the current number of 52 by 2007. Catch and effort in the fishery has varied considerably as the number of boats operating in the fishery has changed over time.

There are two major sub-fisheries in the NPF: first season targeting Banana Prawns, whose highly variable stock abundance and catches are largely driven by monsoonal rainfall; the second season targeting the less variable stocks of tiger prawns.

This workshop is focused on the second season tiger prawn fishery.

NPF Tiger Prawn Fishery Workshop

Background

This survey is designed to support the upcoming Northern Prawn Tiger Fishery Strategic Planning Workshop to be held on 23-24th February 2023. . More detailed information is provided below, but generally, this survey is designed to start you thinking about the issues being presented at the workshop and for the organisers to understand your views on the management and assessment of the fishery so we can focus discussions.

You can remain anonymous if you prefer, by avoiding the initial "About You" questions. You can also put your name and email at the end of the survey if you like.

It requires about 15 minutes of you time.

Please complete this survey by 18th February 2023

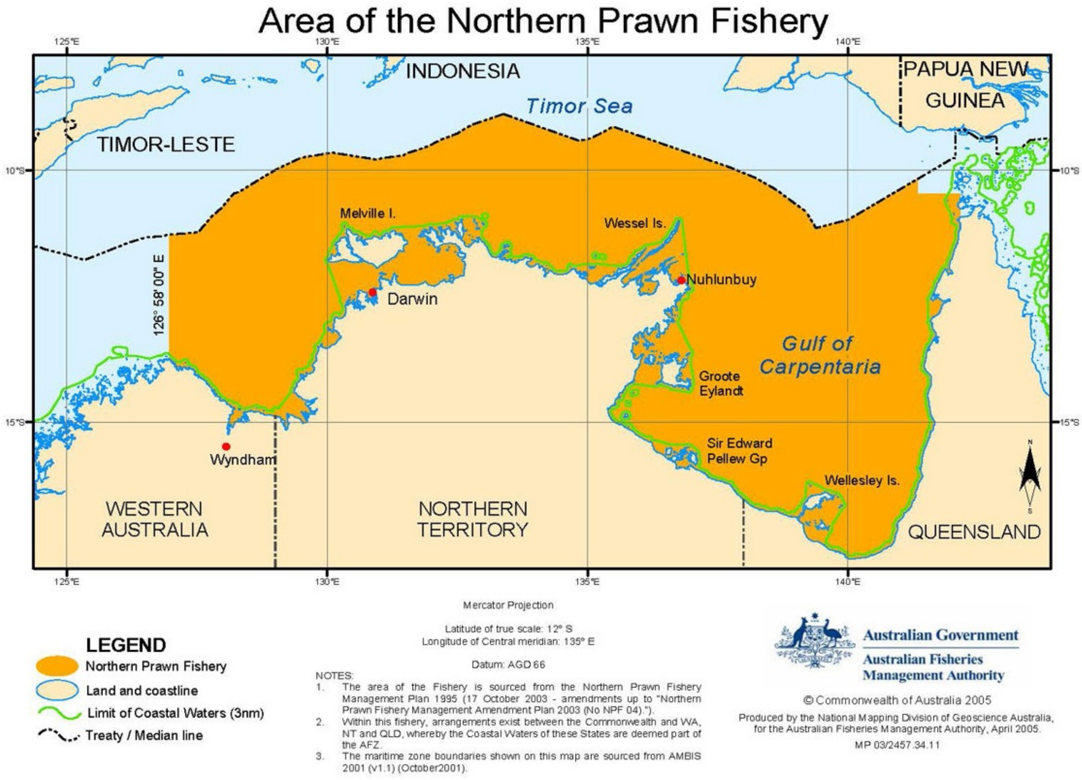
The NPF occupies an area of 780 000 square kilometres off Australia’s northern coast (Figure 1). It extends from the low water mark to the outer edge of the Australian Fishing Zone (AFZ) along approximately 6 000 kilometres of coastline between Cape York in Queensland and Cape Londonderry in Western Australia.

While the NPF covers a wide area, only around 11% of the total NPF area is fished with the major trawl grounds of the NPF being in the Gulf of Carpentaria and the area to the north and south-west of Darwin.

Through a combination of voluntary buybacks, internal industry restructuring/adjustments and compulsory acquisition programs, the number of licences in the fishery has been reduced from 302 in 1985, to 132 by 2000 to the current number of 52 by 2007. Catch and effort in the fishery has varied considerably as the number of boats operating in the fishery has changed over time.

There are two major sub-fisheries in the NPF: first season targeting Banana Prawns, whose highly variable stock abundance and catches are largely driven by monsoonal rainfall; the second season targeting the less variable stocks of tiger prawns.

This workshop is focused on the second season tiger prawn fishery.



Main commercial species in the NPF Tiger Prawn Fishery fishery include:
Tiger prawns
- grooved tiger prawn (Penaeus semisulcatus)
- brown tiger prawn (Penaeus esculentus)
Endeavour prawns
- blue endeavour prawn (Metapenaeus endeavouri)
- red endeavour prawn (Metapenaeus ensis)
King prawns
- western king prawn (Melicertus latisulcatus)
- red spot king prawn (Melicertus longistylus)
Black tiger prawn (Penaeus monodon

Management measures
The NPF is managed through a suite of input controls including:

- limited entry to the fishery,
- gearrestrictions,
- In-season catch triggers
- bycatch restrictions
- and a complex system of seasonal, spatial and temporal closures including:
    - permanent fishery closures of all known shallow water seagrass beds (2.1% of the total area);
    - seasonal fishery closures (11% of the total area);
    - parts of Commonwealth and state marine parks are closed to trawling;
    - unsuitability of areas to trawling due to large reef outcrops;
    - low density of the target prawn species (e.g. central Gulf of Carpentaria).

Stock Assessment
The stock assessment model used for the NPF Tiger prawn fishery is critical to providing robust science-based advice on the status of the key target species (Grooved and Brown Tiger Prawns) and the major byproduct species (Blue and Red Endeavour Prawns) to support management of the fishery. The Tiger prawn stock assessment model comprises 4 separate models including Tiger prawns, Endeavour prawns, stock recruitment and Emey level determination models. Several stock assessment methods

for the tiger prawn fishery have been developed over time – a delay difference model, Bayesian hierarchical biomass dynamic model and a size-based model. The models can be used in any combination for the different species but the key assessment model, developed over 15 years ago, is an innovative size-structured bio-economic model that uses a weekly time series of data to predict optimal effort and catch trajectories required to achieve long-term maximum economic yield (MEY) for the fishery as a whole.

Why are we having a workshop?
Because of its importance to the fishery in meeting both Commonwealth Harvest Strategy Policy (HSP) requirements and underpinning the Marine Stewardship Council (MSC) assessment, the NPF Resource Assessment Group (RAG) regularly reviews different inputs and components of the tiger prawn assessment. Although fundamentally unchanged, it has been incrementally improved over this time through ongoing research and development projects. More recently, the RAG has noted some concerns and issues facing the fishery that might influence the design of the stock assessment into the future, specifically: potential impacts of climate change on the fishery; current and future volatility in fishery economics; and, indications of spatial variability and localised depletion in tiger prawn abundance in some regions. The RAG and MAC supported running a workshop to ensure a strategic approach for the future management of the tiger prawn fishery and that the design of the underlying tiger prawn model remains fit-for-purpose over the next decade.

Objectives
To improve the biological and economic performance of the Northern Prawn Fishery (NPF) by identifying:

- concerns and trends regarding the productivity of the tiger prawn fishery
- deficiencies in the tiger prawn stock assessment model/s and data collection framework that impede the NPF meeting management objectives including legislative requirements and Marine Stewardship Council (MSC) certification.
- key projects that will address the deficiencies above to improve the tiger prawn stock assessment model/s;

NPF Tiger Prawn Fishery Workshop

About you

Please tell us a little bit about yourself

* 1. What participant group best describes you?

- ◯ Fishing / Seafood Industry
- ◯ Fisheries Manager
- ◯ Fisheries Researcher
- ◯ NGO
- ◯ Other (please specify)

2. What is your age?

- ◯ 17 or younger
- ◯ 18-20
- ◯ 21-29
- ◯ 30-39
- ◯ 40-49
- ◯ 50-59
- ◯ 60 or older
- ◯ Prefer not to admit it

3. How long have you been closely involved in the NPF?

- ◯ Less than six months
- ◯ Six months to a year
- ◯ 1 - 2 years
- ◯ 3 - 5 years
- ◯ 6 - 10 years
- ◯ Greater than 10 years
- ◯ Prefer not to say

NPF Tiger Prawn Fishery Workshop

Current management of the NPF Tiger Prawn Fishery

In this section of the survey we are trying to gauge your thoughts on the mangement of the tiger prawn fishery.

* 4. Overall, how would you rate the ***current*** management of the NPF Tiger Prawn Fishery?

* 5. How would you rate the ***current*** NPF Tiger Prawn Fishery with regard to SUSTAINABILITY objectives?

- ◯ Extremely effective
- ◯ Very effective
- ◯ Somewhat effective
- ◯ Not so effective
- ◯ Not at all effective
- ◯ Not sure

* 6. How would you rate the ***current*** NPF Tiger Prawn Fishery with regard to ECONOMIC objectives?

- ◯ Extremely effective
- ◯ Very effective
- ◯ Somewhat effective
- ◯ Not so effective
- ◯ Not at all effective
- ◯ Not sure

* 7. How would you rate the ***current*** NPF Tiger Prawn Fishery with regard to SOCIAL objectives?

- ◯ Extremely effective
- ◯ Very effective
- ◯ Somewhat effective
- ◯ Not so effective
- ◯ Not at all effective
- ◯ Not sure

* 8. Where do you think the balance lies in what the ***current*** NPF Tiger Prawn Fishery Management delivers?

Sustainability vs Economics

Sustainability **Economics**

* 9. Economics vs Social

Economics **Social**

* 10. Social vs Sustainability

Social	Sustainability

11. Considering the future of NPF Tiger Prawn Fishery over the next decade, please indicate what YOU think is the level of risk associated with the following issues:

	Low Risk		Medium Risk		High Risk	Not sure
Climate / environmental change	○	○	○	○	○	○
Costs of fishing	○	○	○	○	○	○
Prawn markets	○	○	○	○	○	○
Stock sustainability	○	○	○	○	○	○
Localised depletion	○	○	○	○	○	○
Overfishing	○	○	○	○	○	○
Overcapitalisation	○	○	○	○	○	○
Social licence to operate	○	○	○	○	○	○
Impact on threatened species	○	○	○	○	○	○
Poor management	○	○	○	○	○	○
Disease / biosecurity	○	○	○	○	○	○

Other (please specify)

NPF Tiger Prawn Fishery Workshop

Use of Management Controls

In this section of the survey we are trying to gauge your thoughts on the mangement controls used in the fishery.

* 12. Please rank their importance in achieving good ***ECONOMIC*** outcomes from the fishery.

	Low		Medium		High	N/A
TAEs	○	○	○	○	○	○
Seasonal closures	○	○	○	○	○	○
Catch rate triggers	○	○	○	○	○	○
Closed Areas	○	○	○	○	○	○
Gear restrictions	○	○	○	○	○	○
Bycatch reduction devices	○	○	○	○	○	○
Other	○	○	○	○	○	○

Describe Other
Any comments?

* 13. Please rank their importance in achieving good ***SUSTAINABILITY*** outcomes from the fishery.

	Low		Medium		High	N/A
TAEs	○	○	○	○	○	○
Seasonal closures	○	○	○	○	○	○
Catch rate triggers	○	○	○	○	○	○
Closed Areas	○	○	○	○	○	○
Gear restrictions	○	○	○	○	○	○
Bycatch reduction devices	○	○	○	○	○	○
Other	○	○	○	○	○	○

Describe Other
Any comments?

* 14. Please rank their importance in achieving good ***SOCIAL*** outcomes from the fishery.

	Low		Medium		High	N/A
TAEs	◯	◯	◯	◯	◯	◯
Seasonal closures	◯	◯	◯	◯	◯	◯
Catch rate triggers	◯	◯	◯	◯	◯	◯
Closed Areas	◯	◯	◯	◯	◯	◯
Gear restrictions	◯	◯	◯	◯	◯	◯
Bycatch reduction devices	◯	◯	◯	◯	◯	◯
Other	◯	◯	◯	◯	◯	◯

Describe Other
Any comments?

NPF Tiger Prawn Fishery Workshop

Use of Management Controls

In this section of the survey we are trying to gauge your thoughts on the specific mangement controls used in the fishery.

* 15. If you could **CHANGE** just one aspect of the current NPF Tiger Prawn Fishery management.....

What would it be?

* 16. Why?

* 17. What management control would you use to achieve it?

- [ ] TAEs
- [ ] Closed areas
- [ ] Seasonal closures
- [ ] Size limits
- [ ] Catch rate triggers
- [ ] Gear restrictions
- [ ] Bycatch reduction devices
- [ ] Other (please specify)

  ____

- [ ] Please provide and explanation

* 18. Which aspects of the NPF Tiger Prawn Fishery management would you definitely keep?

What would it be?

- [ ] TAEs
- [ ] Closed areas
- [ ] Seasonal closures
- [ ] Catch rate triggers
- [ ] Gear restrictions
- [ ] Bycatch reduction devices
- [ ] Other (please specify)

  ____

* 19. Would you like to provide an explanation for your answer?

____

* 20. Thinking about the future risks to the NPF tiger prawn fishery, where do you think responsibility to address that risk lies?

You can tick more than one box on each row.

	Industry (NPFI)	Stock assessment	Harvest strategy	Monitoring and research	Industry (SIA)	AFMA management	Other government agency	N/A
Climate / environmental change	☐	☐	☐	☐	☐	☐	☐	☐
Costs of fishing	☐	☐	☐	☐	☐	☐	☐	☐
Prawn markets	☐	☐	☐	☐	☐	☐	☐	☐
Stock sustainability	☐	☐	☐	☐	☐	☐	☐	☐
Localised depletion	☐	☐	☐	☐	☐	☐	☐	☐
Overfishing	☐	☐	☐	☐	☐	☐	☐	☐
Overcapitalisation	☐	☐	☐	☐	☐	☐	☐	☐
Social licence to operate	☐	☐	☐	☐	☐	☐	☐	☐
Impact on threatened species	☐	☐	☐	☐	☐	☐	☐	☐
Poor management	☐	☐	☐	☐	☐	☐	☐	☐
Disease / biosecurity	☐	☐	☐	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐	☐	☐	☐

Other (please specify)

Stock assessment

In this section of the survey we are trying to gauge your thoughts on the stock assessment used in the fishery.

* 21. Recognising that you are a {{ Q1 }}, how clearly do you think you understand the NPF tiger prawn stock assessment?

- Extremely clearly
- Very clearly
- Somewhat clearly
- Not so clearly
- Not at all clearly
- Not sure

* 22. Thinking about the NPF tiger prawn fishery ***over the PAST 10 years***, how well do you think that the current stock assessment supported fishery management?

- A great deal
- A lot
- A moderate amount
- A little
- Not at all
- Not sure

* 23. Thinking about the NPF tiger prawn fishery over the ***NEXT 10 years***, how well do you think that the current stock assessment will support fishery management?

- A great deal
- A lot
- A moderate amount
- A little
- None at all
- Not sure

* 24. Recognising that you are a {{ Q1 }}, how clearly do you think you understand the NPF tiger prawn fishery harvest strategy?

- Extremely clearly
- Very clearly
- Somewhat clearly
- Not so clearly
- Not at all clearly
- Not sure

* 25. There are a range of inputs into the NPF Tiger Prawn Fishery stock assessment.

How would you rate their importance for the stock assessment?

	Low		Medium		High	Not Sure
Commercial catch and effort data	◯	◯	◯	◯	◯	◯
Length frequency data	◯	◯	◯	◯	◯	◯
Fishery Independent Survey - Spawning indices	◯	◯	◯	◯	◯	◯
Fishery Independent Survey - Recruitment indices	◯	◯	◯	◯	◯	◯
Species split	◯	◯	◯	◯	◯	◯
Economic data (from survey)	◯	◯	◯	◯	◯	◯
Fishing Power indices	◯	◯	◯	◯	◯	◯
Something we should add?	◯	◯	◯	◯	◯	◯

What data inputs should we add?

In very simple terms, the tiger prawn fishery stock assessment uses all of this data to assess the status of the two key tiger prawn species (Brown and Grooved) as well as the main byproduct species: Red and Blue endeavour prawns. It then sets a level of fishing effort required to move towards achieving MEY for the fishery.

* 26. Fundamentally, how confident are you that this is the right approach?

- ◯ Extremely confident
- ◯ Very confident
- ◯ Somewhat confident
- ◯ Not so confident
- ◯ Not at all confident

Please explain your answer.

NPF Tiger Prawn Fishery Workshop

GENERAL COMMENTS

27. Do you have other comments, questions or concerns regarding the NPF Tiger Prawn Fishery management or stock assessment you would like to raise for consideration at the workshop?

28. Many thanks for completing the survey.

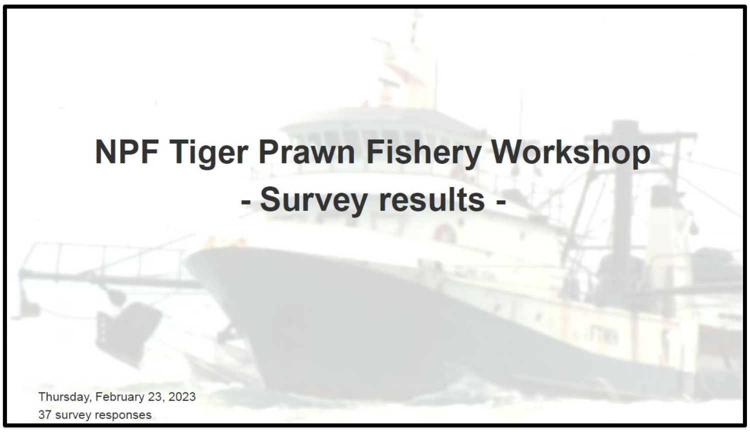
If you are happy to be identified and contacted about your survey answers, please provide your name and email address.

Name

Email Address

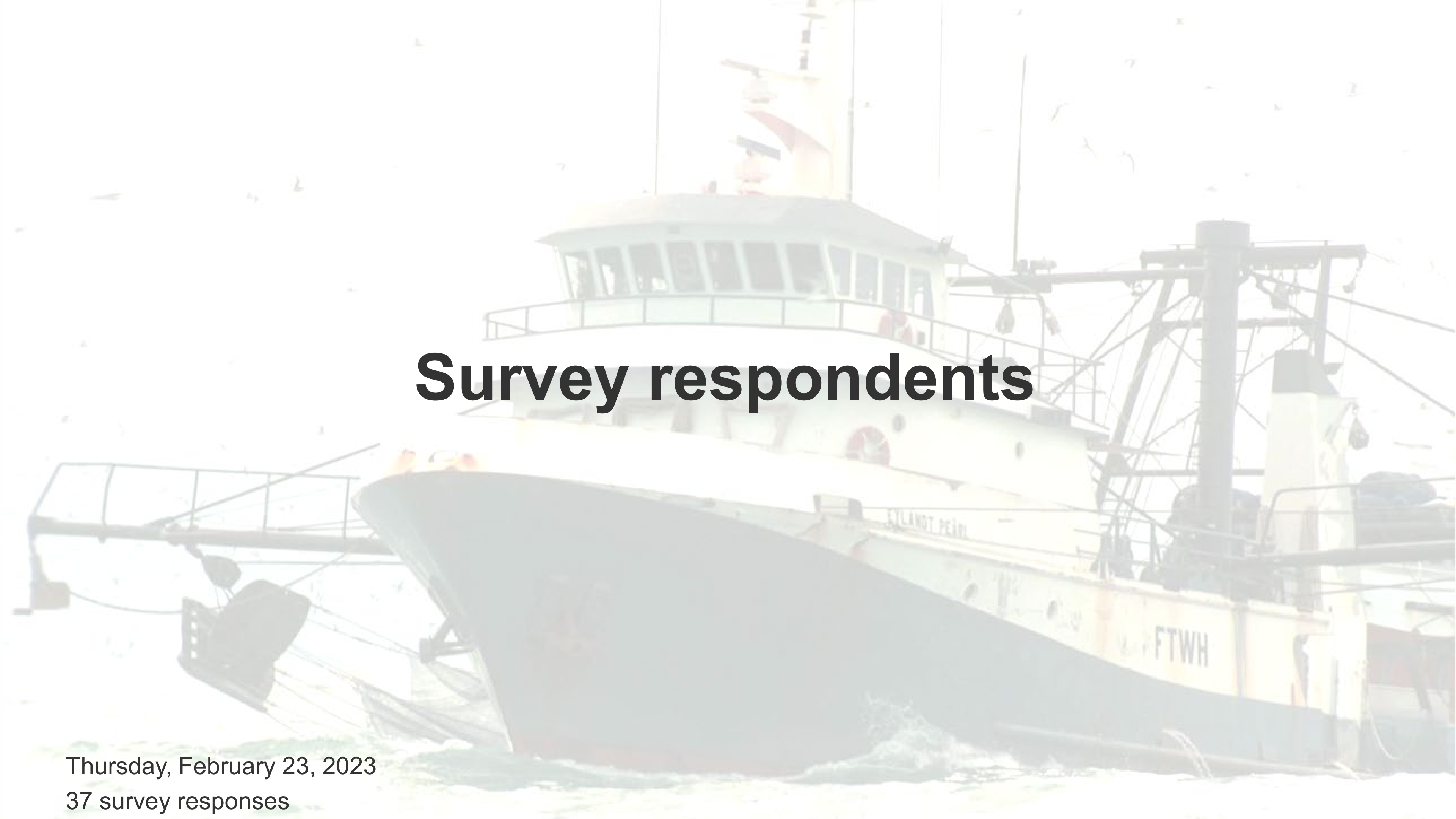
Phone Number

2. Pre-workshop survey results



NPF Tiger Prawn Fishery Workshop
- Survey results -

Thursday, February 23, 2023
37 survey responses

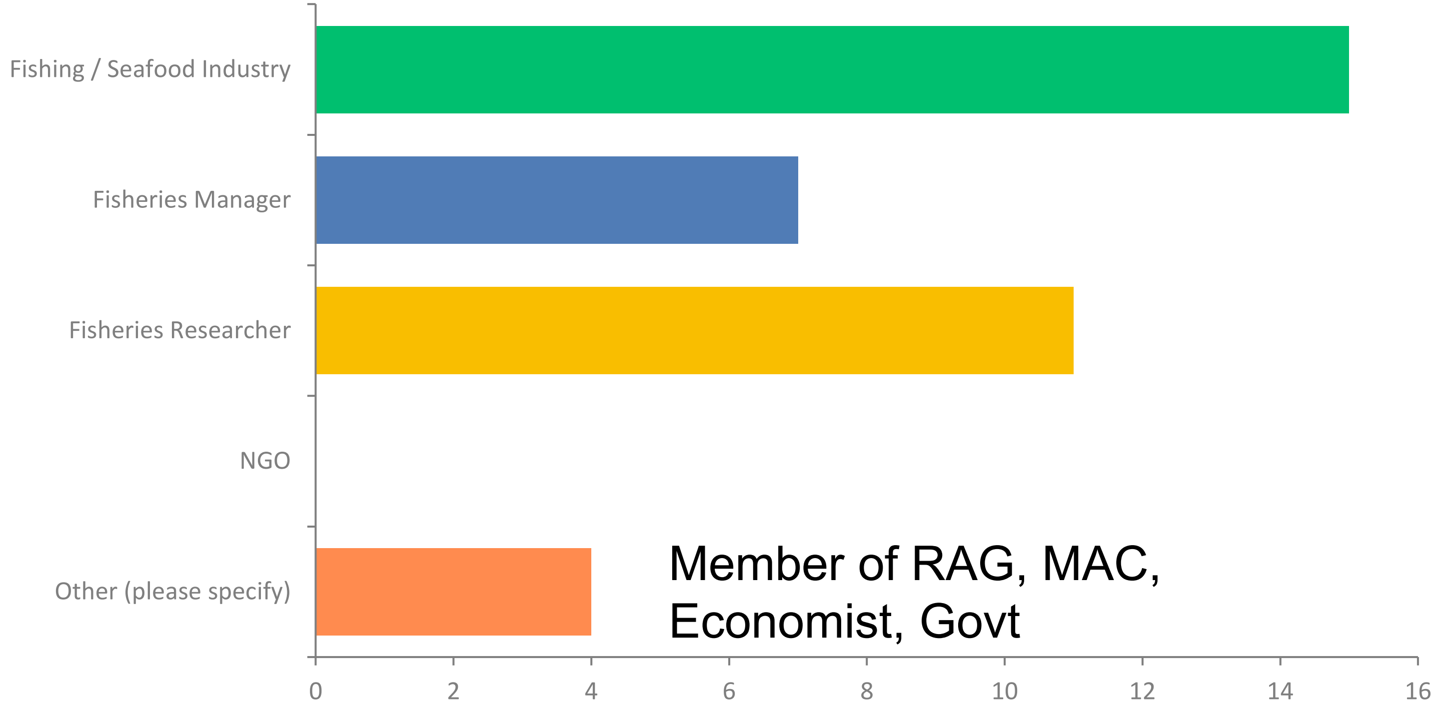


Survey respondents

Thursday, February 23, 2023
37 survey responses

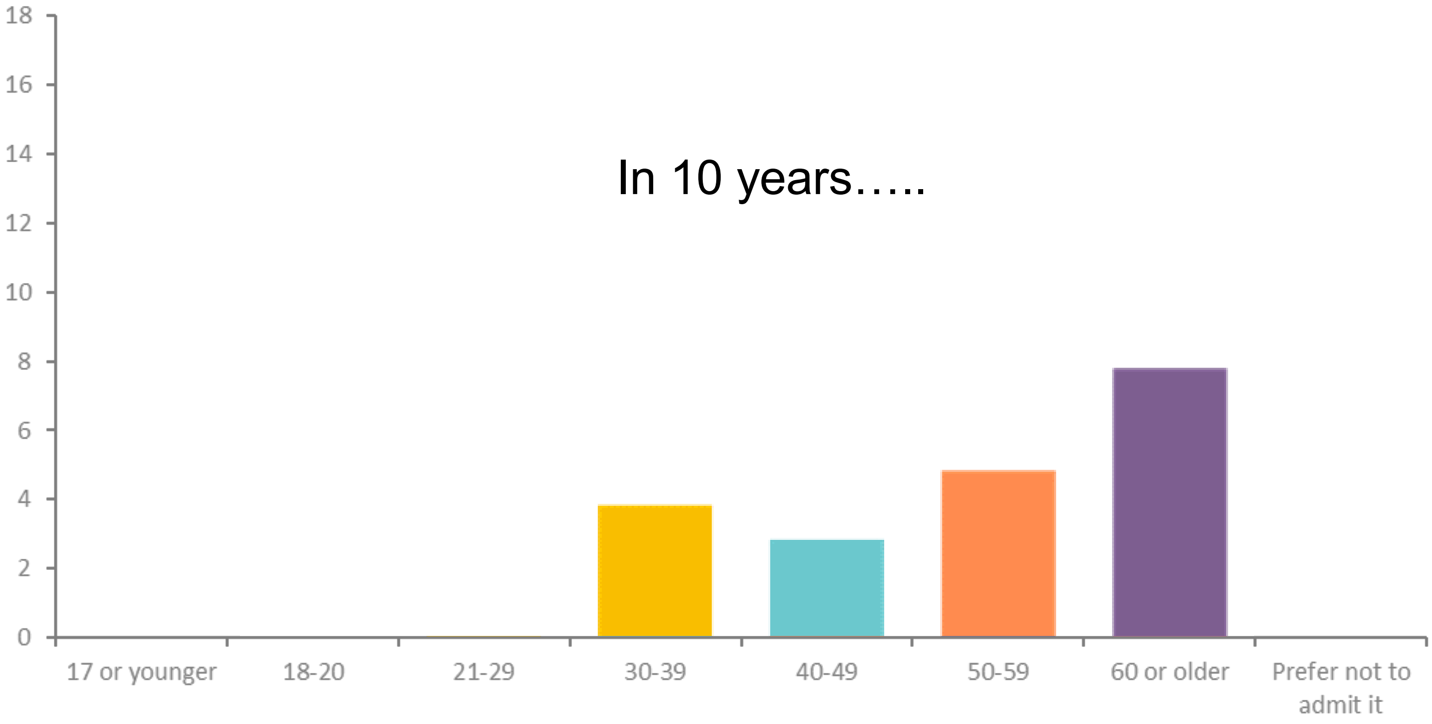
Q1: What participant group best describes you?

Answered: 37 Skipped: 0



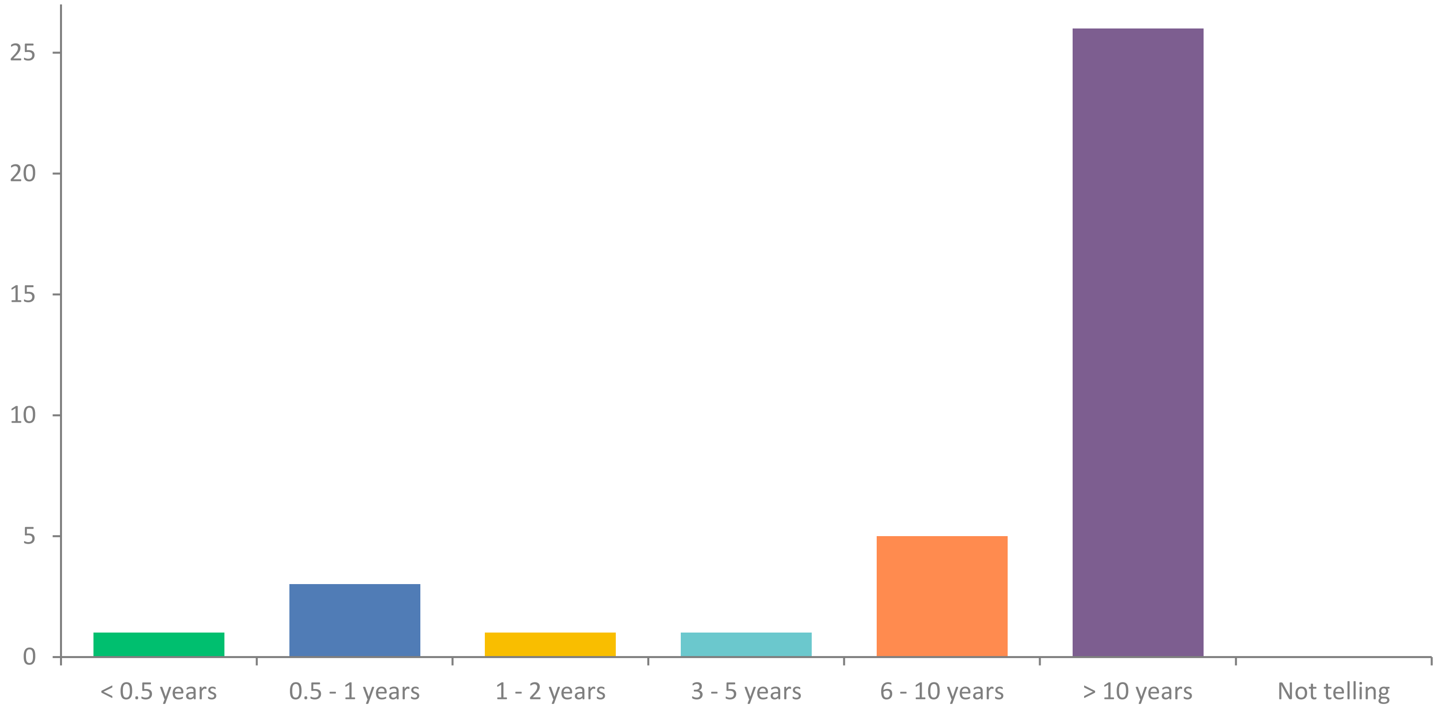
Q2: What is your age?

Answered: 37 Skipped: 0



Q3: How long have you been closely involved in the NPF?

Answered: 37 Skipped: 0

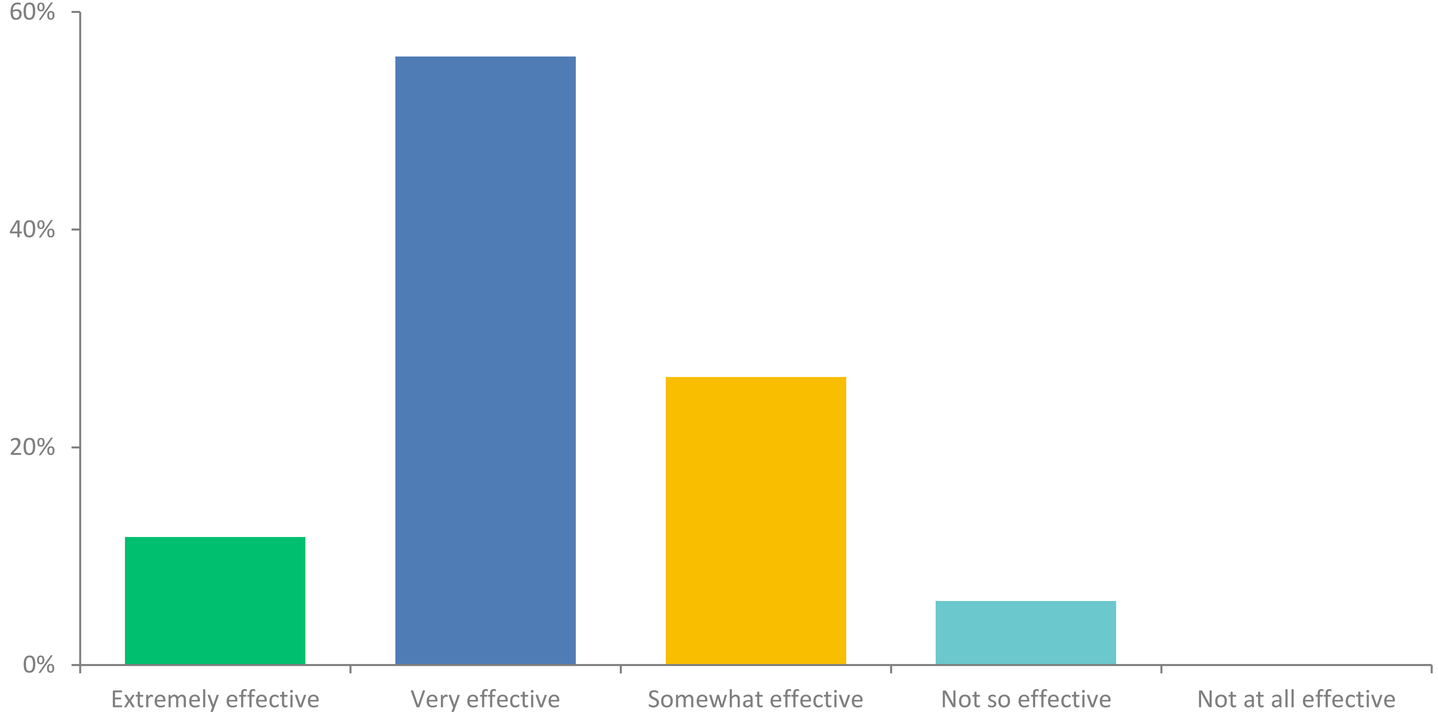


Fishery Management (Sustainability, Economics, Social)

Thursday, February 23, 2023
37 survey responses

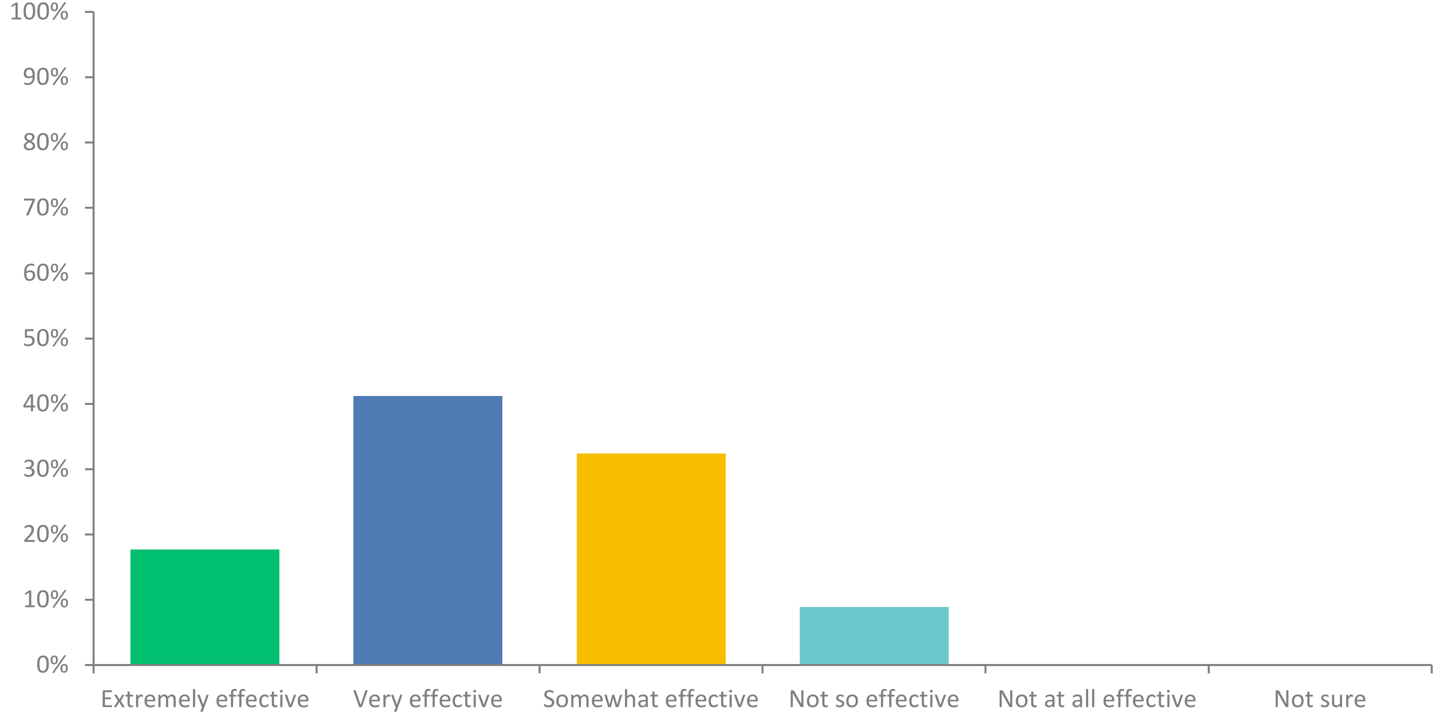
Q4: Rate the current management of the NPF Tiger Prawn Fishery?

Answered: 34   Skipped: 3



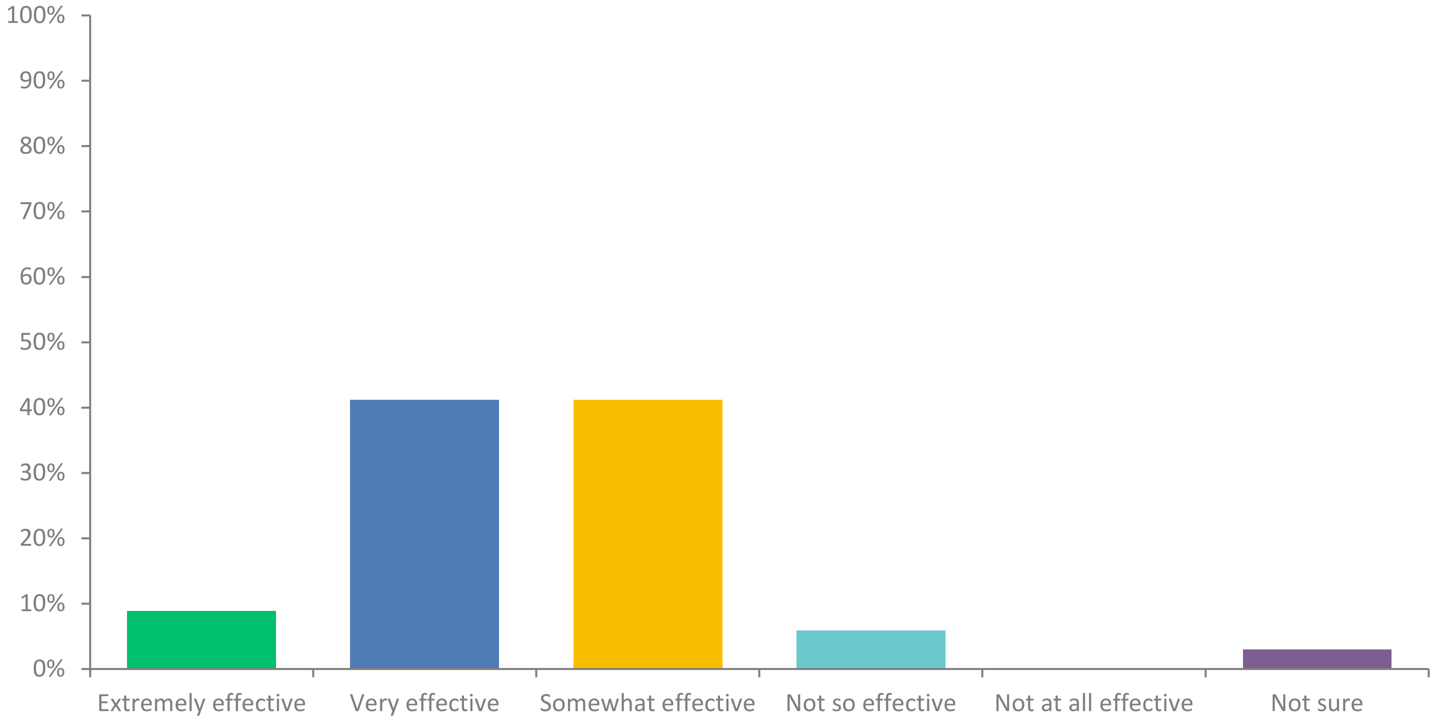
Q5: NPF Tiger Prawn Fishery with regard to SUSTAINABILITY objectives?

Answered: 34 Skipped: 3



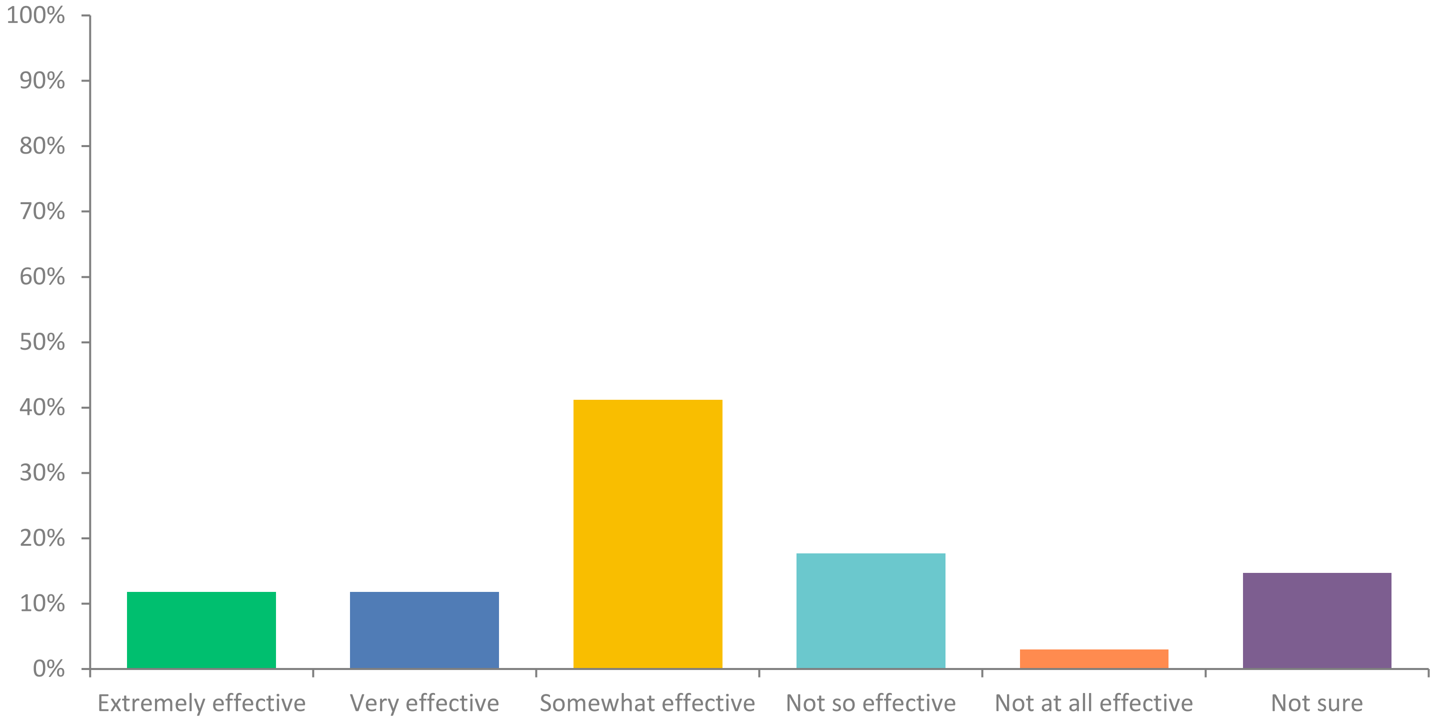
Q6: NPF Tiger Prawn Fishery with regard to ECONOMIC objectives?

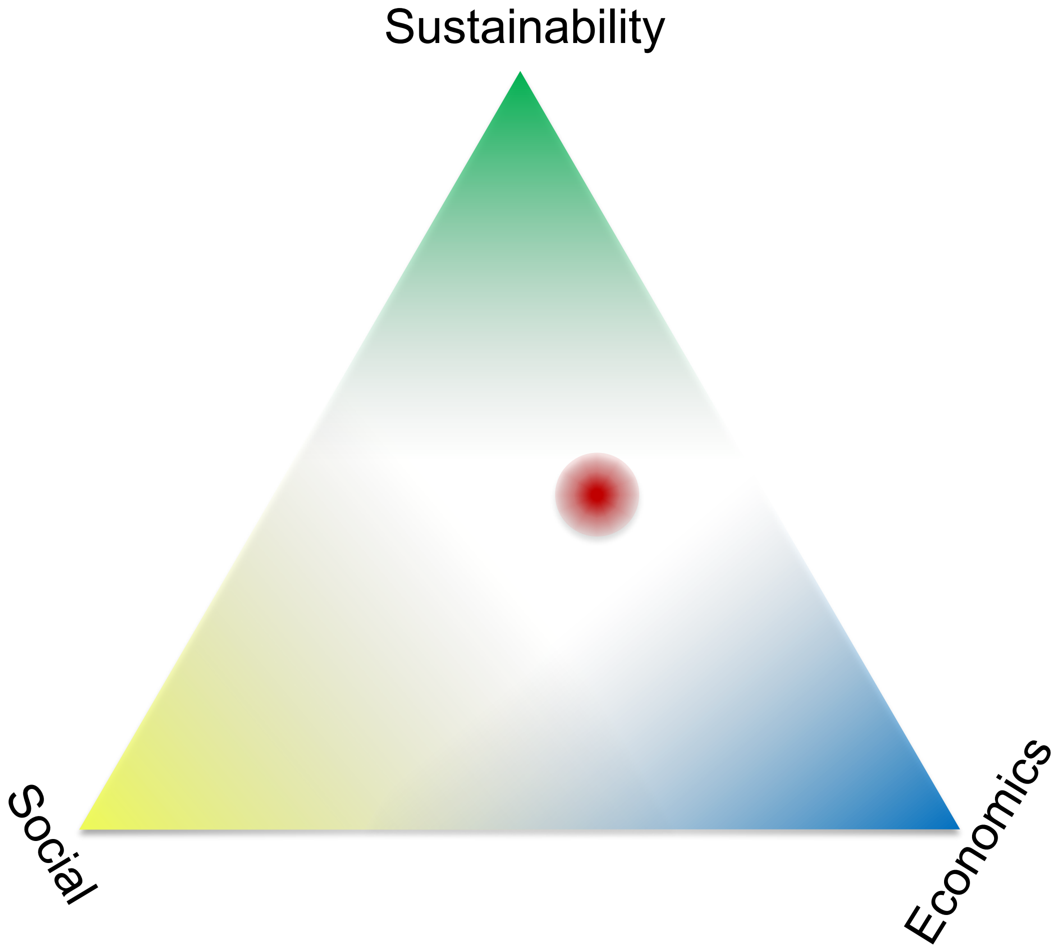
Answered: 34 Skipped: 3



Q7: NPF Tiger Prawn Fishery with regard to SOCIAL objectives?

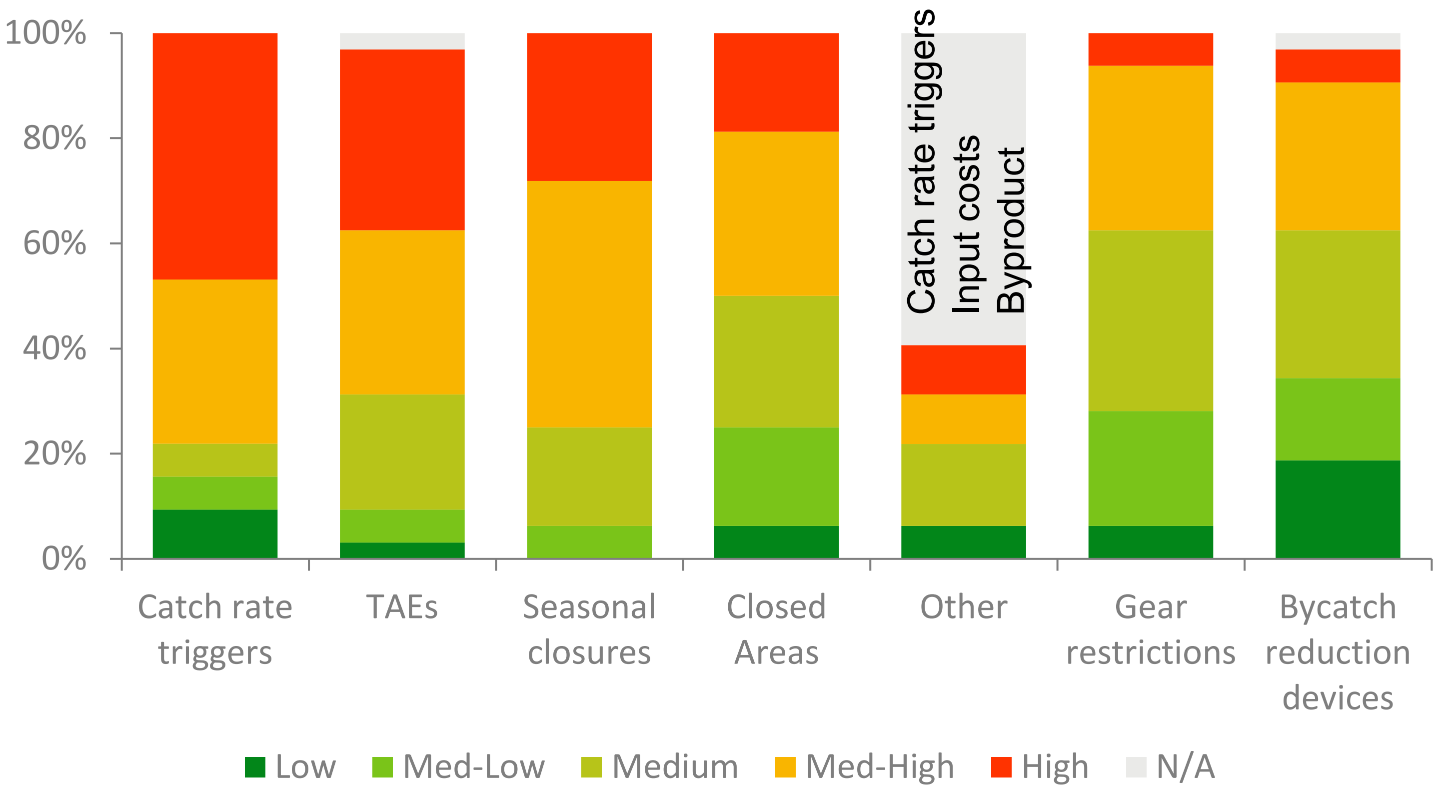
Answered: 34   Skipped: 3




Sustainability
Social
Economics

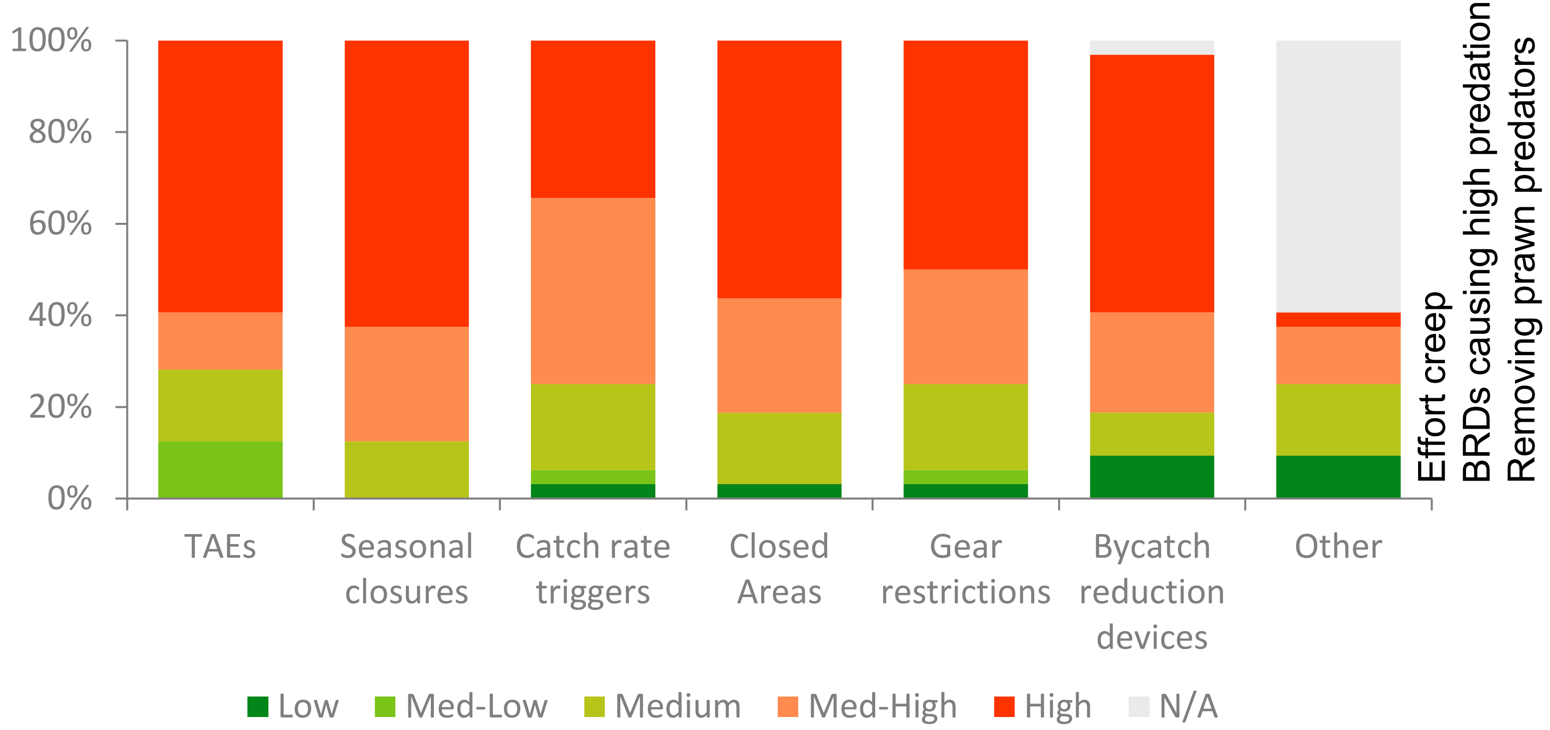
Q12: Management tool value to achieve good ECONOMIC outcomes from the fishery.

Answered: 32 Skipped: 5



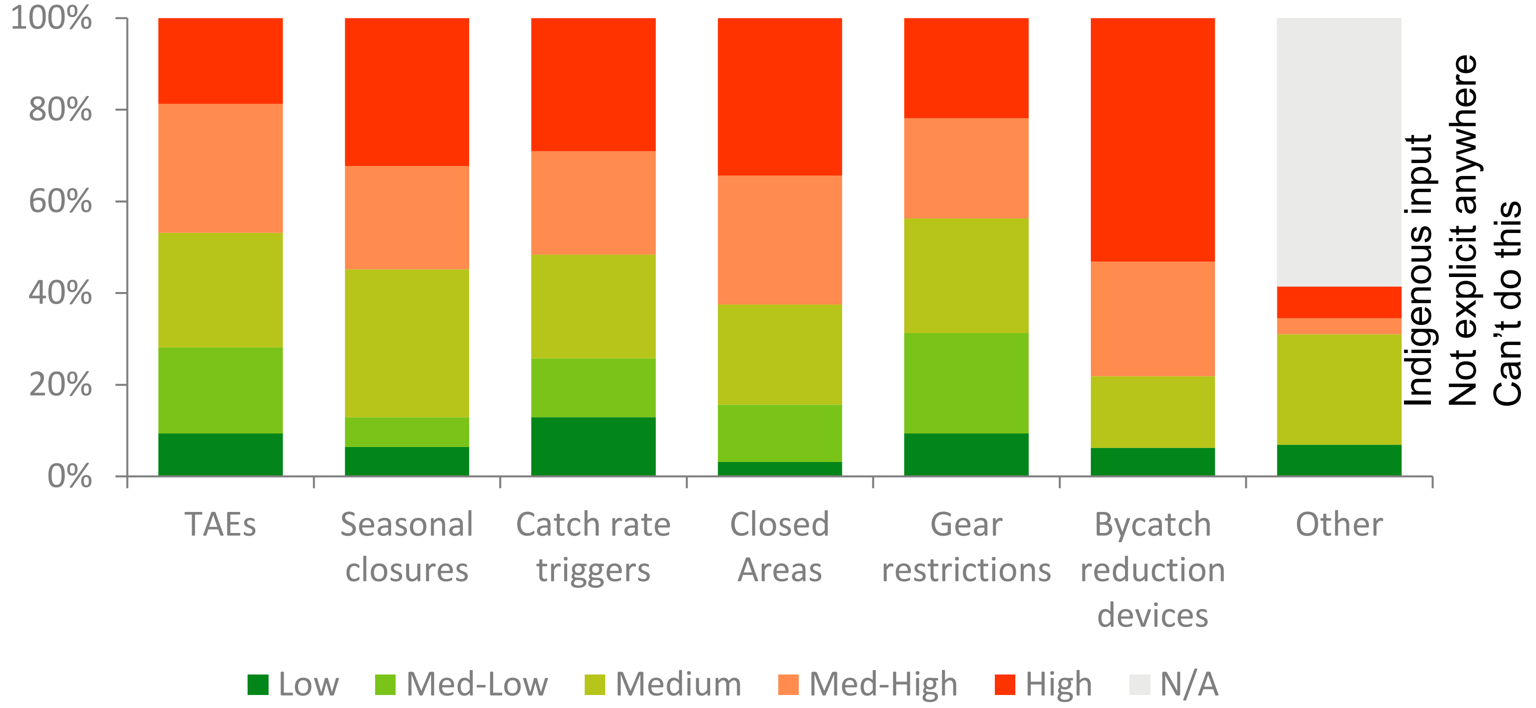
Q13: Management tool value to achieve good SUSTAINABILITY outcomes from the fishery.

Answered: 32 Skipped: 5



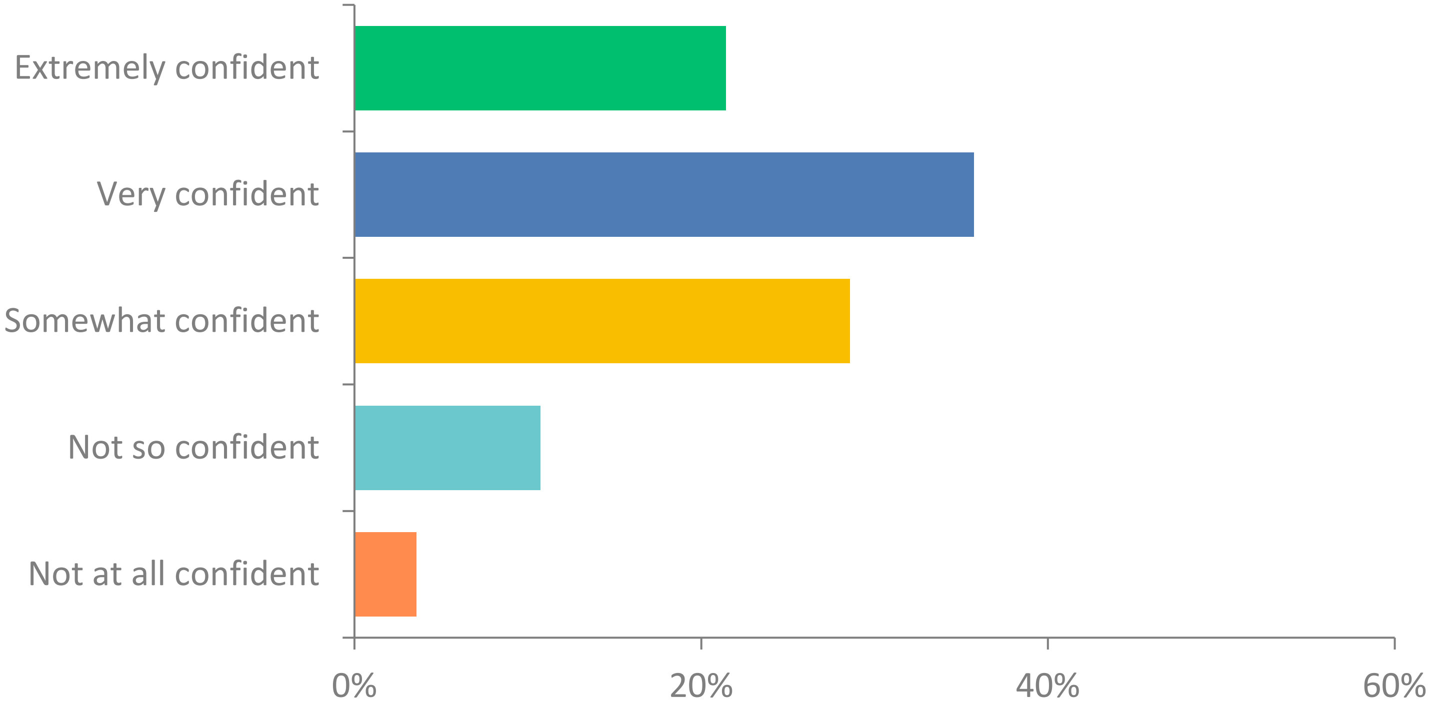
Q14: Management tool value to achieve good SOCIAL outcomes from the fishery.

Answered: 32 Skipped: 5



Q26: How confident are you that we have the right fishery management approach?

Answered: 28   Skipped: 9



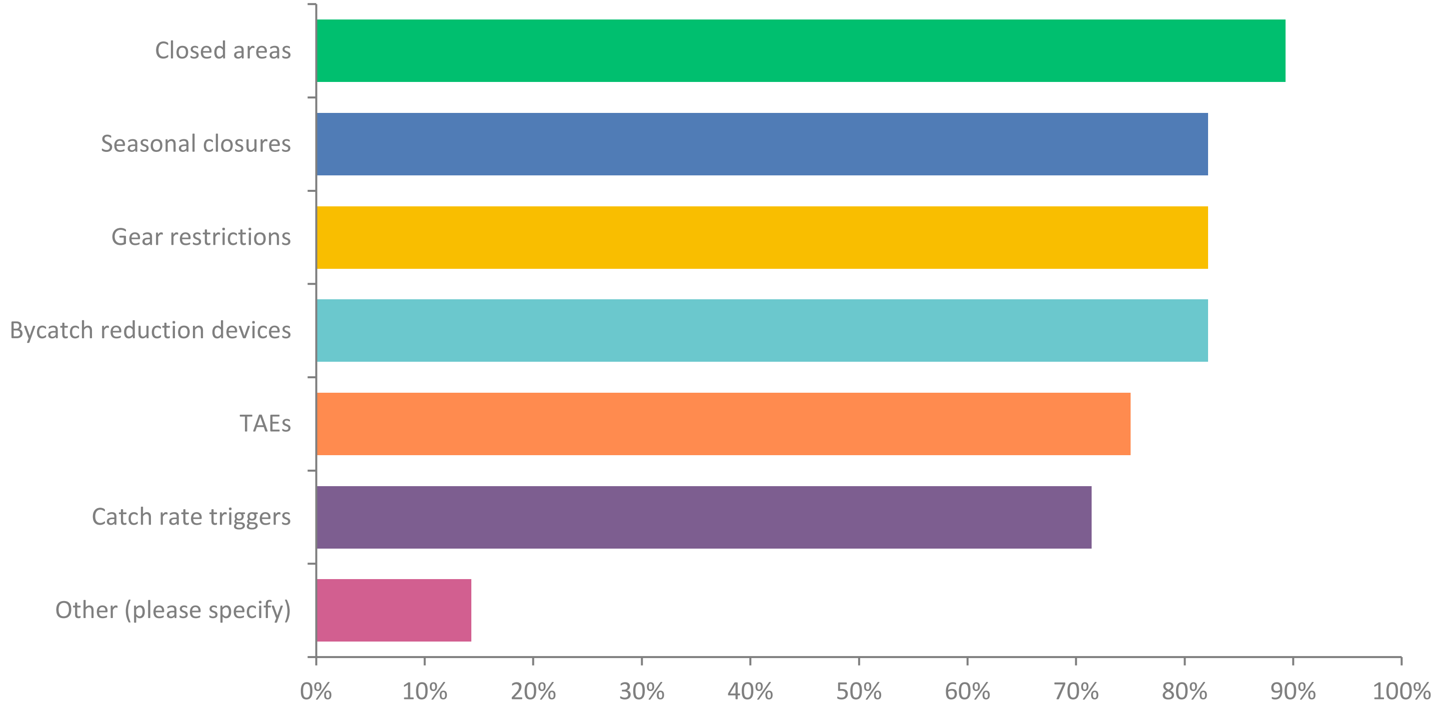
Fishery Management (Management tools)

Thursday, February 23, 2023

37 survey responses

Q18: Which management tools would you definitely keep?

Answered: 28 Skipped: 9

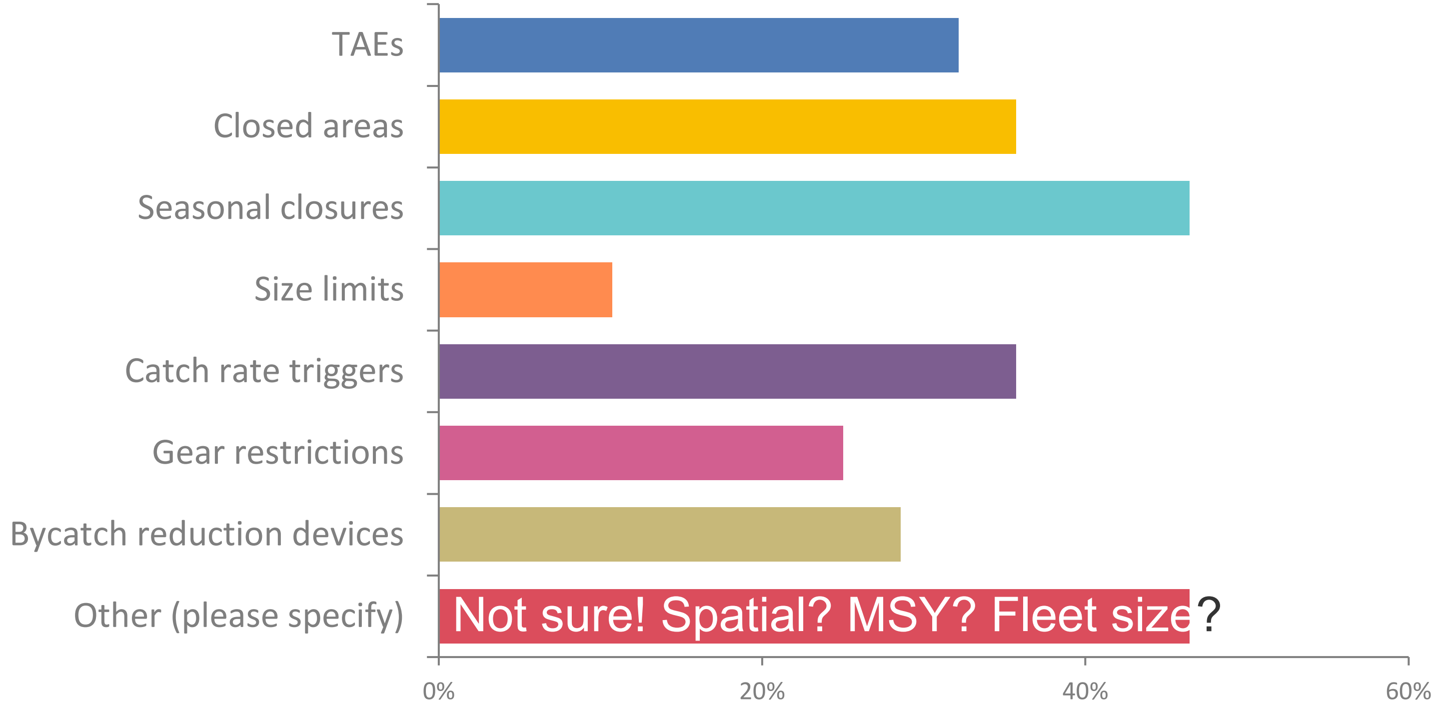


Q16: If you could change just one thing?

Answered: 28   Skipped: 9

Q17: What management control would you use to achieve it?

Answered: 28   Skipped: 9

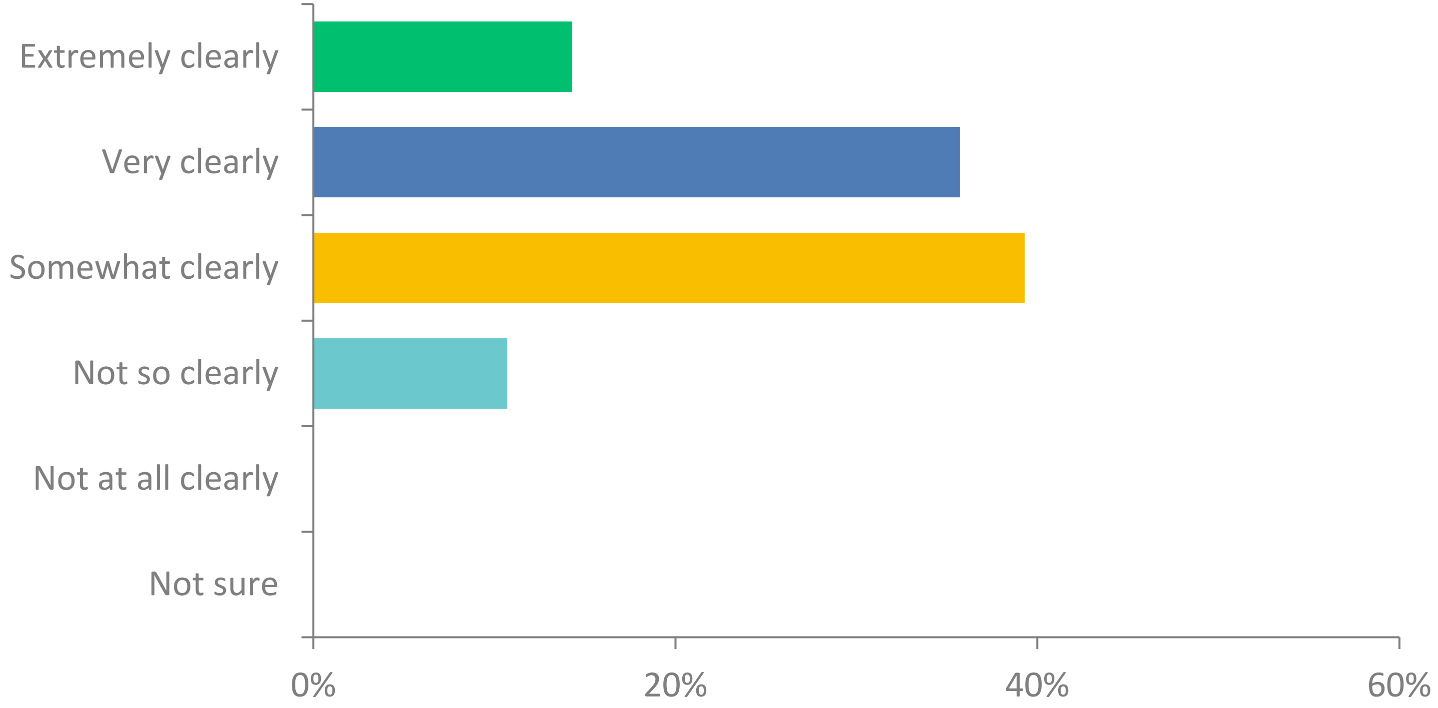


Fishery Management (Stock assessment)

Thursday, February 23, 2023
37 survey responses

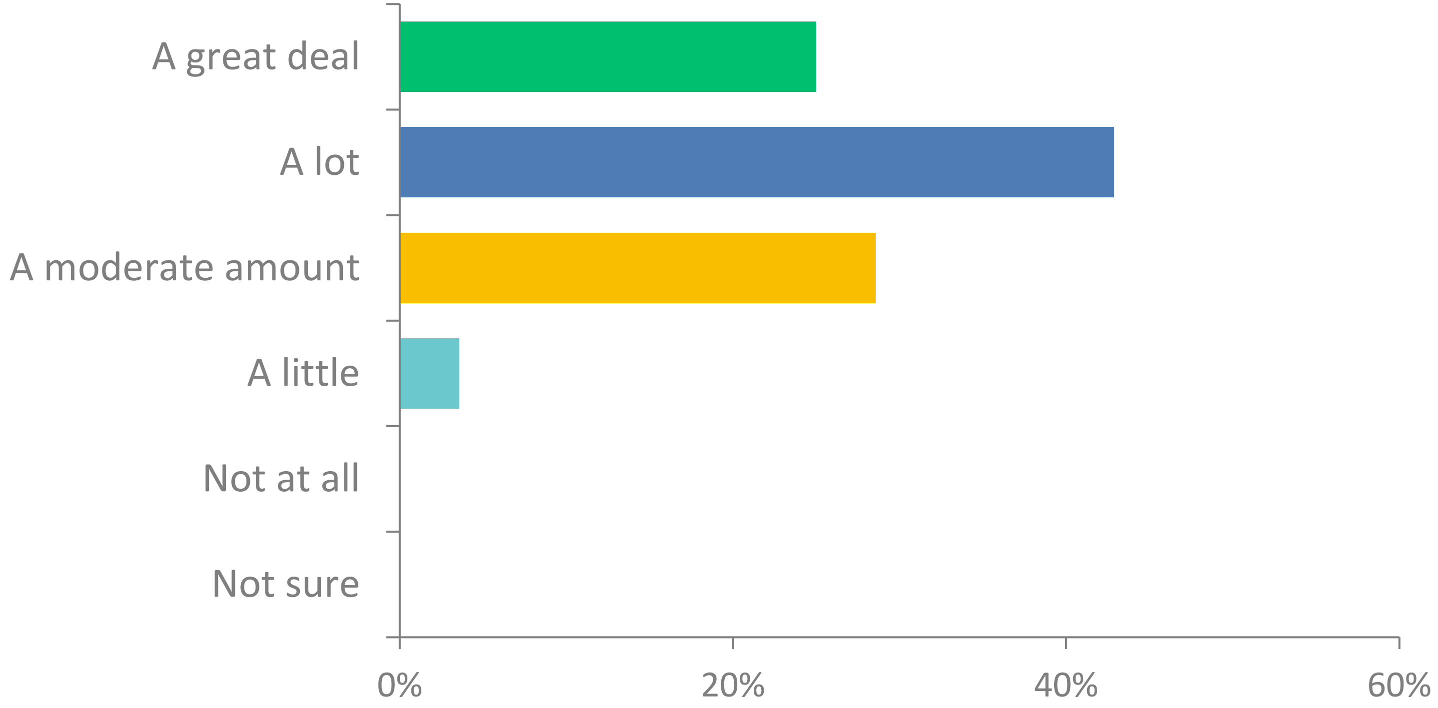
Q21: Understanding of the NPF tiger prawn stock assessment?

Answered: 28 Skipped: 9



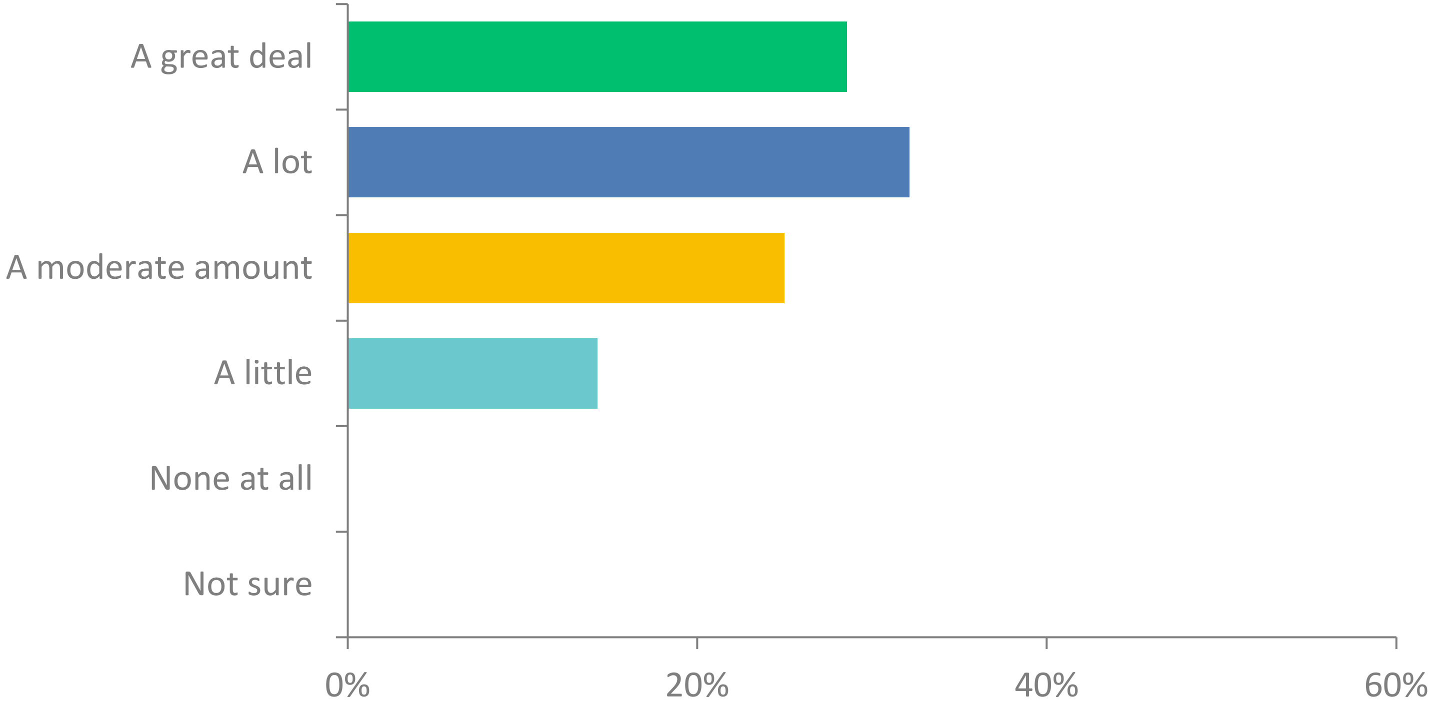
Q22: Support of current stock assessment to management over the *LAST* decade?

Answered: 28 Skipped: 9



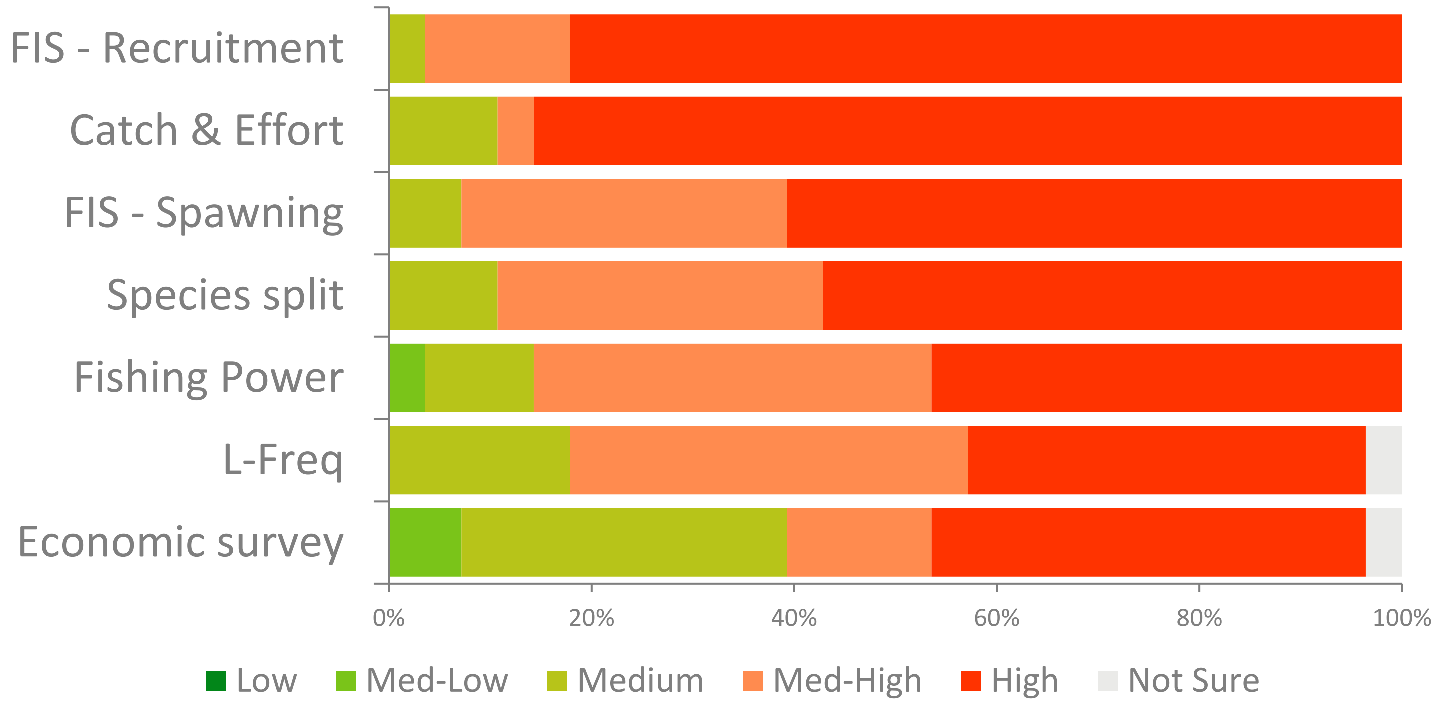
Q23: Support of current stock assessment to management over the *NEXT* decade?

Answered: 28 Skipped: 9



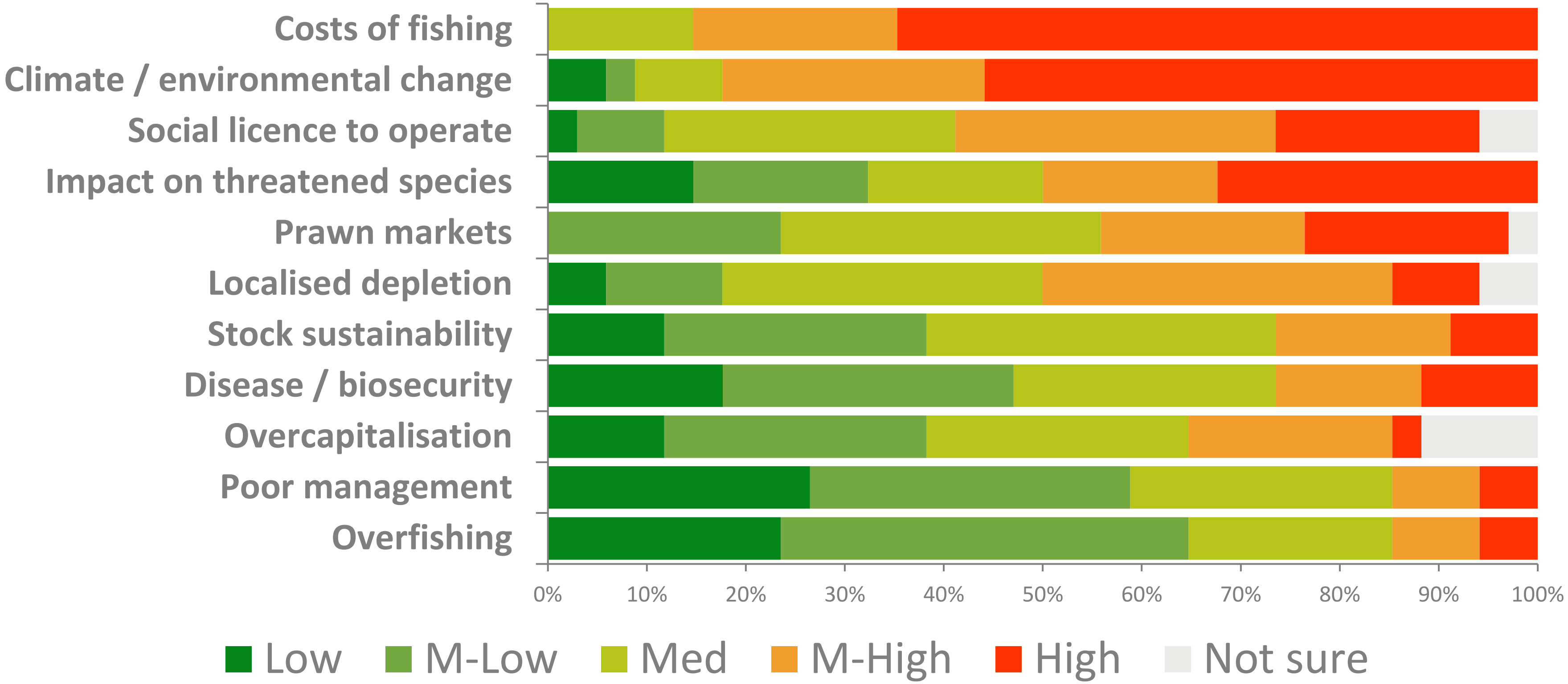
Q25: Importance of the various data inputs to the stock assessment

Answered: 28 Skipped: 9



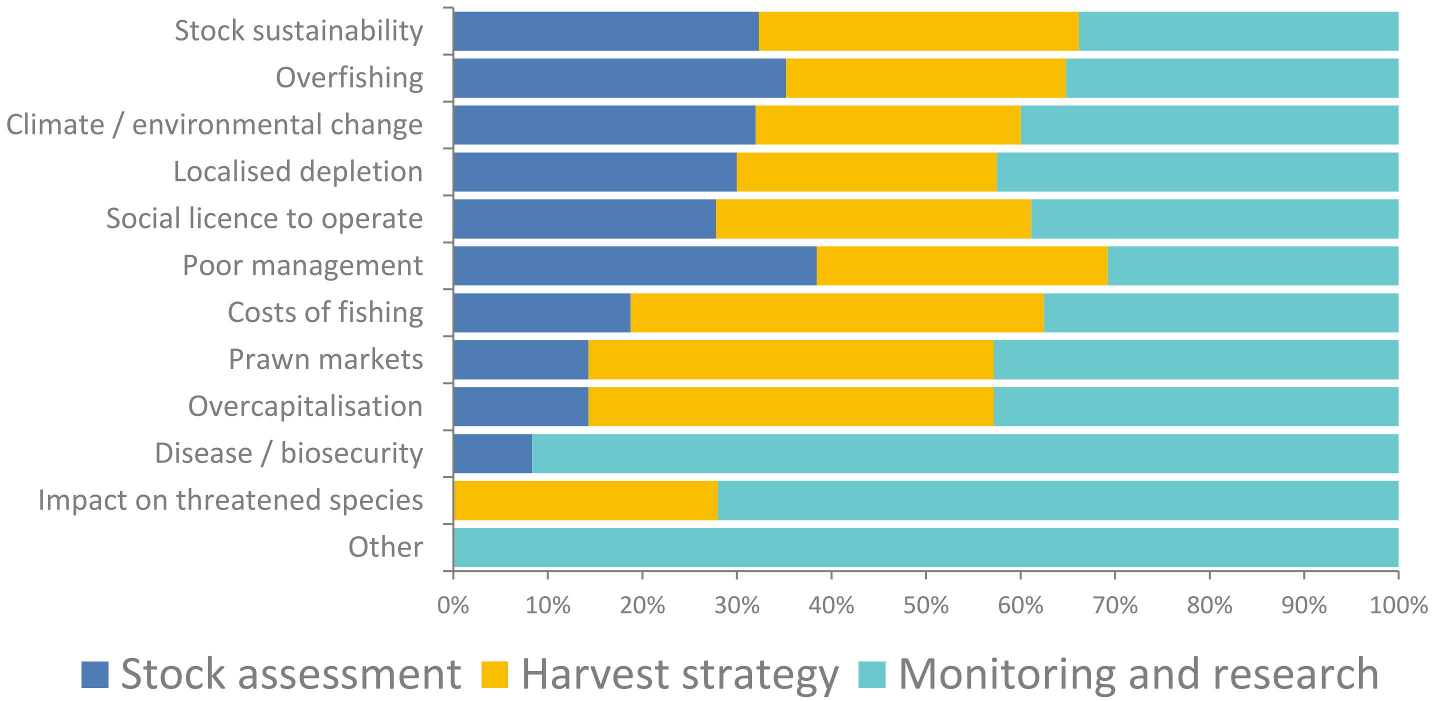
Q11: Risks over the next decade associated with the following issues:

Answered: 34 Skipped: 3



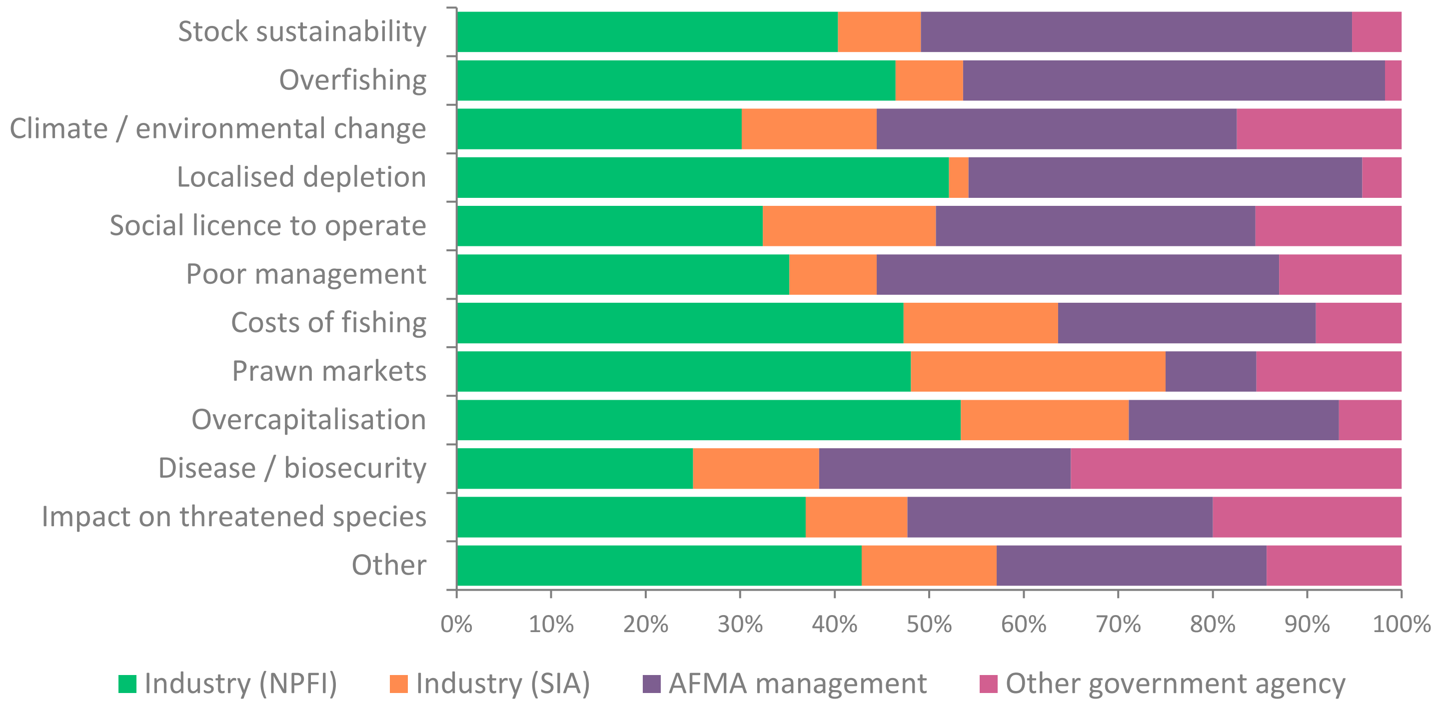
Q20: Process responsible for considering future risks to the NPF tiger prawn fishery?

Answered: 28 Skipped: 9



Q20: Agency responsible for considering future risks to the NPF tiger prawn fishery?

Answered: 28   Skipped: 9



Appendix C: Factsheets provided to participants in preparation for the meeting

1. Summary of key issues to inform strategic planning for the NPF tiger prawn fishery

Summary of key issues to inform strategic planning for the NPF tiger prawn fishery

André E. Punt, Roy Deng, Trevor Hutton, Sean Pascoe, Éva Plagányi, Shijie Zhou

CSIRO

Summary

Below is a summary of some key issues for consideration to future proof the models and harvest strategy for the primary NPF species[1].

Stock assessment-related issues

1. Review of suitability or suggested changes to fishing power analyses for key species (see accompanying Factsheet summary)
2. Future plan for updating endeavour CPUE standardisation and inclusion in model (see Factsheet summary)
3. Changes that might be necessary in response to outcomes of the species split project (see accompanying Factsheet summary)
4. Review pros and cons of moving to a spatial assessment model (or other means of testing this) (see accompanying Factsheet summaries re spatial models and lessons from MICE) [also has implications for the bio-economic model]
5. Review of current understanding of environmental/climate factors affecting tiger prawns, possible implications for stock assessment model and approaches for addressing this (see accompanying Factsheet summary on environmental variables, progress with MICE and noting research proposal submitted) [also has implications for the bio-economic model]

Issues with the bio-economic model

- Should future applications be based on a minimum effort threshold at the fishery level and is there an objective basis for this threshold? (see also Factsheet)
- How can the setting for the model be modified to address the (recent/current/projected) anomalous economic situation
- What is the effect of ignoring banana prawn bioeconomics (which are related) and approaches/motivation for integrating this aspect (see also summary below and technical specifications Factsheet)

[1] We note that there are also other important issues such as bycatch but that these are not the focus or within the scope of this workshop

Summary of key issues to inform strategic planning for the NPF tiger prawn fishery

André E. Punt, Roy Deng, Trevor Hutton, Sean Pascoe, Éva Plagányi, Shijie Zhou

CSIRO

Summary

Below is a summary of some key issues for consideration to future proof the models and harvest strategy for the primary NPF species[1].

Stock assessment-related issues

1. Review of suitability or suggested changes to fishing power analyses for key species (see accompanying Factsheet summary)
2. Future plan for updating endeavour CPUE standardisation and inclusion in model (see Factsheet summary)
3. Changes that might be necessary in response to outcomes of the species split project (see accompanying Factsheet summary)
4. Review pros and cons of moving to a spatial assessment model (or other means of testing this) (see accompanying Factsheet summaries re spatial models and lessons from MICE) [also has implications for the bio-economic model]
5. Review of current understanding of environmental/climate factors affecting tiger prawns, possible implications for stock assessment model and approaches for addressing this (see accompanying Factsheet summary on environmental variables, progress with MICE and noting research proposal submitted) [also has implications for the bio-economic model]

Issues with the bio-economic model

- Should future applications be based on a minimum effort threshold at the fishery level and is there an objective basis for this threshold? (see also Factsheet)
- How can the setting for the model be modified to address the (recent/current/projected) anomalous economic situation
- What is the effect of ignoring banana prawn bioeconomics (which are related) and approaches/motivation for integrating this aspect (see also summary below and technical specifications Factsheet)

---

[1] We note that there are also other important issues such as bycatch but that these are not the focus or within the scope of this workshop

Data-related issues

- Many of the biological parameters for the tiger prawns (e.g. temporal availability, growth, fecundity) are very dated (studies from the 1980s and early 1990s). This is particularly of concern given changing environmental conditions.
- To what extent do we have information to understand the scale or range of variability (temporally and spatially) in biological parameters?

2. Technical description of the NPF Stock Assessment Method and bio-economic TAE setting method

Technical description of the NPF stock assessment method and bio-economic TAE setting method

**André E. Punt, Roy Deng, Trevor Hutton, Sean Pascoe,
Éva Plagányi, Shijie Zhou**

CSIRO

Summary

Two species in Australia's northern prawn fishery (*Peneaus semisulcatus* and *P. esculentus*) are assessed using a size-structured population model that operates on a weekly time-step and one species (*Metapenaeus endeavouri*) is assessed using a biomass dynamics model that operates on an annual time-step. The parameters of this multispecies population model are estimated using data on catches, catch rates, length-frequency data from surveys and the fishery, and tag release–recapture data. The model allows for the technical interaction among the three species. Specifically, the population models assume that fishing effort can be directed at two fishing strategies – one catching predominantly grooved tiger prawns and the other catching predominantly brown tiger prawns. Both tiger prawn species, as well as the other commercial species modelled, are caught in differing proportions by each of the fishing strategies.

The results from the multispecies stock assessment are used to calculate the time-series of catches and levels of fishing effort that maximize net present value using a bio-economic model (section 3). The bio-economic model takes into account costs that are proportional to catches, and those that are proportional to fishing effort, as well as fixed costs. The bioeconomic model is primarily concerned with what is commonly referred to as the second season or the "tiger prawn fishery". This mostly occurs after the mid-season closure (15 June-1 August), although some fishing for tiger prawns is permitted before the closure and this is included in the model. The bio-economic model currently excludes most fishing activity during the first season (the common "banana prawn fishery") although variants of the model exist that experimentally include this component (see section 4.2). The model also excludes fishing activity in the red-leg banana prawn fishery, which competes with the tiger prawn fishery for fishing effort. The model is optimised, maximising the net present value of economic profits, over a 50-year period, assuming that stocks are close to equilibrium after seven years. Profits after the terminal year (i.e., year 50) are assumed to be maintained in perpetuity (as the fishery is in equilibrium).

Technical description of the NPF stock assessment method and bio-economic TAE setting method

André E. Punt, Roy Deng, Trevor Hutton, Sean Pascoe, Éva Plagányi, Shijie Zhou

CSIRO

Summary

Two species in Australia's northern prawn fishery (*Peneaus semisulcatus* and *P. esculentus*) are assessed using a size-structured population model that operates on a weekly time-step and one species (*Metapenaeus endeavouri*) is assessed using a biomass dynamics model that operates on an annual time-step. The parameters of this multispecies population model are estimated using data on catches, catch rates, length-frequency data from surveys and the fishery, and tag release–recapture data. The model allows for the technical interaction among the three species. Specifically, the population models assume that fishing effort can be directed at two fishing strategies – one catching predominantly grooved tiger prawns and the other catching predominantly brown tiger prawns. Both tiger prawn species, as well as the other commercial species modelled, are caught in differing proportions by each of the fishing strategies.

The results from the multispecies stock assessment are used to calculate the time-series of catches and levels of fishing effort that maximize net present value using a bio-economic model (section 3). The bio-economic model takes into account costs that are proportional to catches, and those that are proportional to fishing effort, as well as fixed costs. The bioeconomic model is primarily concerned with what is commonly referred to as the second season or the "tiger prawn fishery". This mostly occurs after the mid-season closure (15 June-1 August), although some fishing for tiger prawns is permitted before the closure and this is included in the model. The bio-economic model currently excludes most fishing activity during the first season (the common "banana prawn fishery") although variants of the model exist that experimentally include this component (see section 4.2). The model also excludes fishing activity in the red-leg banana prawn fishery, which competes with the tiger prawn fishery for fishing effort. The model is optimised, maximising the net present value of economic profits, over a 50-year period, assuming that stocks are close to equilibrium after seven years. Profits after the terminal year (i.e., year 50) are assumed to be maintained in perpetuity (as the fishery is in equilibrium).

Table of Contents

1 Size-structured stock assessment method

1.1 Population dynamics model

The population dynamics model operates on a weekly time-step:

$$\underline{N}_{k,y,w+1,g} = \mathbf{X}_{k,g}\mathbf{H}_{k,y,w,g}\,\underline{N}_{k,y,w,g} + 0.5\,\underline{R}_{k,y,w+1} \tag{1}$$

where $N_{k,y,w,g,l}$ is the number of prawns of species *k* (grooved tiger and brown tiger) and sex *g* in size-class *l* (1-mm size-classes between lengths of 15 and 55 mm) alive at the start of week *w* of year *y* ($\underline{N}_{k,y,w,g}$ denotes the vector of numbers by length), $\mathbf{H}_{k,y,w,g}$ is the survival matrix for species *k* and sex *g* during week *w* of year *y* (a diagonal matrix with $\mathrm{e}^{-Z_{k,y,w,l}}$ on the diagonal), $\mathbf{X}_{k,g}$ is the size-transition matrix (the probability of an animal of species *k* and sex *g* in size-class *i* growing into size-class *j*) during a week, $\underline{R}_{k,y,w}$ is the vector by length of recruitment of species *k* to the population during week *w* of year *y* (the sex ratio of the recruits is assumed to be 50 : 50 in the absence of data to the contrary).

$$R_{k,y,w,l} = \begin{cases} \alpha_{k,w}\, R_{k,\tilde{y}(y,w)} & \text{if } l = 15\,\text{mm} \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

$\alpha_{k,w}$ is the expected fraction of the annual recruitment for species *k* that occurs during week *w*, $R_{k,\tilde{y}}$ is the recruitment of species *k* during "biological year" $\tilde{y}$, and $\tilde{y}(y,w)$ is the biological year corresponding to week *w* of year *y*:

$$\tilde{y}(y,w) = \begin{cases} y & w < 40 \\ y+1 & \text{otherwise} \end{cases} \tag{3}$$

Total mortality, $Z_{k,y,w,l}$, on animals of species *k* in size-class *l* during week *w* of year *y* is given by:

$$Z_{k,y,w,l} = M_k + F_{k,y,w,l} \tag{4}$$

where M_k is the average (over week) weekly instantaneous rate of natural mortality (assumed to be independent of sex, length, and time), and $F_{k,y,w,l}$ is the fishing mortality rate for animals of species *k* in size-class *l* during week *w* of year *y:*

$$F_{k,y,w,l} = A_{k,w}\,\gamma_{y,w}\,S^F_{k,l}\,(q^G_k E^G_{y,w} + q^B_k\,E^B_{y,w}) \tag{5}$$

where $E^G_{y,w}$ and $E^B_{y,w}$ are the levels of effort during week *w* of year *y* by the *P. semisulcatus* (*G*) and *P. esculentus* (*B*) fishing strategies, respectively, q^G_k and q^B_k are the catchability coefficients for the fishing strategies targeting *P. semisulcatus* and *P. esculentus*, respectively, $A_{k,w}$ is the relative availability of animals of species *k* during week *w*, $\gamma_{y,w}$ is the relative efficiency (aka fishing power) of the two fishing strategies during week *w* of year *y*, and $S^F_{k,l}$ is the selectivity of the fishery on animals of species *k* in size-class *l*.

The catch (kg) of prawns of species k of size-class l during week w of year y ($\hat{Y}_{k,y,w,l}$) is given by:

$$\hat{Y}_{k,y,w,l} = \sum_{g} \tilde{w}_{k,g,l}\, \tilde{Y}_{k,y,w,g,l} \tag{6}$$

where $\tilde{w}_{k,g,l}$ is the mass of an animal of species k and sex g in size-class l, and

$$\tilde{Y}_{k,y,w,g,l} = \tfrac{F_{k,y,w,l}}{Z_{k,y,w,l}} N_{k,y,w,g,l}(1-\mathrm{e}^{-Z_{k,y,w,l}}) \tag{7}$$

Equation (3) implies that the biological year ranges from week 40 (roughly the start of October) to week 39 (roughly the end of September), whereas Eqn 2 implies that recruitment contributes only to the first size-class in the model. Growth is assumed to be time-invariant (seasonally and annually), and the seasonal recruitment pattern (defined by $\alpha_{k,w}$) is assumed to be the same each year in the absence of data to parameterize seasonal growth and time-dependent recruitment patterns.

The spawner-stock size index for species k and calendar year y, $\tilde{S}_{k,y}$, is computed using the equation

$$\tilde{S}_{k,y} = \sum_{w} \beta_{k,w} \sum_{l} \omega_{k,l} \frac{1-\mathrm{e}^{-Z_{k,y,w,l}}}{Z_{k,y,w,l}} N_{k,y,w,\mathrm{fem},l} \tag{8}$$

where $\beta_{k,w}$ is a relative measure of the quantity of spawning by species k during week w, and $\omega_{k,l}$ $\omega_{k,l}$ is the proportion of females of species k in size-class l that are mature.

The probability that an animal in (1 mm) size-class i grows into size-class j during each time-step is assumed to be governed by a normal distribution, i.e., for each species k:

$$X_{k,g,i,j} = \int_{L_j}^{L_{j+1}} \tfrac{1}{\sqrt{2\pi}\sigma^{I}_{k,g}} \exp\left(-\frac{\{L-(\tilde{L}_i + I_{k,g,i})\}^2}{2(\sigma^{I}_{k,g})^2} \right) \mathrm{d}L \tag{9}$$

where $\sigma^{I}_{k,g}$ determines the variability in the growth increment for animals of species k and sex g, $\tilde{L}_i$ is the midpoint of size-class i, $L_{i/j}$ is the lower limit of size-classes i / j, and $I_{k,g,i}$ is the growth increment for animals of species k and sex g in size-class i, determined according to a von Bertalanffy growth curve parametrized in terms of $\kappa_{k,g}$ and $\ell_{\infty,k,g}$, i.e.:

$$I_{k,g,i} = (\ell_{\infty,k,g} - \tilde{L}_i)(1-\mathrm{e}^{-\kappa_{k,g}}) \tag{10}$$

1.2 Stock-recruitment analysis

Annual recruitments for the years for which information on catches and survey indices of recruitment are available (1970 onwards) are treated as estimable parameters, and those for other (future) years are assumed to be related to $\tilde{S}_{k,y}$ according to a Ricker stock–recruitment relationship:

$$\hat{R}_{k,y+1} = \tilde{\alpha}_k \tilde{S}_{k,y}\, \mathrm{e}^{-\tilde{\beta}_k \tilde{S}_{k,y}} \tag{11}$$

where $\hat{R}_{k,y}$ is the conditional mean for the recruitment during biological year y (i.e., the recruitment from October of year y–1 to September of year y) based on the stock–recruitment relationship, and $\tilde{\alpha}_k$ and $\tilde{\beta}_k$ are the parameters of that relationship.

The relationship between the actual recruitment for future year y and the conditional mean based on the stock–recruitment relationship is given by:

$$R_{k,y} = \hat{R}_{k,y}\, e^{\eta_{k,y}} \qquad \eta_{k,y+1} = \rho_{r,k}\eta_{k,y} + \sqrt{1-\rho_{r,k}^2}\,\xi_{k,y+1} \qquad \xi_{k,y+1} \sim N(0;\sigma_{r,k}^2) \tag{12}$$

where $\rho_{r,k}$ is the environmentally-driven temporal correlation in recruitment [taken into account because the residuals about the fit of Equation (12) exhibit autocorrelation], and $\sigma_{r,k}$ is the (environmental) variability in recruitment about the stock–recruitment relationship.

1.3 Parameterization

The values for most of the parameters of the population model are assumed to be known, and the estimable parameters are those that define selectivity, growth, and annual recruitment (Table 1; Figure 1). Recruitment in the first year (1969) is assumed to be same as that in the second year (1970), and the population is assumed to be at the unfished equilibrium corresponding to that recruitment at the start of 1970. The former assumption is made because there are no catches for 1969, so the 1969 recruitment is essentially non-estimable.

The recruitment pattern is assumed to depend on month (with the monthly recruitment allocated equally among weeks within a month). The value for the first month is set to 1, resulting in eleven parameters together to define the entire weekly recruitment pattern for each species. The maximum likelihood estimates for the monthly recruitment patterns can vary substantially (and unrealistically) among months if these parameters are unconstrained. A smoothness penalty based on the second derivative of the recruitment pattern is therefore imposed on the monthly recruitment proportions (cf. Maunder and Watters, 2003).

Selectivity for the fishery and spawning fishery are assumed to be logistic functions of length while selectivity for the recruitment survey is assumed to be a gamma function of length.

1.4 Data used for parameter estimation

The data available to fit the size-structured assessment model are catch and effort by week and species since 1970 (the start of the fishery), size composition data for the catch, tag-recapture data, and a 20-year series of fishery-independent survey indices of abundance, species' spatial distribution and the associated size-composition information. Although catches are recorded in logbooks by species group (e.g., both tiger species combined), on-board observer and fishery-independent data on the separation of the species groups to individual species by location allows commercial catches to be split fairly accurately to species (e.g., Venables and Dichmont, 2004;

Venables *et al*., 2006). The species-dedicated effort data are divided into two fishing 'strategies' (aka metiers), one targeting *P. semisulcatus* and another targeting *P. esculentus*, using a model of the expected catch of each species. There are, however, technical interactions between the two strategies in that effort targeted at *P. semisulcatus* will also catch *P. esculentus*, and vice versa (Dichmont *et al*., 2003).

Although the fishery has collected information on the size composition of the catches for several decades, the data were by broad commercial grade category. Unfortunately, although grades are relevant for understanding the revenue of the fishery (prices are by grade), the small number of grade categories and lack of consistency in grading among companies means that past size data are of limited use for assessment purposes. More recent data from on-board observer sampling has been used to construct size compositions of the catch, and these data are used in the analyses herein. In addition, since 2002, fishery-independent surveys of commercial prawns in the Gulf of Carpentaria have been undertaken (see below). In conjunction with the indices of abundance that they produce, length-frequency data (mm CL categories) for male and female prawns of each species have been recorded. The size data are recorded a month or two prior to the first and second commercial fishing seasons.

Tag-recapture data are available from experiments conducted in the northwestern Gulf of Carpentaria in 1983 and 1984 (Somers and Kirkwood, 1991; Buckworth, 1992). In common with Somers and Kirkwood (1991) and Wang *et al*. (1995), the data used in the analyses were restricted to animals that were at liberty for at least two weeks and which were not infected (at release or recapture) by the bopyrid parasite *Epipenaeon ingens*. Only prawns for which species, sex, length-at-release, length-at-recapture, and time-at-liberty are known, were included in the size-structured assessment.

Fishery-independent surveys of the Gulf of Carpentaria within the NPF have been conducted biannually since August 2002 (Kenyon *et al.*, 2021). Surveys in January/February each year (recruitment surveys) are designed to sample the spatial distribution of the smaller prawns (recruits), whereas those during July (spawning surveys, every second year since 2014) are designed to sample larger prawns on the fishing grounds (Dichmont *et al*., 2002; Kenyon *et al*., 2021). The two Gulf of Carpentaria surveys use the same gear, but the former survey trawls sites closer inshore, some being within inshore spatial closures, to capture the smaller recruits of the year, which are emigrating from littoral habitats and hence are closer inshore. Including sites further offshore, the July survey also extends to some fishing grounds not fished during January. The data available from each survey include the index of abundance for each of eight commercial prawn species, an annual measure of the spatial extent of their distribution and the associated size composition data by species and sex.

Effective sample sizes for the length frequency data from the catches and the surveys are computed using the approach of a Dirichlet-multinomial distribution method with which the length frequency data was fitted using a likelihood maximization technique given by Minka (2012).

1.5 Objective function

The values for the estimable parameters of the size-structured model are determined by minimizing an objective function that involves data on catches (in weight), survey indices of relative abundance, tag-recapture data, survey size-composition, and catch size-composition and penalties on the parameters of the model. The summations in Equations (13), (15), and (17) are restricted to the years and weeks for which data are available, e.g., those in which the catch is non-zero for Equation (13).

1.5.1 Data components

Assuming that the square root of the observed catch is normally distributed (Dichmont *et al.*, 2003), the contribution of the catch in weight data to the negative log-likelihood function is:

$$L_1 = \sum_k \sum_y \sum_w \{\log \sigma_k^C + \frac{1}{2(\sigma_k^C)^2}[\sqrt{Y_{k,y,w}^{\text{obs}}} - \sqrt{\hat{Y}_{k,y,w}}]^2\} \tag{13}$$

where σ_k^C is the (estimated) residual standard deviation for species *k*, $Y_{k,y,w}^{\text{obs}}$ is the observed catch (in weight) of prawns of species *k* during week *w* of year *y*, and $\hat{Y}_{k,y,w}$ is the model estimate of the catch of species *k* during week *w* of year *y*, summed over size-classes *l*, i.e. $\hat{Y}_{k,y,w} = \sum_l \hat{Y}_{k,y,w,l}$.

The contribution of the total catch (summed over weeks) to the objective function is based on the assumption that the total catches are log-normally distributed with a standard error of the log of 0.1, with an extra weighting factor of 1,000 imposed to ensure that the total annual catch is removed with near-perfect accuracy, i.e.

$$L_2 = 1000 \sum_k \sum_y \{\ell n \sigma_k^{CT} + \frac{1}{2(\sigma_k^{CT})^2}[\ell n Y_{k,y}^{\text{obs}} - \ell n \hat{Y}_{k,y}]\}^2 \tag{14}$$

where σ_k^{CT} is the residual standard deviation for species *k* (set to 0.1), $Y_{k,y}^{\text{obs}}$ is the observed total (over weeks) catch of prawns of species *k* during year *y*, and $\hat{Y}_{k,y}$ is the model estimate of the total catch of species *k* during year *y*, i.e. $\hat{Y}_{k,y} = \sum_w \sum_l \hat{Y}_{k,y,w,l}$.

The contribution of the data for the recruitment and spawning surveys to the negative log-likelihood function is given by:

$$L_3 = \sum_k \sum_y \left\{\log \tilde{\sigma}_{k,y}^S + \frac{1}{2(\tilde{\sigma}_{k,y}^S)^2}[\log I_{k,y}^S - \log \hat{I}_{k,y}^S]^2\right\} \tag{15}$$

where $I_{k,y}^S$ is the survey index for species *k* during year *y*, $\tilde{\sigma}_{k,y}^S$ the standard error of the logarithm of $I_{k,y}^S$, i.e. $(\tilde{\sigma}_{k,y}^S)^2 = (\sigma_k^E)^2 + (\sigma_{k,y}^S)^2, \sigma_{k,y}^S$ the standard error of the logarithm of $I_{k,y}^S$ attributable to sampling error, σ_k^E is an (estimated) measure of the variation caused by sources other than sampling for species *k*, $\hat{I}_{k,y}^S$ the model estimate corresponding to $I_{k,y}^S$ (for a survey conducted during week *w* of year *y*):

$$I_{k,y}^S = q_k^S \sum_g \sum_l \tilde{w}_{k,s,l} S_{k,l}^S \frac{1 - e^{-Z_{k,y,w,l}}}{Z_{k,y,w,l}} N_{k,y,w,g,l} \tag{16}$$

q_k^S the survey catchability for species *k*, and $S_{k,l}^S$ is the selectivity of the survey gear on prawns of species *k* in size-class *l*.

The size-composition data (fishery and survey) are assumed to be multinomially distributed (although account is taken of overdispersion), e.g., for the fishery catch size-composition data:

$$L_4 = -\phi \sum_k \sum_y \sum_w \sum_g \tilde{N}_{k,y,w,g} \sum_l p^C_{k,y,w,g,l} \log(\hat{p}^C_{k,y,w,g,l}) \tag{17}$$

where $p^C_{k,y,w,g,l}$ is the proportion of the catch of prawns of species *k* and sex *g* during week *w* of year *y* that were in size-class *l*, $\tilde{N}_{k,y,w,g}$ the effective sample size for the catch size-composition data for prawns of species *k* and sex *g* during week *w* of year *y*, ϕ a parameter that determines the extent of overdispersion (set separately for the catch and survey size-composition data), and $\hat{p}^C_{k,y,w,g,l}$ is the model-estimate of $p^C_{k,y,w,g,l}$:

$$\hat{p}^C_{k,y,w,g,l} = \tilde{Y}_{k,y,w,g,l} / \sum_{l'} \tilde{Y}_{k,y,w,g,l'} \tag{18}$$

where *l'* is an index of size-class. The overdisperson parameters have been set to 0.55 based on an application of the McAllister-Ianelli method (McAllister and Ianelli, 1997).

After assigning the data to each size-class and week, the tag–recapture data can be summarized by sets of triplets (l_1, *t*, and l_2, where l_1 is the length-at-release, *t* the time-at-liberty, and l_2 the length-at-recapture). The contribution of the tag–recapture data to the likelihood function is then the product over animals of the probability of observing that a prawn tagged at length l_1, and at liberty for *t* time-steps was recaptured at length l_2 (McGarvey and Feenstra, 2001; Punt *et al.*, 2009). This probability is the (l_1, l_2) entry of the matrix $\mathbf{X}_k^t$.

1.5.2 Penalties

The penalties added to the objective functions are:

- A 2nd derivative penalty is placed on the parameters that determine the within-year distribution of recruitment (i.e., $\alpha_{k,w}$). The weight assigned to this penalty is 1000.
- A weak penalty is placed on the recruitment derivations by species and year. These are assumed to be log-normally distributed about a log-mean with a weight of 0.001 – equivalent to a log-standard deviation of 22.36.
- The code also contains various (small) penalties to keep parameters away from boundaries (e.g., for the additional variance, growth, selectivity and alpha parameters).

There can be a penalty on how much catchability can vary among areas if catchability is not pre-specified. However, this penalty is not used for the base-case model.

2 Biomass dynamics stock assessment method

The stock assessment of endeavour prawns (blue and red) is based on a biomass dynamics model with an annual time-step applied separately to four stock areas (Zhou *et al*., 2009; Figure 2). The population dynamics are governed by a state-space formulation of the standard Schaefer biomass dynamics model, i.e.:

$$B_{k,s,y} = (B_{k,s,y-1} + r_{k,s} B_{k,s,y-1}(1 - B_{k,s,y-1} / K_{k,s}) - Y^{\text{obs}}_{k,s,y-1}) e^{\varepsilon_{k,s,y}} \qquad \varepsilon_{k,s,y} \sim N(0; \tau^2_{B,k,s}) \tag{19}$$

where $B_{k,s,y}$ is the biomass of stock s of species k at the start of year y, $r_{k,s}$ is the intrinsic rate of growth of stock s of species k, $K_{k,s}$ is the carrying capacity of stock s of species k, $Y^{\text{obs}}_{k,s,y}$ is the catch of stock s of species k during year y, and $\tau^2_{B,k,s}$ the variance of the process error of stock s of species k. The model is fitted to catch-rate data under the assumption that the catch-rates are log-normally distributed, i.e.:

$$U^f_{k,s,y} = q^f_{k,s}\, P_y\, B_{k,s,y} e^{\eta^f_{k,s,y}} \qquad \eta^f_{k,s,y} \sim N(0; \tau^2_{U,k,s,f}) \tag{20}$$

where $U^f_{k,s,y}$ is the catch-rate of stock s of species k during year y for fishing strategy f (targeted at grooved or brown tiger prawns), P_y is the fishing power during year y, $q^f_{k,s}$ is the catchability coefficient of stock s of species k for fishing strategy f, and $\tau^2_{U,k,s,f}$ is the variance of the observation error of stock s of species k for fishing strategy f. The model is fitted within the Bayesian framework. The priors for the parameters are:

$$\ell\text{n}K_{k,s} \sim N(\mu_{K,k}, \tau^2_{K,k}) \; \ell\text{n}r_{k,s} \sim N(\mu_{r,k}, \tau^2_{r,k}) \; \ell\text{n}q^f_{k,s} \sim N(\mu_{q,k,f}, \tau^2_{q,k,f}) \tag{21}$$

where $\mu_{K,k}$, $\mu_{r,k}$ and $\mu_{q,f,k}$ are respectively the log-scale prior means for K, r and fishing strategy-specific catchability $q^f_{k,s}$ for species k, and $\tau^2_{K,k}$, $\tau^2_{r,k}$ and $\tau^2_{q,k,f}$ are the corresponding prior variances. The species-specific hyper-priors were uninformative normal and gamma priors (Zhou *et al*., 2009). The priors for the inverses of the process and observation error variances were G(0.001,0.001) priors.

3 Bio-economic projection and optimization method

3.1 Objective function

The objective is to maximize total discounted profit (Π) (i.e., net present value, or NPV) given the time-trajectory of effort by fishing strategy, accounting for contributions from tiger and endeavour prawns, i.e.:

$$\Pi = \sum_{y=1}^{T-1} \pi_y \big/ (1+i)^{y-1} + \left[\pi_T / i\right] \big/ (1+i)^{T-1} \tag{22}$$

where i is the discount rate (equivalent to the opportunity cost of capital, and assumed to be 5% per annum), π_y is the economic profits (revenue less costs, see below) during year y, and π_T is the level of economic profit during the terminal year of the optimisation (i.e. year 50). Profits were assumed to continue at the level π_T indefinitely after the terminal year of the optimisation on the basis that the system is in equilibrium.

The level of economic profit in each year (including the terminal year) is given by

$$\pi_y = \sum_k \tilde{R}_{k,y} - \sum_f (c_K + c_{F,y}) E_y^f - \Omega_y V_y \tag{23}$$

where $\tilde{R}_{k,y}$ is the net revenue obtained from catches of species *k* during year *y* (net revenue being revenue less costs that are proportional to the size of the catch, such as freight, crew and marketing costs), E_y^f is the total effort expended by fishing strategy *f* (that targeted towards *P. semisulcatus* or *P. esculentus*)[a] during year *y*, c_K is the cost of repairs and maintenance per unit of effort, $C_{F,y}$ is the cost of fuel and grease per unit of effort during (future) year *y*, V_y is the number of vessels during year *y* (generally assumed to be 52), Ω_y is the average fixed costs associated with a vessel operating in the tiger prawn fishery during year *y*, and includes a measure of the opportunity cost of capital, such that:

$$\Omega_y = \Gamma_y + (o + d)\Psi_y \tag{24}$$

Γ_y is the proportion of annual vessel costs (i.e., those not related to the level of fishing effort) allocated to the tiger prawn fishery based on a moving average of revenue share (i.e., the proportion of revenue not derived from banana prawns), o is the opportunity cost of capital (equivalent to the discount rate), d is the economic depreciation rate, and Ψ_y is the average value of capital allocated to the tiger prawn fishery, again based on a moving average of revenue share, during year *y*.

The choice of the appropriate formula for the net revenue for species *k* during year *y*, $\tilde{R}_{k,y}$, depends on the model of the population dynamics, i.e.:

$$\tilde{R}_{k,y} = \begin{cases} \sum_l \left[(1-c_L)v_{k,y,l} - c_M\right] \sum_w \hat{Y}_{k,y,w,l} & \text{Size-structured model} \\ \left[(1-c_L)\bar{v}_{k,y} - c_M\right] \sum_s E[\hat{Y}_{k,s,y}] & \text{Biomass dynamics model} \end{cases} \tag{25}$$

where $v_{k,y,l}$ is the average price per kilogram for prawns of species *k* in size-class *l* during (future) year *y*, $\bar{v}_{k,y}$ is the average price per kilogram for prawns of species *k* during (future) year *y*, $\hat{Y}_{k,y,w,l}$ is the catch (kg) of prawns of species *k* in size-class *l* during week *w* of year *y* (based on the size-structured model; Eqn 7), $E[\hat{Y}_{k,i,y}]$ is the expected catch of prawns of stock *i* and species *k* during year *y* (based on the biomass dynamics model; Eqn 19), c_L is the share cost of labour (labour costs are assumed to be proportional to fishery revenue), and cM is cost of packaging and marketing (assumed to be proportional to the fishery catch in weight).

The population dynamics in the size-structured models require estimates of fishing effort by week while the annual total effort used to update the population dynamics in the biomass dynamics model is the annual effort by stock area. The effort by week (and fishing strategy) is computed by multiplying the annual effort by the proportion of effort by week, where p_w^f is the proportion of total effort expended by fishing strategy *f* during week *w* (such that $\sum_w p_w^f = 1$). This proportion is generally assumed to be static over time.

[a] This implies that costs are assumed to be independent of where in the NPF a vessel fishes.

The key choice variable in the model is fishing effort by fishing strategy, and year. Effort for the first seven years of the projection period is selected to maximize Equation (22), with effort for the seventh and all future years set to that of the seventh year (Dichmont *et al*., 2008). A key reason for estimating just a subset of the possible time-series of effort levels is that effort converges to a constant value when the dynamics are deterministic, and because the results of the model are only used to set effort levels for the two years following the year for which the most recent data are available. Further, the reliability of forecasts of economic parameters (input and output prices) decreases with the length of the forecast, so attempting to use the model to determine optimal effort levels over anything other than the relatively short term would be unrealistic. $E^f_{y,w} = 0$ for the weeks that the fishery is closed (i.e., during the pre-season ($w \leq 13$), mid-season ($25 \leq w \leq 30$) and end of season closures, which vary but occur close to the end of the year ($\text{approx.}\, w \geq 47$)).

3.2 Economic data

The key parameters of the profit equation are prices, and variable and fixed costs. With the exception of fuel costs, all other costs are assumed to remain constant in real terms. Prices are also assumed to change over the period of the optimisation.

All values in the model (including historical values) are real values, expressed in prices of the financial year when conducting the assessment. Cost and price data are derived from the annual NPFI fishery economic survey. Vessel capital values are derived from ABARE surveys and are based on the most recent value available, indexed up to the year of the assessment using the index of capital paid.[b] The proportion of vessel capital and fixed costs allocated to the tiger prawn fishery are based on a five-year moving average of the revenue share of tiger prawns and associated prawn byproduct species to total revenue of all prawn species (i.e., excluding non-prawn byproduct).

The key cost parameters in the economic component of the model are shown in Table 2. Crew are paid a share of the revenue (c_L). The unit packaging and marketing costs (c_M) were estimated by dividing the reported costs by the total catch to give a cost per kg. Average repairs and maintenance costs per day (c_K) were estimated by dividing the total reported costs by the number of days fished over the whole year. Fuel costs per day ($c_{F,y}$) were estimated in a similar manner to repair costs, although account was taken also of the different number of hours fished per day in the banana prawn and tiger prawn fisheries.

The price of each grade relative to the average price is used to estimate prawn prices by size class (Table 3). These were derived from the price data provided by David Carter in 2014, but have not since been updated. Current assumed prawn prices by grade ($v_{k,y,w,l}$) are given in Table 3. The main market for NPF tiger prawns is Asia (especially Japan), and the price received is largely dependent on the Yen–A$ exchange rate and the total supplies to this market.

As noted above, prawn and fuel prices are assumed to change over time, with a seven-year forecast produced by Tom Kompas and derived from expected changes in exchange rate and energy prices. For the current (2022) assessment, the price of fuel is expected to increase by 5% from its current high value (for an indexed value of 100 in 2022) over the next seven years, and to remain constant in real terms after 2028 (Table 3a). Price forecasts for prawns over the period 2022–2028 were based on an otherwise standard ARIMA (autoregressive moving average) model,

[b] ABARES has not published the index of capital paid since 2020, and the last assessment instead used the index of average material costs for 2020 and 2021. However, ABARES have subsequently advised that the index is now again estimated (but not published) and can be made available again for future assessments.

where the main drivers were the exchange rate and projected increases in world output (including aquaculture supplies in Asia). On that basis, the price of tiger prawns is expected to increase over the next seven years in real terms by 8%, owing largely to a reduced stock. Prices after 2028 are assumed to remain constant in real terms. The price projections are given in Table 3b.

All prices and input costs are financial, although the prices should reflect their true economic values with the assumption of properly operating markets. Costs associated with interest payments and rent are excluded as these are non-economic costs and reflect returns to the owners of the investment capital (financial or physical), and hence are part of the total profits generated by the fishery. Depreciation is calculated using an economic depreciation rate rather than an accounting rate (Zhou *et al*., 2013).

3.3 Constraints

Maximization of Equation (22) is subject to various constraints.

- Minimum effort penalty. This penalty applies by species and year and is of the form:

$$P_1 = 10000/(E_y^f - E_{min}^f)^4 \tag{26}$$

  where E_y^f is the effort for year *y* and fishing strategy *f*, and E_{min}^f is the minimum effort for fishing strategy *f*. Between 2010 and 2022, the effort threshold used in the assessment was based on the total nominal effort in 2007 (5,142 days). This was divided equally amongst grooved and brown tiger prawns (2,571 days), giving an effort threshold of 2,777 days for both brown and grooved tiger prawns (1.08 multiplied by 2 571).
- *Maximum effort penalty***.** This penalty penalizes attempts to have effort exceed 52*7 days per week. It is 1000 multiplied by the square of the amount by which effort exceeds the maximum.
- *Negative profit penalty*. This penalty penalizes cases in which the annual profit is negative (ensuring that the model does not “close” the fishery or reduce effort to a level that would result in short-term losses to obtain longer-term gains). It is 100 multiplied by the negative of profit (which is negative). Annual profits are constrained to be positive because vessels in the fishery do not have a viable alternative use. Under such circumstances, unless the stocks are severely depleted, it is not optimal to close down the fishery (Clark *et al*., 1979). As a corollary to this, from a fisher perspective, it is not desirable to impose short-term losses on the fishery if these can be avoided (Dichmont *et al*., 2010).
- *Total effort penalty*. This penalty penalizes cases where the total annual effort (over both fishing strategies) exceeds a cap on maximum effort. It is:

$$P_2 = 100(\sum_f E_y^f - E_{\max})^2 \tag{27}$$

  where $E_{\max}$ is the maximum total effort. This penalty only applies when the effort pattern is estimated. If the pattern of effort by week is estimated (it is usually pre-specified) there is a penalty on how much it will differ from constant effort.

3.4 Maximum Sustainable Yield

The maximum sustainable yield and the associated spawning stock size are computed by maximizing the sum of the equilibrium catches by species obtained by projecting the model forward 50 years with deterministic recruitment and time-invariant, but fish strategy-specific, fishing mortality. This calculation is not equivalent to calculating MSY and S_{MSY} by species because of the effect of the technical interactions.

4 Potential extensions not included in the models used for management decision making

4.1 Additional penalties in the bio-economic model

There are several potential penalties that are available in the bio-economic model but are not applied during the applications of the bio-economic model:

- *Minimum effort penalty*. This penalty applies by year and to the total effort, and is of the form:

$$P = 10000 \sum_y \left(\sum_f E_y^f - E_{\min}\right)^2 \tag{28}$$

  where $E_{\min}$ is the minimum effort over all fishing strategies.
- *Effort change penalty.* This penalty applies when the effort for a year and fishing strategy changes from the effort in the last actual year (or the minimum effort whichever is larger) by more than a given amount. The penalty is of the form:

$$P_2 = \Omega_2 |E_y^f - (1-\lambda) E_{last}^f|^2 \tag{29}$$

  where λ determines the extent to which effort can differ the last effort, E_{last}^f is the last effort, and Ω_2 is the weight assigned to the penalty.
- *Inclusion of red endeavour prawns in the bio-economic model*. This involves fitting a biomass dynamics model to the catch and effort data for red endeavour prawns and including the net revenue due to red endeavour prawns into the equation for net revenue.

4.2 Integrating banana prawns into the bio-economic model

The focus of the assessment and bio-economic model has been on the tiger prawn component of the fishery (which mostly takes place during the second season), as this was the component that was most considered in need of management. Research on the banana prawns that are targeted during the first season has been more limited. As the model optimizes profits over time (i.e., a dynamic definition of MEY), a constraint has been added to avoid "bang-bang" outcomes, i.e., closing the fishery to achieve long-term profits (Clark, 1976). The model is consequently forced to ensure that existing vessels do not operate at a financial loss through allocating a share of the fixed costs (including capital use costs) to the tiger prawn fishery by making it subject to a "minimum level of effort". If all the stocks are included and the total fixed costs are in the same model – then this constraint could be removed. The share of fixed costs was based on a five-year moving average of the revenue share of tiger and endeavour prawns to total revenue. Given the highly variable nature of the banana prawn component of the fishery, this resulted in changes to the assumed cost structure each time the model was applied. This was a less than desirable, but necessary, assumption to operationalise the bioeconomic model. This section summarized how a banana prawn component can be added to the bio-economic model.

The objective remains to maximize total discounted profit (Π) (i.e., net present value, or NPV) given the time-trajectory of effort by fishing strategy, but now including contributions from banana, tiger, and endeavour prawns. The banana prawn component of the fishery is essentially a depletion fishery, with catch rates (and hence revenue per day) declining over the season (Pascoe *et al.*, 2018), as the cohort that recruits to the fishery is fished down and depleted leaving a small portion to be the spawners for the next season. Previous studies have found that the level of fishing effort applied to banana prawns was a function of initial biomass and the relative price of banana and tiger prawns (when tiger prawns were available for fishing given the management constraints) (Pascoe *et al.*, 2015 and references therein). Based on this, a fishing effort model for banana prawns was estimated (see Hutton *et al*., 2022; Supplementary Material S2):

$$E_{y,w}^{\text{Banana}} = \beta_0 + \beta_1 \frac{B_{B,y,w}}{\bar{B}_0} + \beta_2 \frac{p_{T,y} D_{T,w}}{p_{B,y}} + \beta_3 D_{w>22} \tag{30}$$

where $\beta_0, \beta_1, \beta_2$ and β_3 are the regression coefficients, $B_{B,y,w}$ is the biomass (tonnes) of banana prawns at the start of week w of year y, $\bar{B}_0$ is the average biomass of banana prawns at the start of the fishing season, $P_{T,y}$ is the average price of tiger prawns during year y, $P_{B,y}$ is the average price of banana prawns during year y, $D_{T,w}$ is a dummy variable representing whether tiger prawns are available for capture (i.e. $D_w = 0$ for $w < 18$, otherwise $D_w = 1$), and $D_{w>22}$ is a dummy variable representing the last few weeks of the fishing season (i.e. $D_{w>22} = 0$ for $w \leq 22$, otherwise $D_{w>22}$ = 1) during which effort declines more substantially. The model cannot fully capture the heterogeneity in cost structures in the fishery that result in some vessels ceasing fishing for banana prawns earlier than others; some vessels moving to tiger prawns if available and others finishing their season earlier (to restart in the second season) but provides an adequate fit to the available data (Hutton *et al.*, 2022; Supplementary Fig. S2).

Effort in the banana prawn fishing strategy is controlled based on a catch rate trigger, where effort for week w is zero if the catch per unit effort for week w-2 is less than a critical value determined on the basis of prices and fishing costs (Pascoe *et al*., 2018). Banana prawns are generally not targeted during the second season, so $E_{y,w}^{\text{Banana}}$ for weeks $w \geq 31$.

4.2.1 Population dynamics and catch

The population dynamics and associated catch equations for the tiger prawn component of the fishery (including endeavour prawns) are detailed above. The banana prawn model is used to predict effort by week directed at banana prawns given the initial biomass of banana prawns (Hutton *et al.*, 2022; Supplementary Material S2). The population dynamics of banana prawns are modelled as:

$$B_{B,y,w} = \begin{cases} B_{0,y} \\ (B_{B,y,w-1}\, e^{-0.5M_B}(1+0.5\rho_w) - C_{B,y,w})e^{-0.5M_B}(1+0.5\rho_w) \end{cases} \tag{31}$$

where $B_{0,y}$ is the initial biomass of banana prawns (in week w=14), M_B is natural mortality for banana prawns (which may depend on $B_{0,y}$), ρ_w is the growth rate for week w, and $C_{B,y,w}$ is the catch during week w of year y, given by:

$$C_{\mathrm{B},y,w} = q_B\, E_{y,w}^{\mathrm{Banana}} B_{B,y,w-1}\, e^{-0.M_B}(1+0.5\rho_w) \tag{32}$$

where q_B is catchability (which may depend on $B_{0,y}$) and $E_{y,w}^{\mathrm{Banana}}$ is effort directed towards banana prawns during week w of year y. Natural mortality is assumed to be 0.025 week^{-1}, and catchability is computed using the method of Zhou *et al.* (2015).

4.2.2 Economic component

Tiger and endeavour prawns are exported. However, Australian tiger prawn exports represent a relatively small proportion of the global shrimp/prawn market, and changes in quantities landed would have little impact on the prices received so the prices of these species can be assumed to be exogenously determined and price flexibility[c] ignored. Banana prawns, however, are mainly sold on the domestic market, and changes in landings could influence the price received. Estimates of price flexibility - the percentage change in prices due to a 1% change in quantity landed – have not been estimated at the species level for the Australian domestic market. Schrobback *et al*. (2019) estimated price flexibilities for prawns at an aggregated level in Australia and found long-term price flexibilities of around -1.0 for Australian wild-caught prawns on the domestic market. Banana prawns from the NPF make up between 25% and 40% of total wild-caught prawns sold on the domestic market, so a 1% change in NPF banana prawn landings could result in a 0.25-0.4% change in total prawns supplied to the domestic market (depending on whether it was a poor or good year), with a subsequent change in prices of around 0.25-0.40%, assuming all other wild caught Australia prawn fisheries are operating at their same level of catch. Regression of prices received and landings of banana prawns in the NPF also suggested a price flexibility of between -0.17 and -0.38 (Hutton *et al*., 2022; Supplementary Material S5). Given this, prices for banana prawns in the model were estimated as:

$$\tilde{p}_{k,y} = \frac{f_k\, \tilde{p}_{k,y^*} \sum_w Y_{k,y,w}}{\sum_w Y_{k,y^*,w}^{\mathrm{Obs}}} \quad \text{where } k\text{=banana prawns} \tag{33}$$

where f_k is the own price flexibility for banana prawns on the domestic market (assumed to be -0.4), and $\tilde{p}_{k,y^*}$ is the observed price received of banana prawns in a reference year y*.

[c] Price flexibility refers to the percentage change in price due to a 1 percent change in quantity landed.

5 References

5.1 References to NPF stock assessment methods

Deng, R.A., Punt, A.E., Dichmont, C.M., Buckworth, R.C., Burridge, C.Y. 2015. Improving catch prediction for tiger prawns in the Australian northern prawn fishery. *ICES Journal Marine Science* 72: 117-129.

Dichmont, C.M., Punt, A.E., Deng, A., Dell, Q., and Venables, W. 2003. Application of a weekly delay-difference model to commercial catch and effort data in Australia's northern prawn fishery. *Fisheries Research* 65: 335–350.

Hutton, T., Pascoe, S., Deng, R., Punt, A.E., Zhou, S. 2022. Effects of re-specifying the Northern Prawn Fishery bio-economic model to include all the target species. *Fisheries Research* 247: 106190

Punt, A.E., Deng, R.A, Dichmont, C.M. Kompas, T., Venables, W.N., Zhou, S., Pascoe, S., Hutton, T., Kenyon, R., van der Velde, T., Kienzle, M. 2010. Integrating size-structured assessment and bio-economic management advice in Australia's Northern Prawn Fishery. *ICES Journal Marine Science* 67: 1785-1801.

Punt, A.E., Deng, R., Pascoe, S., Dichmont, C.M., Zhou, S., Plaganyi, E.E, Hutton, T., Venables, W.N., Kenyon, R., van der Velde, T. 2011. Calculating optimal effort and catch trajectories for multiple species modeled using a mix of size-structured, delay-difference and biomass dynamics models. *Fisheries Research* 101: 201-211.

Zhou, S., Punt, A.E., Deng, R., Dichmont, C.M., Ye, Y., Bishop, J. 2009. Modified hierarchical Bayesian biomass dynamics models for assessment of short-lived invertebrates: a comparison for tropical tiger prawns. *Marine and Freshwater Research* 60: 1298–1308.

5.2 Other references

Buckworth, R.C. 1992. Movements and growth of tagged blue endeavour prawns *Metapenaeus endeavouri* (Schmitt 1926) in the western Gulf of Carpentaria, Australia. *Australian Journal of Marine and Freshwater Research* 43: 1283–1299.

Clark, C.W. 1976. Mathematical Bioeconomics: The Optimal Management of Renewable Resources. USA: John Wiley and Sons; USA.

Clark, C.W., Clarke, F.H., Gordon R.M. 1979. The optimal exploitation of renewable resource stocks: problems of irreversible investment. *Econometrica* 47: 25–47.

Dichmont, C. M., Burridge, C., Deng, A., Jones, P., Taranto, T., Toscas, P., Vance, D., *et al*. 2002. Designing an integrated monitoring program for the NPF optimising costs and benefits. Australian Fisheries Management Authority report Number R01/1144. 101 pp.

Dichmont, C.M., Pascoe, S., Kompas, T., and Punt, A.E. 2010. On implementing maximum economic yield in commercial fisheries. *Proceedings of the National Academy of Science of the USA* 107: 16–21.

Dichmont, C.M., Deng, A., Punt, A. E., Ellis, N., Venables, W.N., Kompas, T., Zhou, S., *et al*. 2008. Beyond biological performance measures in management strategy evaluation: bringing economics and the effects of trawling on the benthos. *Fisheries Research* 94: 238–250.

Kenyon, R.A., Deng, R., Donovan, A.G., van der Velde, T.D., Fry, G., Tonks, M., Moeseneder, M., Salee, K. 2021. An integrated monitoring program for the Northern Prawn Fishery 2018–2021. AFMA 2017/0819 Final Report. CSIRO Oceans and Atmosphere, Brisbane. 221 pp.

Maunder, M.N., Watters, G.M. 2003. A-SCALA: an age-structured statistical catch-at-length analysis for assessing tuna stocks in the eastern Pacific Ocean. *Bulletin of the Inter-American Tropical Tuna Commission* 22: 433–582.

McAllister, M.K., Ianelli, J.N. 1997. Bayesian stock assessment using catch-age data and the sampling-importance-resampling algorithm. *Canadian Journal of Fisheries and Aquatic Sciences* 54: 284-300.

McGarvey, R., Feenstra, J.E. 2001. Estimating length-transition probabilities as polynomial functions of premoult length. *Marine and Freshwater Research* 52: 1517–1526.

Minka, T.P., 2000. Estimating a Dirichlet distribution. Technical report. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://tminka.github.io/papers/dirichlet/minka-dirichlet.pdf

Pascoe, S.D., Sharp, J.A., Buckworth, R.C., 2015. Modelling effort levels in a sequential fishery. *ICES Journal of Marine Science* 73: 503-511.

Pascoe, S., Hutton, T., Coglan, L., Nguyen, V.Q. 2018. Implications of efficiency and productivity change over the season for setting MEY-based trigger targets. *Australian Journal of Agricultural and Research Economics* 62: 199-216.

Punt, A.E., Buckworth, R.C., Dichmont, C.M., Ye, Y. 2009. Performance of methods for estimating size transition matrices using tag–recapture data. *Marine and Freshwater Research* 60: 168–182.

Schrobback, P., Pascoe, S., Zhang, R. 2019. Market integration and demand for prawns in Australia. *Marine Resource Economics* 34: 311-326.

Somers, I.F., Kirkwood, G.P. 1991. Population ecology of the grooved tiger prawn, *Paneaus semisulcatus*, in the north-western Gulf of Carpentaria, Australia: growth, movement, age structure and infestation by the bopyrid parasite *Epipenaeon ingens*. *Australian Journal of Marine and Freshwater Research* 42: 349–267.

Venables, W.N., Dichmont, C.M. 2004. A generalized linear model for catch allocation: an example from Australia's northern prawn fishery. *Fisheries Research* 70: 409–426.

Venables, W.N., Kenyon, R.A., Bishop, J.F.B., Dichmont, C.M., Deng, R.A., Burridge, C., Taylor, B.R., Donovan, A.G., Thomas, S.E., Cheers, S.J. 2006. Species distribution and catch allocation: data and methods for the NPF, 2002 - 2004 : final report January 2006.

Wang, Y-G., Thomas, M.R., Somers, I.F. 1995. A maximum likelihood approach for estimating growth from tag–recapture data. *Canadian Journal of Fisheries and Aquatic Sciences* 52: 252–259.

Zhou, S., Buckworth, R.C., Ellis, N., Deng, R.A., Pascoe, S., 2015. Getting all information out of logbooks: estimating banana prawn fishable biomass, catchability, and fishing power increase, with a focus on natural mortality. *ICES Journal Marine Science* 72, 54-61.

Zhou, S., Pascoe, S., Dowling, N., Haddon, M., Klaer, N.L., Larcombe, J., Smith, A.D.M., Thébaud, O., Vieira, S. and Wayte, S. (2013). Quantitatively defining biological and economic reference points in data poor fisheries, *Final Report on FRDC Project 2010/044*. CSIRO Marine and Atmospheric Research, Canberra, Australia.

5.3 Assessment reports

Buckworth, R.C., Deng, R.A., Hutton, T., Upston, J., Miller, M., Pascoe, S. 2016. Status of the Northern Prawn Fishery Tiger Prawn Fishery at the end of 2015, with an estimated TAE for 2016. Report to the Australian Fisheries Management Authority, September 2016. CSIRO. Brisbane. 71 p.

Buckworth, R.C., Deng, R.A., Pascoe, S., Miller, M., Hutton, T. 2014. Status of the Northern Prawn Fishery Tiger Prawn Fishery at the end of 2013 with an estimated TAE for 2014. Report to the Northern Prawn Fishery Resource Assessment Group, April 2014. CSIRO. Brisbane. 60 p.

Deng, R.A., Miller, M., Upston, J., Hutton, T., Moeseneder, C., Punt, A.E., Pascoe, S., 2022. Status of the Northern Prawn Fishery Tiger Prawn Fishery at the end of 2021 with estimated TAEs for 2022 and 2023. Report to the Australian Fisheries Management Authority, October 2022. CSIRO. Brisbane. 100 p.

Deng, R.A., Hutton, T., Punt, A., Upston, J., Miller, M., Moeseneder, C., Pascoe, S. 2020. Status of the Northern Prawn Fishery Tiger Prawn Fishery at the end of 2019 with estimated TAEs for 2020 and 2021. Report to the Australian Fisheries Management Authority, September 2020. CSIRO. Brisbane. 71 p.

Hutton, T., Deng, R.A., Plaganyi, E., Pascoe, S., Miller, M., Upston, J., Punt, A., Moeseneder, C., Kompas, T., Sterling, D., Lawrence, E. 2018. Northern Prawn Fishery Assessments 2015-18. Final Report. Report to the Australian Fisheries Management Authority, September 2018. CSIRO. Brisbane. (29pages plus Addendums).

Tables and Figures

Table 1. Parameters of the size-structured population model for each tiger prawn species.

Parameter	Treatment
Recruitment and spawning	
Annual recruitment, R_y	Estimated
Relative weekly recruitment, α_w	Estimated (by month)
Relative weekly spawning, β_w	Based on auxiliary analyses (see Figure 1a)
Maturity-at-length, κ_l	Based on auxiliary analyses (see Figure 1b)
Stock–recruitment relationship parameters, $\tilde{\alpha}$, $\tilde{\beta}$	Estimated
Temporal correlation in recruitment, ρ_r	Estimated
Variance in recruitment, σ_r	Estimated
Effort – fishing mortality related	
Catchability, *P. semisulcatus* strategy, q^G ($\times 10^{-5}$)	8.8; 0.792*
Catchability, *P. esculentus* strategy, q^B ($\times 10^{-5}$)	1.0648; 8.8*
Relative weekly availability, A_w	Based on auxiliary analyses (see Figure 1c)
Relative efficiency, $\gamma_{y,w}$	Based on auxiliary analyses (see Figure 1d)
Biological parameters	
von Bertalanffy growth curve parameters, $\ell_\infty, \kappa, \sigma^I$	Estimated by sex
Length–weight regression	Based on auxiliary analyses (see Figure 1e/1f)
Natural mortality, M	0.045 week^{-1}
Selectivity	
Fishery	Estimated (logistic function of length)
Recruitment survey	Estimated (gamma function of length)
Spawning survey	Estimated (logistic function of length)
Observation model	
Additional survey variance, σ_k^E	Estimated
Catch-rate observation error variance, σ_k^C	Estimated
Survey catchability, q_k^S	Estimated
Extent of overdispersion, ϕ	Tuned

* *P. semisulcatus*; *P. esculentu*

Table 2. Parameters of the profit equation related to costs from the most recent five assessments.

Parameter	2014	2016	2018	2020	2022
Unit cost of labour, c_L (% revenue)	0.21	0.20	0.24	0.27	0.24
Unit cost of other costs, c_M (A$ / kg)	1.200	1.000	1.400	1.011	1.695
Unit cost of repairs and maintenance, c_K (A$ / day)	321	409	231	323	504
Base unit cost of fuel and oil, c_F (A$ / day)	2,267	1,699	945	1,295	2,330
Annual vessel costs, W_y (A$ / vessel)	244,938	255,044	269,143	268,687	310,130
Opportunity cost of capital, *o (prop of vessel value)*	0.05	0.05	0.05	0.05	0.05
Economic depreciation rate, *d (prop of vessel value)*	0.02	0.02	0.02	0.02	0.02
Average value of capital, K_y (A$ / vessel)	417,016	443,755	473,663	493,807	493,657

Table 3. Prawn and fuel prices

a) Prawn prices (A$ per kg) by species group and size class (derived from the price data provided by David Carter 2014).

Assessment	Species group	**All sizes**	**<40 mm**	**40–45 mm**	**45–50 mm**	**50–55 mm**	**>55 mm**
2022	Tiger	20.30	16.03	20.91	23.00	27.18	32.06
	Endeavour	11.10					
2020	Tiger	21.60	17.06	22.25	24.47	28.92	34.12
	Endeavour	8.80					
2018	Tiger	26.5	20.77	27.09	29.80	35.22	41.54
	Endeavour	14.10					
2016	Tiger	22.00	17.37	22.66	24.93	29.46	34.75
	Endeavour	13.30					
2014	Tiger	18.85	14.89	19.42	21.36	25.24	29.77
	Endeavour	10.32					

b) Prawn and fuel price index forward in 2022

Step	Prawn price index	Fuel price index
2022	100	100
2023	104.1	103.4
2024	106.8	104.8
2025	107.2	104.9
2026	107.8	105.2
2027	108.1	105.3
2028	108.2	105.4

Table 4. Recruitment indices from the fishery-independent survey (numbers per hectare)

	Grooved Tiger Prawns		Brown Tiger Prawns	
Year	**Recruitment index (no/h)**	**CV**	**Recruitment index (no/h)**	**CV**
2003	10.96	0.096	7.85	0.107
2004	4.94	0.076	3.40	0.074
2005	5.71	0.054	6.29	0.096
2006	12.11	0.218	6.87	0.071
2007	8.19	0.071	6.66	0.087
2008	5.23	0.072	9.87	0.091
2009	5.18	0.071	10.41	0.087
2010	8.58	0.069	9.47	0.063
2011	7.56	0.143	5.71	0.090
2012	7.00	0.073	8.54	0.087
2013	9.56	0.092	11.98	0.097
2014	5.84	0.061	10.71	0.103
2015	11.16	0.078	11.09	0.086
2016	5.95	0.077	17.37	0.096
2017	4.85	0.061	8.9	0.088
2018	6.54	0.066	6.15	0.091
2019	4.42	0.067	11.7	0.085
2020	5.19	0.072	7.93	0.077
2021	4.58	0.067	5.10	0.074
2022	3.84	0.077	5.69	0.081

Table 5. Spawning indices from the fishery-independent survey (numbers per hectare)

	Grooved Tiger Prawns		Brown Tiger Prawns	
Year	**Spawning index (no/h)**	**CV**	**Spawning index (no/h)**	**CV**
2002	5.16	0.104	8.24	0.090
2003	4.09	0.094	6.90	0.072
2004	3.72	0.087	5.47	0.104
2005	3.02	0.098	7.77	0.078
2006	5.33	0.103	9.12	0.117
2007	3.19	0.086	8.65	0.098
2008	2.68	0.135	8.72	0.072
2009	3.92	0.107	11.61	0.082
2010	NA	NA	NA	NA
2011	4.08	0.099	6.39	0.092
2012	3.38	0.116	7.56	0.108
2013	5.01	0.080	15.48	0.106
2014	3.43	0.107	12.3	0.106
2015	NA	NA	NA	NA
2016	4.13	0.082	13.22	0.092
2017	NA	NA	NA	NA
2018	2.67	0.102	4.76	0.098
2019	NA	NA	NA	NA
2020	2.53	0.111	6.06	0.142

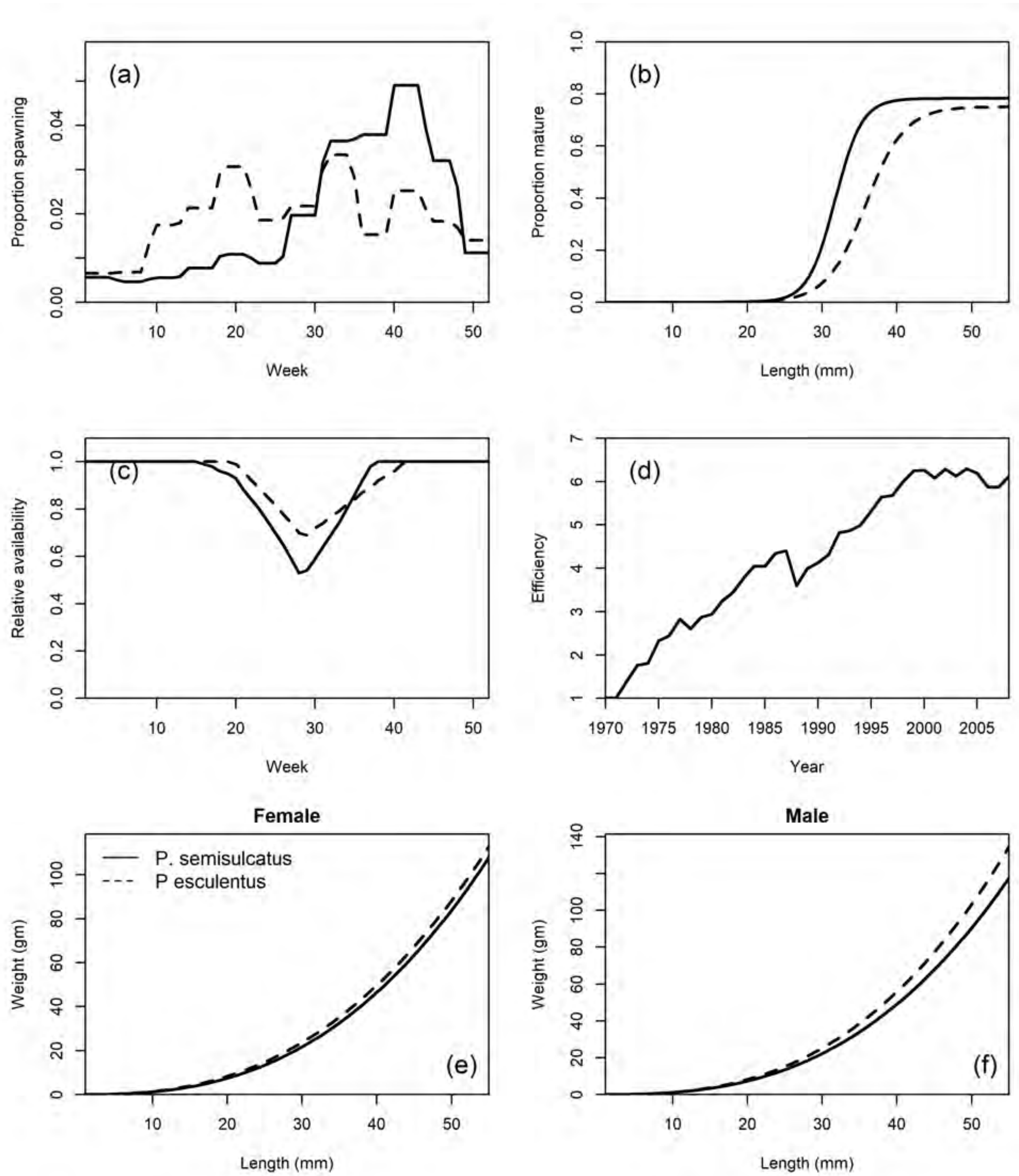


Figure 1. Pre-specified parameters of the size-structured population dynamics model.

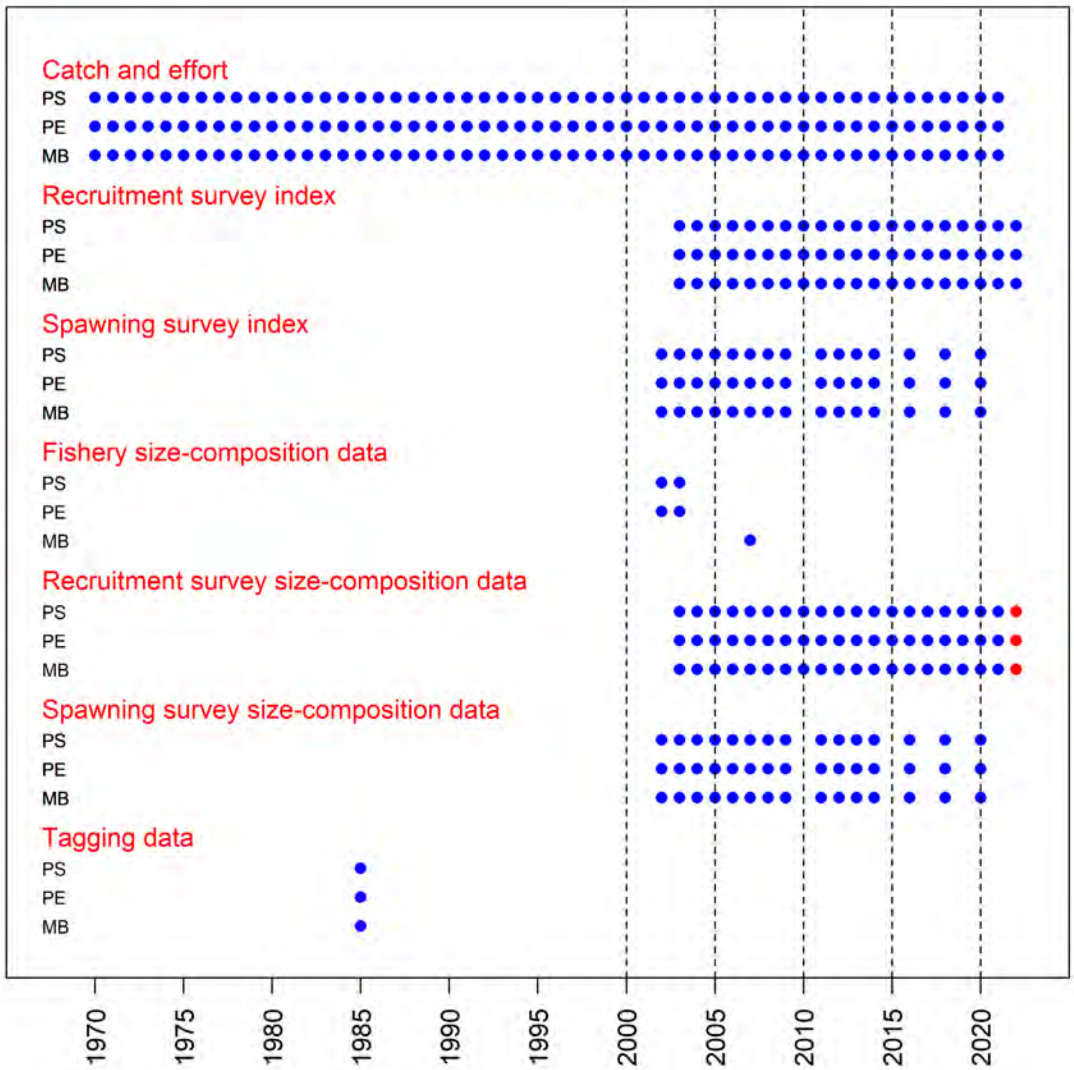


Figure 2. Summary of the available data. The circles indicate data that are available for assessment purposes in the size-structured model. The red circles denote data denote data excluded from the assessment (Deng *et al*., 2015)

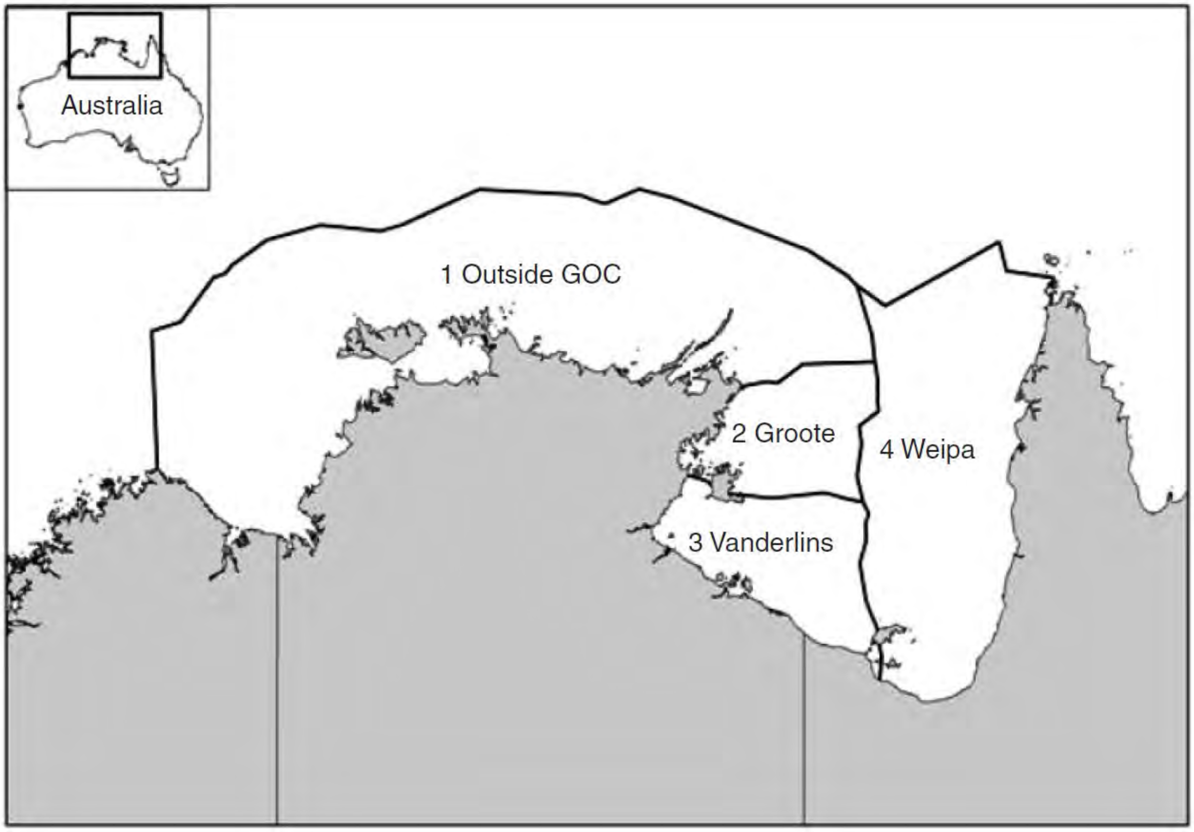


Figure 3. The four stock regions on which assessments for endeavour prawns are based.

Appendix A: List of symbols.

(a) Indices

Symbol	Description	Model
g	Sex	Size-structured
k	Species	All
l	Size-class	Size-structured
s	Stock	Biomass dynamics
w	Week	Size-structured
y	Year (calendar)	All
$\tilde{y}$	Year (biological)	Size-structured
$\tilde{y}(y,w)$	Biological year corresponding to week *w* of year *y*	Size-structured
$\tilde{L}_i$	Midpoint of size-class *i*	Size-structured
L_i	Lower limit of size-class *i*	Size-structured

(b) Variables

Symbol	Description	Model
$B_{k,s,y}$	Biomass of stock *s* of species *k* at the start of year *y*	Biomass dynamics & banana
$\bar{B}_0$	Average biomass of banana prawns at the start of the fishing season	Banana model
$C_{B,y,w}$	Catch of banana prawns during week *w* of year *y*	Banana model
$E^f_{y,w}$	Effort during week *w* of year *y* by fishing strategy *f*	Size-structured & banana
E^f_y	Total effort (over weeks) expended by fishing strategy *f* during year *y*	Bio-economic
$F_{k,y,w,l}$	Fishing mortality on animals of species *k* in size-class *l* during week *w* of year *y*	Size-structured
F_y	Total fixed costs during year *y*	Bio-economic
$\mathbf{H}_{k,y,w,g}$	Survival matrix for species *k* and sex *g* during week *w* of year *y*	Size-structured
$I_{k,g,i}$	Growth increment for animals of species *k* and sex *g* in size- class *i*	Size-structured
$\hat{I}^S_{k,y}$	Model estimate corresponding to $I^S_{k,y}$	Size-structured
$N_{k,y,w,g,l}$	Number of prawns of species *k* and sex *g* in size-class *l* at the start of week *w* of year *y*	Size-structured
$\underline{N}_{k,y,w,g}$	Number of prawns of species *k* and sex *g* at the start of week *w* of year *y*	Size-structured
P_y	Fishing power during year *y*	Biomass dynamics
$\underline{R}_{k,y,w}$	Recruitment of species *k* to the population during week *w* of year *y*	Size-structured
$R_{k,y}$	Recruitment of species *k* during biological year *y*	Size-structured
$\hat{R}_{k,\tilde{y}}$	Conditional mean for the recruitment of species *k* during biological year $\tilde{y}$	Stock-recruitment
$\tilde{R}_{k,y}$	Net revenue obtained from catches of species *k* during year *y*	Bio-economic
$S^F_{k,l}$	Selectivity of the fishery on animals of species *k* in size-class *l*	Size-structured
$S^S_{k,l}$	Selectivity of the survey gear on prawns of species *k* in size- class *l*	Size-structured
$\tilde{S}_{k,y}$	Spawner-stock size index for species *k* and calendar year *y*	Size-structured
V_y	number of vessels	Bio-economic
$\mathbf{X}_{k,g}$	Weekly size-transition matrix for species *k* and sex *g*	Size-structured
$\hat{Y}_{k,y,w,l}$	Catch (kg) of prawns of species *k* of size-class *l* during week *w* of year *y*	Size-structured / bio-economic
$\tilde{Y}_{k,y,w,g,l}$	Catch (number) of prawns of species *k* and sex *g* of size-class *l* during week *w* of year *y*	Size-structured / bio-economic
$\hat{Y}_{k,y,w}$	Catch (in weight) of species *k* during week *w* of year *y*	Size-structured
$\hat{Y}_{k,s,y}$	Catch (weight) of stock *s* and species *k* during year *y*	Biomass dynamics
$\hat{Y}_{k,y}$	Catch of species *k* during year *y*	Size-structured

$Z_{k,y,w,l}$	Total mortality on animals of species *k* in size-class *l* during week *w* of year *y*	Size-structured
$\hat{p}^{C}_{k,y,w,g,l}$	model-estimate of $p^{C}_{k,y,w,g,l}$	Size-structured
$\tilde{w}_{k,g,l}$	Mass of an animal of species *k* and sex *g* in size-class *l*	Size-structured
π_{y}	Gross margin during year *y*	Bio-economic
$\tilde{\sigma}^{S}_{k,y}$	Standard error of the logarithm of $I^{S}_{k,y}$,	Size-structured
Ω_{y}	Average fixed costs associated with a vessel operating during year *y*	Bio-economic

(c) Parameters

Symbol	Description	Model
$A_{k,w}$	The relative availability of animals of species *k* during week *w*	Size-structured (pre-specified)
$B_{0,y}$	Initial biomass of banana prawns in year *y*	Banana model (tuned)
$E_{\min}$	Minimum total annual effort over all fishing strategies	Bio-economic (pre-specified)
$E^f_{\min}$	Minimum annual effort by fishing strategy *f*	Bio-economic (pre-specified)
$E_{\max}$	Maximum total annual effort over all fishing strategies	Bio-economic (pre-specified)
$K_{k,s}$	Carrying capacity of stock *s* of species *k*	Biomass dynamics (estimated)
M_k	Weekly instantaneous rate of natural mortality for species *k*	Size-structured (pre-specified) and Banana model
$c_{F,y}$	Cost of fuel and grease per unit of effort during year *y*	Bio-economic (pre-specified)
c_K	Cost of repairs and maintenance per unit of effort	Bio-economic (pre-specified)
c_L	Share cost of labour	Bio-economic (pre-specified)
c_M	Cost of packaging and gear maintenance	Bio-economic (pre-specified)
d	Economic depreciation rate	Bio-economic (pre-specified)
f_k	Own price flexibility	Banana prawn model
i	Discount rate	Bio-economic (pre-specified)
o	Opportunity cost of capital	Bio-economic (pre-specified)
p^f_w	Proportion of total effort expended by fishing strategy *f* during week *w*	Bio-economic (pre-specified)
$\tilde{p}_{k,y}$	Price of banana prawns in year *y*	Banana model
q_B	Catchability coefficient for banana prawns	Banana model
q^f_k	Catchability coefficient for species *k* by fishing strategy *f*	Size-structured (pre-specified)
$q^f_{k,s}$	Catchability coefficient of stock *s* of species *k* for fishing strategy *f*	Biomass dynamics (estimated)
q^S_k	Survey catchability for species *k*	Size-structured (estimated)
$r_{k,s}$	Intrinsic rate of growth of stock *s* of species *k*	Biomass dynamics (estimated)
$v_{k,y,l}$	Average price per kilogram for prawns of species *k* in size-class *l* during (future) year *y*	Bio-economic (tiger prawns) (pre-specified)
$\bar{v}_{k,y}$	Average price per kilogram for prawns of species *k* during (future) year *y*,	Bio-economic (endeavour prawns) (pre-specified)
Γ_y	Annual vessel costs during year *y*	Bio-economic (pre-specified)
Ψ_y	Average value of capital during year *y*	Bio-economic (pre-specified)
$\ell_{\infty,k,g}$	Asymptotic length for species *k* and sex *g*	Size-structured (estimated)
$\beta_0, \beta_1, \beta_2, \beta_3$	Regression coefficient for banana prawns	Banana prawn model
$\alpha_{k,w}$	Expected fraction of the annual recruitment for species *k* that occurs during week *w*	Size-structured (estimated)
$\tilde{\alpha}_k$	Stock-recruitment parameter for species *k*	Stock-recruitment (estimated)
$\beta_{k,w}$	Relative measure of the quantity of spawning by species *k* during week *w*	Size-structured (pre-specified)
$\tilde{\beta}_k$	Stock-recruitment parameter for species *k*	Stock-recruitment (estimated)
ϕ	parameter that determines the extent of overdispersion (separately for the catch and survey size composition data)	Size-structured (tuned)

$\gamma_{y,w}$	Fishing power of the two fishing strategies during week *w* of year *y*	Size-structured (pre-specified)
$\kappa_{k,g}$	Growth rate for species *k* and sex *g*	Size-structured (estimated)
$\mu_{K,k}$	Prior mean for *K* for species *k*	Biomass dynamics (estimated)
$\mu_{r,k}$	Prior mean for *r* for species *k*	Biomass dynamics (estimated)
$\mu_{q,f,k}$	Prior mean for fishing strategy-specific catchability for species *k*	Biomass dynamics (estimated)
$\rho_{r,k}$	Environmentally driven temporal correlation in recruitment for species *k*	Stock-recruitment (estimated)
ρ_w	Growth rate of banana prawns during week *w*	Banana (pre-specified)
σ_k^C	Residual standard deviation (catches by week) for species *k*	Size-structured (estimated)
σ_k^{CT}	Residual standard deviation (catches by year) for species *k*	Size-structured (pre-specified)
σ_k^E	Additional variance (separately for the spawning and recruitment surveys)	Size-structured (estimated)
$\sigma_{k,g}^I$	Determines the variability in the growth increment for animals of species *k* and sex *g*	Size-structured (estimated)
$\sigma_{r,k}$	Environmental variability in recruitment about the stock–recruitment relationship for species *k*	Stock-recruitment (estimated)
$\tau_{B,k,s}^2$	Variance of the process error of stock *s* of species *k*	Biomass dynamics (estimated)
$\tau_{U,k,s,f}^2$	Variance of the observation error of stock *s* of species *k* for fishing strategy *f*.	Biomass dynamics (estimated)
$\tau_{K,k}^2$	Prior variance for *K* for species *k*	Biomass dynamics (estimated)
$\tau_{r,k}^2$	Prior variance for *r* for species *k*	Biomass dynamics (estimated)
$\tau_{q,k,f}^2$	Prior variance for fishing strategy-specific catchability for species *k*	Biomass dynamics (estimated)
$\omega_{k,l}$	Proportion of females of species *k* in size-class *l* that are mature	Size-structured (pre-specified)

(d) Data

Symbol	Description	Model
$I^S_{k,y}$	Survey index for species *k* during year *y*	Size-structured
$\tilde{N}_{k,y,w,g}$	Effective sample size for the catch size-composition data for prawns of species *k* and sex *g* during week *w* of year *y*	Size-structured
$U^f_{k,s,y}$	Catch-rate of stock *s* of species *k* during year *y* for fishing strategy *f*	Biomass dynamics
$Y^{\text{obs}}_{k,y,w}$	Catch (in weight) of prawns of species *k* during week *w* of year *y*	Size-structured / banana model
$Y^{\text{obs}}_{k,s,y}$	Catch of stock *s* of species *k* during year *y*	Biomass dynamics
$Y^{\text{obs}}_{k,y}$	Total (over weeks) catch of prawns of species *k* during year *y*	Size-structured
$p^C_{k,y,w,g,l}$	Proportion of the catch of prawns of species *k* and sex *g* during week *w* of year *y* that were in size-class *l* (fishery, recruitment survey, spawning survey)	Size-structured
$P_{T,y}$	Average price of tiger prawns during year *y*	Bio-economic
$P_{B,y}$	Average price of banana prawns during year *y*	Bio-economic
$\sigma^S_{k,y}$	Standard error of the logarithm of $I^S_{k,y}$ attributable to sampling error	Size-structured

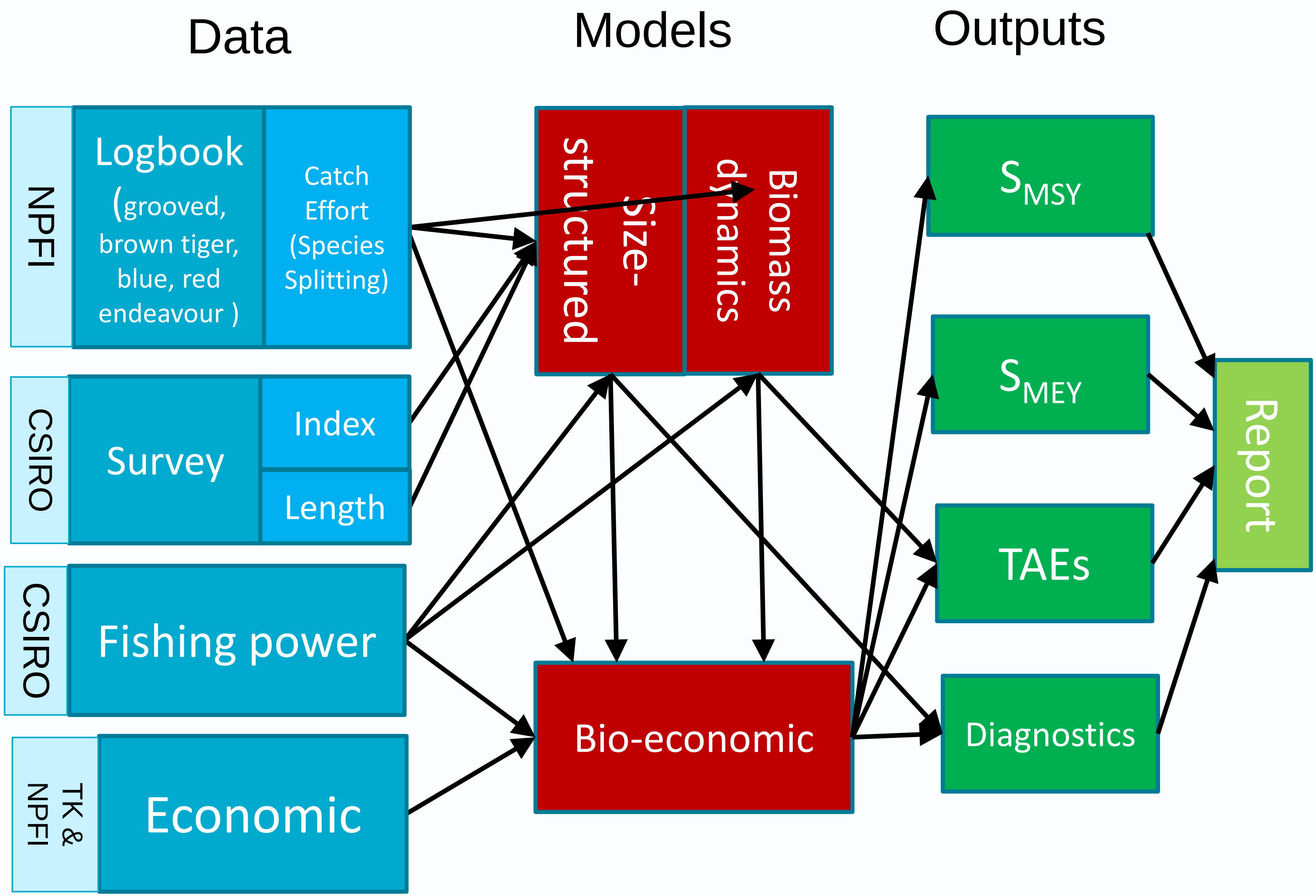
3. NPF Tiger Prawn Stock Assessment Process Flowchart

NPF Tiger Prawn Stock Assessment Process flow chat

CSIRO
www.csiro.au

The components of the NPF tiger prawn stock assessment process include :

- Data (Logbook, Tagging, Biological, Survey, Fishing power, Economic)
- Models (Size-structured, biomass dynamics, bio-economic)
- Outputs (S_{MSY} and S_{MEY} stock status, TAEs)
- Report


Data
Models
Outputs
NPFI
Logbook (grooved, brown tiger, blue, red endeavour)
Catch Effort (Species Splitting)
CSIRO
Survey
Index
Length
CSIRO
Fishing power
TK & NPFI
Economic
Size-structured
Biomass dynamics
Bio-economic
S_{MSY}
S_{MEY}
TAEs
Diagnostics
Report

Thank you

CSIRO

Oceans & Atmosphere

e roy.deng@csiro.au
w www.csiro.au

4. Integrated Monitoring of the Northern Prawn Fishery 2002-22: Gulf-wide and regional indices of abundance

Integrated Monitoring of the Northern Prawn Fishery 2002-2022; Gulf-wide and regional indices of abundance

Rob Kenyon, Roy Deng, Anthea Donovan, Gary Fry, Chris Moeseneder, Kinam Salee, Mark Tonks, Tonya van der Velde

CSIRO

Summary, 2002-2022

The February surveys and their corresponding abundance index (historically referred to as the Recruitment Index) have been undertaken annually since 2003. Currently, a 20-year series exists. In contrast, the July surveys and abundance index (historically referred to as the Spawning Index) have been undertaken since 2002. Although they were undertaken annually from 2002 to 2014 (apart from 2010), they have only occurred every second year since 2016.

Management actions to reduce fishing effort were undertaken just prior to or during the period over which the surveys have been undertaken. A seasonal spatial closure in the vicinity of Mornington Island was instigated in 1988 and the boundaries have not changed since 2002. The closure was targeted at brown tiger prawns, a species that had been heavily fished as small commercial-grade prawns in inshore locations within this region in the 1980s. Other inshore seasonal and permanent closures to protect small prawns and/or inshore habitats in the vicinity of Groote Eylandt, the Sir Edward Pellew Islands and Mornington Island were instigated in the 1980/90s and have not changed since 2002 or earlier. In addition, NPF-wide decreases in effort in the form of a reduction in the numbers of vessel licences in the fishery was active until 2009.

After 2009, there was a general trend of improvement in both the February and July indices for both tiger prawn species, as well as for blue endeavour prawns until about 2016. From 2015/2016 to 2022, (depending on species) the trends in both the February and July indices have been trends of decline in prawn abundance, punctuated by some increases in particular years. Unfortunately, the 2021 and 2022 indices for each prawn species were some of the lowest of the series.

The surveys are conducted in five 'regions' in February (Groote, Vanderlins, Mornington, Karumba, and Weipa) and three 'regions' in July (Groote, Vanderlins and Mornington) (Figure 1). The Mornington and Karumba regions abut each other in the southern Gulf of Carpentaria (GoC).

Integrated Monitoring of the Northern Prawn Fishery 2002-2022; Gulf-wide and regional indices of abundance

Rob Kenyon, Roy Deng, Anthea Donovan, Gary Fry, Chris Moeseneder, Kinam Salee, Mark Tonks, Tonya van der Velde

CSIRO

Summary, 2002-2022

The February surveys and their corresponding abundance index (historically referred to as the Recruitment Index) have been undertaken annually since 2003. Currently, a 20-year series exists. In contrast, the July surveys and abundance index (historically referred to as the Spawning Index) have been undertaken since 2002. Although they were undertaken annually from 2002 to 2014 (apart from 2010), they have only occurred every second year since 2016.

Management actions to reduce fishing effort were undertaken just prior to or during the period over which the surveys have been undertaken. A seasonal spatial closure in the vicinity of Mornington Island was instigated in 1988 and the boundaries have not changed since 2002. The closure was targeted at brown tiger prawns, a species that had been heavily fished as small commercial-grade prawns in inshore locations within this region in the 1980s. Other inshore seasonal and permanent closures to protect small prawns and/or inshore habitats in the vicinity of Groote Eylandt, the Sir Edward Pellew Islands and Mornington Island were instigated in the 1980/90s and have not changed since 2002 or earlier. In addition, NPF-wide decreases in effort in the form of a reduction in the numbers of vessel licences in the fishery was active until 2009.

After 2009, there was a general trend of improvement in both the February and July indices for both tiger prawn species, as well as for blue endeavour prawns until about 2016. From 2015/2016 to 2022, (depending on species) the trends in both the February and July indices have been trends of decline in prawn abundance, punctuated by some increases in particular years. Unfortunately, the 2021 and 2022 indices for each prawn species were some of the lowest of the series.

The surveys are conducted in five 'regions' in February (Groote, Vanderlins, Mornington, Karumba, and Weipa) and three 'regions' in July (Groote, Vanderlins and Mornington) (Figure 1). The Mornington and Karumba regions abut each other in the southern Gulf of Carpentaria (GoC).

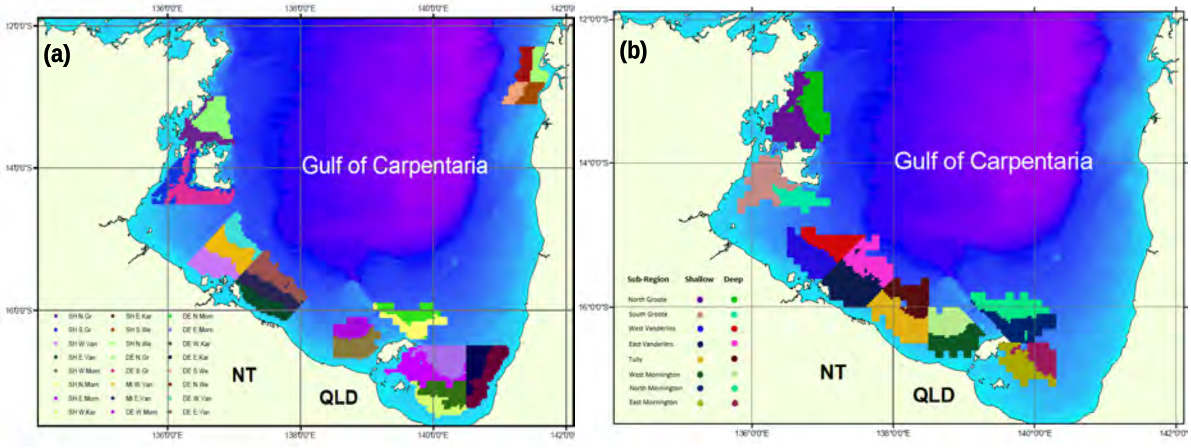


Figure 1: The five regions trawled during the February survey (a) and the three regions trawled during the July survey (b) spanning 20 years from 2002/03 to 2022.

GULF-WIDE indices

Grooved tiger prawns

In 2022, the Gulf-wide grooved tiger prawn **February index** of abundance (3.30±0.29 prawns ha^{-1}) was the second lowest of the series and the lowest since 2018. Only five indices have been lower than 4 prawns ha^{-1} and four of those have been in the past six years (Figure 2). High-level indices were ~10 prawns ha^{-1}.

In 2022, the grooved tiger prawns **July index** (3.0±0.3 prawns ha^{-1}) was a 25% increase on the 2020 lowest index on record (2.41±0.27 ha–1). The index had increased to be within the historical range 2.5–5 prawns per hectare. Five indices have been lower than 3 prawns ha^{-1}. Eleven indices have been equal-to or above 3 prawns ha^{-1}, including the 2022 index (Figure 2).

Brown tiger prawns

In 2022, the brown tiger prawn **February index** of abundance (4.90±0.43 prawns ha^{-1}) was the fourth lowest of the series. Only four indices have been lower than 5 prawns ha^{-1} including 2021 and 2022. High indices were ~10 prawns ha^{-1}; the highest index was in 2016 (15 prawns ha^{-1}) (Figure 2).

In 2022, the brown tiger prawn **July index** of abundance was moderate (7.3±0.6 prawns ha^{-1}) and higher than the indices for both 2018 and 2020; and no longer below 6 prawns ha^{-1}. Only three indices have been lower than 6 prawns ha^{-1} including 2004, 2018 and 2020 (the 2020 index was 5.78±0.85 ha^{-1}). The indices from 2018 to 2022 were ~50% of those from 2013 to 2016 (Figure 2).

Blue endeavour prawns

In 2022, the blue endeavour prawn **February index** of abundance was the second lowest of the series. Only two indices have been lower than 2 prawns ha^{-1}, 2004 and 2022. High indices were 4–5 prawns ha^{-1} (Figure 2).

The 2022 blue endeavour prawns **July index** of abundance (3.86±0.27 prawns ha^{-1}) was no different to the 2020 index (3.67±0.23 prawns ha^{-1}) which was the second lowest of the series and similar to 2018. Six of the July indices for blue endeavour prawns have been lower than 4 prawns ha^{-1}, including 2022. However, until 2018, each of the indices that were lower than 4 prawns ha^{-1} were followed by a higher abundance (typically ≥6 prawns ha^{-1}). The three most-recent indices (2018, 2020, 2022) have all been lower than 4 prawns ha^{-1} (Figure 2).

Red endeavour prawns

In 2022, the red endeavour prawn **February index** was moderate relative to the series (0.30±0.04 prawns ha^{-1}). The range of the indices for red endeavour prawns for the entirety of the NPG monitoring surveys was 0.07 to 0.8 prawns ha^{-1}, apart from 2012 when the index was 1.6 prawns ha^{-1}.

In 2022, the red endeavour prawn **July index** was moderate relative to the series (0.06±0.01 prawns ha^{-1}). During July, red endeavour prawns consistently were found at very low abundances (0.02–0.1 prawns ha^{-1}). The 2020 index was the lowest of the series (0.02±0.01 prawns ha^{-1}) (Figure 2).

King prawns

In 2022, the western king prawn **February index** was moderate relative to the series (0.88±0.39 prawns ha^{-1}). The range of the indices for western king prawns was 0.4 to 1.6 prawns ha^{-1}.

In 2022, the western king prawn **July index** was the highest of the series (3.37±0.87 prawns ha^{-1}) and four times the 2020 index. Until 2016, western king prawns consistently were found at relatively low abundances (1.0–2.5 prawns ha^{-1}), while the 2018 and 2020 indices were the lowest indices of the series.

Since 2002, during both **February** and **July** red-spot king prawns have been found at abundances <0.01 prawns ha^{-1}.

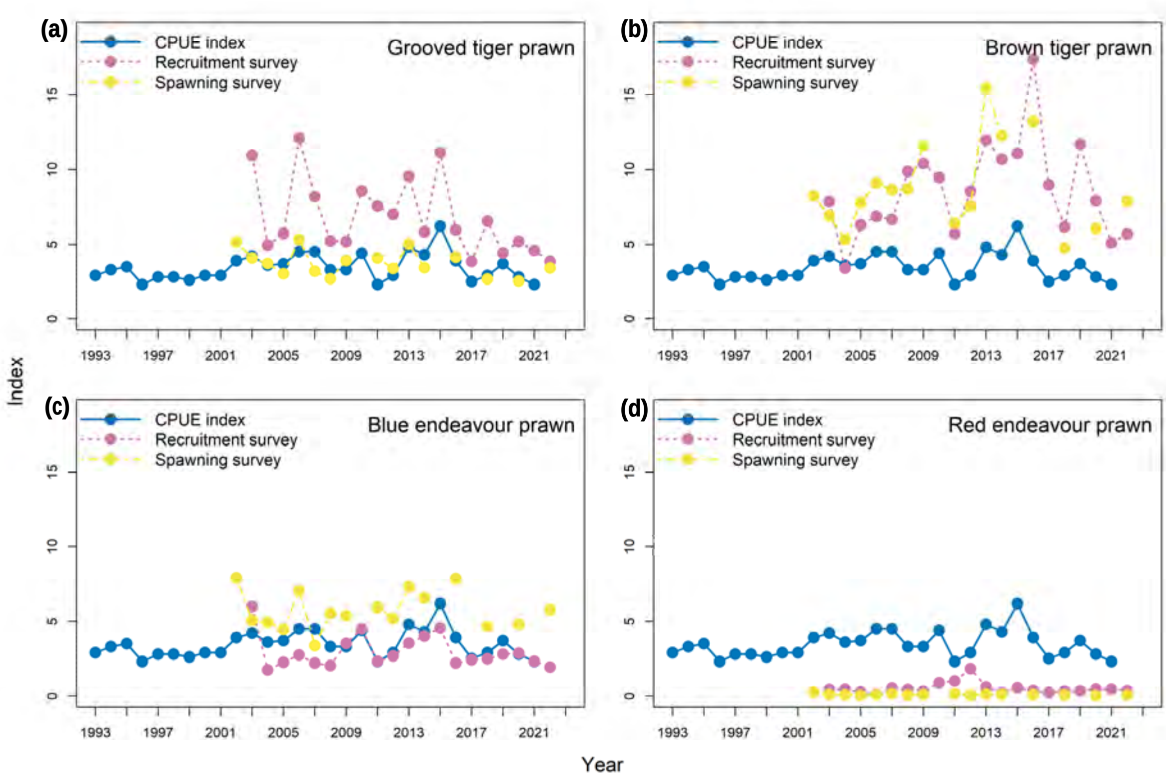


Figure 2: Comparisons of Recruitment and Spawning Survey indices compared to CPUE index for (a) grooved tiger prawns, (b) brown tiger prawns, (c) blue endeavour prawns and (d) red endeavour prawns

<u>REGIONAL Indices</u>

In 2022, the grooved tiger prawn **February 'Groote' regional index** (3.77±0.42 prawns ha^{-1}) was the lowest of the series, and since 2016, each of the annual indices have been below 8 prawns ha^{-1}. During the first decade of the series, the indices varied between 4 and 15 prawns ha^{-1}. In 2015 the highest index observed (~26 prawns ha^{-1}) coincided with Cyclone Lam bisecting Arnhemland and dropping 600 mm of rainfall over the catchments of the rivers that flow into Blue Mud Bay, an area supporting grooved tiger prawn juvenile seagrass habitats (Figure 3).

In 2022, the grooved tiger prawn **February 'Weipa' regional index** (11.00±1.04 prawns ha^{-1}) was the third lowest of the series. During the first decade of the series, the indices varied between 7 and 35 prawns ha^{-1}. In 2013, the highest index was observed (55 prawns ha^{-1}).

In 2022, the grooved tiger prawn **July 'Groote' regional index** at Groote was the lowest on record (3.63±0.66 ha–1) and lower than the 2020 index (4.10±0.87 ha–1) which had been the lowest of the series. Higher-level indices are about 7 to 9 prawns ha^{-1}. The lowest-of-series July index matched the lowest-of-series February index and was in line with poor commercial catches taken at north Groote in 2022 (Figure 4). Anecdotal reports suggest that the low 2022 regional index at Groote matched low commercial fishing effort in the Groote region during the 2022 tiger prawn season (particularly at north Groote).

In 2022, the grooved tiger prawn **July 'Vanderlins' regional index** (3.99±0.45 ha–1) was a 40% improvement on the 2020 index (2.88±0.31 ha–1), and a continued improvement on the 2018 index, which was the lowest of the series. Anecdotal reports suggest that the higher 2022 regional index at the Vanderlins matched a focus of commercial fishing effort in key locations in the Vanderlins region during the 2022 tiger prawn season.

Brown tiger prawns

In 2022, the brown tiger prawn **February 'Groote' regional index** was the third lowest of the series (4.62±0.83 prawns ha^{-1}) and the lowest of the last decade. During the first decade of the series, the indices varied between 4 and 11 prawns ha^{-1}. In 2014, 2016 and 2020 the regional indices were >9 prawns ha^{-1} (Figure 3).

In 2022, the brown tiger prawn **February 'Mornington' regional index** was moderate (8.46±1.24 prawns ha^{-1}) and about 20% higher than in 2021. The 2022 index was one third of the highest index in 2016. During the first decade of the series, the indices varied between 3 and 15 prawns ha^{-1}.

In 2022, the brown tiger prawn **July 'Groote' regional index** (6.01±1.37 prawns ha^{-1}) and the **July 'Vanderlins' regional index** (5.28±0.89 prawns ha^{-1}) were at near-historical lows, having dropped considerably since historical highs over 2013 to 2016. Both regions have previously recorded indices > 10 prawns ha^{-1} (Figure 4).

In 2022, the brown tiger prawn **July 'Mornington' regional index** (10.83±0.78 prawns ha^{-1}) had improved, being moderate with a 100% increase on 2018 and 2020 levels (4 to 5 prawns ha^{-1}). Higher-level indices are 12 to 18 prawns ha^{-1}. Anecdotal reports suggest that the higher 2022 regional index for brown tiger prawns at Mornington matched relatively high commercial fishing effort during the 2022 tiger prawn season.

Blue endeavour prawns

In 2022, the blue endeavour prawn **February 'Groote' regional index** was the third lowest of the series (2.80±0.28 prawns ha^{-1}) and the lowest of the last decade. During the first decade of the series, the indices varied between 2 and 11 prawns ha^{-1}. In 2015, the equal highest index (with 2003) observed (~11 prawns ha^{-1}) coincided with Cyclone Lam bisecting Arnhemland and dropping 600 mm of rainfall over the catchments of the rivers that flow into Blue Mud Bay, an area supporting blue endeavour prawn juvenile seagrass habitats.

In 2022, the blue endeavour prawn **February 'Vanderlins' regional index** was moderate (2.31±0.21 prawns ha^{-1}) between the 1.5 and 5 prawns ha^{-1} estimated over most of the series (Figure 3).

In 2022, the blue endeavour prawn **July 'Groote' regional index** was the third lowest of the series (4.63±0.77 prawns ha^{-1}) though higher than the 2020 index which was the lowest of the series (3.87±0.57 prawns ha^{-1}). Higher indices from 2011 to 2018 ranged between the 5 and 11 prawns ha^{-1}.

In 2022, the blue endeavour prawn **July 'Vanderlins' regional index** of abundance (4.04±0.34 prawns ha^{-1}) continued to improve to moderate levels (the 2018 and 2020 indices were 1.98±0.22 prawns ha^{-1} and 3.16±0.28 prawns ha^{-1}, respectively). High indices were about 7 prawns ha^{-1} (Figure 4).

In 2022, the blue endeavour prawn **July 'Mornington' regional index** (2.97±0.29 prawns ha^{-1}) was lower than that in 2020 (4.14±0.39 prawns ha^{-1}) and 2018 but remained higher than the low index in 2016 (~2 prawns ha^{-1}). High indices were about 6 prawns ha^{-1}.

Red endeavour prawns

Throughput the data series, the **February indices** of red endeavour prawns at Mornington (<0.01 prawns ha^{-1}), Groote and Vanderlins (<0.53 prawns ha^{-1}) were very low; in many years none were caught in the Mornington region. Within the Weipa region, red endeavour prawns were the most abundant often at densities of ~3 prawns ha^{-1} , though at times <1 prawn ha^{-1}. In 2010 and 2011, ~7 prawns ha^{-1} were caught in the Weipa region and catch peaked in 2012 at ~11 prawns ha^{-1} (Figure 2). The high abundances of red endeavour prawns in the Weipa region are due to small recruits (<20 mm CL) that are common in February. Interestingly, in the Karumba region catches also peaked in 2012 with ~3 prawns ha^{-1} caught. In the remaining years at Karumba, catches were mostly nil and occasionally <0.5 prawns ha^{-1}. In 2022, the red endeavour prawn regional **February indices** were characteristic of the years apart from 2010-2012 (Groote, 0.20±0.04 prawns ha^{-1}; Weipa, 1.92±0.43 prawns ha^{-1}; Vanderlins, 0.36±0.09 prawns ha^{-1}).

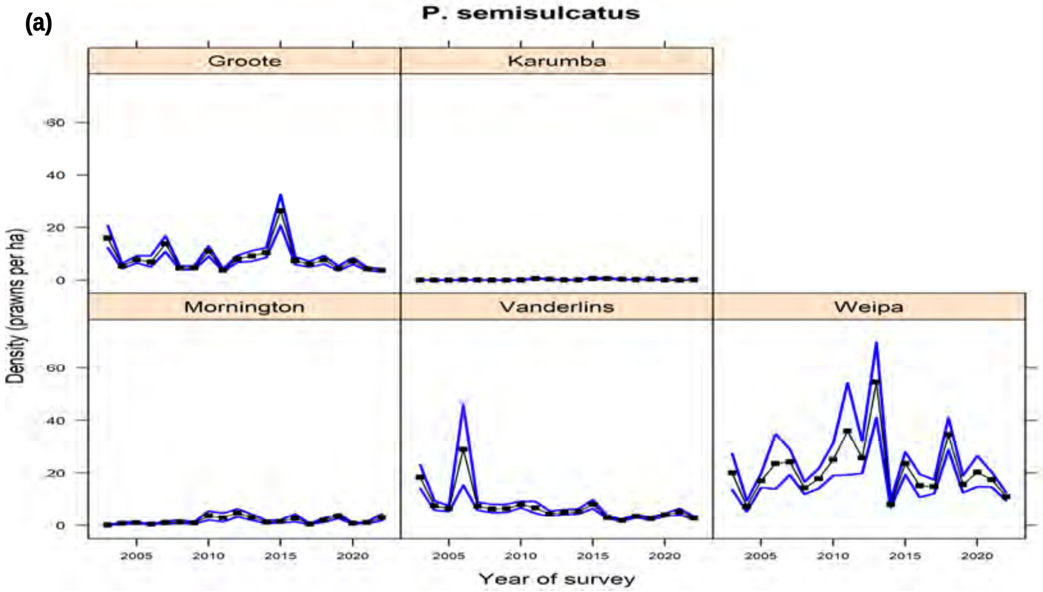
In 2022, only the Groote regional **July index** for red endeavour prawns displayed catches of consequence (0.21±0.05 prawns ha^{-1}). No red endeavour prawns were caught during July at Mornington and <0.02 prawns ha^{-1} were caught at Vanderlins. The July 2022 regional indices were similar to series trends.

King prawns

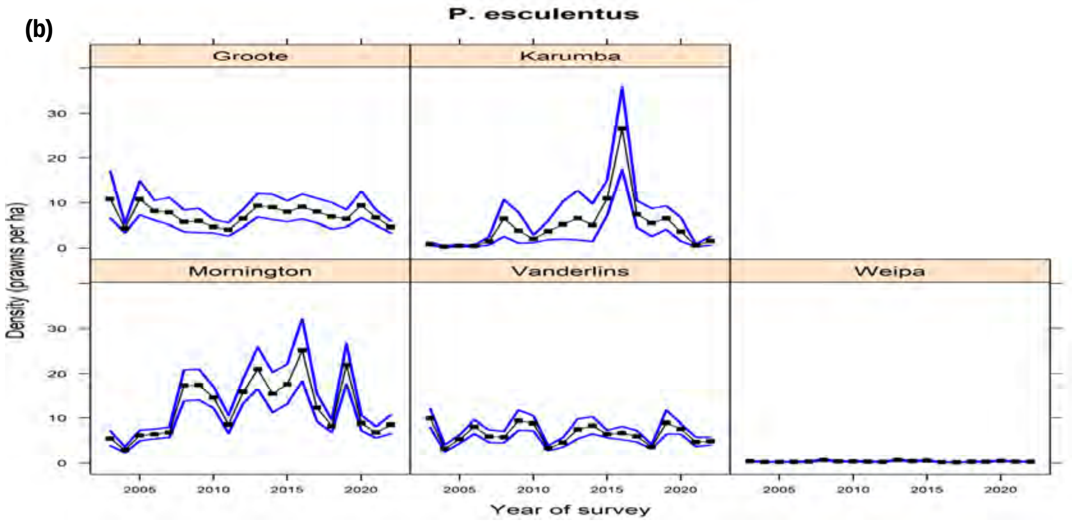
In 2022, the western king prawn **July regional indices** for **'Groote'** (1.92±1.71 prawns ha^{-1}), **'Vanderlins'** (4.85±1.79 prawns ha^{-1}) and **'Mornington'** (2.78±0.47 prawns ha^{-1}) each were the highest of the 20-year series, matching the high Gulf-wide 2022 index. In each region, the 2022 indices were double the majority of past indices, many of which were <1.5 prawns ha^{-1} at Vanderlins and Mornington, and <1 prawn ha^{-1} at Groote. Reports of higher proportions of 'whites' (endeavour and king prawns) in the commercial catch in 2022 match the high indices for king prawns.

Since 2002, in each region during both **February** and **July** red-spot king prawns have been found at abundances <0.1 prawns ha^{-1}.

(a)



(b)



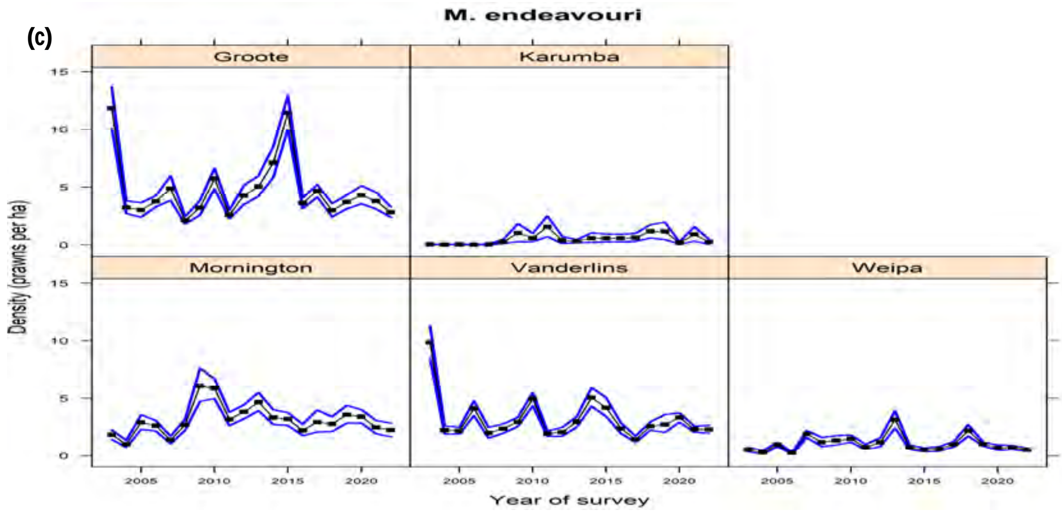
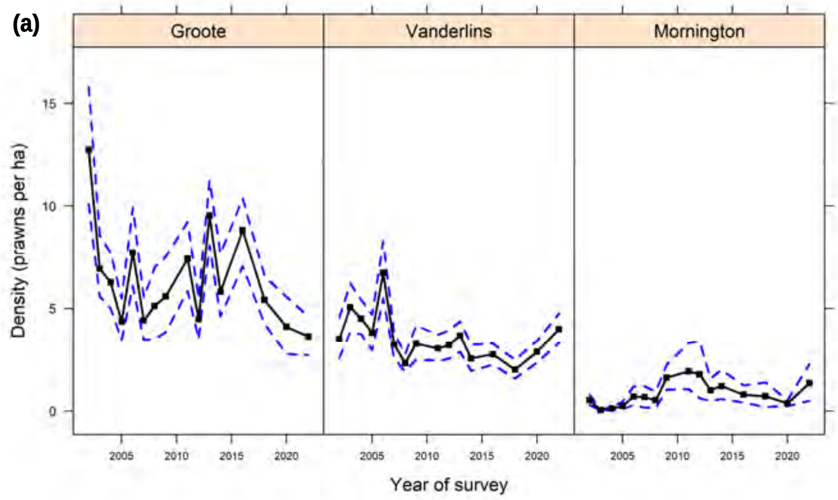
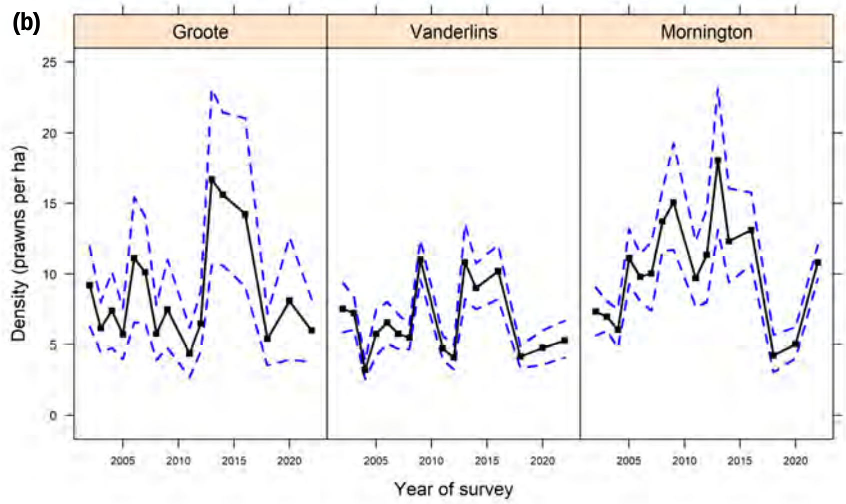


Figure 3: Regional Recruitment Survey indices for (a) grooved tiger prawns (*P. semisulcatus*), (b) brown tiger prawns (*P. esculentus*) and (c) blue endeavour prawns (*M. endeavouri*).





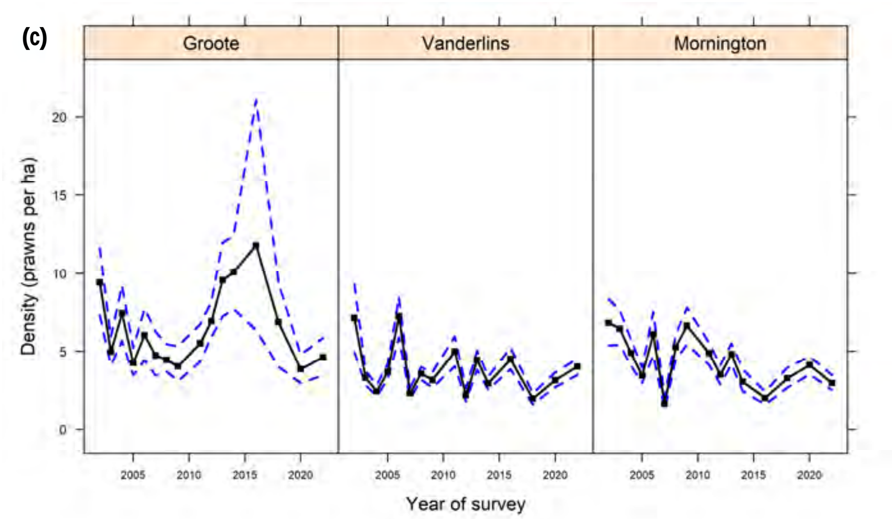


Figure 4: Regional Spawning Survey indices for (a) grooved tiger prawns, (b) brown tiger prawns and (c) blue endeavour prawns

The gulf-wide and regional abundance indices match the distribution of the commercial catch of tiger prawns within the Gulf of Carpentaria and the historical distribution of each prawn species determined via fishery-independent surveys since the 1970s and 1980s. In addition, annual trends for regional abundance indices reflect the spatial distribution of each prawn species mapped from the survey catches that are taken and higher commercial catches in some years in each NPF reporting sector.

Gulf-wide, in the recent decade, the commercial grooved tiger prawn catch peaked in 2015, with 2405 tonnes of prawns caught. This catch was the highest since the 1980s and 1990s and matched the survey catch distribution and February highest index of the series for grooved tiger prawns (Figure 5). Prior to that, the grooved tiger prawn catches in 2013 and 2014 were 1470 and 1196 tonnes, respectively. In 2016, the grooved tiger prawn catch halved to 1241 tonnes which matched a moderate grooved tiger prawn February index. In 2016, the distribution of higher survey catches was noticeable lower in key regions for grooved tiger prawns such as north Groote. The 2017 grooved tiger prawn catch (724 tonnes) was the lowest since 2011 and was matched by the lowest grooved tiger prawn February index. Catches improved in 2018 and 2019, to 1097 and 1178 tonnes respectively, despite a moderate February index in 2018 and a low index in 2019 (Figure 5). The July index for grooved tiger prawns remained low in 2018. The 2020 and 2021 grooved tiger prawn commercial catch continued a general decline (957 and 693 tonnes, respectively), matching low February indices for both years and the low July 2020 index (Figure 6). The February Gulf-wide grooved tiger prawn index in 2022 was the second lowest of the series and not numerically different to 2017, the lowest index. However, the 2022 Vanderlins and (west) Mornington July regional indices for grooved tiger prawns were higher than the 2020 indices (Figure 6) and anecdotally comparatively good catches of commercial prawns have been taken in the Vanderlins and Mornington in 2022.

Historically, grooved tiger prawns have been the dominant species in the northern Gulf of Carpentaria, particularly in the north Groote region, the Weipa region, and deeper waters at the Vanderlins. In 2015, 1386 tonnes of tiger prawns were caught in the Groote NPF reporting sector, matched by the series-highest February survey region index for Groote (no July survey was undertaken in 2015) (Figure 5). Similarly, in the Weipa regions, the high grooved tiger prawn February regional index in 2018 was matched by a high commercial catch (107 tonnes of tiger prawns).

The indices and commercial catches suggest that the population of grooved tiger prawns in the Groote region is subject to stressors, either past fishing pressure or environmental stressors (perhaps high water temperature within shallow littoral habitats). The population at Groote responded positively to high levels of rainfall (600 mm) over the catchments of the rivers that flow into Blue Mud Bay (Cyclone Lam tracked through Arnhemland in 2015). The Blue Mud Bay littoral zone supports juvenile grooved tiger prawn seagrass nursey habitats and freshwater influences may have cued juveniles to move seaward from the bay. Since 2016, El Nino conditions have stressed the Gulf of Carpentaria. In the Mornington region, the abundance and distribution of grooved tiger prawns has been enhanced in the last decade, particularly at west Mornington, however the reason for this is unclear.

In the recent decade Gulf-wide, the commercial brown tiger prawn catch peaked in 2016 and 2019, with 898 and 908 tonnes of prawns (respectively) caught in the corresponding year. These catches were the highest since the 1990s and matched the February highest and near-highest indices of the series for 2016 and 2019 and near-highest 2016 July index for brown tiger prawns. Historically, brown tiger prawns are abundant in the Mornington and Sweers NPF commercial catch sectors; spatially overlapping the NPF Monitoring Mornington survey region. The Mornington February regional index for brown tiger prawns were highest of the series in 2016, while the July index was high. The spatial abundance of brown tiger prawns in the Mornington Region in 2016 and 2019 was clear (Figure 5, Figure 6). Prior to that, the catches in 2013, 2014 and 2015 were 731, 492 and 763 tonnes, respectively. These catches matched the highest July index in 2013 and high February and July indices in the other years. In 2017 and 2018, the brown tiger prawn catches were substantially lower (356 and 366 tonnes, respectively), which matched the very low February and July brown tiger prawn indices in 2018. The 2017 and 2018 commercial catches were the lowest since 2011 and only the early-to-mid 2000s were lower. In 2020, the Gulf-wide February index for brown tiger prawns was moderate while the July index was the third lowest on record (and the second lowest in the Mornington region). Low commercial catches of brown tiger prawns were taken Gulf-wide in 2020 (409 tonnes) and especially in the Mornington/Sweers catch sectors (147 tonnes of both brown (predominantly) and grooved tiger prawns) as reflected by the low indices. In 2022, the February brown tiger prawn index was again low, slightly higher than in 2021, but lower than the decade prior to 2021. The low 2021 February index matched the 2021 brown tiger prawn commercial catch (341 tonnes), similar to decade lows. In 2022, a low February index for brown tiger prawns was not matched by continuing low commercial catches of prawns. The 2022 July brown tiger prawn index was 25% higher than the 2021 index and the increase in abundance of brown tiger prawns in the Mornington region was evident via their spatial mapping (Figure 6), especially at east Mornington. Although commercial catch data for 2022 are not available, anecdotal reports suggest that the species-combined tiger prawn catch for 2022 has been greater than 2021 and good catches were taken in the Mornington region.

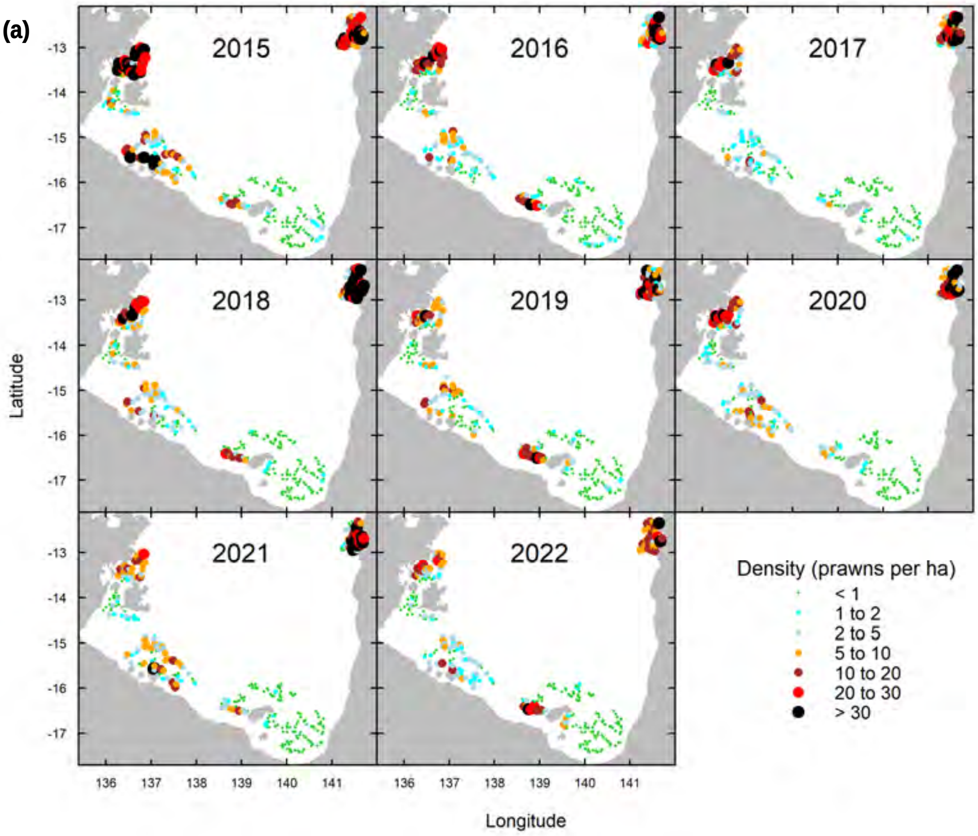
Historically, brown tiger prawns have been the dominant species in the southern Gulf of Carpentaria, particularly in the inshore Vanderlins and Mornington regions. In 2016, 296 tonnes of tiger prawns were caught in the Mornington commercial catch reporting sector and 257 tonnes were caught in the 'Sweers' reporting sector (combined they match the NPF Monitoring project's 'Mornington' region). The combined catch of 553 tonnes matched the series-highest February survey region index and high July region index for brown tiger prawns at Mornington.

The drivers of the high abundance indices and commercial catch of brown tiger prawns in 2016 and 2019 are not clear. The spatial extent of the prawn distribution increased in February 2016 and prawns were abundant in the 'west Karumba' region for the first time during the series (Figure 5). The 2016 Karumba regional index was 250% higher than any other index of the series and 500% higher than most other indices. The region is east of the usual distribution of brown tiger prawns east and north-east of Mornington Island.

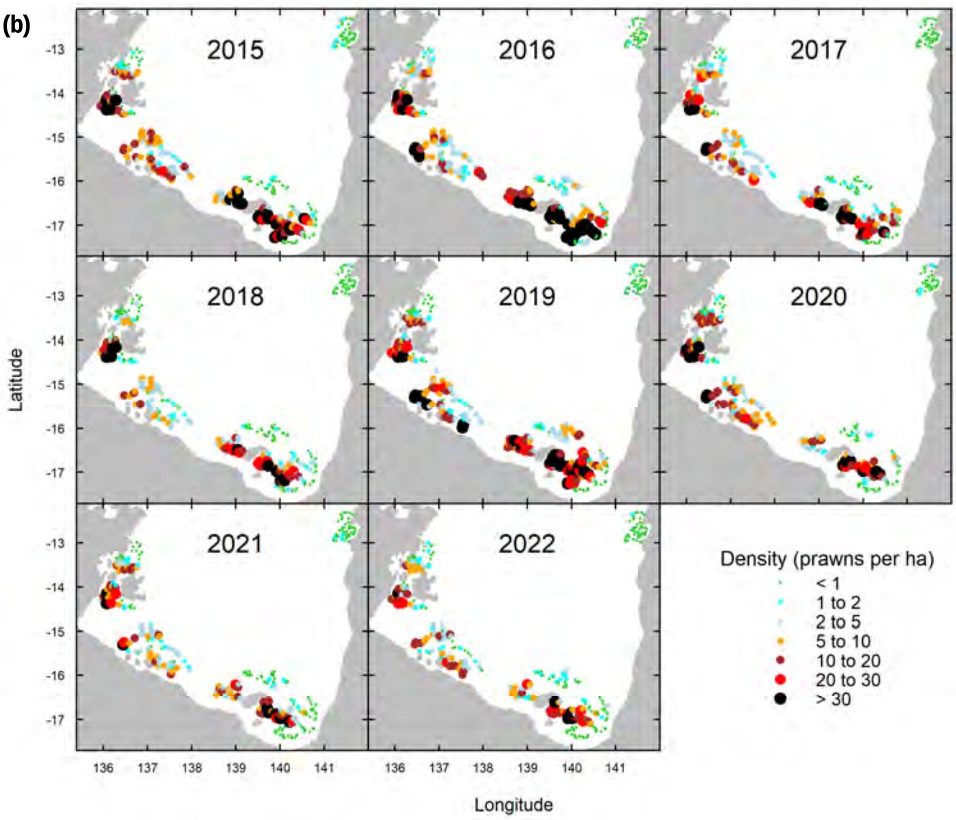
In 2022, the February blue endeavour prawn abundance index was the second lowest of the series. Since 2016, the February blue endeavour prawn indices have been low and match the low commercial blue endeavour prawn catches (<300 tonnes, apart from 2019 when the catch was 509 tonnes). Similar to grooved tiger prawns, the February regional abundance index of blue endeavour prawns was high at Groote in 2015, a year when 348 tonnes of blue endeavour prawns were caught Gulf-wide (Figure 5).

The survey catch and indices during both February and July for red endeavour prawns do not reflect the commercial catch of the species (Figure 2). The distribution of higher survey catches in the northern Gulf of Carpentaria does reflect their natural abundance (Figure 2). The indices are relatively low in all regions and often nil or very low abundances of red endeavour prawns were caught, particularly in the southern Gulf of Carpentaria. The high abundances of red endeavour prawns in the Weipa region are due to small recruits (<20 mm CL) that are common in Albatross Bay in February. At north Groote, higher catches of large prawns are sometimes taken in deeper offshore waters adjacent to Cape Grey.

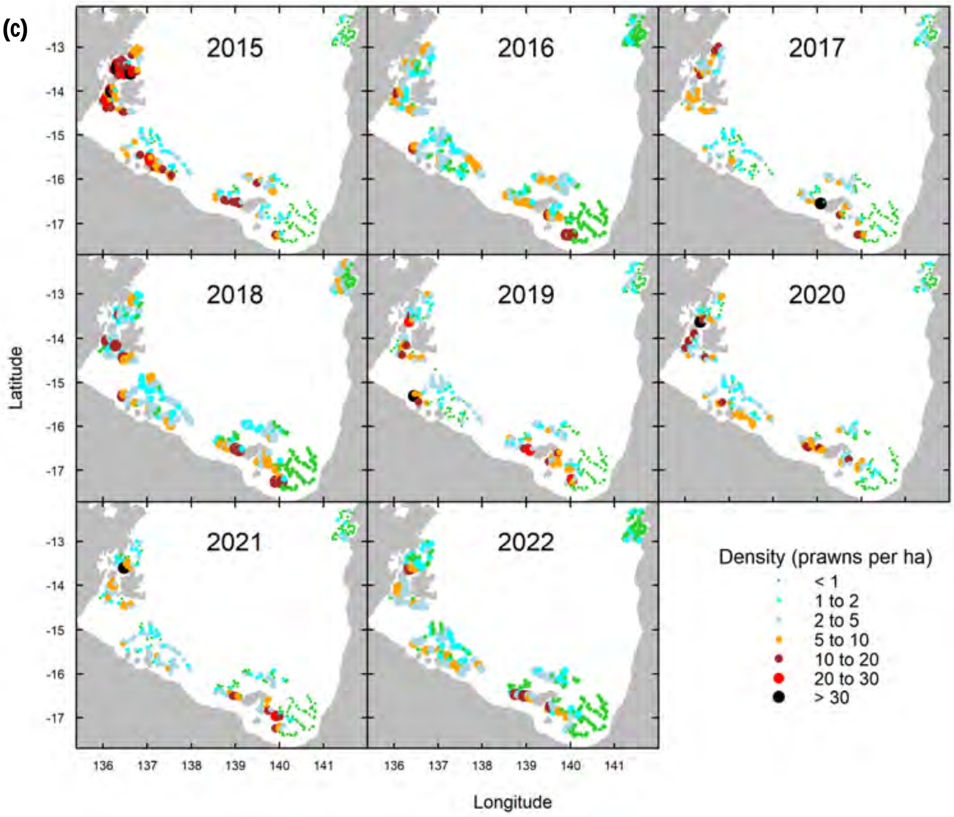
(a)


2015
2016
2017
2018
2019
2020
2021
2022
Latitude
Longitude
Density (prawns per ha)
< 1
1 to 2
2 to 5
5 to 10
10 to 20
20 to 30
> 30

(b)


2015
2016
2017
2018
2019
2020
2021
2022
Latitude
Longitude
Density (prawns per ha)
< 1
1 to 2
2 to 5
5 to 10
10 to 20
20 to 30
> 30

(c)



(d)

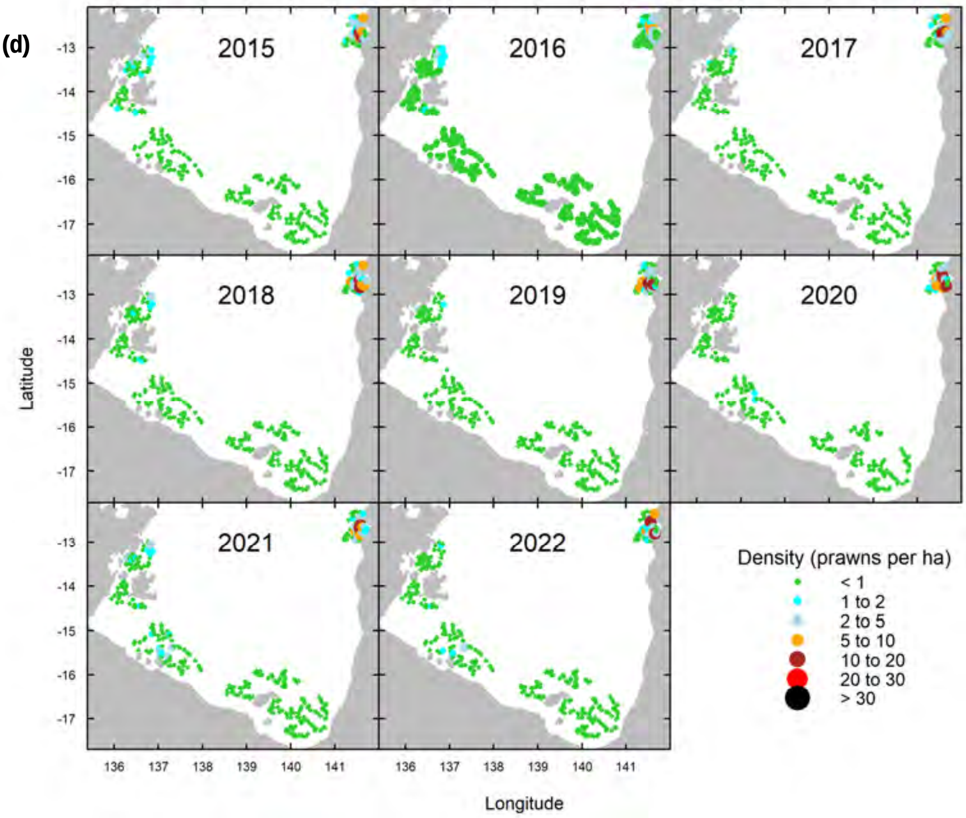


Figure 5: Gulf-wide (regional) distribution of (a) grooved tiger prawns, (b) brown tiger prawns, (c) blue endeavour prawns and (d) red endeavour prawns caught during the February surveys

In 2020, the Gulf-wide July index for grooved tiger prawns was the lowest on record and matched the low commercial catches gulf-wide (957 tonnes) and in the north Groote region the 2020 index was the lowest index on record (before 2022) and matched the low commercial catch in the Groote sector (345 tonnes for both tiger prawn species). The July 2022 Gulf-wide index for grooved tiger prawns was a 25% increase on the 2020 lowest index on record (Figure 6). The 2022 Groote July regional index for grooved tiger prawns was the lowest of the series and anecdotal reports suggest that commercial tiger prawn catches at both north and south Groote in 2022 were poor. The lowest-of-series July index matched the lowest-of-series February index and was in line with poor commercial catches taken at north Groote in 2022.

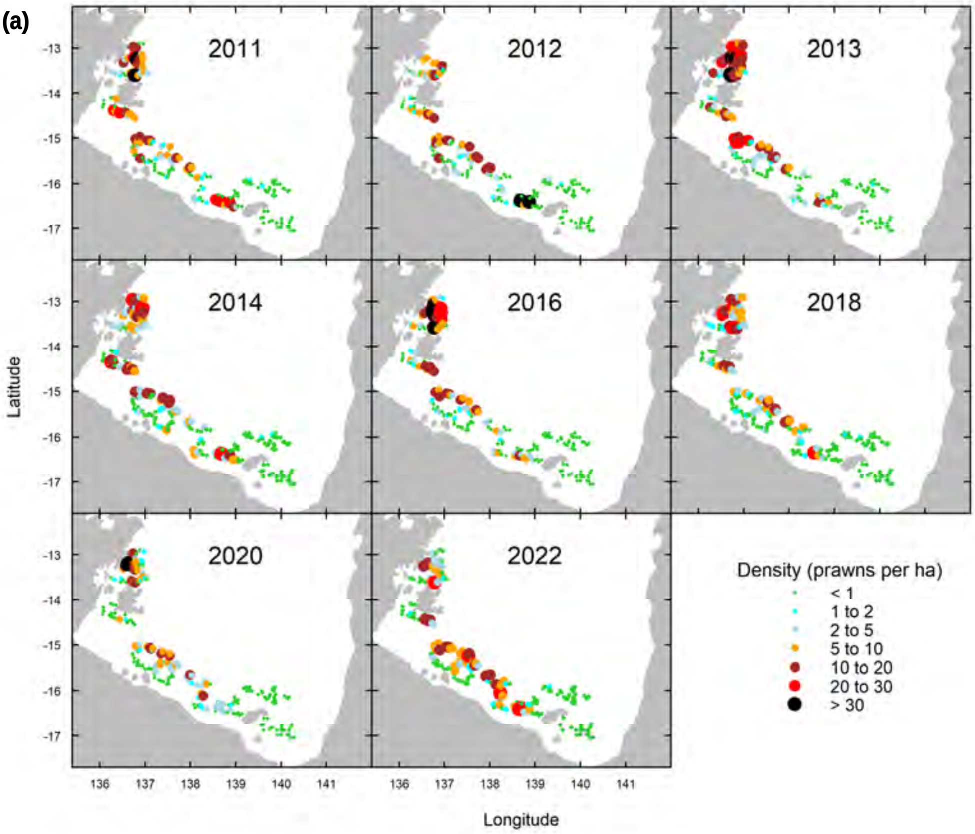
The Vanderlins July regional index for grooved tiger prawns was a 40% improvement on the 2020 index, and a continued improvement on the 2018 index, which was the lowest of the series. The higher 2022 regional index at the Vanderlins matched the commercial fishing effort on tiger prawns in the Gulf of Carpentaria which focussed on the Vanderlins area, as opposed to the historical deployment of fishing effort at Groote. Though low compared to Groote and Vanderlins regional indices, prior to 2018 the July grooved tiger prawn index for Mornington had been high relative to early years of the surveys (2002–2005). The 2022 index was much higher than the low 2018 and very low 2020 indices and the fourth highest on record. Grooved tiger prawn populations seem to be more resilient in the Vanderlins region and encroaching to the south-east towards Mornington Island.

In 2022, the Gulf-wide July index for brown tiger prawns was higher than in 2018 and 2020 and no longer among the lowest of the series. By region, at Groote and Vanderlins, the July regional abundance indices for brown tiger prawns were at near-historical lows in 2022, having dropped considerably since historical highs over 2013 to 2016. The Mornington regional index had improved in 2022, being moderate with a 100% increase on 2018 and 2020 levels (Figure 6). The Mornington regional index would have provided most of the contribution to the improved Gulf-wide index for brown tiger prawns. In 2022 at Vanderlins, the brown tiger prawn July index, though low, had steadily improved from 2018 through 2020 to 2022. Anecdotally, comparatively good catches of commercial prawns have been taken in Mornington in 2022. The population of brown tiger prawns has the capacity for large increases in abundance without a clear driver evident.

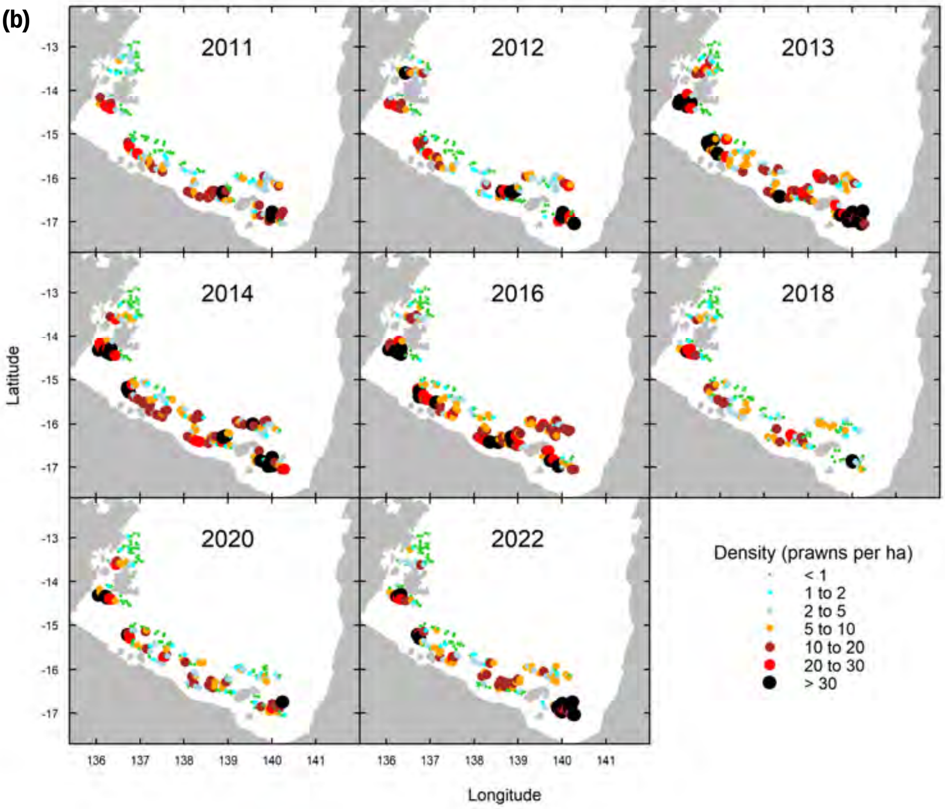
The 2022 July gulf-wide abundance index for blue endeavour prawns was not numerically different to the 2020 index, which was the second lowest of the series and similar to 2018. Recent indices have been much lower than those from 2009 to 2016. The 2022 July regional abundance index for blue endeavour prawns in the Groote region was higher than the 2020 lowest index on record, though not high relative to the 2011 to 2018 indices. The Vanderlins abundance index continued to improve to moderate levels from the 2020 index, while at Mornington the blue endeavour prawn abundance index was lower than that in 2020 but remained higher than the low index in 2016 (Figure 6).

The regional indices and survey catches of red endeavour prawns reflect their distribution and favoured habitats in the northern portion of the Gulf of Carpentaria (Figure 5, Figure 6). Few red endeavour prawns were caught in the Mornington and Karumba regions.

(a)


2011
2012
2013
2014
2016
2018
2020
2022
Latitude
Longitude
Density (prawns per ha)
< 1
1 to 2
2 to 5
5 to 10
10 to 20
20 to 30
> 30

(b)


2011
2012
2013
2014
2016
2018
2020
2022
Latitude
Longitude
Density (prawns per ha)
< 1
1 to 2
2 to 5
5 to 10
10 to 20
20 to 30
> 30

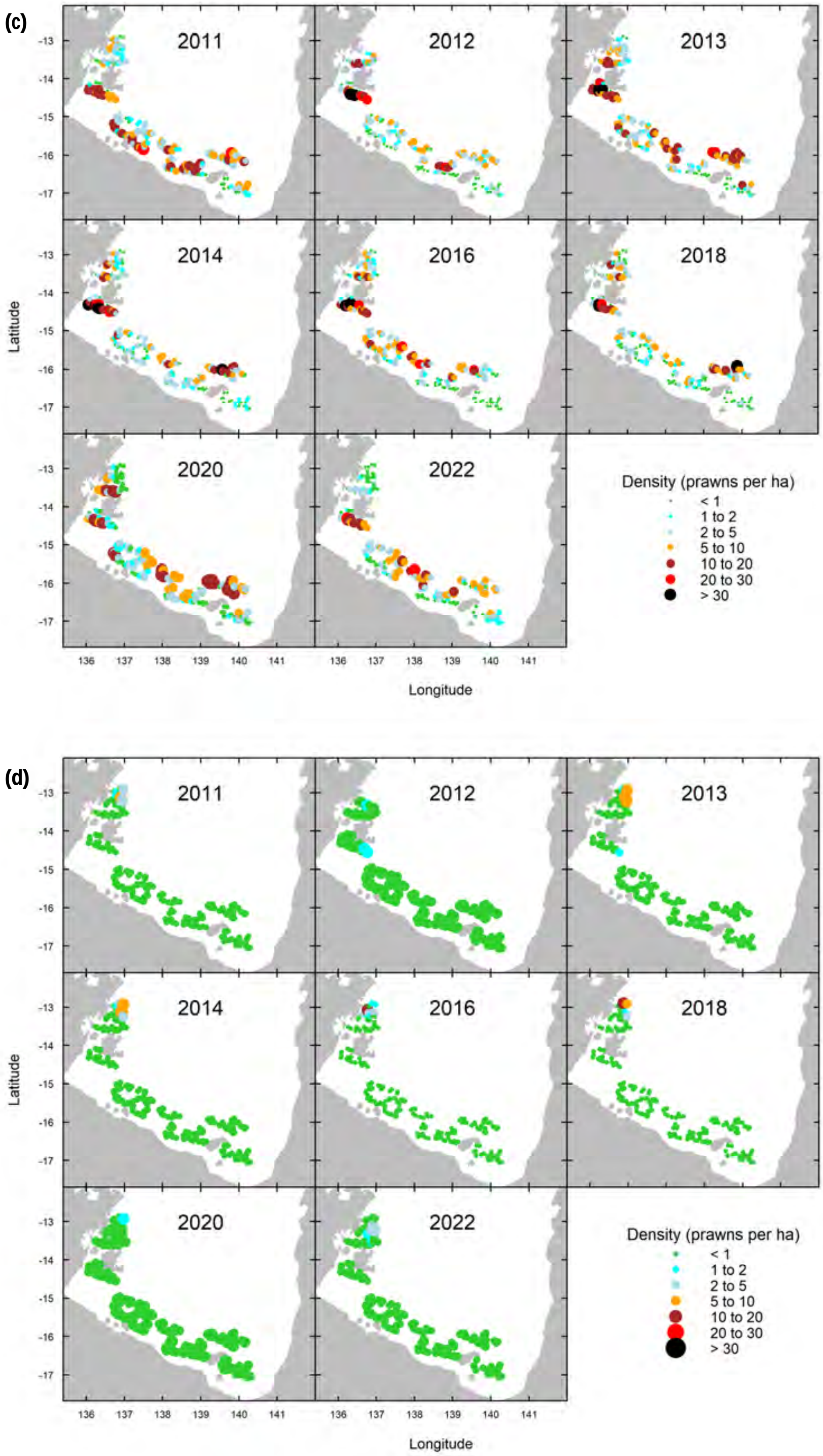


Figure 6: Gulf-wide (regional) distribution of (a) grooved tiger prawns, (b) brown tiger prawns, (c) blue endeavour prawns and (d) red endeavour prawns caught during the July surveys

5. Review of the NPF fishing power analysis

Review of the NPF fishing power analyses

CSIRO Environment

February 2023

SUMMARY

Estimating fishing power is a method used to assess the relative efficiency of fishing activities over time. It accounts for improvements in fishing technology and techniques over time, and uses this information to standardize the catch data collected. The current method for estimating fishing power, called the "2009 integrated model", involves modelling daily catch per boat-day, predicting the catch rate of a hypothetical standard vessel, and calculating the ratio between the fitted and standardized catch rates. The most important factor in this process is the "swept area index" (SATIG), which explains 50-60% of the variation in the seasonal catching performance of trawlers. Combined, the SATIG and offset variables account for 80% of the increase in fishing power. A review of the NPF fishing power methodology prompted several discussions, which are organised under four key questions:

1. *Should we explore direct use of vessel and gear information instead of the SATIG index?*
2. *Should we estimate species-specific annual fishing power?*
3. *Should we fit the offset variables in the model?*
4. *Should we be developing a standardised CPUE index?*

More detail to questions 2 and 3 is provided as appendices.

BACKGROUND

The NPF is a mixed penaeids trawl fishery managed by input controls. Since inception, the fishery has undergone large changes in fleet composition and technology. Effort standardization remains a major source of uncertainty within the stock assessment and management decision-making process (Bishop et al., 2008). Estimating fishing power is an extension to the regular CPUE standardization process that accounts for improved catchability in the stock assessment models. The method used in the NPF was developed in early 2000s (Dichmont *et al.*, 2003) and has been revised since (Bishop *et al.*, 2008; Dichmont *et al.*, 2010). The current method for estimating fishing power, referred to as "2009 integrated model", involves the following steps: (1) Modelling daily catch per boat-day (i.e., CPUE) by a series of covariates; (2) Predicting catch rate of a hypothetic standard vessel; and (3) Calculating the ratio between the fitted CPUE and standardised CPUE as fishing power.

Since 1970, estimates of annual fishing power have increased six-fold. To better understand the drivers of the consistent increase in NPF fishing power, a review of the analyses was undertaken. During this process, several questions were discussed - this paper provides a summary of these discussions. More detail to questions 2 and 3 is provided as appendices.

Review of the NPF fishing power analyses

CSIRO Environment

February 2023

SUMMARY

Estimating fishing power is a method used to assess the relative efficiency of fishing activities over time. It accounts for improvements in fishing technology and techniques over time, and uses this information to standardize the catch data collected. The current method for estimating fishing power, called the "2009 integrated model", involves modelling daily catch per boat-day, predicting the catch rate of a hypothetical standard vessel, and calculating the ratio between the fitted and standardized catch rates. The most important factor in this process is the "swept area index" (SATIG), which explains 50-60% of the variation in the seasonal catching performance of trawlers. Combined, the SATIG and offset variables account for 80% of the increase in fishing power. A review of the NPF fishing power methodology prompted several discussions, which are organised under four key questions:

1. *Should we explore direct use of vessel and gear information instead of the SATIG index?*
2. *Should we estimate species-specific annual fishing power?*
3. *Should we fit the offset variables in the model?*
4. *Should we be developing a standardised CPUE index?*

More detail to questions 2 and 3 is provided as appendices.

BACKGROUND

The NPF is a mixed penaeids trawl fishery managed by input controls. Since inception, the fishery has undergone large changes in fleet composition and technology. Effort standardization remains a major source of uncertainty within the stock assessment and management decision-making process (Bishop et al., 2008). Estimating fishing power is an extension to the regular CPUE standardization process that accounts for improved catchability in the stock assessment models. The method used in the NPF was developed in early 2000s (Dichmont *et al.*, 2003) and has been revised since (Bishop *et al.*, 2008; Dichmont *et al.*, 2010). The current method for estimating fishing power, referred to as “2009 integrated model”, involves the following steps: (1) Modelling daily catch per boat-day (i.e., CPUE) by a series of covariates; (2) Predicting catch rate of a hypothetic standard vessel; and (3) Calculating the ratio between the fitted CPUE and standardised CPUE as fishing power.

Since 1970, estimates of annual fishing power have increased six-fold. To better understand the drivers of the consistent increase in NPF fishing power, a review of the analyses was undertaken. During this process, several questions were discussed - this paper provides a summary of these discussions. More detail to questions 2 and 3 is provided as appendices.

1. *Should we explore direct use of vessel and gear information (speed, net dimension, etc.) instead of the SATIG index?*

The swept area index (SATIG) is the most influential explanatory variable in the fishing power analyses, explaining between 50% - 60% of the variation in the seasonal catching performance of trawlers in the NPF (Sterling, 2005). The SATIG estimate increased by a factor of 2.86 for the period 1970 – 2021 (**Figure 1**). Provided accurate vessel and gear information is available, these variables can be incorporated directly into the fishing power estimation model. Alternatively, if we continue to use the SATIG index, we may include it as a continuous variable in the model instead of an offset (**Appendix b**). Furthermore, a smoothing term can be used in a GAM.

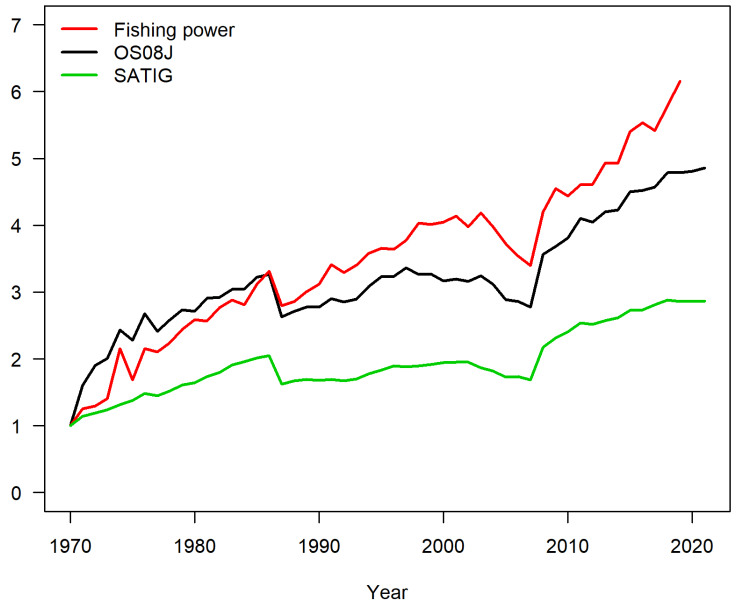


Figure 1. Contribution of swept area index (SATIG) and offset (OS08J) to fishing power increment.

2. *Should we estimate species-specific annual fishing power?*

Catchability and fishing power can be affected by both gear efficiency and the spatial distribution of both prawns and fishing effort. The four species of prawns are known to have different spatial distributions; therefore, it may be more appropriate to estimate fishing power for each species separately.

Furthermore, the two tiger prawn species are treated as target and bycatch species (**Appendix a**). Theoretically, fishing power differs between target and bycatch species in that the former should increase more given technological improvements associated with targeting a specific species (i.e., locating, accurate deployment etc.) and gear efficiency (e.g., increasing swept area per hour) while the latter may not be affected by targeting efficiency - increases in fishing power related to bycatch species should be less. Effort distribution, across both season and space, also differs depending on the target species. It is, therefore, likely that fishing power and its temporal trend should differ between the two treatments (target; bycatch).

Preliminary results (**Figure 2**) suggest differences in annual estimates of fishing power for each species when considered as the target species or bycatch. Given the recent progress in the species split models that allows for more accurate species-specific catch, and therefore targeting information, it seems appropriate to explore species-specific variation in fishing power, as well as whether the species under consideration was targeted or not.

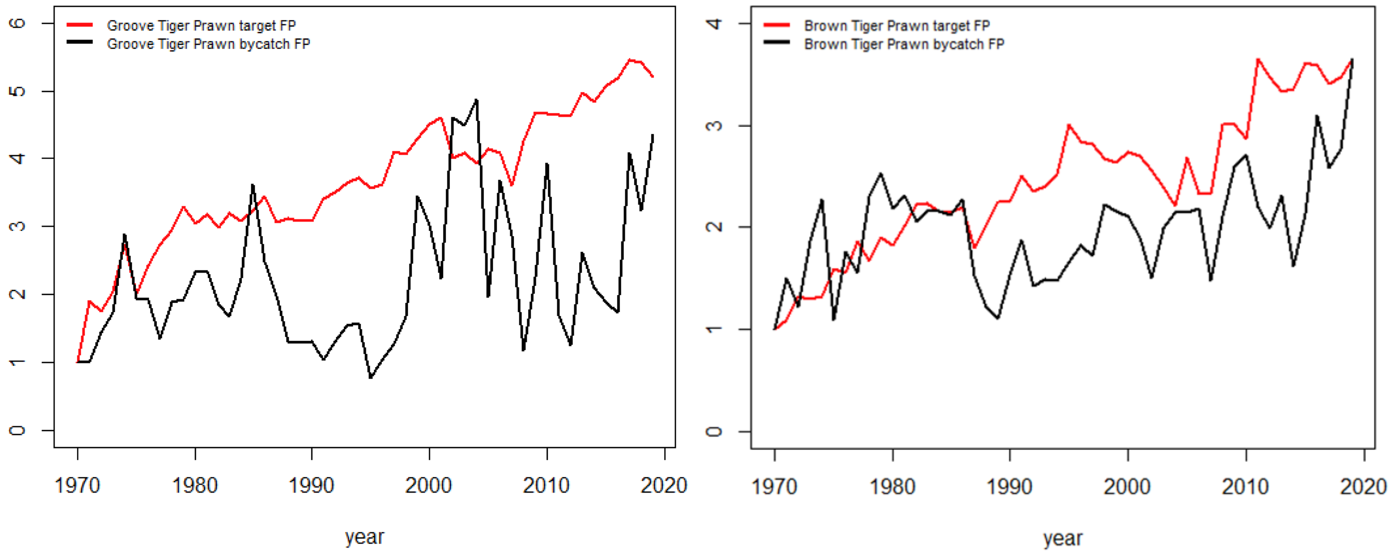


Figure 2. Preliminary results for species-specific annual estimates of fishing power for Groove Tiger Prawn (left) and Brown Tiger Prawn (right) as target (red) or bycatch (black).

3. Should we fit the offset variables in the model?

There are 17 independent variables used to model catch rate in the "2009 integrated model", several of which are included as offsets which are subtracted directly from the model estimate before the model is fitting (**Appendix b**). The multiple offsets, including SATIG, are combined to form a single variable (OS08J – "Low Model"; OS08R – "Mid-high Model") which is cumulatively added to the model outputs as an offset. The summed offset for Low Model increased by a factor of 4.86 for the period 1970 – 2021. Combined, SATIG and the offsets (i.e., OS08J) account for the majority (approx. 80%) of the increase in fishing power (**Figure 1**). Furthermore, sensitivity runs in the original development of NPF fishing power analyses (Bishop et al., 2008) indicate substantial variation when fitting parameters in the model compared to including the same parameters as offsets - the latter always resulted in increased catchability (see Figures c and d in the **Appendix b**). Should we be using alternative modelling frameworks (e.g., GAMs) to estimate these variables within the model?

4. Should we be developing a standardised CPUE index?

The "2009 integrated model" method appears not to account for spatial variation over time. Spatial heterogeneity is one of the primary interests in CPUE standardisation. Although *Stock Region* or *Sub-stock Area* is intended to capture spatial variability, this level of resolution is often too coarse for species with patchy distributions and for gear types that have a relatively small affective area per unit effort. Conventional CPUE standardisation is derived by constructing a prediction dataset which includes abundance variables (Lat-Lon grid, year), but fixes variables that affect fishing efficiency (all vessel and technology variables) and environmental condition (including month, days, time of the day, depth, moon phase, water temperature, etc.). Thus, variation in spatial distribution is inherently modelled. Given question 1-3, should we consider a conventional method for CPUE standardisation as opposed to estimating fishing power?

REFERENCES

Bishop, J., Venables, W. N., Dichmont, C. M., and Sterling, D. J. 2008. Standardizing catch rates: Is logbook information by itself enough? ICES Journal of Marine Science, 65: 255–266.

Dichmont, C. M., Bishop, J., Venables, W. N., Sterling, D. J., Eayrs, S., and Rawlinson, N. 2003. A new approach to fishing power analysis and its application in the Northern Prawn Fishery. CSIRO R99/1494, Cleveland, Australia.

Dichmont, C. M., Deng, A. R., A.E. Punt, Venables, W. N., Pascoe, S., Zhou, S., Kompas, T., *et al.* 2010. Developing techniques to estimate total allowable catches for the NPF major prawn species. FRDC Project 2007/018 Final Report. 369 pp.

Punt, E. A., Deng, R., Hutton, T., Pascoe, S., Plaganyi, E., Zhou, S. 2023. Technical description of the NPF stock assessment method and bio-economic TAE setting method.

Sterling, D. 2005. Modelling the physics of prawn trawling for fisheries management. PhD thesis, School of Applied Physics, Curtin University of Technology, Perth. 270 pp.

APPENDIX

a. Should we estimate species-specific annual fishing power?

Fishing power is included in both size-structured models for tiger prawns such that the time-series of relative fishing power is used to adjust nominal fishing effort when estimating fishing mortality rate (Punt et al. 2023):

$$F_{k,y,w,l} = A_{k,w}\, \gamma_{y,w}\, S^F_{k,l}\, (q^G_k E^G_{y,w} + q^B_k\, E^B_{y,w}) \qquad (1)$$

where $E^G_{y,w}$ and $E^B_{y,w}$ are the levels of nominal effort during week *w* of year *y* by the fleet targeting grooved (G) and brown (B) tiger prawns, respectively, q^G_k and q^B_k are the catchability coefficients for the fishing strategies targeting G and B, respectively, $A_{k,w}$ is the relative availability of animals of species *k* during week *w*, $\gamma_{y,w}$ is the relative fishing power of the two fishing strategies during week *w* of year *y*, and $S^F_{k,l}$ is the selectivity of the fishery on animals of species *k* in size-class *l*.

In the current form, the catchability coefficients q^G_k and q^B_k are fixed, species-specific values. This equation implies that any change in fishing power is identical for both target and bycatch species. Theoretically, fishing power differs between target and bycatch species in that the former should increase more given technological improvements associated with targeting a specific species (i.e., locating, accurate deployment etc.) and gear efficiency (e.g., increasing swept area per hour) while the latter may not be affected by targeting efficiency - increases in fishing power related to bycatch species should be less.

b. Should we fit the offset variables in the model?

There are 17 independent variables used to model catch rate in the “2009 integrated model” (Table 1), several of which are included as offsets which are subtracted directly from the model estimate of log(C_{ijkt}) before the model is fitting. For example, prior to fitting the Low Model, the following treatment is performed:

$$LC08J = LC - OS08J$$

where *LC* is log-catch and *OS08J* is Offset for Low Model. Once the model fitted values are obtained, the offset values (Offset OS08J) are added to the predicted log-scale catch. The rationale for introducing offsets into the “2009 integrated model” is twofold:

a) The possible confounding with population trends when estimating the influence of a specific technological advance - *Three types of preliminary investigation were made while developing the estimation models…….(iii) as confounding of technological variables with abundance was suspected, the effect of supplying tentative or hypothetical additional information on the impact of a given variable was investigated by fixing (or offsetting; McCullagh and Nelder, 1983) the coefficient for that parameter at some reasonable value, and observing the effect on all the other technology coefficient estimates* (taken from Bishop et al., 2008).

b) Model stability and/or convergence - *However, it was found necessary to fix the coefficients for the three most unstable variables, to stabilize the remainder of the results* (taken from Bishop et al., 2008).

For the “2009 integrated model”, the following offsets are included in the GLM:

I. OFFSET2J = SUM(OFFAUTO2J, OFFECHO2J, OFFRADAR2J);
II. OFFTRY2009 = FTRYGEAR*0.1;
III. OFFPLOT2009 = FPLOTTER*0.045;
IV. OS08J = SUM(O_BRDN , LOGSA, 0.95*LOGHOURS, OFFSET2J);
V. OS08R = SUM(OS08J, OFFTRY2009, OFFPLOT2009);

whereby OS08J is defined as the “Low Model” and OS08R is the “Mid-High Model”.

Sensitivity runs in the original development of NPF fishing power analyses (Bishop et al., 2008) indicate substantial variation when fitting parameters in the model compared to including the same parameters as offsets - the latter always resulted in increased catchability (see Figures c and d in the Appendix). Furthermore, the summed offset for “Low Model,” OS08J, increased by a factor of 4.86 between 1970 and 2021.

As stated above, the inclusion of parameters as offsets, as opposed to parameters within the model framework, was to avoid confounding with changes in biomass but also to improve model stability (i.e., convergence). Confounding is particularly problematic when the uptake of a novel technology takes several years, thus, during that period the model is unable to separate whether variation in catches is a result of a variations in catchability (fishing power) or abundance. Here, the adoption of technology within the NPF is quick and generally vessels introduce the technology in less than 5 years of the first adoption (**Figure 3**). Moreover, the latest technology included as an offset was fully adopted in the early 2000’s. It may, therefore, be more accurate to now include these parameters as categorical variables (apart from SATIG which is a continuous variable) within the chosen modelling framework (GLM or GAM) and estimated their influence on catchability.

Modelling frameworks, and computational power, have developed significantly since the first implementation of the “2009 integrated model”. Previous issues regarding model stability and/or convergence can be overcome with the use of more flexible and readily available modelling frameworks, such as Generalized Additive Models (GAMs).

Table 1. Reported explanatory variables from Dichmont et al. 2010

Variable Name	Variable explanation	Data type
YEAR	Fishing year	Category
MONTH	Fishing month	Category
STOCK_SUB_REGION	Stock sub-region	Category
CDAY	Calendar day	Numeric
DEPTH	Depth	Numeric
HULLG	Hull groups	Category
SATIG	Swept area rate	Offset
IMP1_HOURS	Corrected trawl hours	Offset
O_BRDN	TED and BRD	Offset
Radar	Radar	Offset
NAV_ACCG	SatNav, GPS, D_GPS	Category
B&W_Echo	Black and white echosounder	Offset
TRYGEAR	Try gear used	Category
PLOTTER	Plotter used	Category
PC_SAT	connection	Category
Autopilot	Autopilot	Offset
LTEG	Local tiger effort group	Category
ECHOCOL	Colour echosounder	Category

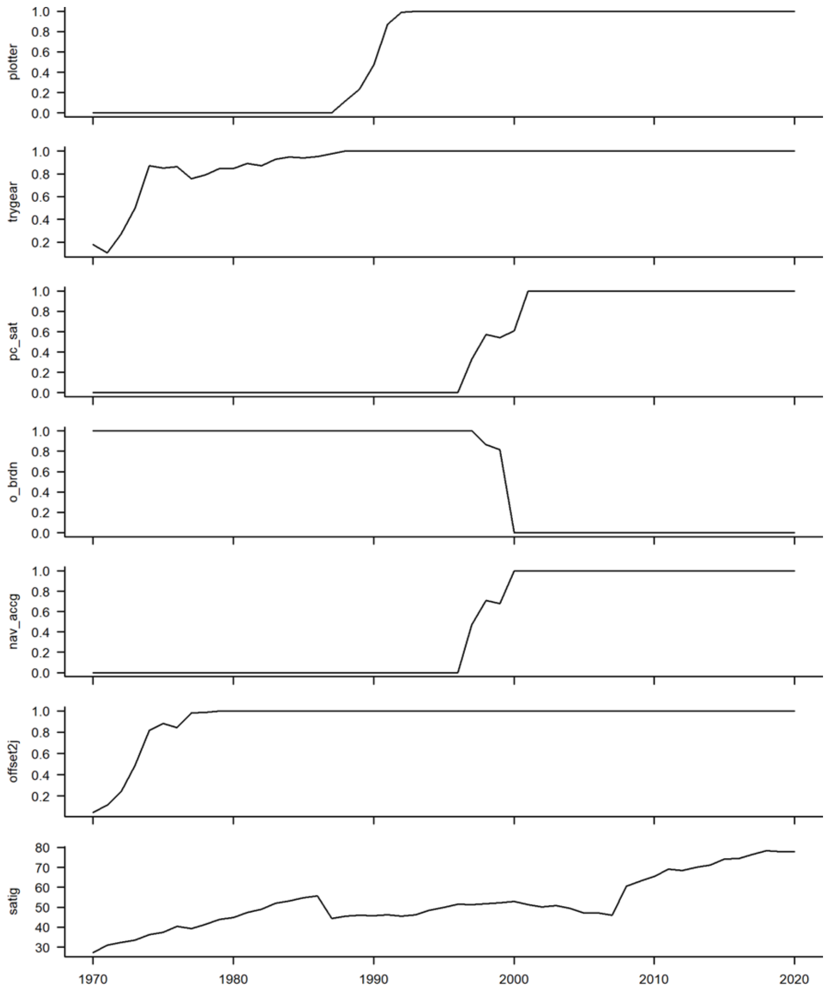


Figure 3. Examples of technology adoption in the NPF over time. The y-axis scale is proportion of vessels adopting the technologies (except for the swept area index - SATIG).

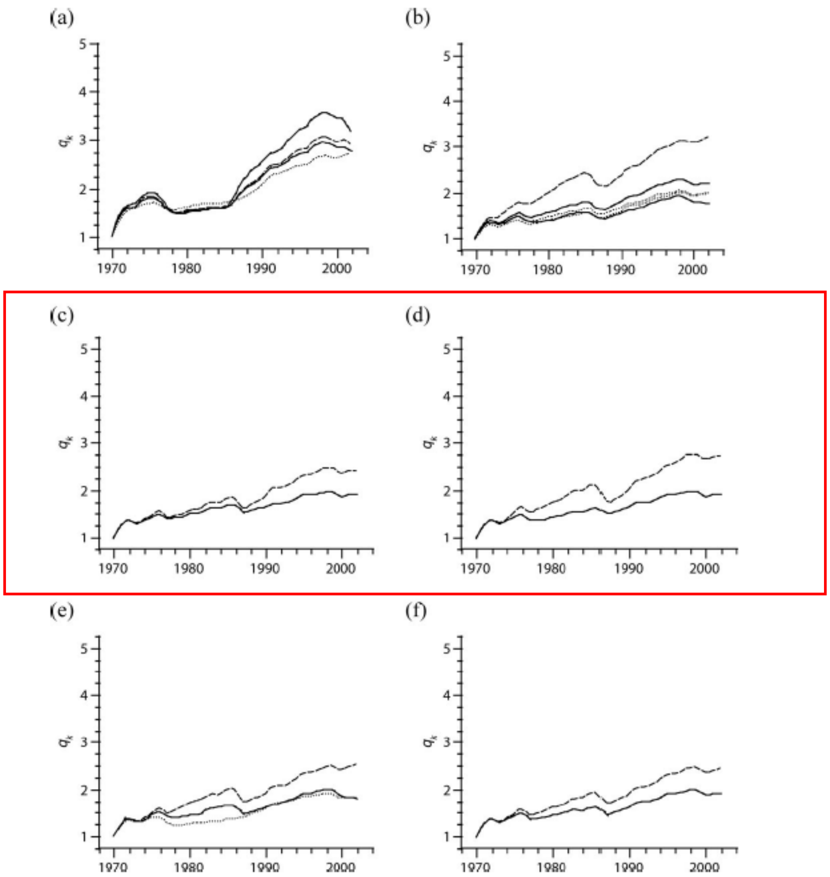


Figure 3. Some of the factor impacts from sensitivity experiments. Results for all levels of each factor are summarized by local smoothing of relative fishing power against year. (a) Inputs are daily records (dotted line), or catch and effort aggregated over months (upper solid line), weeks (dashed line), or years (lower solid line). (b) Alternative variables to represent abundance and availability (upper dashed line has a weekly timestep, others are monthly). (c) Log (h) fitted in the model (solid line), or offset (dashed line). (d) Vessel capacity variable fitted in the model (solid line) or offset (dashed line). (e) Alternative vessel capacity variables: swept area performance (dashed line), headline length (solid line), or five variables for hull size, nets, engines, and kort nozzle (dotted line). (f) Skipper variables included in the model (dashed line), or not (solid line).

6. Preliminary Update of the NPF Species Split Project

Preliminary Update of the NPF Species Split Project

CSIRO Environment
3 February 2023

NON-TECHNICAL SUMMARY

A preliminary update has been made to the species split models using additional data from the NPF monitoring surveys since 2005 and the commercial sampling conducted during 2019–2021.The results suggest that the split of the catch of endeavour prawns to *Metapenaeus endeavouri* (Blue Endeavour) and *M. ensis* (Red Endeavour) is a function of location (6"x6" grid cell) and day of the year but does not change among years. This appears not to be the case for tiger prawns for which the proportion of *Penaeus semisulcatus* (Grooved Tiger) in a tiger prawn catch at a given location on a given day within the year changes between years, with grid cells with tiger prawns more likely now to contain *P. semisulcatus* than in the past. The new species split models lead to changes to the estimates of the catches by prawn species, in particular, larger catches of *P. semisulcatus,* and smaller catches of *P. esculentus* (Brown Tiger) in recent years.

The changes to the catches will impact the outputs of the stock assessment model and ultimately the management advice based on the bio-economic model. The results are preliminary, given further data checking needs to occur and additional species split models need to be examined.

BACKGROUND

Catches in the Northern Prawn Fishery (NPF) are recorded by "species group" (tiger, endeavour and banana prawns), and "species split models" are used to split catches to species (tiger prawns: *Penaeus semisulcatus* and *P. esculentus*; endeavour prawns: *Metapenaeus endeavouri* and *M. ensis*) so that species-specific assessments can be undertaken given the various prawn species differ in terms of their biological parameters (Punt et al., 2010, 2011).

Venables et al. (2006) developed species split models using data from 1976 to 2004 collected during a variety of projects. These models have been used to construct the catch and effort data used as the basis for recent assessments. However, the data used by Venables et al. (2006) were not collected with the intention to apply a species-split algorithm and, at the time, there was limited evidence that the relative proportions of species by location (6' x 6' grid squares) were not time-invariant (aka a "static" or "non-stationary" model). Since that time, considerable new data on species splits have been collected from the NPF monitoring surveys, but these surveys do not take place when (and where) the fishery operates, so a new species split project was developed. The objectives of this project were:

1. To design and implement a survey program using the protocols established by Venables et al. (2006) to extend the historical survey data used for species split to include current (Season 2, 2019 to Season 1, 2021) well-targeted survey data (good spatial and temporal coverage, particularly 'in-season' data from fished areas) focusing on tiger prawns, and subject to a funding agreement for endeavour prawns.
2. Develop a protocol for assessing adequacy of species split data collected by the AFMA Scientific Observer program (using concurrent survey data from Objective 1 as the reference set) and optimise the sampling design for this component, with a view to regular ongoing monitoring of species composition (in-season).
3. Develop a method for including current well-targeted species composition data into a composite species split data series, which could be included in species split models on a

Preliminary Update of the NPF Species Split Project

CSIRO Environment
3 February 2023

NON-TECHNICAL SUMMARY

A preliminary update has been made to the species split models using additional data from the NPF monitoring surveys since 2005 and the commercial sampling conducted during 2019–2021.The results suggest that the split of the catch of endeavour prawns to *Metapenaeus endeavouri* (Blue Endeavour) and *M. ensis* (Red Endeavour) is a function of location (6"x6" grid cell) and day of the year but does not change among years. This appears not to be the case for tiger prawns for which the proportion of *Penaeus semisulcatus* (Grooved Tiger) in a tiger prawn catch at a given location on a given day within the year changes between years, with grid cells with tiger prawns more likely now to contain *P. semisulcatus* than in the past. The new species split models lead to changes to the estimates of the catches by prawn species, in particular, larger catches of *P. semisulcatus,* and smaller catches of *P. esculentus* (Brown Tiger) in recent years.

The changes to the catches will impact the outputs of the stock assessment model and ultimately the management advice based on the bio-economic model. The results are preliminary, given further data checking needs to occur and additional species split models need to be examined.

BACKGROUND

Catches in the Northern Prawn Fishery (NPF) are recorded by "species group" (tiger, endeavour and banana prawns), and "species split models" are used to split catches to species (tiger prawns: *Penaeus semisulcatus* and *P. esculentus*; endeavour prawns: *Metapenaeus endeavouri* and *M. ensis*) so that species-specific assessments can be undertaken given the various prawn species differ in terms of their biological parameters (Punt et al., 2010, 2011).

Venables et al. (2006) developed species split models using data from 1976 to 2004 collected during a variety of projects. These models have been used to construct the catch and effort data used as the basis for recent assessments. However, the data used by Venables et al. (2006) were not collected with the intention to apply a species-split algorithm and, at the time, there was limited evidence that the relative proportions of species by location (6' x 6' grid squares) were not time-invariant (aka a "static" or "non-stationary" model). Since that time, considerable new data on species splits have been collected from the NPF monitoring surveys, but these surveys do not take place when (and where) the fishery operates, so a new species split project was developed. The objectives of this project were:

1. To design and implement a survey program using the protocols established by Venables et al. (2006) to extend the historical survey data used for species split to include current (Season 2, 2019 to Season 1, 2021) well-targeted survey data (good spatial and temporal coverage, particularly 'in-season' data from fished areas) focusing on tiger prawns, and subject to a funding agreement for endeavour prawns.
2. Develop a protocol for assessing adequacy of species split data collected by the AFMA Scientific Observer program (using concurrent survey data from Objective 1 as the reference set) and optimise the sampling design for this component, with a view to regular ongoing monitoring of species composition (in-season).
3. Develop a method for including current well-targeted species composition data into a composite species split data series, which could be included in species split models on a

regular ongoing basis. Develop a protocol for assessing data quality and identifying gaps in spatial and temporal coverage of species split data (consistent with Objective 2).

4. Calibrate the species split model with a consolidated data set including contemporary data collected in this project, and including recent data from the Scientific Observer program, and other available datasets (after applying a minimum data quality threshold).
5. Test the impact of the new species split data on the stock assessment (re-run the bioeconomic model with the new data as a sensitivity test for peer review from scientific members on NPRAG).

This document provides initial and preliminary analyses to explore whether the data collected since the species-split models were developed (Venables et al., 2006) provide evidence that the proportions by species by location have changed over time, how this might impact the catch and effort by prawn species, and the consequences for the results of stock assessments, including the outputs of the bio-economic model used to estimate the management reference points (B_{MSY} and B_{MEY}) as well as the levels of effort needed to achieve MEY.

METHODS

Species-split models

The data on which the analyses conducted by Venables et al. (2006) were based came from a variety of research projects and sampling programs. The more recent data were obtained from NPF monitoring survey (2002–2022) and the sampling conducted as part of this project (2019–2021; 2022 data are limited and have yet to checked). Models were fit separately for the tiger and endeavour prawns. The predictor variables considered in the models (see Appendix for technical specifications) were Longitude and Latitude, Rdist and Rland, Depth_av, Mud_av, days_of_year, and days. The days variable (number of days since 1970) was not included in the final models of Venables et al. (2006) and reflects a way to model non-stationarity[1] effects (i.e., time-trends in the proportion of species by location). An aim of the project was to determine whether inclusion of the days variable leads to appreciably better fits to the data and changes the outcomes of the assessment.

The four generalized additive models (GAMs) were:

Stationary-1 (Eqn 1)

```
Tiger_gam_static <- bam(psem/Total ~ s(Longitude, Latitude) +
                     te(day_of_year, Rland,    k = c(5, 5), bs = c("cc", "cs")) +
                     te(day_of_year, Depth_av, k = c(5, 5), bs = c("cc", "cs")) +
                     te(Rland,       Depth_av, k = c(5, 5), bs = c("cs", "cs")) +
                     s(Mud_av, k = 5),
                    family = quasibinomial(), data = Tigers_work,
                    knots = list(day_of_year = seq(0, 365, length = 5)),
                    weights = Total/mean(Total))
```

[1] A time series is said to be "stationary" if its mean and variance does not change over time. This is not the case for a "non-stationary" time series, the mean and variance of which depends on the time-period examined. Not accounting for the stationarity properties of a time series may lead to spurious correlation and potentially misleading results.

Stationary-2 (Eqn 2)

```
Tiger_gam_stat_alt <- update(Tiger_gam_static, . ~ . + s(Rdist))
```

Non-stationary-1 (Eqn 3)

```
Tiger_gam_dynamic <- update(Tiger_gam_static, . ~ . + s(days))
```

Non-stationary-2 (Eqn 4)

```
Tiger_gam_dyn_alt <- update(Tiger_gam_stat_alt, . ~ . + s(days))
```

As noted in the appendix, the "-2" models include a new predictor variable Rdist to allow for greater sensitivity to unmeasured local coastal features.

The models are applied to the full data set and a version of the data set that excluded data before 1 April and during the mid-season closures given the resulting models will be applied to split catches and no catches of tiger prawns occur before 1 April and during the closure. The species split models were evaluated in terms of patterns in the relationships between the predictor variables and the response variable (proportion of species), and by the explained variance.

Assessment and bio-economic model

The assessment (see Punt et al. [2010, 2011] for details) involves applying a size-structured population dynamics model to data for the tiger prawns and a hierarchical Bayesian production model to the data for *M. endeavouri* and *M. ensis*. Assessment configurations were run for a subset of the eight models (the four models 1-4 for the full and restricted data sets) and results are reported as spawning biomass indices relative to S_{MSY} and S_{MEY} as well as time-series of target effort given the base specifications of the four-species version of the assessment. Results are also shown when the current species split algorithm is applied to evaluate the implications of the additional data given the current predictor model.

A complication arises for the non-stationary models (i.e., the models with the s(days) covariate) given that the assessment starts in 1970 but the first species split data are for 1976. For the purposes of this preliminary work, the species splits for 1976 were assumed to relate to the model predictions for 1970–1975 (i.e., non-stationary split proportions before 1976).

RESULTS

Data used

Figure 1 shows the number of samples by year and month for the tiger and endeavour prawns, highlighting the sampling from the NPF monitoring surveys and the sampling conducted as part of this project. Figure 2 plots the number of samples (annually) by location and year.

Species split models

Table 1 summarizes the results in terms of explained variance and the GAM scale parameter. The models explained a substantial fraction of the deviance (≥78% for all models). As expected, the more complex models explained more of the variance. The models for endeavour prawns lead to higher levels of explained variance because most of the catch of endeavour prawns is *M. endeavouri*. Figure 3 shows the long-term components for the four non-stationary models for the tiger and endeavour prawns. The Appendix shows predicted species distributions by location and among models. Figure 3 shows that there is limited evidence for non-stationarity for the endeavour prawns but there is such evidence for the tiger prawns. Restricting the data set to when the fishery was open (Figure 3a, lower panels) and downweighting the data for the closure period by 50% (results not shown) continue to support non-stationarity, albeit with poorer precision.

Given the results in Table 1, the subsequent analyses are based on four species split models: (a) the model used for recent assessments and based on the work of Venables et al. (2006) ("Original"), (b) the update of this model using the new data (a static model without the s(Rdist) covariate) ("Original updated"), (c) the model with the s(Rdist) covariate for both species groups and non-stationarity for tiger prawns ("Tiger dynamic (full)"), and (d) as for the third model but based on the temporally restricted data set ("Tiger dynamic (restricted)").

Figure 4 plots the differences between the catch by species and effort by métier[2] from the current species-split model and the selected alternative models by year and week and Table 2 summarizes these differences by year and week blocks. A simple update of the data used in the model ("Original updated") leads to minor differences after 2000, but to quite marked changes in catch and effort prior to 1990 (Figure 4a; Table 2). These differences are likely attributed to changes in model predictions during the latter half of the year (Figure 4b). Allowing for non-stationarity (models "Tiger dynamic (full)" and "Tiger dynamic (restricted)" in Figure 4 and Table 2) leads to changes to recent catches for the tiger prawns (and a different pattern in differences from the "Original" model for the years before 2000). In particular, the catch of, and effort targeted towards, *P. semisculcatus* is increased while the catch of, and effort target towards, *P. esculentus* is reduced.

Assessment results and bio-economic model outputs

Figure 5 shows estimated time-series of spawning biomass indices relative to S_{MSY} and S_{MEY} (upper two rows of panels) and catch (third row of panels) for the various models for the historical period and forecasted using the bio-economic model. Qualitatively, the differences among models is relatively small and mimic the temporal differences in catch. The impact of the species split algorithm is most marked for the projection period of the model (to the right of the vertical dotted line). One reason that the species split model has relatively a minor impact on the time-trajectories of spawning biomass (visually) is because the model adjusts recruitment given changed catches (Figure 6). The estimates of reference points (catch and effort by species and métier) vary among species. The catch corresponding to MSY and MEY and the effort for the *P. semisulcatus* metier are higher for all of the alternative models while the opposite effect is evident for *P. esculentus*. The 2022 and 2023 standardized effort values are the same for all of the models given the NPF harvest control rule and the minimum effort level.

DISCUSSION AND CAVEATS

Data sets

The project has substantially increased the number of samples of species composition for times during the year and locations compared to the data on which the previous analyses were based. However, in terms of number of records the data collected during the NPF monitoring survey since 2004 made a larger contribution to the overall data set.

[2] A métier represents a combination of fishing area, target species and fishing gear. In the current bioeconomic models these are loosely described as "fleets", although the concept of métier allows for greater spatial considerations.

Species split models

This document is based on a reimplementation of the original model of Venables et al. (2006), a new covariate that attempts to address sensitivity to unmeasured local coastal features better, and most importantly a variable to capture non-stationarity. The larger data set than used by Venables et al. (2006) continues to not support non-stationarity for the endeavour prawns, but suggests that the assumption of non-stationarity for the tiger prawns is likely violated.

Implications for stock assessment

Simply updating the models led to changes to the historical (pre-2000) estimates of removals of tiger and endeavour prawns. This is somewhat surprising given there are no new historical data and the original models should be the same. However, with stationary models, new data added at different times of year can impact the results for years other than those to which the new data pertain. The contrasts with non-stationary models that allow the species split to be "local" in time, which reduces the effect of new data on past estimates. Nevertheless, this result warrants further examination: (a) to identify the cells that have changed their species split values, (b) to check that the re-implementation of the model has not changed the outputs, and (c) to check that the data used in the current study and by Venables et al. (2006) are indeed unchanged before 2004.

There is still no evidence for non-stationarity in species split proportions for endeavour prawns but this is not the case for tiger prawns (but see "additional caveats" below). The non-stationary effects identified in the models with the `s(days)` covariate led to changes to the catches of all species, and for tiger prawns those in recent years, with some of the removals previously attributed to *P. esculentus* now attributed to *P. semisulcatus*.

The estimates from the stock assessment are broadly robust to updating the species split models. However, the reference points from the stock assessment are impacted to a non-trivial degree (e.g., 5-20% increases in E_{MSY} and E_{MEY} for *P. semisulcatus* and -6 – 20% reductions for *P. esculentus*). There was insufficient time to conduct a full evaluation of model diagnostics for the assessments based on the alternative species split models, and this needs to occur before final conclusions are drawn.

Additional caveats

The analyses conducted to date and reported in this document fail to fully account for the lack of balance in the data. In particular, the putative change in the relative amount of *P. semisulcatus* by location starts roughly when the NPF monitoring survey started, suggesting that it may be availability of data during times of the year that the fishery does not operate that is driving this apparent change. Furthermore, the survey tends to catch smaller prawns than the fishery, which may also impact the predicted species split proportions. As shown by the blue bars in Figure 1, most of the new data (in terms of records with data) are from the NPF monitoring survey. The sensitivity test in which data before the start of the banana fishery and during the mid-season closure were excluded provides evidence that non-stationary may not be related to lack of balance in the data set. However, additional analyses need to be conducted before final conclusions are drawn. These could include applying models that include an interaction between location (perhaps modelled by `Rdist`) and the covariate `days`.

It was necessary to assume that species proportions for 1970–1975 were the same as those for 1976 given the lack of data for 1976 (and the generally limited data for the early years of the fishery; Figure 1). Future work should explore starting the assessment in 1976 (or later) to avoid needing to make this assumption.

REFERENCES

Punt, A.E., Deng, R.A., Dichmont, C.M., Kompas, T., Venables, W.N., Zhou, S., Pascoe, S., Hutton, T., Kenyon, R., van der Velde, T. and M. Kienzle. 2010. Integrating size-structured assessment and bioeconomic management advice in Australia's northern prawn fishery. ICES J. Mar. Sci. 67, 1785–1801.

Punt, A.E., Deng, R., Pascoe, S., Dichmont, C.M., Zhou, S., Plaganyi, ´E.E., Hutton, T., Venables, W.N., Kenyon, R. and T. van der Velde. 2011. Calculating optimal effort and catch trajectories for multiple species modelled using a mix of size-structured, delay-difference and biomass dynamics models. Fish. Res. 109, 201–21

Venables, W.N., Kenyon, R.A., Bishop, J.F.B., Dichmont, C.M., Deng, R.A., Burridge, C., Taylor, B.R., Donovan, A.G., Thomas, S.E. and S.J. Cheers. 2006. Species distribution and catch allocation: data and methods for the NPF, 2002 - 2004 : final report January 2006 for project R01/1149.

Table 1. Deviance percentages explained and scale parameter estimates for the models considered. The models indicated with asterisks are considered further,

(a) Tiger prawns

	Deviance Explained	Scale parameter
Full data set (n=28,527)		
Base model *	78.0%	0.396
Base model + s(Rdist)	78.5%	0.477
Non-stationary model	79.4%	0.274
Non-stationary model + s(Rdist)*	80.0%	0.366
Restricted data set (=8,318)		
Base model	82.9%	0.333
Base model + s(Rdist)	83.1%	0.324
Non-stationary model	84.0%	0.270
Non-stationary model + s(Rdist)*	84.2%	0.259

(a) Endeavour prawns

	Deviance Explained	Scale parameter
Full data set (n=24,376)		
Base model*	92.2%	0.353
Base model + s(Rdist)	92.5%	0.371
Non-stationary model	92.5%	0.428
Non-stationary model + s(Rdist)	92.8%	0.423
Restricted data set		
Base model	92.4%	0.289
Base model + s(Rdist)	92.4%	0.297
Non-stationary model	92.6%	0.421
Non-stationary model + s(Rdist)	92.6%	0.422

Table 2. The differences in total catch and effort by year and week blocks from the current assessment for the three selected alternative models. For tiger prawns, models 1-3 are respectively: the static model without s(Rdist), the dynamic model with s(Rdist), and the dynamic model with s(Rdist), but based on the restricted data set. For endeavour prawns, models 1-3 are respectively: the static model without s(Rdist), the static model with s(Rdist), and the static model with s(Rdist), but based on the restricted data set.

Updated model	Years/ weeks	Change in catch				Change in effort	
		P. semi	*P. esc*	*M. End*	*M. ensis*	*P. semi*	*P.esci*
Original updated (1)	1970-79	904.3	-904.3	-293.2	293.2	3779	-3779
	1980-89	1415.8	-1415.8	-882.3	882.3	6947	-6947
	1990-99	680.2	-680.2	-238.4	238.4	1478	-1478
	2000-09	135.6	-135.6	-283.1	283.1	239	-239
	2010+	241.0	-241.0	-267.8	267.8	209	-209
Tiger dynamic (full) (2)	1970-79	-37.2	37.2	-321.1	321.1	-103	103
	1980-89	-747.9	747.9	-926.4	926.4	-7067	7067
	1990-99	-595.5	595.5	-259.6	259.6	-3767	3767
	2000-09	640.9	-640.9	-300.2	300.2	1367	-1367
	2010+	957.1	-957.1	-278.7	278.7	2082	-2082
Tiger Dynamic (restricted) (3)	1970-79	26.9	-26.9	-520.9	520.9	801	-801
	1980-89	-570.6	570.6	-1214.2	1214.2	-3105	3105
	1990-99	-579.2	579.2	-284.9	284.9	-2286	2286
	2000-09	739.6	-739.6	-330.9	330.9	1913	-1913
	2010+	1522.2	-1522.2	-331.7	331.7	3497	-3497
Original updated (1)	1-13	239.6	-239.6	-116.3	116.3	605	-605
	14-24	1074.3	-1074.3	-212.7	212.7	5912	-5912
	25-30	603.3	-603.3	-67.9	67.9	3587	-3587
	31+	1459.7	-1459.7	-1567.9	1567.9	2548	-2548
Tiger dynamic (full) (2)	1-13	-240.2	240.2	-127.0	127.0	-1301	1301
	14-24	112.7	-112.7	-222.3	222.3	127	-127
	25-30	155.1	-155.1	-66.5	66.5	516	-516
	31+	189.9	-189.9	-1670.3	1670.3	-6830	6830
Tiger dynamic (restricted) (3)	1-13	-226.1	226.1	-291.2	291.2	-1219	1219
	14-24	49.9	-49.9	-289.8	289.8	465	-465
	25-30	19.7	-19.7	-103.7	103.7	542	-542
	31+	1295.4	-1295.4	-1997.8	1997.8	1032	-1032

Table 3. Estimates of the catches and effort corresponding to MSY and MEY by species and the projected 2022 and 2023 efforts by métier given the current harvest control rule for selected models.

Quantity	**Original**	**Original updated**	**Tiger dynamic (full)**	**Tiger dynamic (restricted)**
MSY (*P. semisulcatus*)	1572	1613	1597	1623
MEY (*P. semisulcatus*)	1356	1433	1458	1440
MSY (*P. esculenus*)	1049	1003	1008	956
MEY (*P. esculenus*)	1126	1039	1050	1041
MSY (*M. endevouri*)	794	726	725	710
MEY (*P. endevouri*)	641	601	629	629
E_{MSY} (*P. semisulcatus)*	6716	7191	7341	7067
E_{MEY} (*P. semisulcatus)*	3946	4178	4756	4408
E_{MSY} (*P. esculenus)*	3112	2637	2487	2761
E_{MEY} (*P. esculenus)*	3172	2777	2777	3361
E_{2022} (*P. semisulcatus*)	4926	4926	4926	4926
E_{2023} (*P. semisulcatus*)	4926	4926	4926	4926
E_{2022} (*P. esculenus*)	4926	4926	4926	4926
E_{2023} (*P. esculenus*)	4926	4926	4926	4926

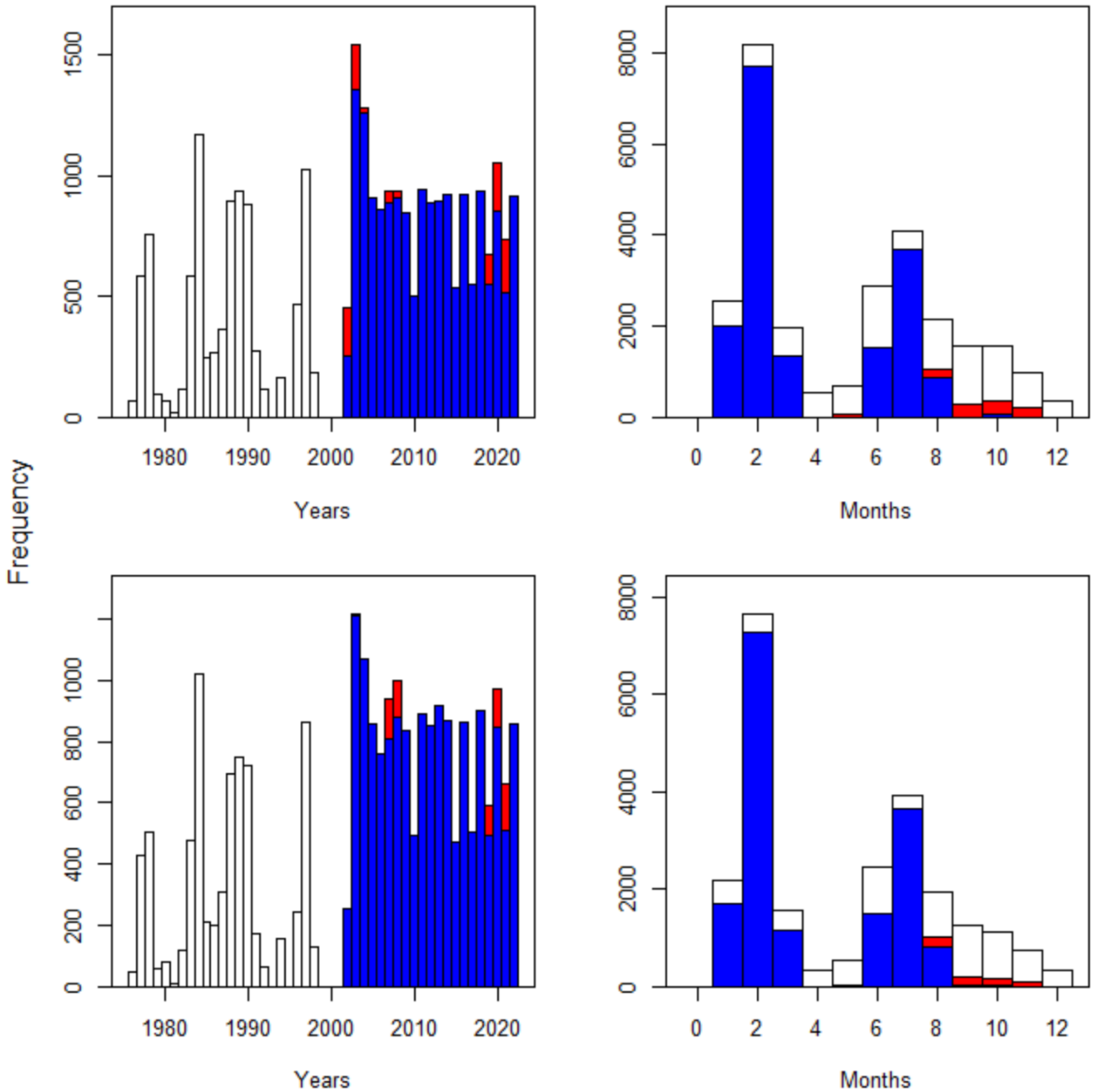


Figure 1. The number of samples by year and month for the tiger and endeavour prawns from the full data set. Records from the NPF monitoring survey are indicated in blue, those from the commercial sampling ("Species Distribution") in red, and remaining records in white.

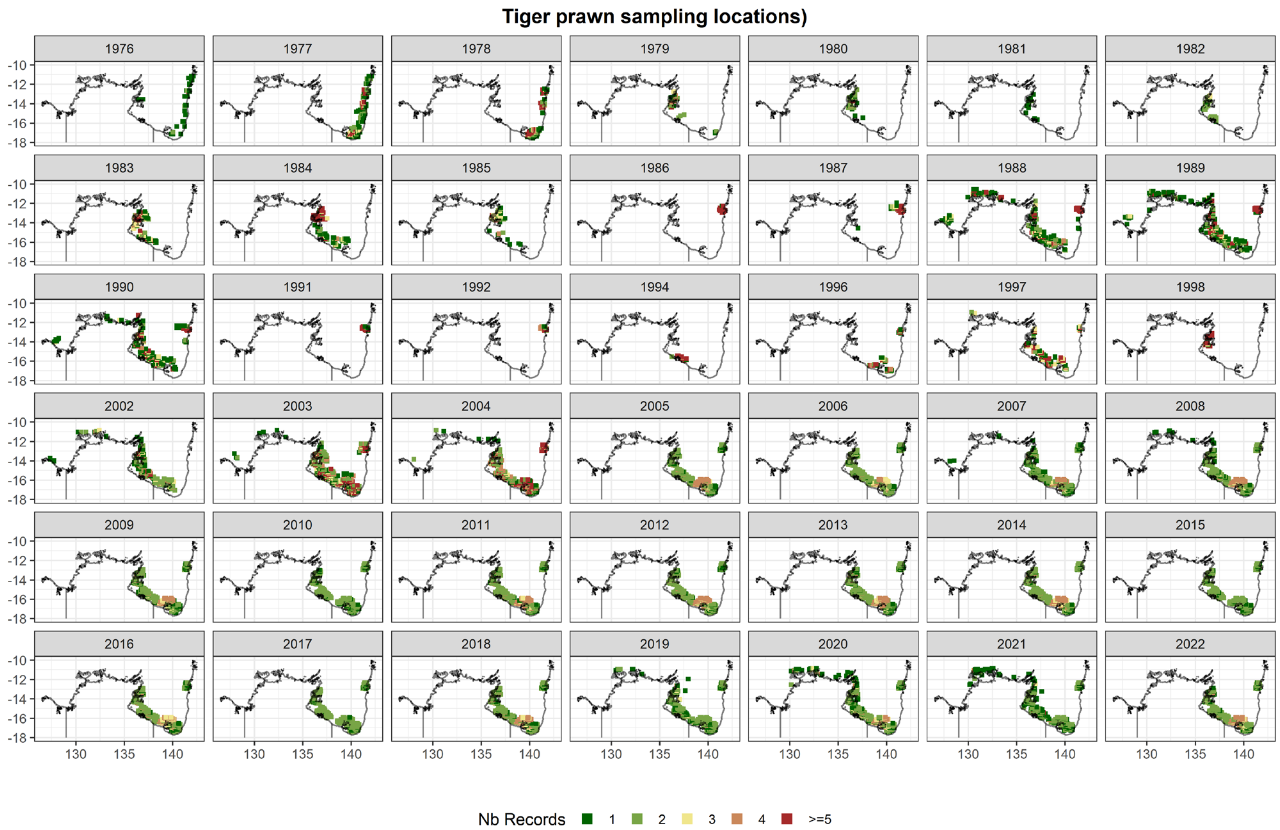


Figure 2a. The number of samples (annually) by location for tiger prawns.

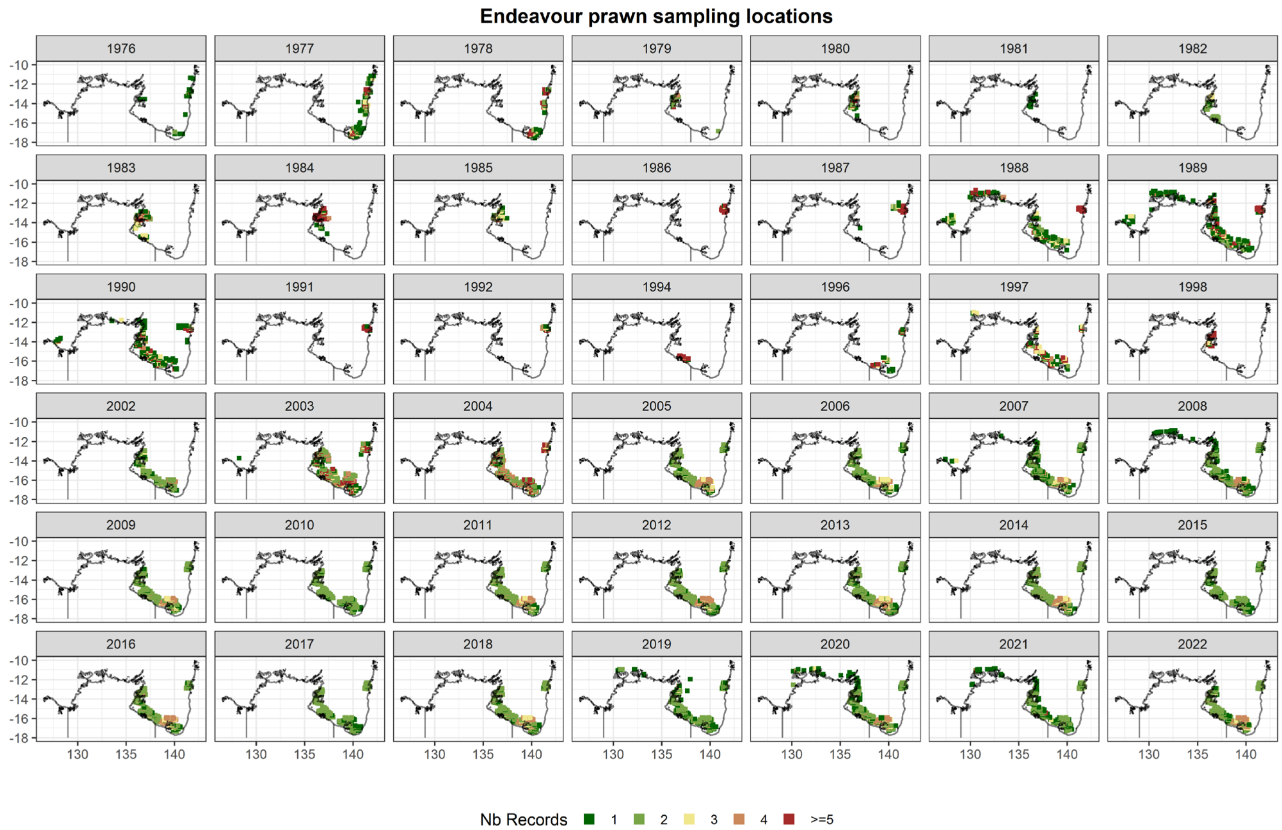


Figure 2b. The number of samples (annually) by location for endeavor prawns.

(a) Tiger prawns:

(b) Endeavour prawns:

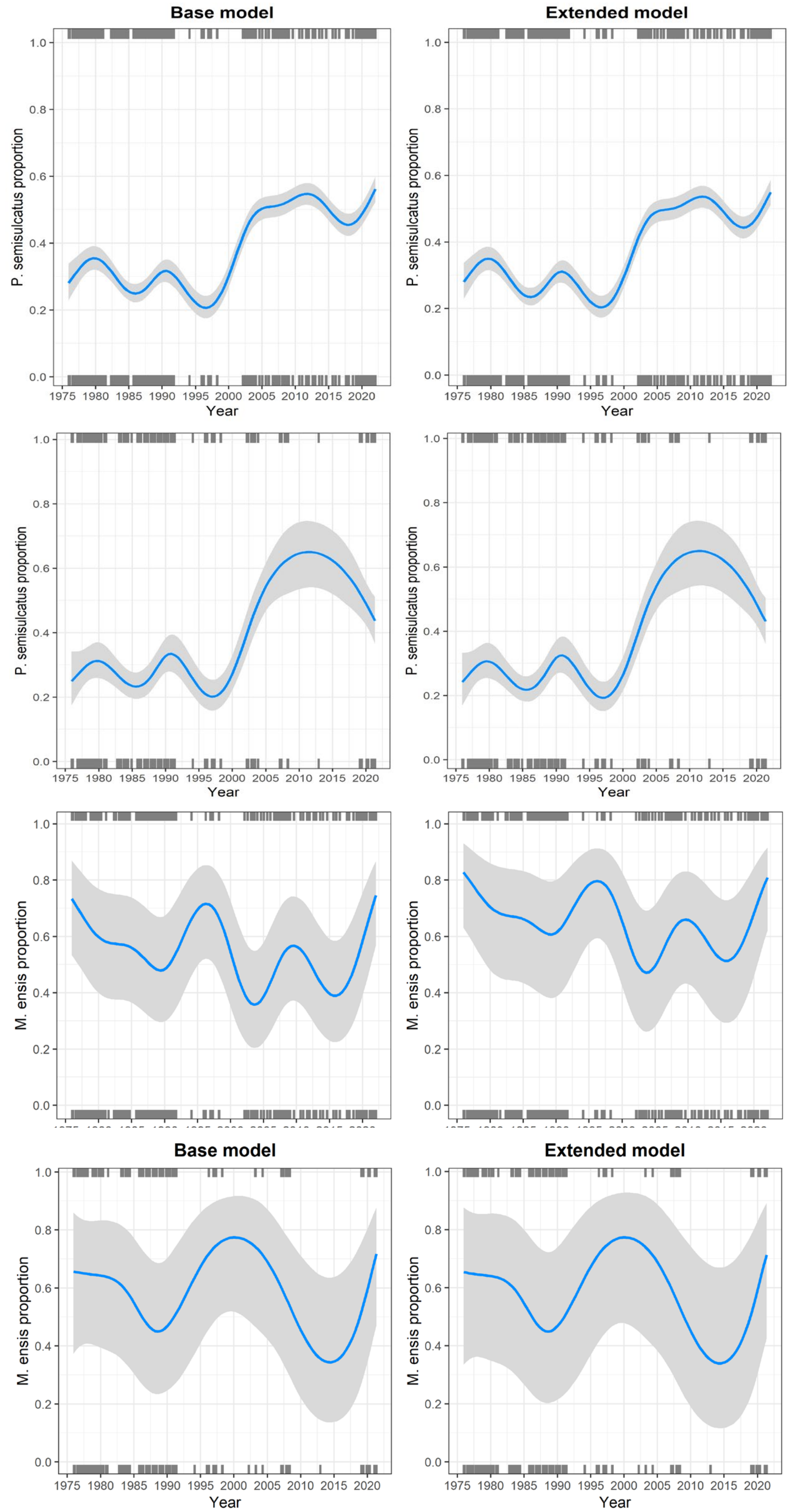


Figure 3. The long-term components for the four non-stationary models (left columns without the s(RDist) covariate, right column with this covariate; upper panels [by species group] full data set, lower panels restricted data set) for the tiger and endeavour prawns. The values for the covariates other than days (location and time of year) were set based on proportions in the stationary model that were about 50-50 to avoid predictions based on locations out of the range of the data.

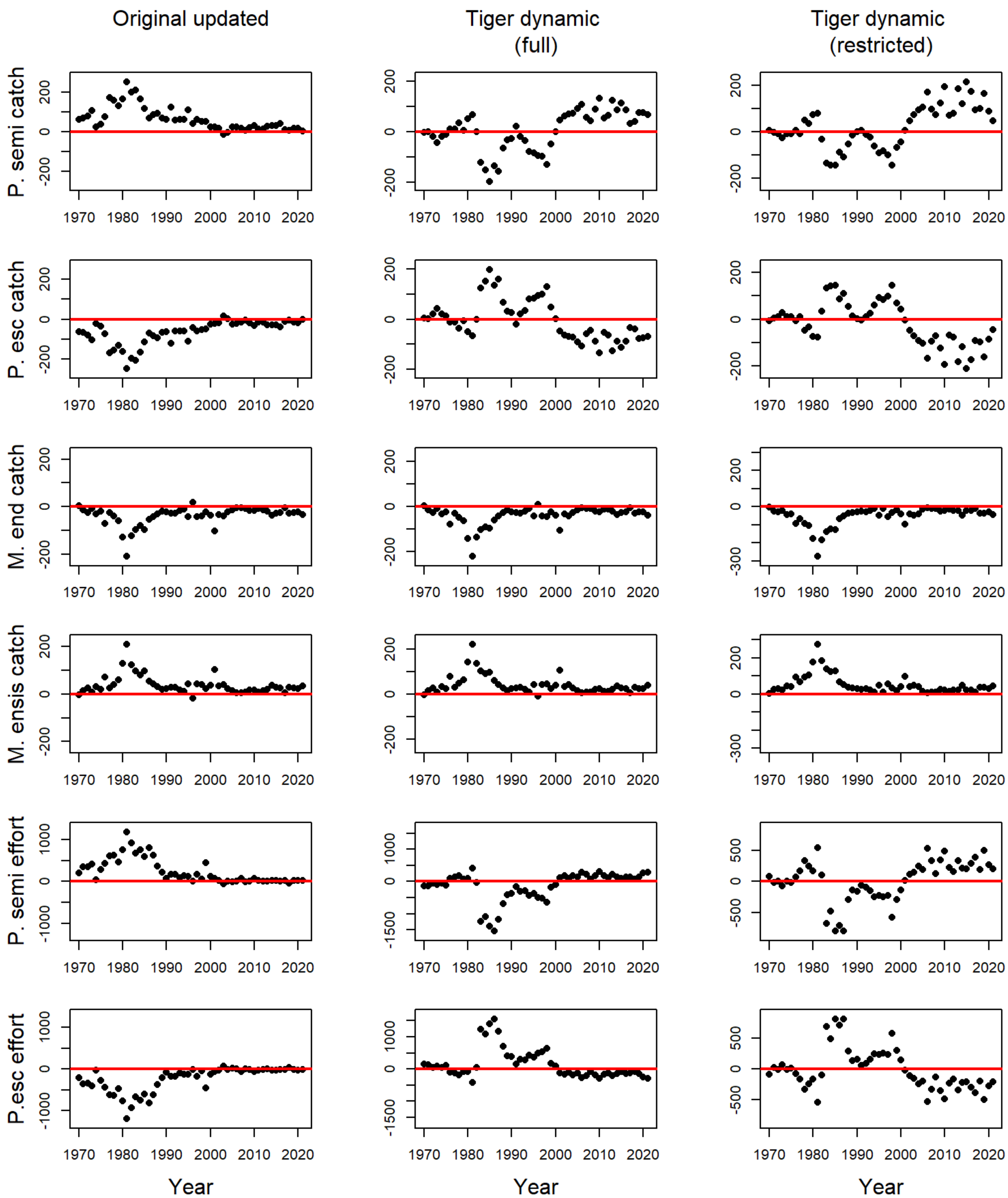


Figure 4a. The differences between the catch by species and effort by métier from the current species-split model and the selected alternative models by year.

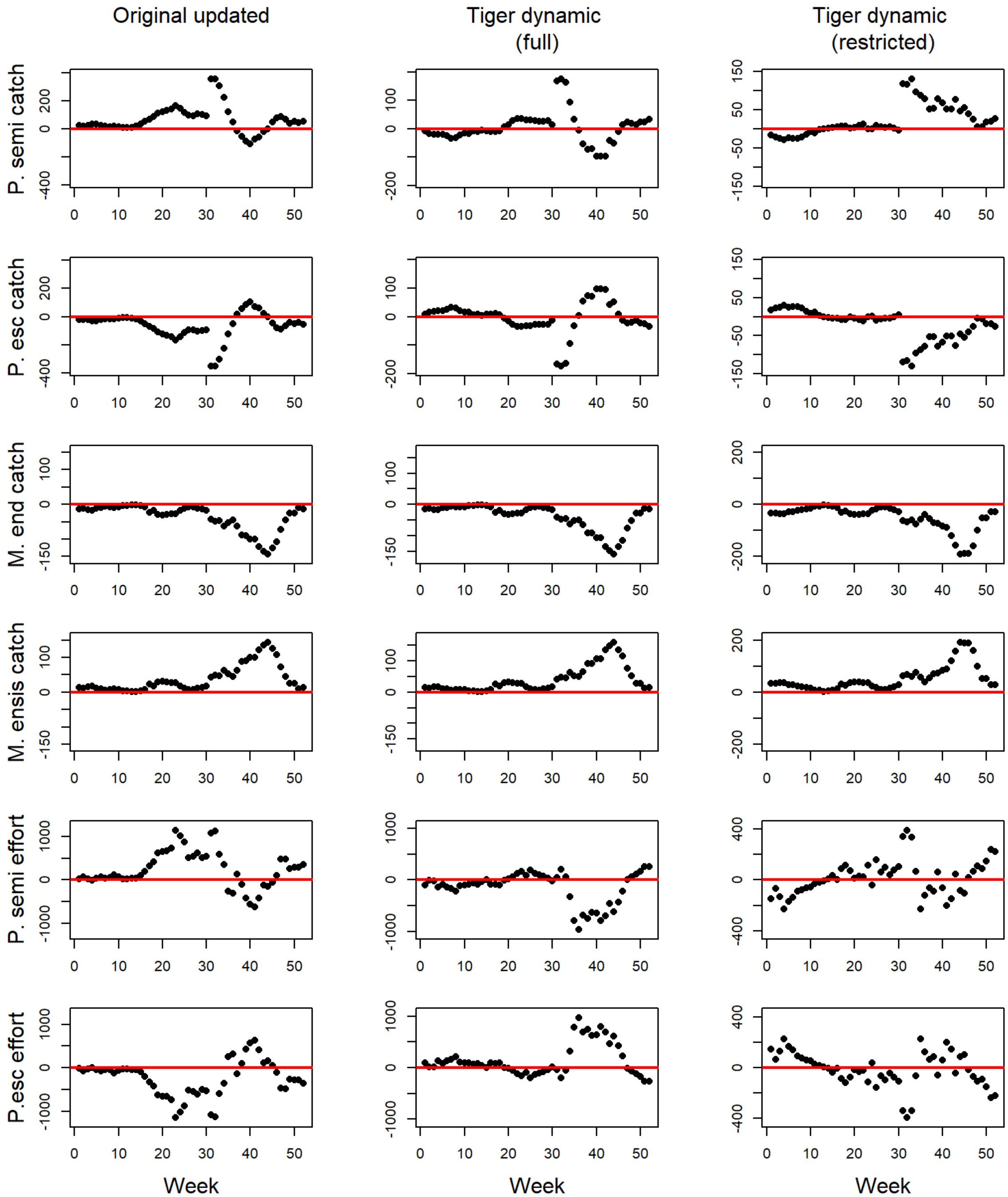


Figure 4b. The differences between the catch by species and effort by métier from the current species-split model and the selected alternative models by week.

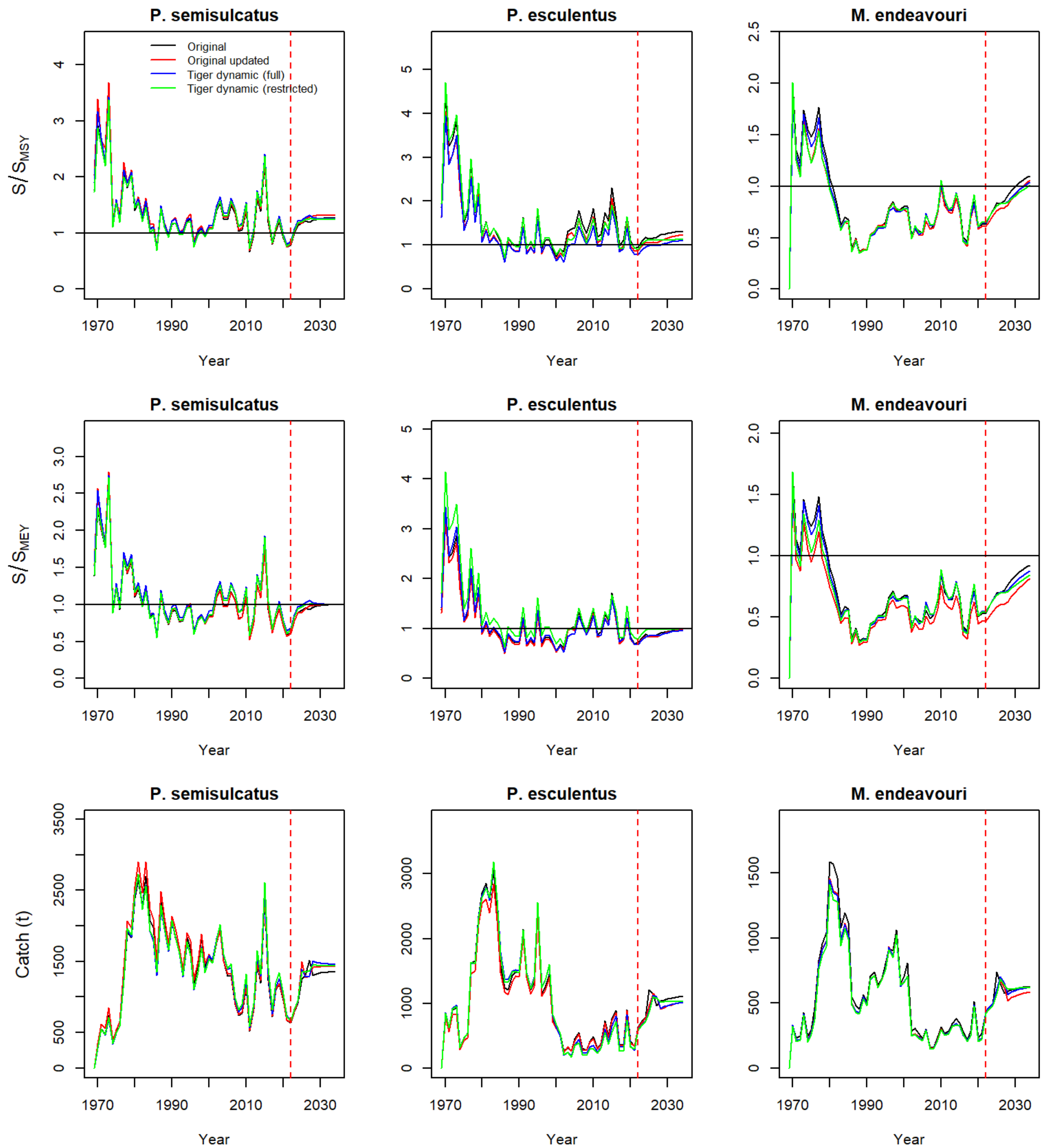


Figure 5. Time-series of spawning biomass indices relative to S_{MSY} and S_{MEY} (upper two rows of panels) and catch (third row of panels) for the various models for the historical period and forecasted using the bio-economic model. The vertical dotted indicates the first year of the projection period (2022).

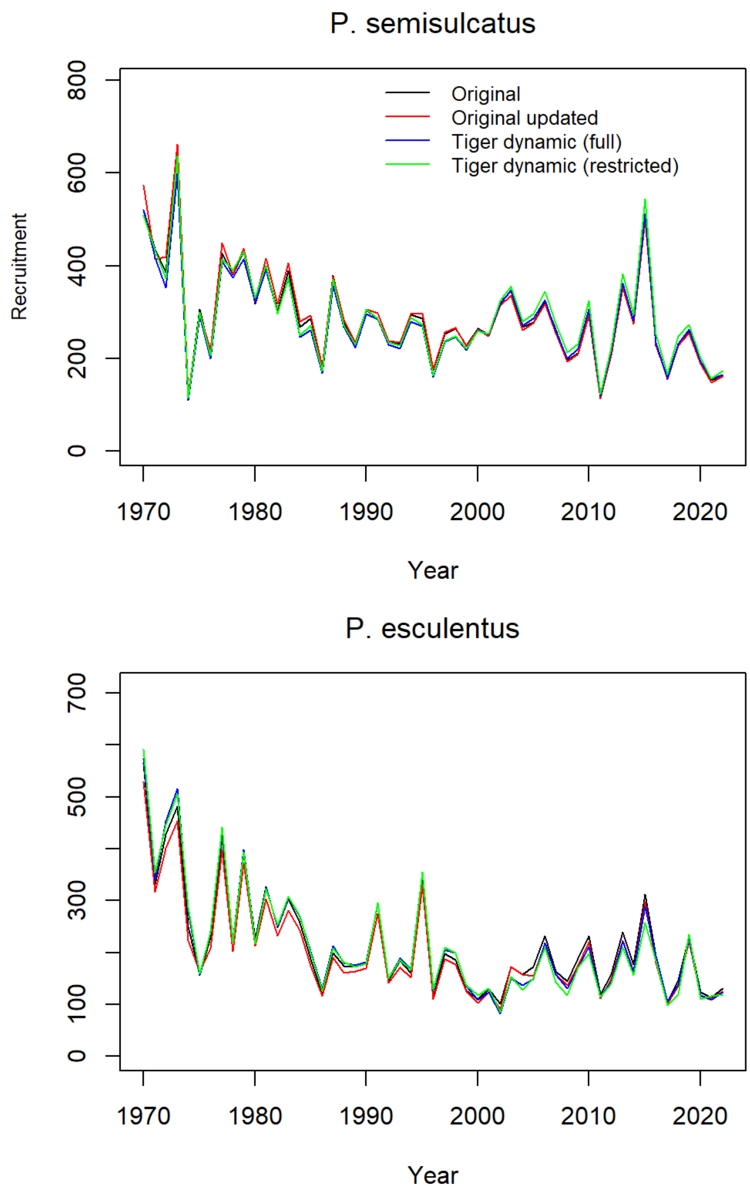


Figure 6. Time-series of recruitment for the various models.

Appendix A

Tiger and Endeavour Species Split Models

CSIRO

1 The available predictors

To build predictive models for the species proportions of Tiger and Endeavour prawn catches in the NPF the predictors we have available are mostly spatial or temporal. These include:

1. `Longitude` and `Latitude`, measured in degrees and treated as Cartesian coordinates, i.e. we do not transform to a projected coordinate system such as Easting and Northing.

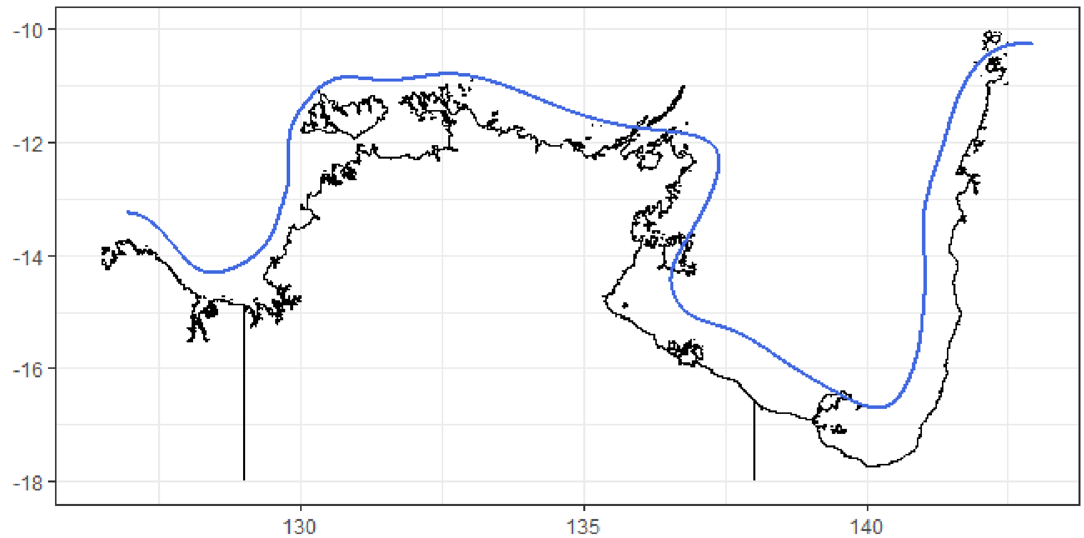
2. Two curvilinear spatial coordinates, termed `Rdist` and `Rland` for historical reasons. The first is measured by first locating the point on a curved line, (known as the “blue line”, see the diagram below), that traverses the NPF coastline approximately central to the main fishing areas. `Rdist` is then the arc length, in degree measure, along the blue line to the closest point from the western end.

   `Rland` is the distance, again in degree measure, from the fishing location to the nearest point on “dry land”, that is, to the coastline.

3. The depth of water at the recorded fishing location, named `Depth_av`, and the sediment composition of the sea floor, the percent mud, named `Mud_av`. Both are averages for the particular $6' \times 6'$ grid cell in which the point of fishing is located.

4. The main temporal predictor is `day_of_year`, the number of days since 1 January of the calendar year. The range is 0-365, but the full range is only achievable in leap years.

   For non-stationary models `days` is used for long-term trends. This is the number of days from 1970-01-01 to the recorded date of fishing.



The NPF coastline and the "blue line" defining the coastline distance predictor.

2 Tiger prawn models

The base model, as used in the previous species split project, was a *generalised additive model* (GAM) with a *quasi-binomial* family and a structure defined as follows.

- The response is *the proportion, by weight*, of grooved tigers, *Penaeus semisulcatus* in the (possibly) mixed catch of grooved and brown (*P. esculentus*) tiger prawns.
- The *total* weight of the tiger prawn catch in the calibrating dataset is used as a *relative* weight when fitting the model.
- The linear predictor for the model consists of the following terms,
  - A 2-d isotropic smooth term in `Longitude` and `Latitude` to capture purely spatial aspects,
  - A 2-d smooth tensor spline term in `Rland` and `day_of_year`, periodic in `day_of_year`, to capture aspects of the relative onshore/offshore differential annual migration patterns for the two species,
  - A 2-d smooth tensor spline term in `Depth_av` and `day_of_year`, periodic in `day_of_year`, to capture further aspects of the relative onshore/offshore differential annual behaviour patterns for the two species,
  - A 2-d smooth tensor spline term in `Rland` and `Depth_av` to capture further behavioural aspects of the two species,
  - A 1-d smooth term in `Mud_av` to capture known benthic type preferences for the two species.

This defines what we call the *stationary* model, in the sense that predictions are the same for all calendar years, (which is a natural requirement for a species split model to be used in the future).

To investigate this implicit assumption that proportions are stable between calendar years an extended model, which we call a *non-stationary* model was fitted with all of the terms in the stationary model together with:

- A 1-d smooth term in `days`, the elapsed time since 1970-01-01, in days.

The previous project found some evidence of an overall upward drift in proportions towards grooved tigers, especially in (then) recent years, and reported on it, but as it was only a small change it was decided that it could be ignored for practical purposes.

2.1 Fitting the stationary and non-stationary models

2.1.1 The stationary models

In this project we propose two versions of the stationary model.

1. The first has the same form as the generalised additive model used in the previous species distribution project.

2. The second is a slightly enhanced model which, in addition to the isotropic smooth term in `Longitude` and `Latitude`, it has a smooth term in distance along the coastline, i.e. the `Rdist` measure.

   A spline term of this form was used in the original species distribution project, but not in the second project.

We suggest that the additional spatial term in the second (alternative) model is included to allow greater sensitivity to unmeasured local coastal features of the fishery thus strengthening the predictive accuracy (hopefully!).

The R fitted model object for the first model is flagged `static` and for the second alternative model `stat_alt`.

```
Tiger_gam_static <- bam(psem/Total ~ s(Longitude, Latitude) +
                          te(day_of_year, Rland,    k = c(5, 5), bs = c("cc", "cs")) +
                          te(day_of_year, Depth_av, k = c(5, 5), bs = c("cc", "cs")) +
                          te(Rland,       Depth_av, k = c(5, 5), bs = c("cs", "cs")) +
                          s(Mud_av, k = 5),
                        family = quasibinomial(), data = Tigers_work,
                        knots = list(day_of_year = seq(0, 365, length = 5)),
                        # control = gam.control(trace = TRUE),
                        weights = Total/mean(Total))

Tiger_gam_stat_alt <- update(Tiger_gam_static, . ~ . + s(Rdist))
```

2.1.2 The non-stationary models

In order to check for long-term changes in species proportions we fit a non-stationary version of each of the previous models by including an extra smooth term in `days`, i.e. the number of days since 1970-01-01.

The counterparts to the static models are flagged by `dynamic` and `dyn_alt` respectively.

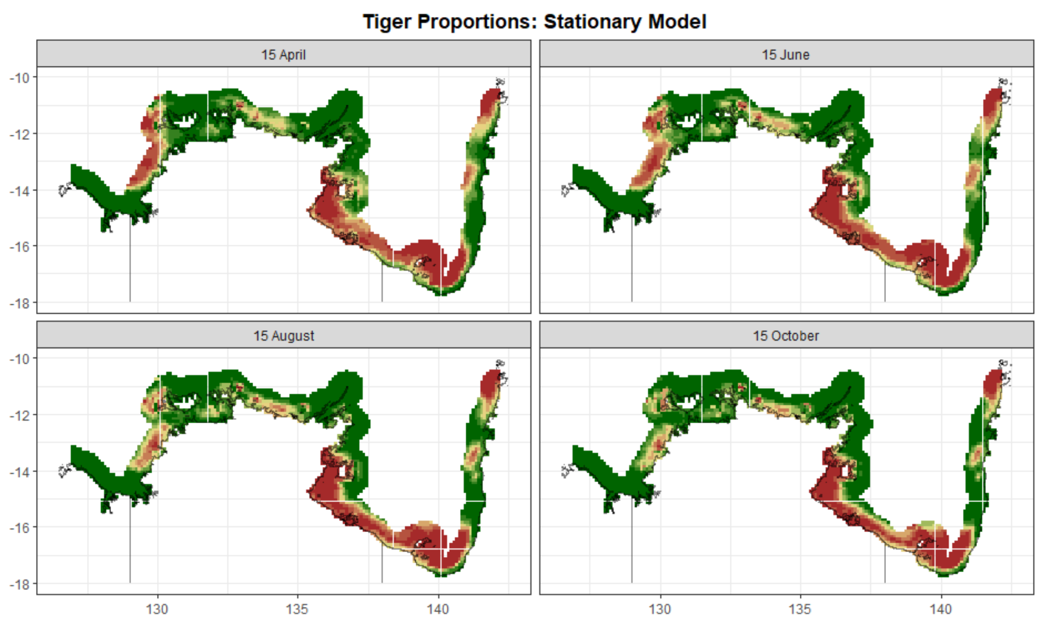
```
Tiger_gam_dynamic <- update(Tiger_gam_static, . ~ . + s(days))   ## add a long-term trend

Tiger_gam_dyn_alt <- update(Tiger_gam_stat_alt, . ~ . + s(days)) ## add a long-term trend
```

2.2 Some model outputs

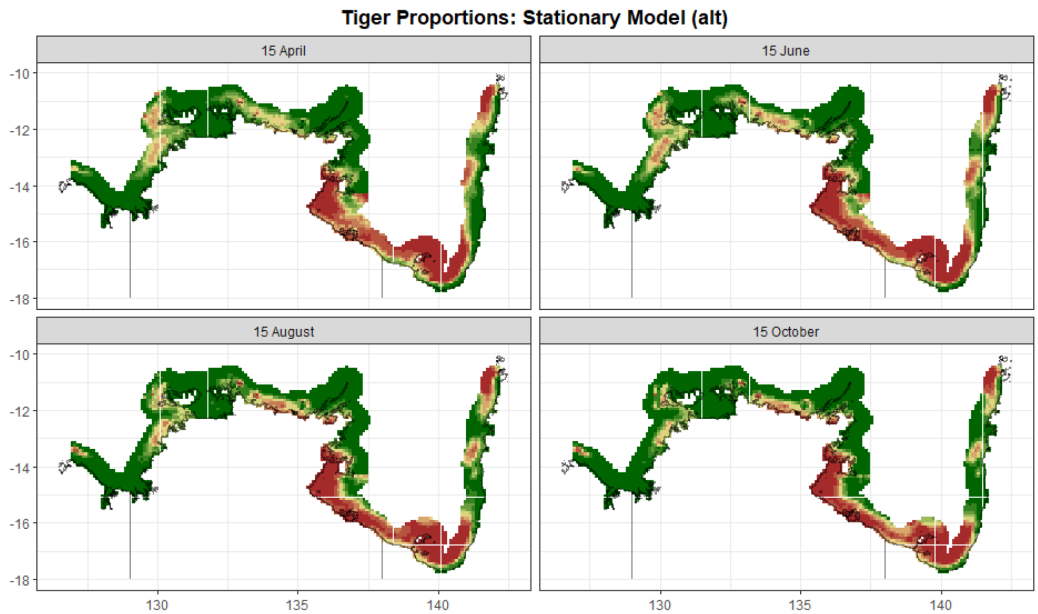
2.2.1 The stationary models

To see how the stationary models predict the species proportions we predict the proportions for a series of $6' \times 6'$ grid cell locations which together cover the majority of fished areas in the NPF. Since the models have a within-year temporal component, to show variation within the year these predictions are made at four time during the year, namely 15 April, (the "ides of April"), 15 June, 15 August and 15 October.

In the following diagrams the greener the colour the higher the proportion of grooved tigers and the browner the higher the proportion of brown tigers in the catch.



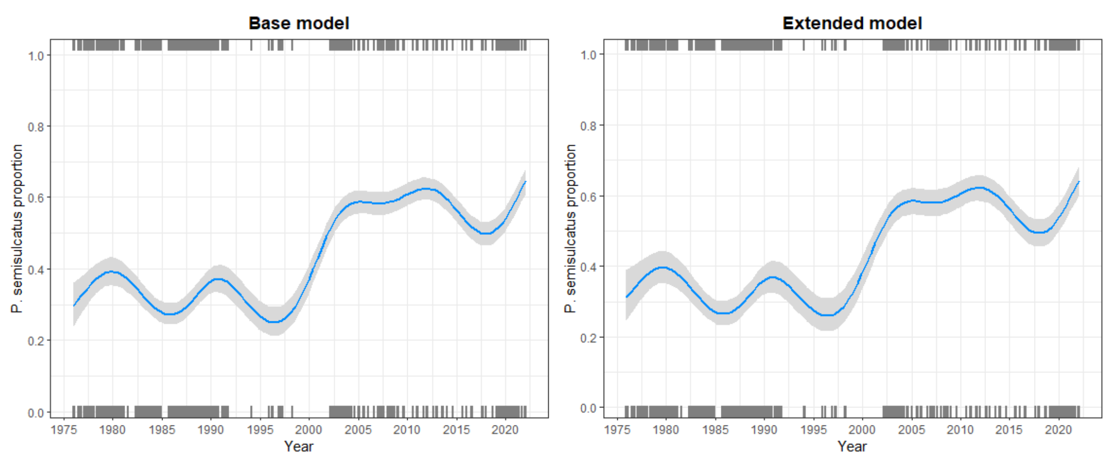
Predicted proportions for grooved (green) vs brown (brown) tiger prawns in a mixed catch



Predicted proportions for grooved (green) vs brown (brown) tiger prawns in a mixed catch using the alternative model.

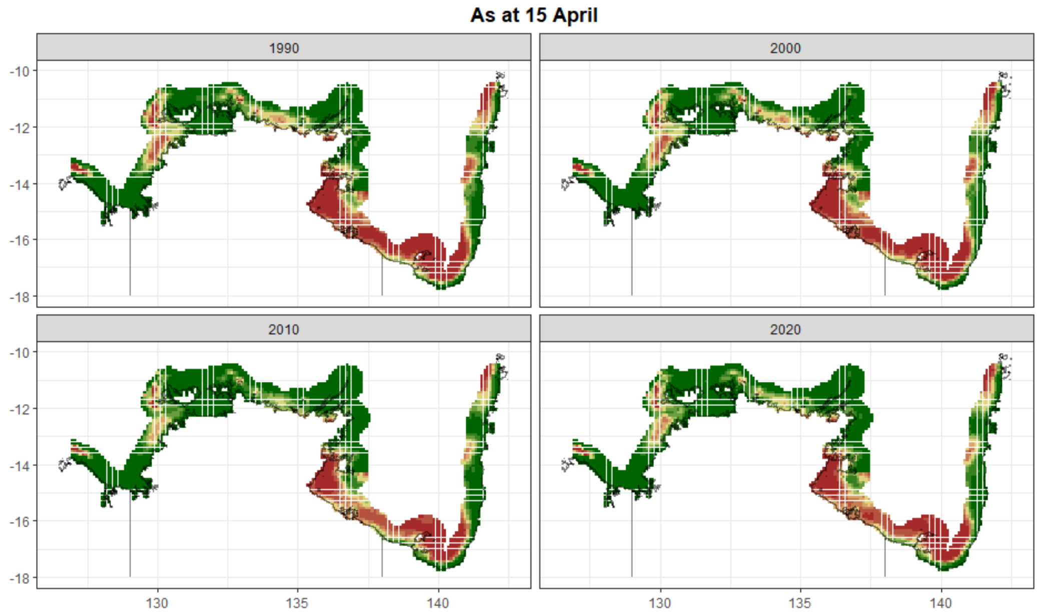
2.2.2 The non-stationary models

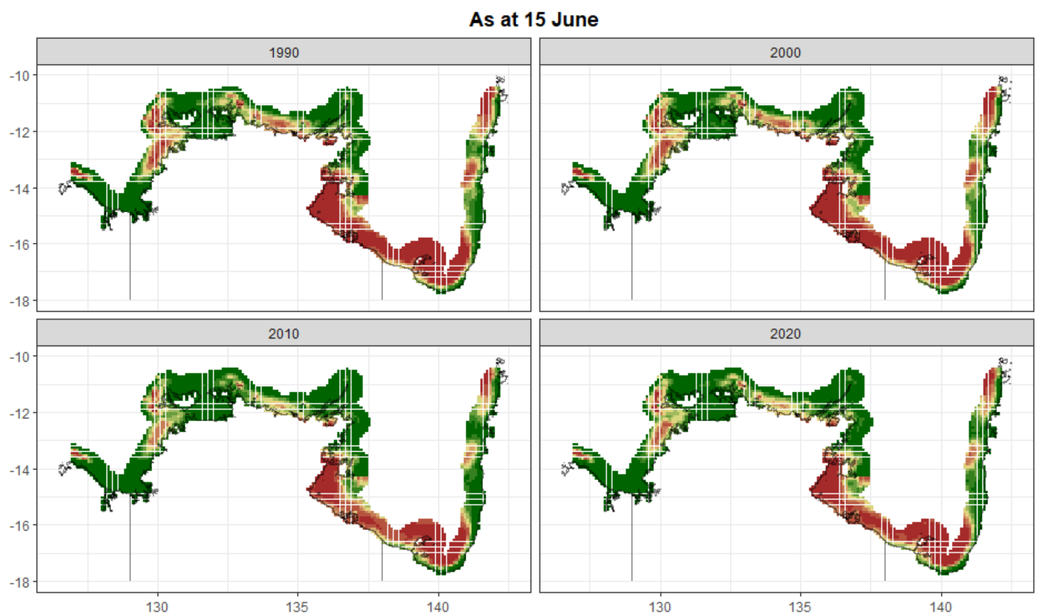
The following diagram shows the long-term trend components for the two "dynamic" models, namely the base model and the alternative. Note that the diagrams use the proportion scale, i.e. the scale of the response, and are predictions for a fixed set of values for the other predictors in the model. Hence only differences in proportions as the number of days progresses are relevant.



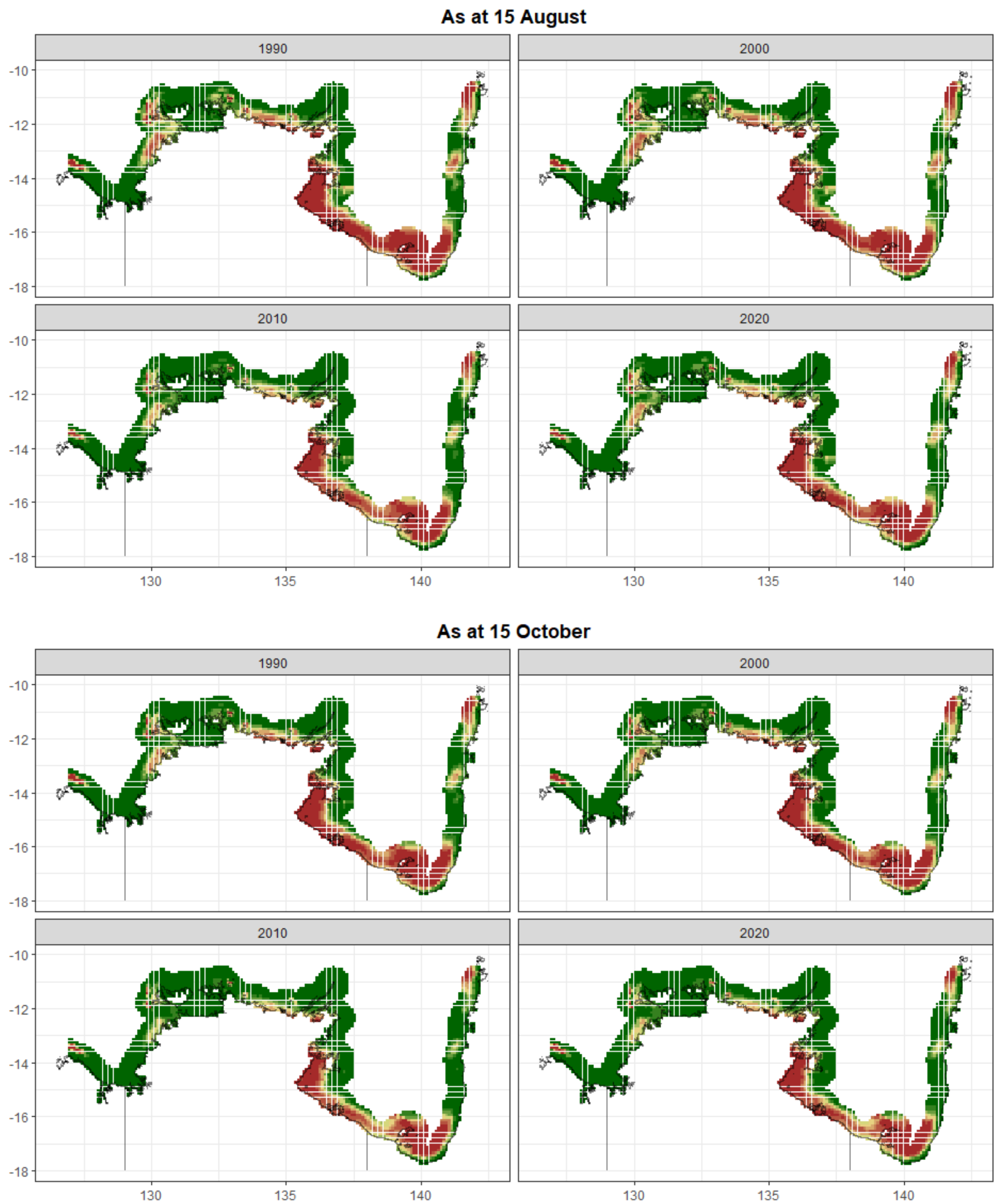
Long-term trend components for the two non-stationary models: the base model (left) and the alternative model (right)

To assess visually the implications for this apparent long-term trend we took four years spanning the latter part of the record, namely 1990, 2000, 2010 and 2020, and for each predicted the grooved tiger proportion for each of the “ides” dates as above. The diagrams below show these predictions for each year, for each of the four test dates. Note that only the extended (alternative) model is used as the components are very similar for both models.





Predicted proportions for grooved (green) vs brown (brown) tiger and the geographic distribution of their predicted changes over time on 15th April and 15th June across four decades.



Predicted proportions for grooved (green) vs brown (brown) tiger and the geographic distribution of their predicted changes over time on 15th August and 15th October across four decades.

3 Endeavour prawn models

The models used for Endeavour prawn species split follow the same model form as for Tiger prawns. We use the same base stationary model and propose an extension that includes an additional spatial predictor of a smooth term in `Rdist`.

- The response for the models is the *proportion of Red Endeavour prawns* (*Metapenaeus ensis*) in the (possibly) mixed catch. The complementary species is the Blue Endeavour prawn, *M. endeavouri*.

3.1 Species proportion stability

A striking model difference in Endeavour prawns compared to Tigers is that for Endeavours the non-stationary models were difficult to fit and results indicated very little evidence of any appreciable long-term trend. For this reason we only present results for the stationary models here.

3.2 Fitting the stationary models

As noted above, the two models are identical in structure to those used for Tigers and the model fitting steps are shown in the following code:

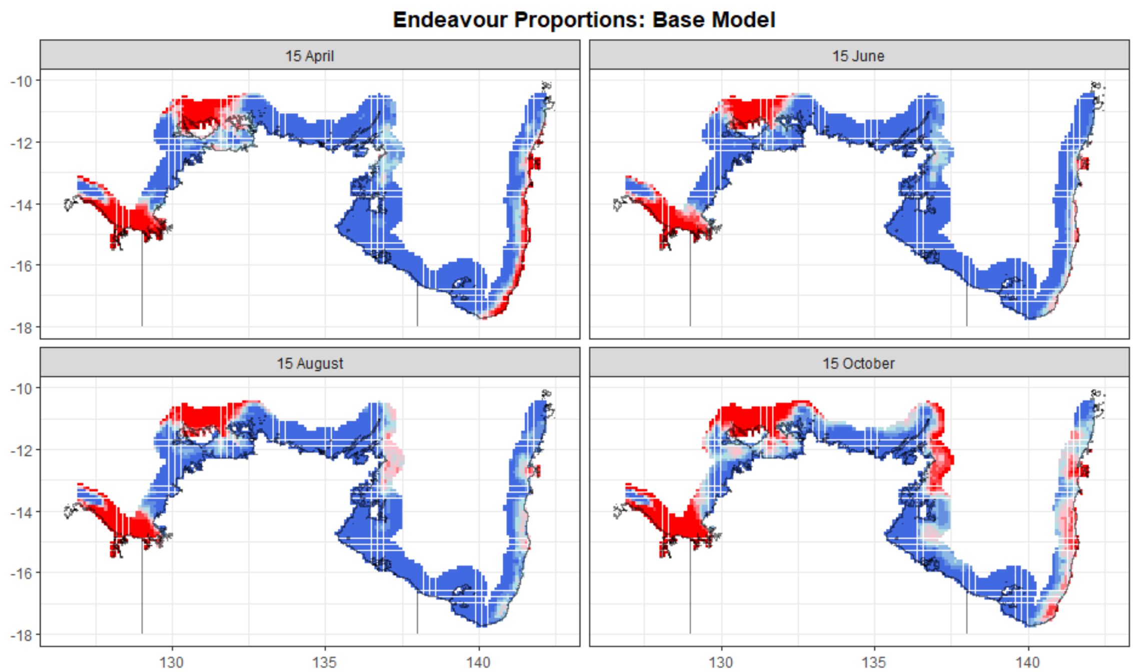
```
Endeavour_gam_static <- bam(mens/Total ~ s(Longitude, Latitude) +
                              te(day_of_year, Rland,    k = c(5, 5), bs = c("cc", "cs")) +
                              te(day_of_year, Depth_av, k = c(5, 5), bs = c("cc", "cs")) +
                              te(Rland,       Depth_av, k = c(5, 5), bs = c("cs", "cs")) +
                              s(Mud_av, k = 5),
                            family = quasibinomial(), data = Endeavours_work,
                            knots = list(day_of_year = seq(0, 365, length = 5)),
                            # control = gam.control(trace = TRUE),
                            weights = Total/mean(Total))                 ## base model

Endeavour_gam_stat_alt <- update(Endeavour_gam_static, . ~ . + s(Rdist))  ## extended model
```

3.3 Some model outputs

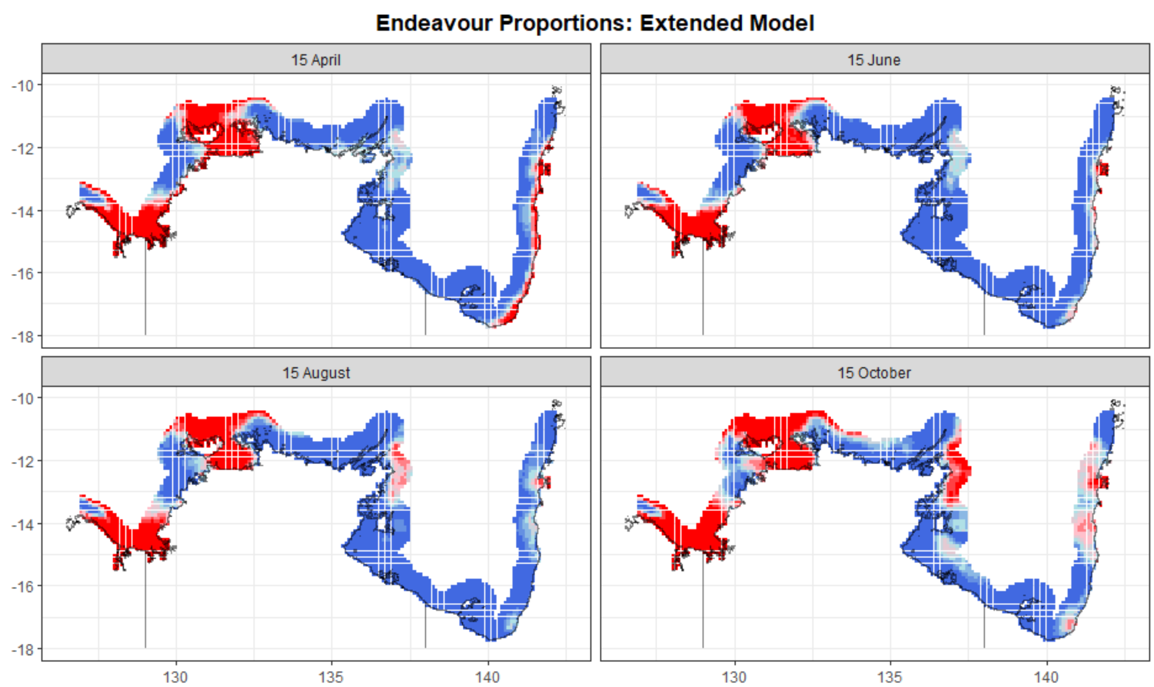
In this case the base and extended model show some appreciable differences in their predicted proportions, but mostly in regions of the fishery where data used to fit the models are sparse, as shown in the following Figures.

Note that there is also some evidence of a differential onshore/offshore within year migration pattern, similar to that for Tiger species.

The colour scheme is the obvious one: the more red the grid the higher the proportion of *M. ensis* and the more blue the higher the proportion of *M. endeavouri*.



Predicted proportions for red vs blue Endeavour prawns in a mixed catch using the base model

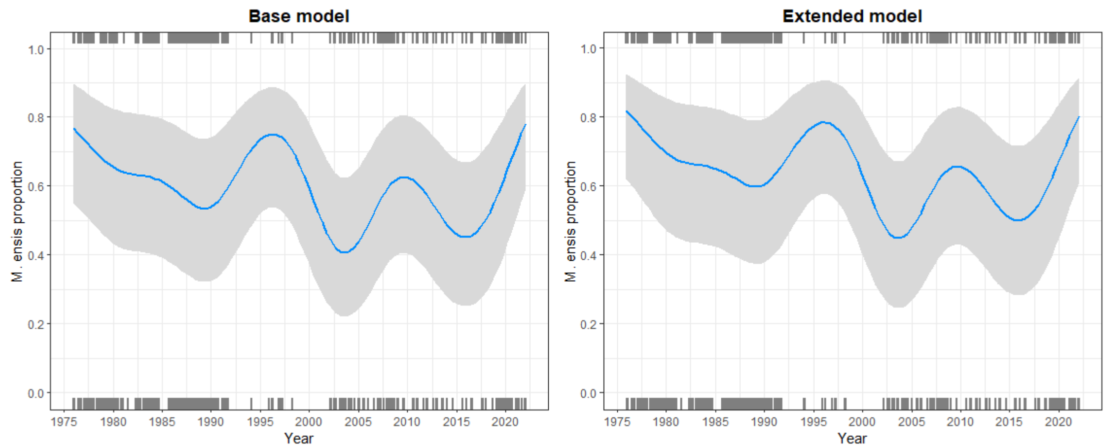


Predicted proportions for red vs blue Endeavour prawns in a mixed catch using the extended model

3.4 Dynamic models for Endeavours

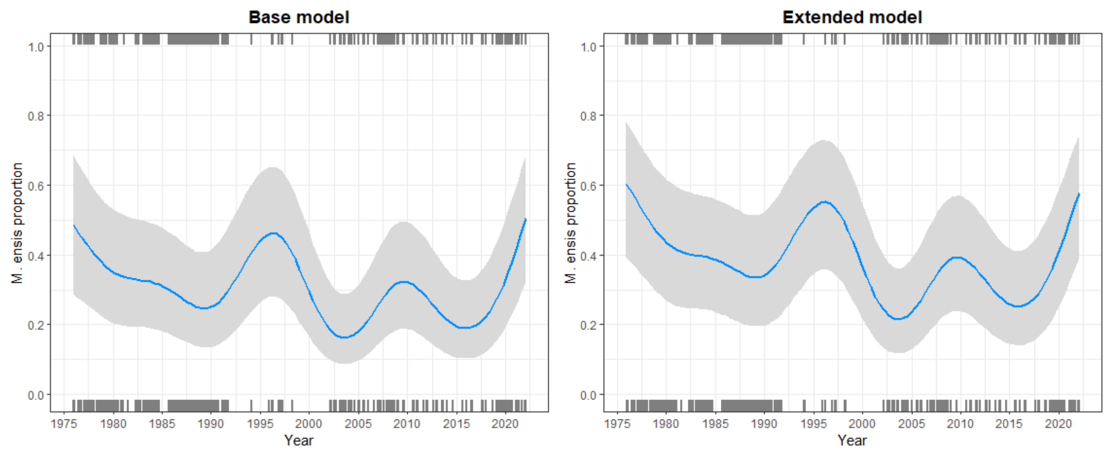
This section considers models that allow the proportion of *M. ensis* to vary over the history of the fishery in a similar way to that allowed by the dynamic models for Tiger prawns in previous sections.

We now look at the long-term trend line over time, again as before.



Long-term trend components for the two non-stationary Endeavour models: the base model (left) and the alternative model (right)

The large uncertainty associated with this trend line suggests strongly that any long-term trend in the proportions is essentially unknown. If we set the reference levels for the ancillary predictors so that the predicted trend line sits lower in the diagrams, the message is clearer.



Long-term trend components for the two non-stationary Endeavour models: the base model (left) and the alternative model (right). A second view.

Note that the period of highest volatility occurs at times when sampling effort, as indicated by the "rug" at the top and bottom of the panels, is weakest.

7. Thoughts on spatial models for the NPF

Thoughts on spatial models for the NPF

Introduction

Few stock assessments are fully spatially structured because there are often too few data to support estimation of the additional parameters. However, the number of spatial assessments is now increasing due to greater availability of integrated models, data and computational resources, and recognition that spatial models can reduce bias in assessments (Punt 2019a). Nonetheless, there are trade-offs in moving to a spatial stock assessment because of the additional number of parameters and assumptions. Although these models no longer assume a single homogeneous stock, this means additional assumptions are needed such as how to model recruitment, connectivity, movement and growth. Below we briefly summarise some considerations to inform whether or not, and how, to move to a spatial NPF model.

Why a spatial model

- The current assumption that a catch anywhere in the NPF affects the entire stock area equally is likely to be violated and catches are not likely to be proportional to biomass so that fishing intensity is not spatially homogeneous.
- The stock assessment model assumes that fishing strategies lead to bycatch mortality on "non-target" prawn species at the entire stock area resolution, but some regions have very low abundance of one or the other species (Dichmont et al. 2006).
- The survey data are only available for some areas (see Figure 1) but are assumed to relate to the entire stock area.
- The spatial resolution of the (historical) size-composition data are likely not representative of the entire stock area (but commercial size-composition will now be available for most putative stock areas).
- Biological data (growth increments, availability, fecundity) were collected from specific areas but are assumed to pertain to all areas – a spatial model will more effectively highlight data needs in this regard and the species split project will help inform spatial differences in some of these parameters.
- Environmental drivers of recruitment (and growth etc) are likely to be local in their impacts (as is also being explored in the MICE modelling).
- The bio-economic model is based on the concept of a day's fishing under the assumption that costs are independent of location.
- Best practice for stock assessment is to at least explore spatial structure and best practice guidelines have now been published and are being implemented (Punt 2019b).
- With spatial functionality it is possible to monitor if local depletion occurs. Anecdotal information from industry suggests that local depletion does occur in some areas.

Implementation details

- There will be a need to identify "stock areas" (some initial stock areas were defined for the MSE work: Dichmont et al. 2013; and MICE: Plagányi et al. 2022 – see accompanying Factsheet).
- Some stock areas will be data poor, necessitating sharing of some parameters via hierarchical priors (aka the current approach applied to blue and red endeavor prawns).
- The current size-structured stock assessment model fits to all data sources unlike the production model. It would desirable (essential) to fit to CPUE and survey index data, size-

Thoughts on spatial models for the NPF

Introduction

Few stock assessments are fully spatially structured because there are often too few data to support estimation of the additional parameters. However, the number of spatial assessments is now increasing due to greater availability of integrated models, data and computational resources, and recognition that spatial models can reduce bias in assessments (Punt 2019a). Nonetheless, there are trade-offs in moving to a spatial stock assessment because of the additional number of parameters and assumptions. Although these models no longer assume a single homogeneous stock, this means additional assumptions are needed such as how to model recruitment, connectivity, movement and growth. Below we briefly summarise some considerations to inform whether or not, and how, to move to a spatial NPF model.

Why a spatial model

- The current assumption that a catch anywhere in the NPF affects the entire stock area equally is likely to be violated and catches are not likely to be proportional to biomass so that fishing intensity is not spatially homogeneous.
- The stock assessment model assumes that fishing strategies lead to bycatch mortality on “non-target” prawn species at the entire stock area resolution, but some regions have very low abundance of one or the other species (Dichmont et al. 2006).
- The survey data are only available for some areas (see Figure 1) but are assumed to relate to the entire stock area.
- The spatial resolution of the (historical) size-composition data are likely not representative of the entire stock area (but commercial size-composition will now be available for most putative stock areas).
- Biological data (growth increments, availability, fecundity) were collected from specific areas but are assumed to pertain to all areas – a spatial model will more effectively highlight data needs in this regard and the species split project will help inform spatial differences in some of these parameters.
- Environmental drivers of recruitment (and growth etc) are likely to be local in their impacts (as is also being explored in the MICE modelling).
- The bio-economic model is based on the concept of a day’s fishing under the assumption that costs are independent of location.
- Best practice for stock assessment is to at least explore spatial structure and best practice guidelines have now been published and are being implemented (Punt 2019b).
- With spatial functionality it is possible to monitor if local depletion occurs. Anecdotal information from industry suggests that local depletion does occur in some areas.

Implementation details

- There will be a need to identify “stock areas” (some initial stock areas were defined for the MSE work: Dichmont et al. 2013; and MICE: Plagányi et al. 2022 – see accompanying Factsheet).
- Some stock areas will be data poor, necessitating sharing of some parameters via hierarchical priors (aka the current approach applied to blue and red endeavor prawns).
- The current size-structured stock assessment model fits to all data sources unlike the production model. It would desirable (essential) to fit to CPUE and survey index data, size-

composition data (fishery and surveys), and growth increment data which is not feasible using the production model but a multi-area size-structured model with a weekly time-step may/will be infeasible with multiple steps.

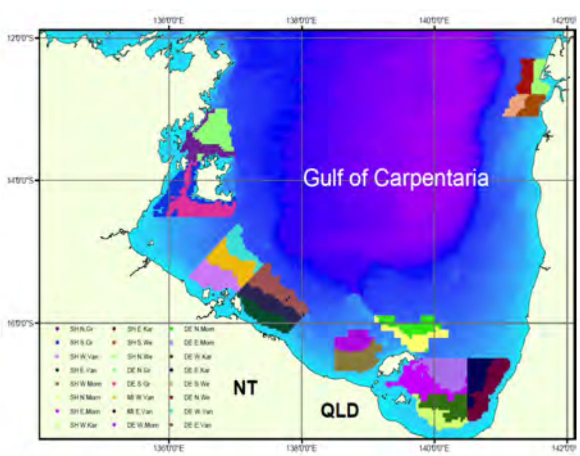
- A compromise modelling framework would be to use the delay-difference model and combine it with a model of growth (aka the Schnute models for the late 1980s and stock synthesis) to enable catch and survey size-compositions and growth increments to be predicted (the ‘extended’ delay-difference model). This would reduce the run time for a non-spatial model by an order of magnitude but has the advantage that (a) a spatial model can be implemented, and (b) there will be no (major) loss of data and output detail.
- A spatial stock assessment model will require that the bio-economic model be extended so that effort by area is estimated (this is already the case to some extent given the endeavor prawns are modelled spatially). Predicting the size-composition of the tiger prawn catch will remain important given prices differ by size. At present costs are assumed to be spatially homogeneous – a revised bio-economic model could have spatial variation in costs. However, location-specific costs will not be able to be estimated with the current data, but inclusion of expert opinion as a sensitivity analysis as to how these costs may change may be possible.

Possible alternatives/additions?

- Expand the number of fleets in the model from the current two to capture a greater range of spatially-influenced catch compositions. This “métier” approach is increasingly being applied in bioeconomic model to capture heterogeneity in catch usually associated with fishing area. This approach, however, will not address stock-related spatial issues.

Next steps (Short term)

- Clarify and document the spatial data for all of the data available for tiger and endeavor prawns (see accompanying Factsheet re survey data).
- Review information on “stock/spatial structure”.
- Compare the extended delay-difference model with the current non-spatial approach before implementing a spatial extended delay-difference model.



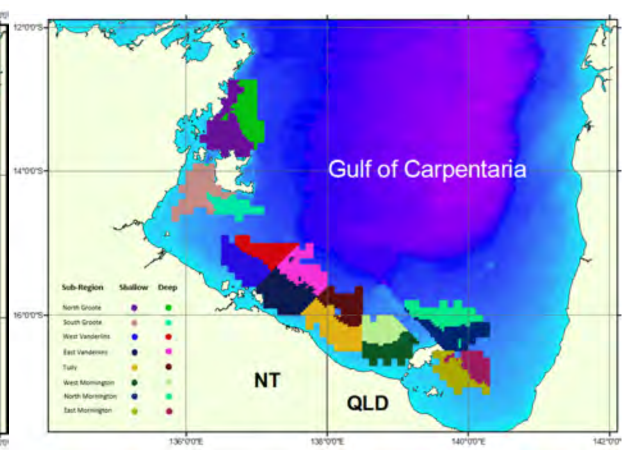


Figure 1: The five regions trawled during the February survey (left) and the three regions trawled during the July survey (right) spanning 20 years from 2002/03 to 2022 (adapted from Kenyon et al, 2021).

References

Dichmont, C.M., Deng, A.R., Punt, A.E., Venables, W. and Haddon, M., 2006. Management strategies for short-lived species: The case of Australia's Northern Prawn Fishery: 1. Accounting for multiple species, spatial structure and implementation uncertainty when evaluating risk. *Fisheries research*, *82*(1-3), pp.204-220.

Dichmont, C.M., Ellis, N., Bustamante, R.H., Deng, R., Tickell, S., Pascual, R., Lozano-Montes, H. and Griffiths, S., 2013. EDITOR'S CHOICE: Evaluating marine spatial closures with conflicting fisheries and conservation objectives. *Journal of Applied Ecology*, *50*(4), pp.1060-1070.

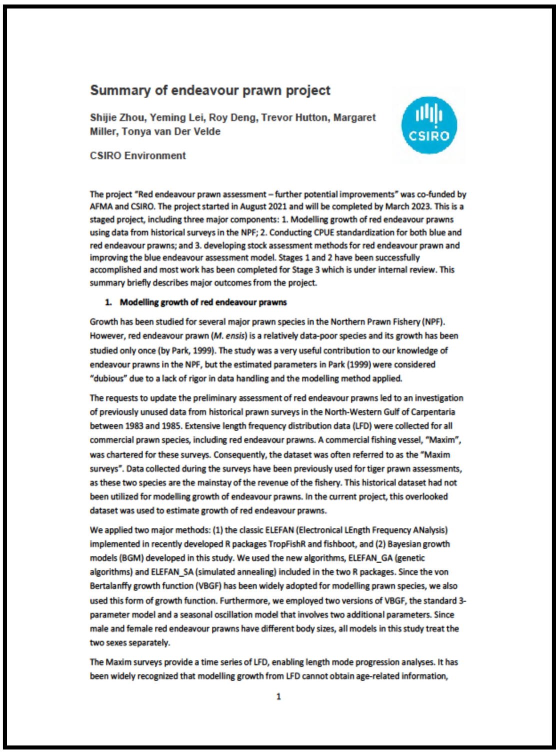
Kenyon, R.A., Deng, R., Donovan, A.G., van der Velde, T.D., Fry, G., Tonks, M., Moeseneder, M. and Salee, K., 2021. An integrated monitoring program for the Northern Prawn Fishery 2018–2021. AFMA 2017/0819 Final Report. CSIRO Oceans and Atmosphere, Brisbane. 221 pp.

Plagányi, É., Kenyon, R., Blamey, L., Burford, M., Robins, J.B., Jarrett, A., Laird, A., Hughes, J., Kim, S., Hutton, T. and Pillans, R., 2022. Ecological modelling of the impacts of water development in the Gulf of Carpentaria with particular reference to impacts on the Northern Prawn Fishery. FRDC Final Report

Punt, A.E., 2019a. Spatial stock assessment methods: a viewpoint on current issues and assumptions. *Fisheries Research*, *213*, pp.132-143.

Punt, A.E., 2019b. Modelling recruitment in a spatial context: a review of current approaches, simulation evaluation of options, and suggestions for best practices. *Fisheries* Research, 217, pp.140-155.

8. Summary of the endeavour prawn project



Summary of endeavour prawn project

Shijie Zhou, Yeming Lei, Roy Deng, Trevor Hutton, Margaret Miller, Tonya van Der Velde

CSIRO Environment

The project "Red endeavour prawn assessment – further potential improvements" was co-funded by AFMA and CSIRO. The project started in August 2021 and will be completed by March 2023. This is a staged project, including three major components: 1. Modelling growth of red endeavour prawns using data from historical surveys in the NPF; 2. Conducting CPUE standardization for both blue and red endeavour prawns; and 3. developing stock assessment methods for red endeavour prawn and improving the blue endeavour assessment model. Stages 1 and 2 have been successfully accomplished and most work has been completed for Stage 3 which is under internal review. This summary briefly describes major outcomes from the project.

1. Modelling growth of red endeavour prawns

Growth has been studied for several major prawn species in the Northern Prawn Fishery (NPF). However, red endeavour prawn (*M. ensis*) is a relatively data-poor species and its growth has been studied only once (by Park, 1999). The study was a very useful contribution to our knowledge of endeavour prawns in the NPF, but the estimated parameters in Park (1999) were considered "dubious" due to a lack of rigor in data handling and the modelling method applied.

The requests to update the preliminary assessment of red endeavour prawns led to an investigation of previously unused data from historical prawn surveys in the North-Western Gulf of Carpentaria between 1983 and 1985. Extensive length frequency distribution data (LFD) were collected for all commercial prawn species, including red endeavour prawns. A commercial fishing vessel, "Maxim", was chartered for these surveys. Consequently, the dataset was often referred to as the "Maxim surveys". Data collected during the surveys have been previously used for tiger prawn assessments, as these two species are the mainstay of the revenue of the fishery. This historical dataset had not been utilized for modelling growth of endeavour prawns. In the current project, this overlooked dataset was used to estimate growth of red endeavour prawns.

We applied two major methods: (1) the classic ELEFAN (Electronical LEngth Frequency ANalysis) implemented in recently developed R packages TropFishR and fishboot, and (2) Bayesian growth models (BGM) developed in this study. We used the new algorithms, ELEFAN_GA (genetic algorithms) and ELEFAN_SA (simulated annealing) included in the two R packages. Since the von Bertalanffy growth function (VBGF) has been widely adopted for modelling prawn species, we also used this form of growth function. Furthermore, we employed two versions of VBGF, the standard 3-parameter model and a seasonal oscillation model that involves two additional parameters. Since male and female red endeavour prawns have different body sizes, all models in this study treat the two sexes separately.

The Maxim surveys provide a time series of LFD, enabling length mode progression analyses. It has been widely recognized that modelling growth from LFD cannot obtain age-related information,

1

Summary of endeavour prawn project

Shijie Zhou, Yeming Lei, Roy Deng, Trevor Hutton, Margaret Miller, Tonya van Der Velde

CSIRO Environment

The project "Red endeavour prawn assessment – further potential improvements" was co-funded by AFMA and CSIRO. The project started in August 2021 and will be completed by March 2023. This is a staged project, including three major components: 1. Modelling growth of red endeavour prawns using data from historical surveys in the NPF; 2. Conducting CPUE standardization for both blue and red endeavour prawns; and 3. developing stock assessment methods for red endeavour prawn and improving the blue endeavour assessment model. Stages 1 and 2 have been successfully accomplished and most work has been completed for Stage 3 which is under internal review. This summary briefly describes major outcomes from the project.

1. Modelling growth of red endeavour prawns

Growth has been studied for several major prawn species in the Northern Prawn Fishery (NPF). However, red endeavour prawn (*M. ensis*) is a relatively data-poor species and its growth has been studied only once (by Park, 1999). The study was a very useful contribution to our knowledge of endeavour prawns in the NPF, but the estimated parameters in Park (1999) were considered "dubious" due to a lack of rigor in data handling and the modelling method applied.

The requests to update the preliminary assessment of red endeavour prawns led to an investigation of previously unused data from historical prawn surveys in the North-Western Gulf of Carpentaria between 1983 and 1985. Extensive length frequency distribution data (LFD) were collected for all commercial prawn species, including red endeavour prawns. A commercial fishing vessel, "Maxim", was chartered for these surveys. Consequently, the dataset was often referred to as the "Maxim surveys". Data collected during the surveys have been previously used for tiger prawn assessments, as these two species are the mainstay of the revenue of the fishery. This historical dataset had not been utilized for modelling growth of endeavour prawns. In the current project, this overlooked dataset was used to estimate growth of red endeavour prawns.

We applied two major methods: (1) the classic ELEFAN (Electronical LEngth Frequency ANalysis) implemented in recently developed R packages TropFishR and fishboot, and (2) Bayesian growth models (BGM) developed in this study. We used the new algorithms, ELEFAN_GA (genetic algorithms) and ELEFAN_SA (simulated annealing) included in the two R packages. Since the von Bertalanffy growth function (VBGF) has been widely adopted for modelling prawn species, we also used this form of growth function. Furthermore, we employed two versions of VBGF, the standard 3-parameter model and a seasonal oscillation model that involves two additional parameters. Since male and female red endeavour prawns have different body sizes, all models in this study treat the two sexes separately.

The Maxim surveys provide a time series of LFD, enabling length mode progression analyses. It has been widely recognized that modelling growth from LFD cannot obtain age-related information, including the theoretical age at length zero, t_0. This is because the time series of LFD includes survey timing but no actual age information. Our Bayesian growth model attempts to overcome this obstacle so that the model can estimate actual ages, including t_0. The main idea behind the BGM is to use LFD from multiple year-classes. We examined the performance of this new BGM using computer simulation. The results from the simulated synthetic LFD show that the BGM can produce reliable posteriors for VBGF parameters (including ages) when three cohorts are available. When only two cohorts are available (as is the case for red endeavour prawns), informative priors are needed for age-related parameters. However, it would be difficult to estimate ages when there is only one cohort. In all cases, the key growth parameters, the asymptotic length L_{inf} and the growth coefficient *K*, can be easily derived.

Our analysis involves a combination of 12 models: 3 methods (GA, SA, and BGM), two forms of VBGF (standard and seasonal), and two sexes. Interestingly, all models lead to comparable results for each sex. While there is some variation in results amongst the methods and growth functions, the estimates of the growth parameters are more consistent than studies for other prawn species. The seasonal oscillation models fit the LFD data better than the standard VBGF, but the differences in fit are not statistically significant. Recommendations regarding the use of growth parameters are made in the report and in the published paper.

In the discussion, the results were compared with existing studies on modelling growth of red endeavour prawns outside Australia and in the NPF. The current analysis is the most rigorous and reliable to date. Nevertheless, there are several weaknesses related to data quality and the amount of data. It would be useful for future studies to simultaneously model LFD data from multiple sources usinga hierarchical modelling framework.

Stage 1 resulted in one research report and one journal paper published in ICES Journal of Marine Science.

2. CPUE standardization for blue and red endeavour prawns

An abundance index is one of the most important types of data used in fisheries stock assessments and CPUE standardisation is an essential procedure to obtain a reliable abundance index. However, there has been no CPUE standardisation, nor fishing power analysis specifically for endeavour prawns in the NPF. The current stock assessment of endeavour prawns applies a fishing power time-series derived largely from tiger prawns to adjust nominal CPUE. This practice may lead to incorrect abundance indices because endeavour prawns differing spatially from tiger prawns and fishing efficiency improvement may differ between target and nontarget species.

In Stage 2, we applied eight alternative statistical models for CPUE standardisation. These models were composed of four generalized linear models (GLM)s and four generalized additive models (GAMs). These techniques assume two alternative statistical distributions: a delta-lognormal distribution and a Tweedie distribution. Moreover, two model structures are investigated: with or without including interaction terms for some predictor variables. A range of fishery and technology variables were explored for their potential inclusion as predictors and about 17 of those were finally adopted in these GLMs and GAMs.

The eight models were applied to the two species separately and to the two species combined as a group of endeavour prawns. Furthermore, the analyses were carried out at two spatial levels: treating the population in the whole NPF area as a single stock and modelling them at four sub-stock regions. Thirty-two models were investigated, resulting from the combination of different statistical models (eight), species/group (three), and regions (5). The statistical models were fitted to catch and effort data from the NPF logbooks between 1970 and 2020. These fitted models were then used for CPUE standardisation based on 1,645 grids of 0.1 by 0.1 degrees that have been fished by the tiger prawn fleet during the 51 years. The models utilize both positive and zero catch records, include the daily number of vessels as a predictor, and the predicted catch rates are based on the same grids every year. Hence, it is hoped that the analyses account for historical management changes that result in spatial and temporal closures and reduction in fleet size, eliminating the effect of changes in the spatial and temporal distribution of fishing effort and intensity.

Several statistics were employed for model evaluation and comparison, including the Akaike Information Criterion (AIC), deviance explained, mean squared error (MSE), and adjusted R^2. Comparing R^2 (between 0.39 and 0.44 from the GAMs) with those from tiger prawn analyses indicated that these models performed reasonably well (describe similar levels of variation within the data), given that endeavour prawns are non-target species. The results suggest that the estimated abundance index can be obtained from modelling the logbook data together with vessel information and can be used for stock assessments of endeavour prawns.

Among the eight statistical models, the generalized additive models that assumed a Tweedie distribution and included interaction terms generally performed best. When this GAM model was applied to the two species combined, and across the whole NPF area, the model described 45.8% of the total deviance and resulted in a MSE (in log-scale) of 0.423. However, the standardized CPUE trends were quite similar among alternative models. The trends of the standardized abundance index over time (SI_y) from alternative models are difficult to distinguish visually and the difference in the abundance index values is small (mean CV 0.046 for four GAMs over the 51 years). Therefore, it is not critical to determine the best model and using time series of abundance index estimated by any of the four GAMs would be appropriate. The time series of SI_y indicates that endeavour prawns were more abundant in the early years but less abundant in recent years based on the raw or nominal CPUE estimates. SI_y declined significantly before 1986 but slowly increased during the 1990s and since early 2000s has tended to be less variable. When the change in standardized CPUE is expressed as a change in relative fishing power FP_y, fishing efficiency on endeavour prawns has increased from $FP_{1970} = 1$ to $FP_{2020} = 2.96$ during the 51 years. The average annual creeping factor is $C\% = (2.96 – 1)/51 = 3.8\%$.

In addition to analysing the two species of endeavour prawns combined as a group, CPUE standardisation was also carried out for blue and red endeavour prawns separately. Interestingly, the temporal trends of SI_y were very similar among the two species and the group. Specifically, blue endeavour prawn and the combined group exhibited a nearly identical pattern. We hypothesised that the similar results were due to the fact that endeavour prawns were recorded as a group in the logbooks but split into two species using a statistical model afterwards. The proportion of one species in the group was fairly stable over time with blue endeavour prawn dominating. Hence, it was unnecessary to model two species independently. It was recommended that the results from the combined two species as a group be used in future stock assessments. It should be noted that this is inconsistent with the current application of CPUE standardization to tiger prawns where fishing power is estimated from the combined catches of two species of tiger prawns plus one half of endeavour prawn catches.

Standardizing CPUE at the sub-stock level was more challenging. When the catch data were divided into four endeavour prawn Stock Regions, low fishing effort in some regions and years reduced model stability and made model comparison difficult. The standardized CPUE trends were distinguishable among the four GAMs, particularly for Stock 1 and Stock 4. When stock assessment was conducted at multi-stock level (as in the current Bayesian hierarchical biomass production model used to assess blue endeavour prawns), stock-specific SI_y can be adopted; otherwise, the region-wide SI_y should be used.

The results from this study were indirectly validated through comparison with estimates for other species or from other fisheries. The changes in relative fishing efficiency gauged by the mean creeping factor could be compared across studies. A preliminary study using a Bayesian state-space depletion model estimated that relative fishing efficiency of the brown tiger prawn fleet on blue endeavour prawn in the NPF only increased 0.22 times between 1970 and 2005, equivalent to less than 1% per year increase during the 35 years. In the Queensland East Coast Trawl Fishery, fishing power for northern endeavour prawns increased by an average of 0.93% per year (13% increase from 1989 to 2003). For other species, mean annual creeping factors are 0.57%, 1.21%, 2.86%, and 0.35% for tiger prawn, red spot king prawn, east king prawn, and saucer scallop, respectively. Our estimated creeping factor of 3.8% for endeavour prawns was larger than the estimates in the Queensland East Coast Trawl Fishery, but close to the creeping factor for the white banana prawns in the NPF (3.88% per year from 1987 to 2011). Globally, most estimated creep factors were around 2–4%/yr, and our estimates was within this range. Independent estimates of changes to the fishing power for endeavour prawns would be complicated by reason of their being a bycatch species rather than a target. Estimating changes to the catching efficiency (or fishing power) of tiger prawn effort that succeeds in taking a bycatch species may be biased for reasons related more to the target tiger prawn fishery than the incidental catch of endeavour prawns in the areas where the distributions of the two types of prawn overlap.

3. Developing stock assessment methods for red endeavour prawn and improving blue endeavour assessment model

Endeavour prawns in the NPF are relatively data-poor compared to targeted grooved and brown tiger prawns. A lack of biological and fisheries data, for example, maturity at size, natural mortality, spawning patterns, availability, and catchability, prevented application of data-rich, shorter time step models to be applied to the endeavour prawns. Consequently, the existing blue endeavour prawn assessment adopts a biomass dynamics model (BDM, aka surplus production model) with an annual time step. Biomass dynamics models require less information and make fewer but stronger assumptions and avoid the need to estimate difficult parameters such as stock-recruitment relationship parameter such as steepness, annual and weekly recruitments, gear selectivity, spawning biomass, etc. We continued to apply the approach to assessing the blue endeavour prawns and adopted Bayesian BDM for both red and blue endeavour prawns. This stage work has been mostly completed and currently is under internal review.

9. Summary of spatial representation of NPF prawns in a tropical MICE

Summary of spatial representation of NPF prawns in a tropical MICE

Éva Plagányi, Roy Deng, Rob Kenyon and Laura Blamey

CSIRO

Introduction

Meaning of MICE (Models of Intermediate Complexity for Ecosystem assessments, (Plagányi et al., 2014): MICE are question-driven, focussed tactical ecosystem models that build on the earlier concept of Minimally Realistic Models (Punt & Butterworth, 1995) but focus on key species as well as key processes such as environmental, economic or human dimension drivers, and use statistical and other approaches to ensure the model is validated against data to the extent possible. MICE are data-driven and aim for the 'sweet spot' in terms of representing just the right amount of complexity to ensure results are robust (Collie et al., 2016). MICE share many features with single-species stock assessment models and therefore have great potential as tactical tools for fishery management (Goethel et al., 2022; Plagányi et al., 2022).

The Gulf of Carpentaria (GoC) MICE: was developed as part of a FRDC-funded project by CSIRO in conjunction with colleagues from Northern Prawn Fishery Industry (NPFI), Griffith University and Queensland Department of Agriculture and Fisheries to quantify the impacts and risks to the (GoC) ecosystem of water resource developments (WRD - anthropogenic alteration of freshwater discharge), applied in particular to the Mitchell, the Flinders and the Gilbert River catchments of northern Australia (Plaganyi et al., 2022). Key model species include common banana prawns, barramundi, mud crabs, largetooth sawfish as well as mangrove and seagrass habitats. Most recently, the MICE included both brown and grooved tiger prawn species *(Penaeus esculentus* and *P. semisulcatus)* but further work is required to refine links to environmental and/or habitat drivers (see https://www.frdc.com.au/sites/default/files/products/2018-079-DLD.pdf)

Fig. 1. Map showing the revised and extended spatial structure of the tropical MICE which now covers entire NPF

Ongoing development and extensions: to this model are being completed as part of a CSIRO Northern Australia Water Resource Assessment (NAWRA2) project, with the first phase focussed on the Roper River, and later phases focussed on a group of 'Southern Gulf' catchments and the Victoria River catchment. To cover the Top End and Joseph Bonaparte Gulf, the MICE has been extended from 8 spatial regions to 12 regions and hence the full extent of the NPF (Fig. 1). Future work will focus on in-depth modelling of grooved and brown tiger prawns, with preliminary modelling to be conducted for purposes of the NAWRA2 project, and planned work as described in an AFMA research proposal entitled: *Methods to account for climate impacts in fishery models and*

1

Summary of spatial representation of NPF prawns in a tropical MICE

Éva Plagányi, Roy Deng, Rob Kenyon and Laura Blamey

CSIRO

Introduction

Meaning of MICE (Models of Intermediate Complexity for Ecosystem assessments, (Plagányi et al., 2014): MICE are question-driven, focussed tactical ecosystem models that build on the earlier concept of Minimally Realistic Models (Punt & Butterworth, 1995) but focus on key species as well as key processes such as environmental, economic or human dimension drivers, and use statistical and other approaches to ensure the model is validated against data to the extent possible. MICE are data-driven and aim for the 'sweet spot' in terms of representing just the right amount of complexity to ensure results are robust (Collie et al., 2016). MICE share many features with single-species stock assessment models and therefore have great potential as tactical tools for fishery management (Goethel et al., 2022; Plagányi et al., 2022).

The Gulf of Carpentaria (GoC) MICE: was developed as part of a FRDC-funded project by CSIRO in conjunction with colleagues from Northern Prawn Fishery Industry (NPFI), Griffith University and Queensland Department of Agriculture and Fisheries to quantify the impacts and risks to the (GoC) ecosystem of water resource developments (WRD - anthropogenic alteration of freshwater discharge), applied in particular to the Mitchell, the Flinders and the Gilbert River catchments of northern Australia (Plaganyi et al., 2022). Key model species include common banana prawns, barramundi, mud crabs, largetooth sawfish as well as mangrove and seagrass habitats. Most recently, the MICE included both brown and grooved tiger prawn species *(Penaeus esculentus* and *P. semisulcatus)* but further work is required to refine links to environmental and/or habitat drivers (see https://www.frdc.com.au/sites/default/files/products/2018-079-DLD.pdf)

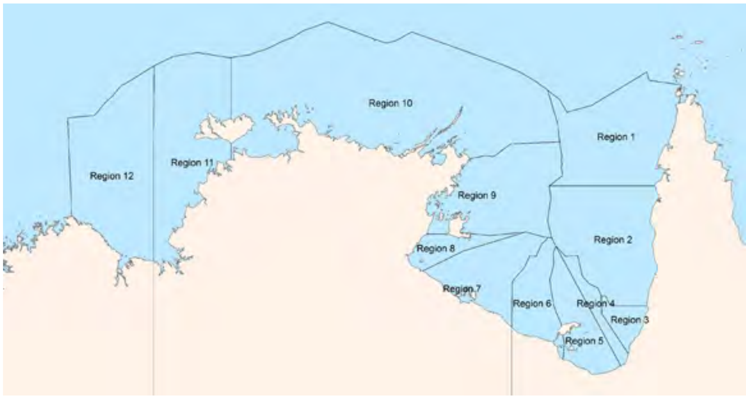


Fig. 1. Map showing the revised and extended spatial structure of the tropical MICE which now covers entire NPF

Ongoing development and extensions: to this model are being completed as part of a CSIRO Northern Australia Water Resource Assessment (NAWRA2) project, with the first phase focussed on the Roper River, and later phases focussed on a group of 'Southern Gulf' catchments and the Victoria River catchment. To cover the Top End and Joseph Bonaparte Gulf, the MICE has been extended from 8 spatial regions to 12 regions and hence the full extent of the NPF (Fig. 1). Future work will focus on in-depth modelling of grooved and brown tiger prawns, with preliminary modelling to be conducted for purposes of the NAWRA2 project, and planned work as described in an AFMA research proposal entitled: *Methods to account for climate impacts in fishery models and* *management: Case study example of environmental contributors that affect tiger prawn population dynamics.*

Summary of approach

The MICE models the population dynamics of prawn species (see e.g. Fig. 2) using a weekly time step from 1970 to current, and as either local populations in each spatial region or connected via a shared spawning biomass as well as regional combined influences of river flow. For common banana prawns, the model uses as inputs the observed fishing effort per spatial region plus the end-of-system flow from CSIRO river models. The model is then fitted to observed catch data, and Plagányi et al. (2022) demonstrated that a significantly improved fit to the data was obtained when explaining past catches was based on fishing effort and flow, as opposed to just fishing effort (see e.g. Fig. 3). In the same way, the model was able to test whether (hypothesis-driven) the inclusion of environmental drivers linked with population dynamics and fishery parameters was consistent with past data or significantly improved representation of variation in abundance. Hence MICE can test hypothesis-driven environmental relationships in a dynamic integrated model.

For brown and grooved tiger prawns, the model can validate – through fitting to weekly spatially-disaggregated data (see Fig.4) - the extent to which spatial, temporal and species-specific changes in population dynamics are attributable to a combination of environmental variables and fishing. Modelling of tiger prawn dynamics can draw on key information from past studies to investigate the temperature and salinity tolerance of tiger prawns and seagrasses (O'brien, 1994; O'Brien et al., 2018), larval advection inshore (Condie et al., 1999), effect of seagrass on recruitment (Kenyon et al., 1997; Loneragan et al., 1994; Loneragan et al., 1998), predation studies (Brewer et al., 1991; Haywood et al., 1998; Kenyon et al., 1995; Loneragan et al., 2001) and changes in timing of movement of adult grooved tiger prawns to aggregate on spawning grounds and for larvae to get back to settlement/nursery areas in seagrass based on changes in rainfall (Bishop et al., 2016). A schematic summary of some of the drivers and links identified as important to explore in the MICE is shown in Fig. 5.

As per accompanying Factsheet, the MICE has already collated and integrated a range of physical variables, spatially-disaggregated to the extent possible, including using as an input a comprehensive spatially-disaggregated timeline of cyclone impacts and intensity by Rob Kenyon.

Role of MICE to support science-based decision-making in the NPF

Below is a short summary of some of the ways the MICE could contribute to efforts to improve modelling focussed on NPF tiger prawns (potentially extrapolatable to endeavour prawns also):

- Modelling and visualising how the data and model-estimated population trajectories vary spatially and temporally by sub-fishery in response to alternative fishing strategies, environmental drivers etc
- Identifying any effect of coastal freshwater outflows and associated inshore salinity declines on tiger prawn recruitment to offshore habitats
- Quantifying the impacts of water extraction on the tiger prawn and the broader ecosystem as per the FRDC and NAWRA studies
- Rigorous framework to test alternative hypotheses such as relative roles of fishing, predation and environmental drivers influencing prawn and fishery dynamics
- Can help identify where more data are needed – i.e. help with prioritising costly fieldwork

- Model structure useful for exploring whether spatial structure makes a difference to the overall assessment of stock abduance and sustainable yields, as a first evaluation before developing a more detailed spatial assessment model
- Integrated model structure for whole of NPF may allow exploration of how different stocks eg. common banana prawns, redleg banana prawns and markets influence tiger prawn fishing strategies and vice versa
- Facilitates understanding and quantifying the impacts of climate change on tiger prawns and broader ecosystem
- Potential use as an operating model in a MSE (Management Strategy Evaluation)

References

Bishop, J., Ye, Y., & Milton, D. A. (2016). What are the effects of climate on the offshore and onshore movements of adult grooved tiger prawns Penaeus semisulcatus in tropical northern Australia? *Fisheries Oceanography, 25*(4), 349-361.

Brewer, D., Blaber, S., & Salini, J. (1991). Predation on penaeid prawns by fishes in Albatross Bay, Gulf of Carpentaria. *Marine Biology, 109*(2), 231-240.

Collie, J. S., Botsford, L. W., Hastings, A., Kaplan, I. C., Largier, J. L., Livingston, P. A., Plagányi, É., Rose, K. A., Wells, B. K., & Werner, F. E. (2016). Ecosystem models for fisheries management: finding the sweet spot. *Fish and Fisheries, 17*(1), 101-125. https://doi.org/https://doi.org/10.1111/faf.12093

Condie, S. A., Loneragan, N. R., & Die, D. J. (1999). Modelling the recruitment of tiger prawns Penaeus esculentus and P. semisulcatus to nursery grounds in the Gulf of Carpentaria, northern Australia: implications for assessing stock-recruitment relationships. *Marine Ecology Progress Series, 178*, 55-68.

Goethel, D. R., Omori, K. L., Punt, A. E., Lynch, P. D., Berger, A. M., de Moor, C. L., Plagányi, É. E., Cope, J. M., Dowling, N. A., & McGarvey, R. (2022). Oceans of plenty? Challenges, advancements, and future directions for the provision of evidence-based fisheries management advice. *Reviews in Fish Biology and Fisheries*, 1-36.

Haywood, M., Heales, D., Kenyon, R., Loneragan, N., & Vance, D. (1998). Predation of juvenile tiger prawns in a tropical Australian estuary. *Marine Ecology Progress Series, 162*, 201-214.

Kenyon, R., Loneragan, N., & Hughes, J. (1995). Habitat type and light affect sheltering behaviour of juvenile tiger prawns (Penaeus esculentus Haswell) and success rates of their fish predators. *Journal of Experimental Marine Biology and Ecology, 192*(1), 87-105.

Kenyon, R., Loneragan, N., Hughes, J., & Staples, D. (1997). Habitat Type Influences the Microhabitat Preference of Juvenile Tiger Prawns (Penaeus esculentusHaswell andPenaeus semisulcatusDe Haan). *Estuarine, Coastal and Shelf Science, 45*(3), 393-403.

Loneragan, N., Haywood, M., Heales, D., Kenyon, R., Pendrey, R., & Vance, D. (2001). Estimating the influence of prawn stocking density and seagrass type on the growth of juvenile tiger prawns (Penaeus semisulcatus): results from field experiments in small enclosures. *Marine Biology, 139*(2), 343-354.

Loneragan, N., Kenyon, R., Haywood, M., & Staples, D. (1994). Population dynamics of juvenile tiger prawns (Penaeus esculentus and P. semisulcatus) in seagrass habitats of the western Gulf of Carpentaria, Australia. *Marine Biology, 119*(1), 133-143.

Loneragan, N., Kenyon, R., Staples, D., Poiner, I., & Conacher, C. (1998). The influence of seagrass type on the distribution and abundance of postlarval and juvenile tiger prawns (Penaeus esculentus and P. semisulcatus) in the western Gulf of Carpentaria, Australia. *Journal of Experimental Marine Biology and Ecology, 228*(2), 175-195.

O'brien, C. (1994). The effects of temperature and salinity on growth and survival of juvenile tiger prawns Penaeus esculentus (Haswell). *Journal of Experimental Marine Biology and Ecology, 183*(1), 133-145.

O’Brien, K. R., Adams, M. P., Ferguson, A. J., Samper-Villarreal, J., Maxwell, P. S., Baird, M. E., & Collier, C. (2018). Seagrass resistance to light deprivation: implications for resilience. In *Seagrasses of Australia* (pp. 287-311). Springer.

Plaganyi, E., Kenyon, R., Blamey, L., Burford, M., Robins, J., Jarrett, A., Laird, A., Hughes, J., Kim, S., Hutton, T., Pillans, R., Deng, R., Cannard, T., Lawrence, E., Miller, M., & Moeseneder, C. (2022). Ecological modelling of the impacts of water development in the Gulf of Carpentaria with particular reference to impacts on the Northern Prawn Fishery. Final Report to FRDC, Canberra, March 2022, 611 pp, CC BY 3.0.

Plagányi, É. E., Blamey, L. K., Rogers, J. G., & Tulloch, V. J. (2022). Playing the detective: Using multispecies approaches to estimate natural mortality rates. *Fisheries Research, 249*, 106229. https://doi.org/https://doi.org/10.1016/j.fishres.2022.106229

Plagányi, É. E., Punt, A. E., Hillary, R., Morello, E. B., Thébaud, O., Hutton, T., Pillans, R. D., Thorson, J. T., Fulton, E. A., & Smith, A. D. (2014). Multispecies fisheries management and conservation: tactical applications using models of intermediate complexity. *Fish and Fisheries, 15*(1), 1-22. https://doi.org/https://doi.org/10.1111/j.1467-2979.2012.00488.x

Punt, A. E., & Butterworth, D. S. (1995). The effects of future consumption by the Cape fur seal on catches and catch rates of the Cape hakes. 4. Modelling the biological interaction between Cape fur seals Arctocephalus pusillus pusillus and the Cape hakes Merluccius capensis and M. paradoxus. *South African Journal of Marine Science/Suid-Afrikaanse Tydskrif vir Seewetenskap, 16*, 255-285.

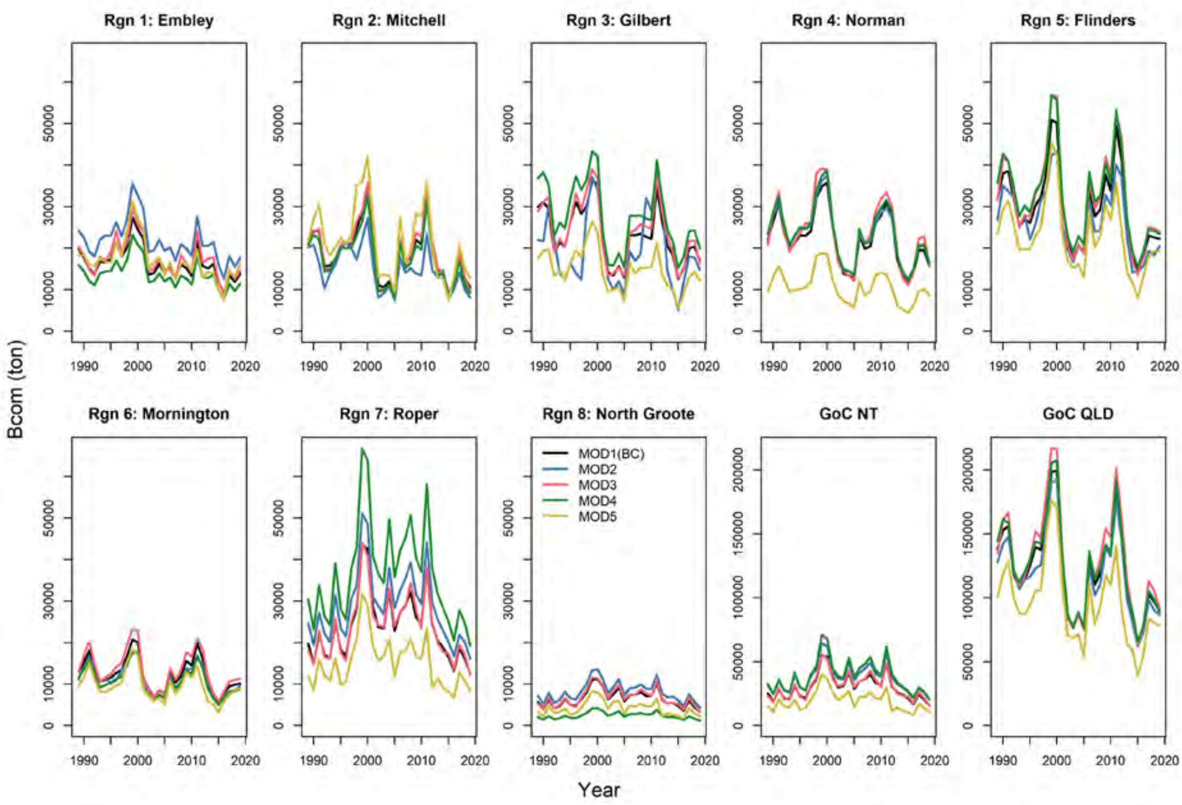


Figure 2. MICE ensemble outputs shown for the five alternative model configurations used to represent common banana prawns. Trajectories show the model-estimated commercially available biomass (Bcom) in units of tonnes shown from 1989 to 2019, for the different model regions and jurisdictions as indicated. See Plagányi et al. (2022) for details.

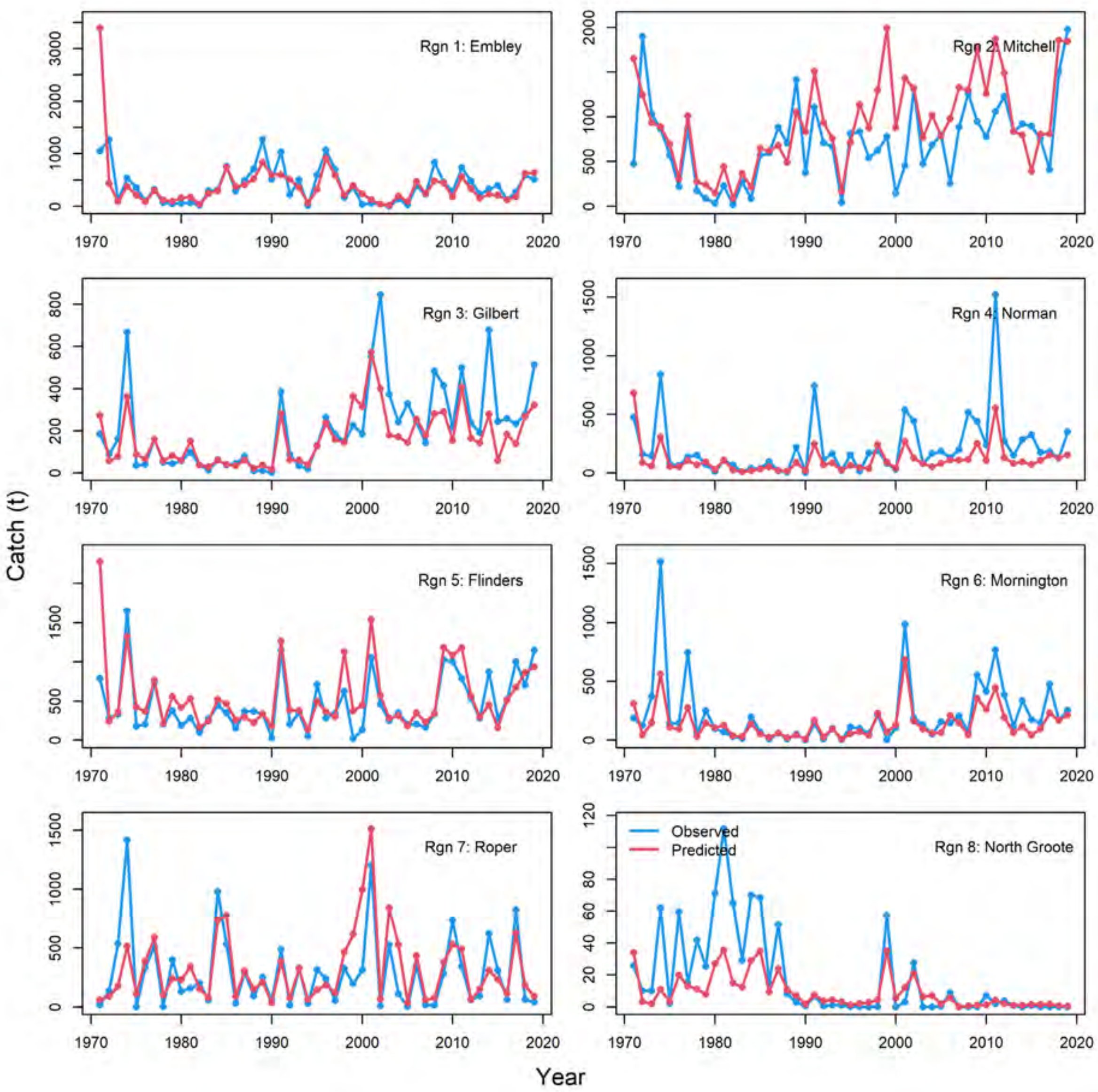


Figure 3. Comparison of the observed and model-predicted annual common banana prawn catch (tonnes) estimated using Model version 5 (driven by baseline flows, prawn survival linked with lagged overall index of primary productivity) and for each of the eight model regions as shown. See Plagányi et al. (2022) for details.

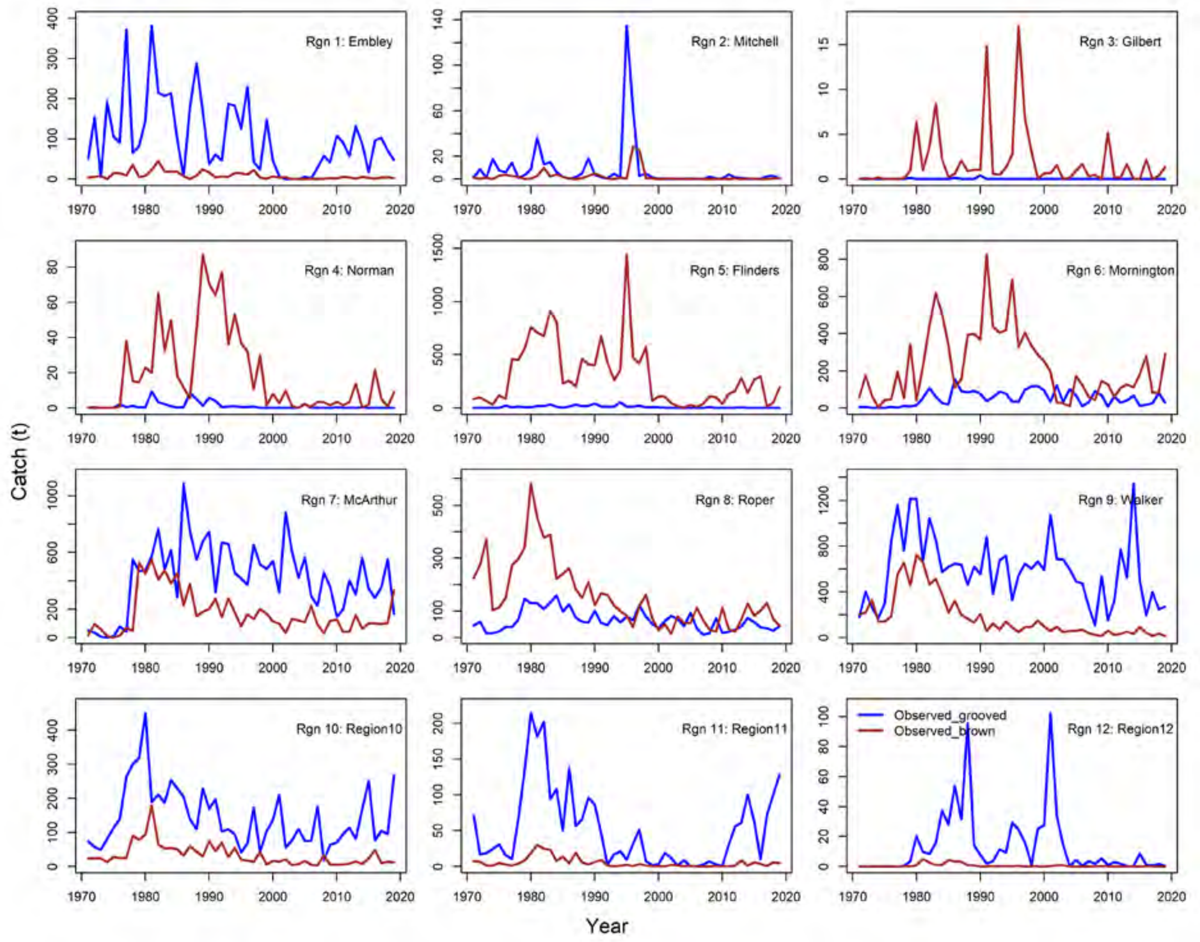


Figure 4. MICE spatial structure showing the observed total annual catches (t) from 1970 to 2019 for grooved (blue lines) and brown (brown lines) tiger prawns in each of the 12 model regions.

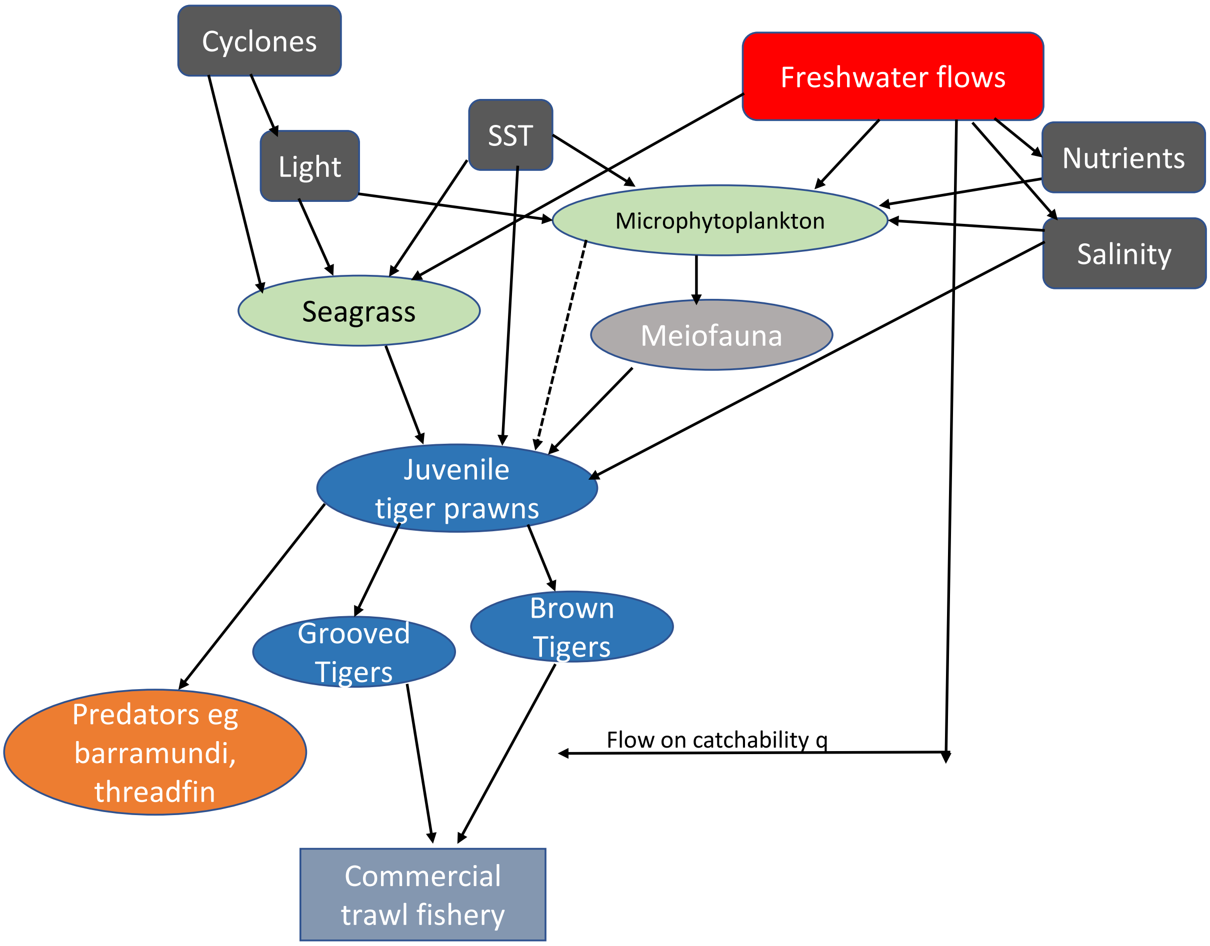


Figure 5. Schematic summary of tropical MICE components and key linkages related to tiger prawns to be explored as part of ongoing modelling.

10. Environmental variables summary to inform strategic planning under climate change for the tiger prawn fishery

Environmental variables summary to inform strategic planning under climate change for the tiger prawn fishery

Laura Blamey, Éva Plagányi, Rob Kenyon, Roy Deng

CSIRO

Summary

Environmental drivers have been identified as influencing the variability of several key resources across northern Australia including common banana prawns, redleg banana prawns, barramundi, and mud crabs. Comparatively little is known regarding the role of the environment in explaining variability of tiger prawns. Data for a variety of environmental variables exist for the Gulf of Carpentaria and have been collated by CSIRO as part of ongoing research (Fig. 1; Table 1). These include river flow, sea level, sea surface temperature (SST), air temperature, solar exposure, the Southern Oscillation Index (SOI) and a Cyclone Index. Similar data have also been collated for the Top End and Joseph Bonaparte Gulf. Understanding how environmental variables influence fisheries is particularly important to inform how to future proof stock assessments and harvest strategies under climate change. A first step involves summarising key trends in a Report card as per Appendix A.

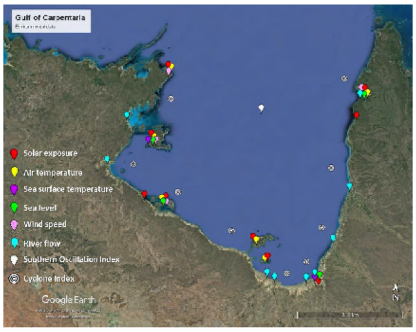


Fig. 1: Spatial overview of various environmental data available for the Gulf of Carpentaria

Environmental variables summary to inform strategic planning under climate change for the tiger prawn fishery

Laura Blamey, Éva Plagányi, Rob Kenyon, Roy Deng

CSIRO

Summary

Environmental drivers have been identified as influencing the variability of several key resources across northern Australia including common banana prawns, redleg banana prawns, barramundi, and mud crabs. Comparatively little is known regarding the role of the environment in explaining variability of tiger prawns. Data for a variety of environmental variables exist for the Gulf of Carpentaria and have been collated by CSIRO as part of ongoing research (Fig. 1; Table 1). These include river flow, sea level, sea surface temperature (SST), air temperature, solar exposure, the Southern Oscillation Index (SOI) and a Cyclone Index. Similar data have also been collated for the Top End and Joseph Bonaparte Gulf. Understanding how environmental variables influence fisheries is particularly important to inform how to future proof stock assessments and harvest strategies under climate change. A first step involves summarising key trends in a Report card as per Appendix A.

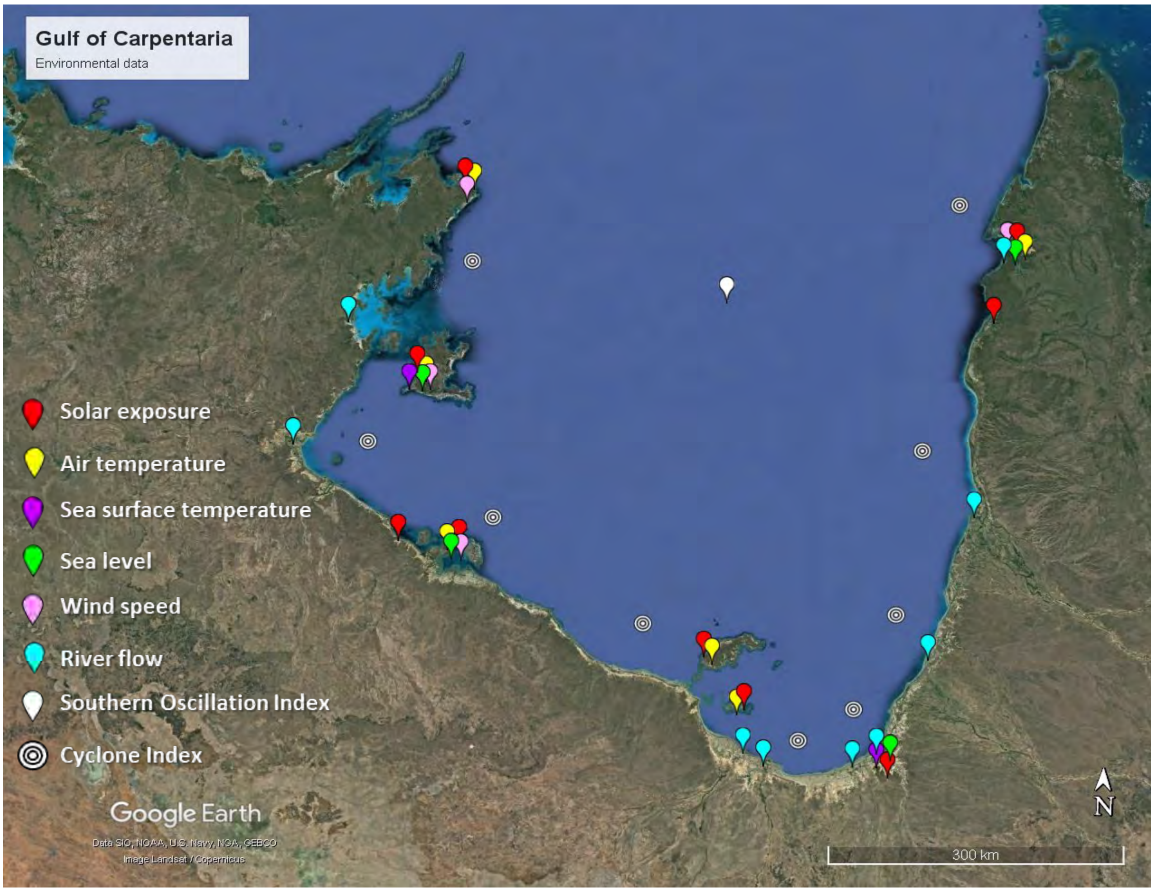
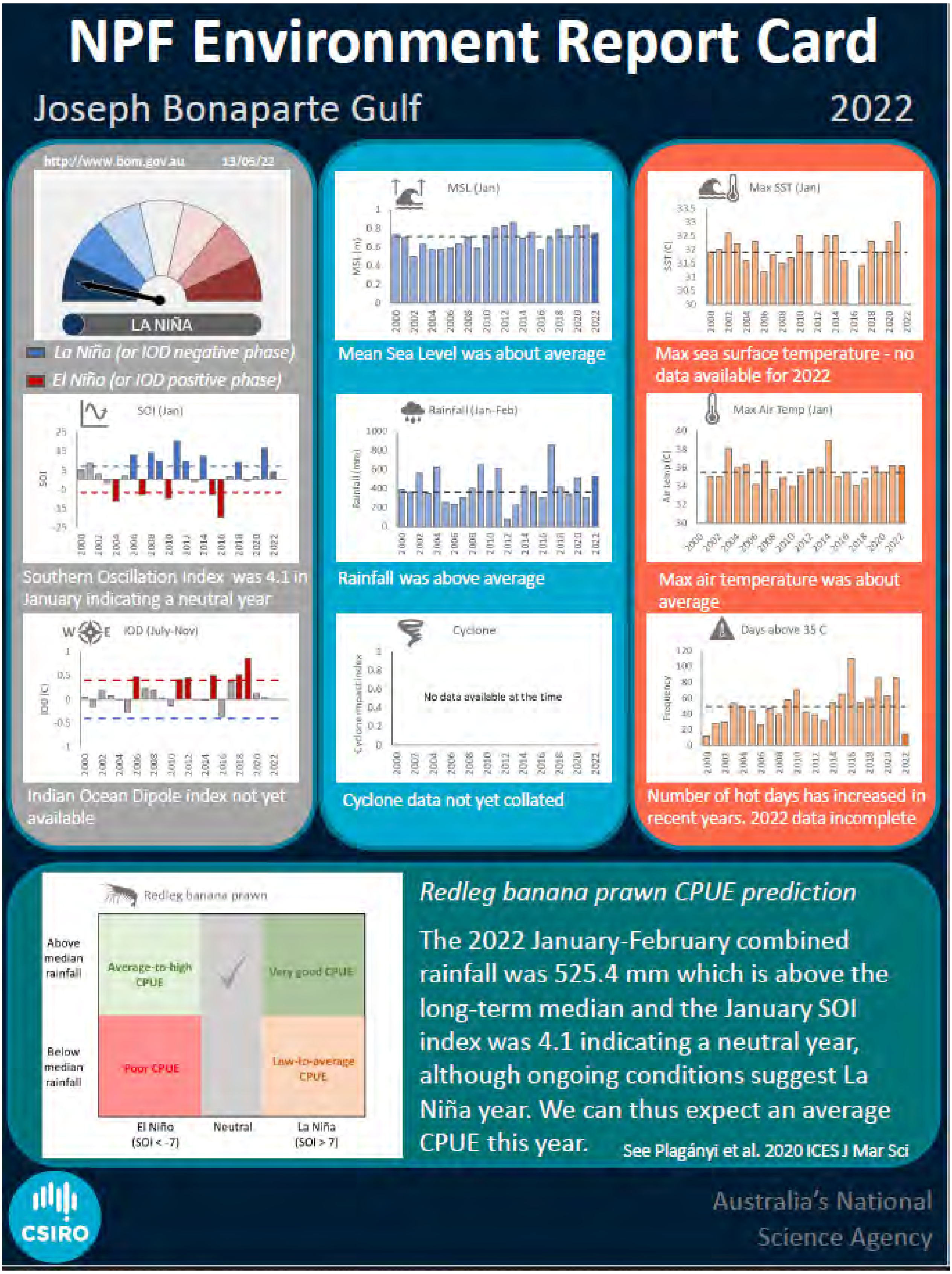


Fig. 1: Spatial overview of various environmental data available for the Gulf of Carpentaria

Table 1: Summary of the relevant environmental data collated for the Gulf of Carpentaria (GoC), including temporal and spatial scale.

	Environmental Variable	Temporal Scale	Spatial Scale
1	River flow	Daily, 1900 – 2019	Selected major rivers in GoC
2	Southern Oscillation Index (SOI)	Monthly, since 1970	
3	Sea Surface Temperature (SST) SST from BOM (min, max, mean)	Weekly average 2016 – 2018 Monthly, 1993 – 2019	Karumba Wharf Groote Eylandt
4	Salinity	Weekly average	Selected sites; calculated based on salinity-flow relationship (see Plagányi et al 2022)
5	Air temperature (min and max)	Daily, for various years depending on site	Weipa station 027045 (1993 – present) Sweers Is. station 029139 (2001 – present) Mornington Is. stations 029039 (1970-2013) and 029182 (2013-present). Centre Is. station 014703 (1975 – 2021) Groote Eylandt Airport station 014518 (2000 – present) Gove Airport station 014508 (1980s – present)
6	Sea level Hourly/Quarter hourly Sea level data also available from tide gauges at some sites	Monthly, for various years depending on site	Weipa station 63620; 1984 – 2020 Karumba station 63580; 1985 – present Groote Eylandt station 63511; 1981–present but some gaps in 1990s Groote Eylandt Karumba Weipa
7	Solar exposure	Daily, since 1990	Weipa station 027042 Karumba airport station 029028 Mornington Is station 029039 Bingbong Port station 014729 Groote Eiland station 014406 Gove Airport station 014508
8	Wind speed	Daily, for various years depending on site	Weipa station 027042 (1992 – 2011) Centre Is station 014703 (1974 – 2010) Groote Eiland station 014406 (1999 – 2022) Gove Airport station 014508 (1966 – 2012)
9	Cyclones	Since 1970	Region specific; compiled for MICE regions 1–12

Appendix A: Example of the NPF Environment Report Card developed for the Joseph Bonaparte Gulf



11. Annual effort threshold issues and solutions in the tiger prawn bio-economic model

Annual effort threshold issues and solutions in the tiger prawn bio-economic model

Roy Deng, André E. Punt, Sean Pascoe, Éva E. Plagányi

CSIRO

Background

The tiger prawn bio-economic model projects future effort for each tiger prawn fishing strategy (one targeted towards grooved tiger prawns and another targeted towards brown tiger prawns) by optimising net present value (NPV) over a 50-year projection period and hence computes the Maximum Economic Yield (MEY) trajectory. The bio-economic model calculates effort by fishing strategy for each of the next seven years, and assumes that the eighth and all future efforts equal that for the seventh projection year. The current base case model sets a minimum effort level at 2,777 (nominal) boat days for each of the two tiger prawn fishing strategies (half of the 2007 fishing effort multiplied by 108%). This constraint was introduced to ensure that the pathway to an MEY trajectory did not include very low effort levels that were not feasible or practical for the fishery. Over recent years, the industry has not fully utilised the fishing days recommended by the bio-economic model. Historically, the base case level of model-predicted effort was consistently above the minimum effort for grooved tiger prawns and mostly above for brown tiger prawns.

However, the 2022 assessment base case suggested optimal effort levels of 2,777 boat days for both tiger prawn fishing strategies (Figure 1). The bio-economic model is also constrained by the minimum effort thresholds for the two tiger prawn fishing strategies in 2023 when attempting to optimise the NPV to achieve MEY so the effort levels for 2022 and 2023 are both equal to the minimum effort level (Table 1). The major reason the bio-economic model is setting effort at the minimum is the higher fishing costs and the flattened future projection of the stock.

The standard sensitivity tests include the scenarios where the minimum effort by fishing strategy set to 0 and 1,000 boat days and the results show that MEY is achieved with lower effort levels (Figure 1).

Table 1. Results from the bio-economic model in which the minimum level of tiger prawn effort by fishing strategy is set.

Scenarios	Base case (Min effort per fishing strategy = 2,777 days)			No minimum effort			Min effort per fishing strategy = 1000 days		
Species	Grooved	Brown	Total	Grooved	Brown	Total	Grooved	Brown	Total
$Catch_{2022}$ (tons)	632	638		121	267		292	425	
Observed C_{2021} (tons)	673	341		673	341		673	341	
Catch at MEY (tons)	1402	1087		1385	1124		1387	1123	
S_{2021}/S_{MEY} (%)	61	66		60	72		60	72	
Observed nominal E_{2021} (days)	3320	1347	4667	3320	1347	4667	3320	1347	4667
Estimated nominal E_{2022} (days)	2777	2777	5554	345	1109	1454	1000	1843	2843
Estimated nominal E_{2023} (days)	2777	2777	5554	2850	2528	5378	2407	1955	4362
Effort at MEY (days)	4356	2777		4175	3217		4195	3199	
E_{2021}/E_{MEY} (%)	76	49		80	42		79	42	

Annual effort threshold issues and solutions in the tiger prawn bio-economic model

Roy Deng, André E. Punt, Sean Pascoe, Éva E. Plagányi

CSIRO

Background

The tiger prawn bio-economic model projects future effort for each tiger prawn fishing strategy (one targeted towards grooved tiger prawns and another targeted towards brown tiger prawns) by optimising net present value (NPV) over a 50-year projection period and hence computes the Maximum Economic Yield (MEY) trajectory. The bio-economic model calculates effort by fishing strategy for each of the next seven years, and assumes that the eighth and all future efforts equal that for the seventh projection year. The current base case model sets a minimum effort level at 2,777 (nominal) boat days for each of the two tiger prawn fishing strategies (half of the 2007 fishing effort multiplied by 108%). This constraint was introduced to ensure that the pathway to an MEY trajectory did not include very low effort levels that were not feasible or practical for the fishery. Over recent years, the industry has not fully utilised the fishing days recommended by the bio-economic model. Historically, the base case level of model-predicted effort was consistently above the minimum effort for grooved tiger prawns and mostly above for brown tiger prawns.

However, the 2022 assessment base case suggested optimal effort levels of 2,777 boat days for both tiger prawn fishing strategies (Figure 1). The bio-economic model is also constrained by the minimum effort thresholds for the two tiger prawn fishing strategies in 2023 when attempting to optimise the NPV to achieve MEY so the effort levels for 2022 and 2023 are both equal to the minimum effort level (Table 1). The major reason the bio-economic model is setting effort at the minimum is the higher fishing costs and the flattened future projection of the stock.

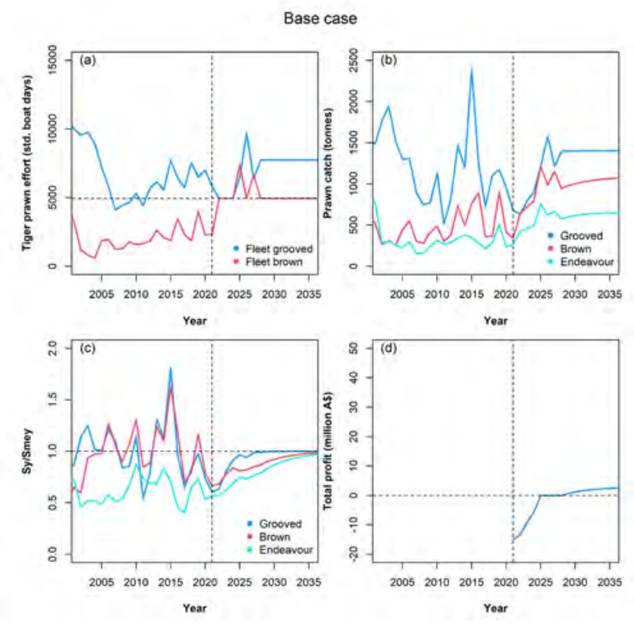
The standard sensitivity tests include the scenarios where the minimum effort by fishing strategy set to 0 and 1,000 boat days and the results show that MEY is achieved with lower effort levels (Figure 1).

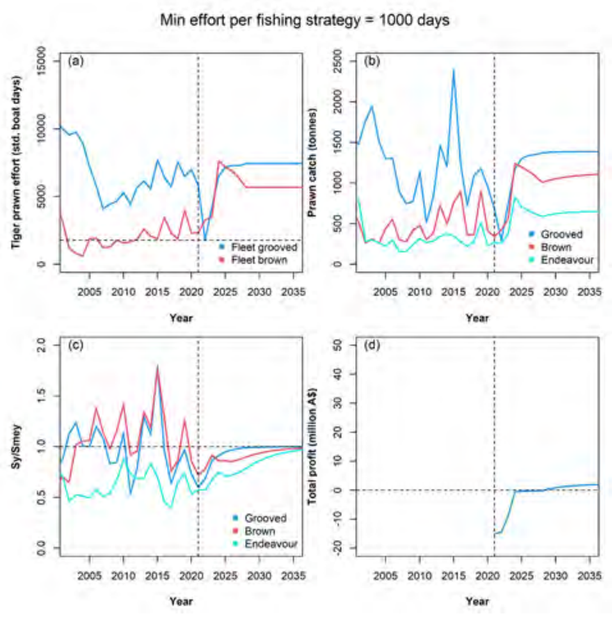
Table 1. Results from the bio-economic model in which the minimum level of tiger prawn effort by fishing strategy is set.

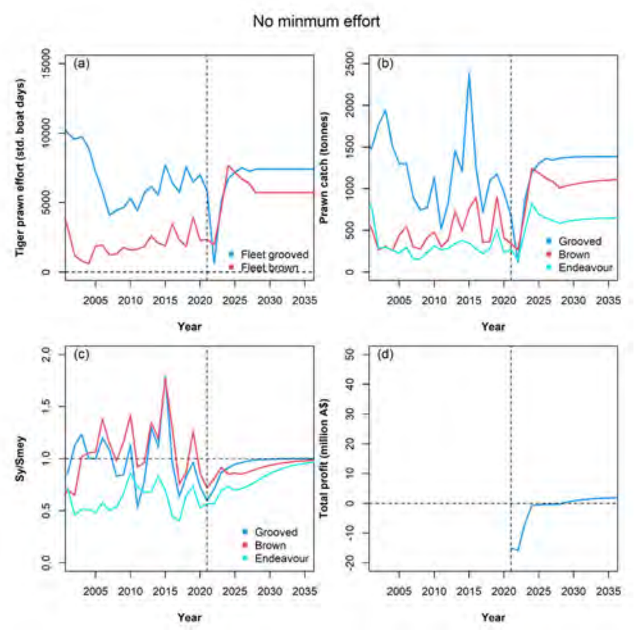
Scenarios	Base case (Min effort per fishing strategy = 2,777 days)			No minimum effort			Min effort per fishing strategy = 1000 days		
Species	Grooved	Brown	Total	Grooved	Brown	Total	Grooved	Brown	Total
$Catch_{2022}$ (tons)	632	638		121	267		292	425	
Observed C_{2021} (tons)	673	341		673	341		673	341	
Catch at MEY (tons)	1402	1087		1385	1124		1387	1123	
S_{2021}/S_{MEY} (%)	61	66		60	72		60	72	
Observed nominal E_{2021} (days)	3320	1347	4667	3320	1347	4667	3320	1347	4667
Estimated nominal E_{2022} (days)	2777	2777	5554	345	1109	1454	1000	1843	2843
Estimated nominal E_{2023} (days)	2777	2777	5554	2850	2528	5378	2407	1955	4362
Effort at MEY (days)	4356	2777		4175	3217		4195	3199	
E_{2021}/E_{MEY} (%)	76	49		80	42		79	42	

Net discount profit value from projection period ($1000,000)	-2,836			-2,331			-2,381		
Relative total loss to base case	1			0.822			0.839		

Figure 1. Projection results from the bio-economic model in which the minimum effort level by fishing strategy is varied.







Model update and results

The TAE for the tiger prawn fishery is computed by adding together the estimated effort for the two tiger prawn fishing strategies, which suggests that the minimum effort level should pertain to the total effort over the two fishing strategies. The bio-economic model was revised so that the total (annual) tiger prawn effort could be constrained.

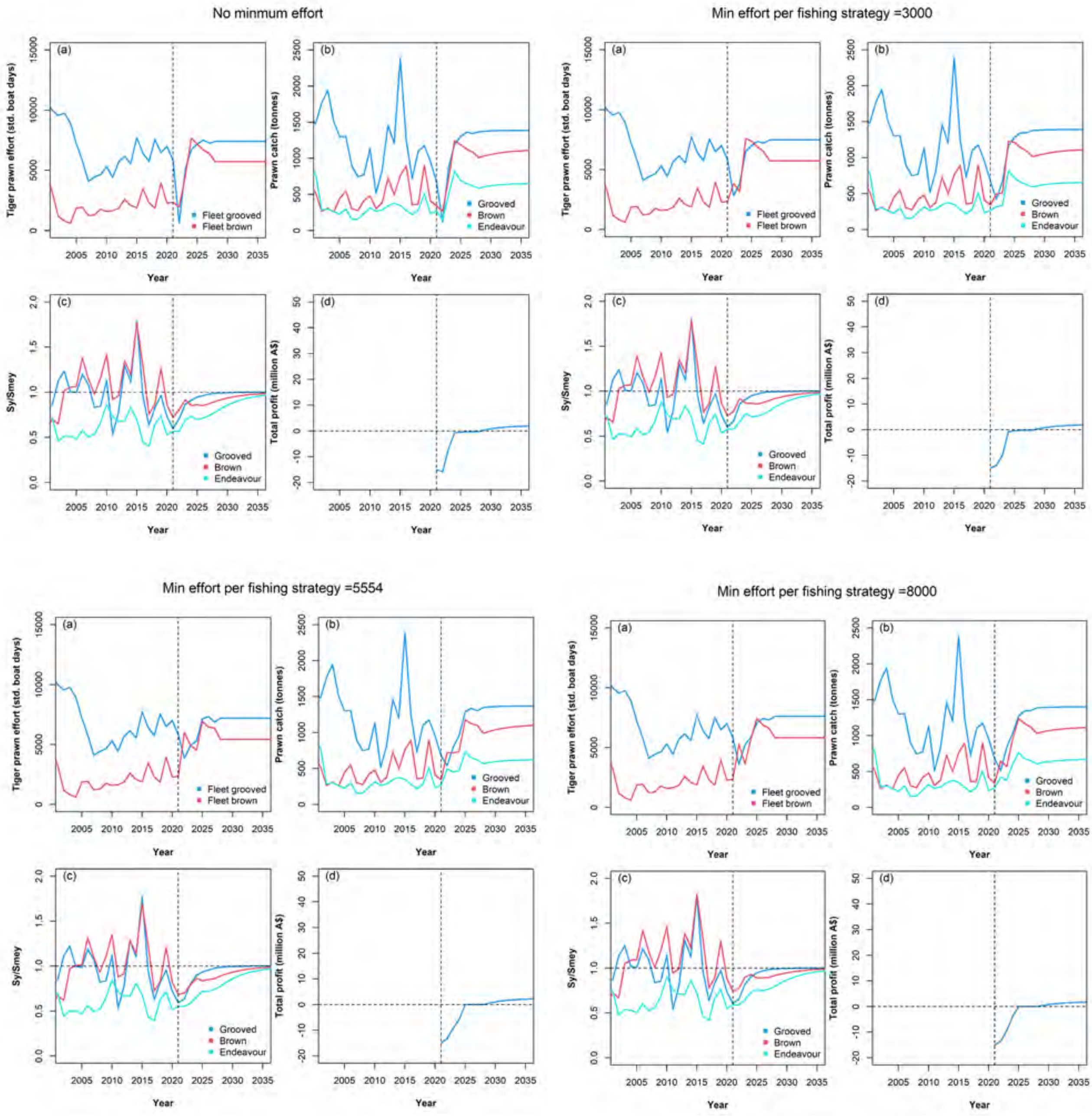
The "Min effort two fishing strategies = 5,554" scenario is equivalent to the base case but with the effort constraint applied to total annual effort. The results suggest that the optimal total effort for 2022 is the minimum (5,554 boat days), but split 2,169 and 3,385 boat days for the grooved and brown tiger prawn fishing strategies respectively (Figure 2, lower left group of plots). The model calculated 2023 effort levels are 2,767 and 2,788 boat days for the two fishing strategies, with a total 2023 effort set slightly larger than the pre-set minimum level (5,555 boat days; Table 2).

Table 2 shows the sensitivity to the (total) minimum effort. The results show that no effort constraint or a low effort constraint (0 or 3,000 total days) does not constrain the solution (Figure 2: upper group of plots). However, a higher effort constraint further constrains the solution compared to the base case value (Table2, Figure 2: lower right group of plots).

Table 2. Results from a revised bio-economic model in which a total minimum level of tiger prawn effort is set.

Scenarios	Min effort two fishing strategies = 0 days			Min effort two fishing strategies = 3,000 days			Min effort two fishing strategies = 5,554 days			Min effort two fishing strategies = 8,000 days		
Species	Grooved	Brown	Total	Grooved	Brown	Total	Grooved	Brown	Total	Grooved	Brown	Total
$Catch_{2022}$ (tons)	121	267		420	494		543	723		790	934	
Observed C_{2021} (tons)	673	341		673	341		673	341		673	341	
Catch at MEY (tons)	1582	1053		1391	1124		1368	1113		1413	1128	
S_{2021}/S_{MEY} (%)	60	72		60	73		59	69		61	85	
Observed nominal E_{2021} (days)	3320	1347	4667	3320	1347	4667	3320	1347	4667	3320	1347	4667
Estimated nominal E_{2022} (days)	345	1109	3761	1589	2172	3761	2169	3385	5554	3788	4211	7999
Estimated nominal E_{2023} (days)	2850	2528	3942	2161	1781	3942	2767	2788	5555	4431	3567	7998
Effort at MEY (days)	4175	3217		4220	3226		4057	3058		4350	3753	
E_{2021}/E_{MEY} (%)	79.5	41.9		78.7	41.7		81.8	44.0		76.3	35.9	
Net discount profit value from projection period ($1000,000)	-2,331			-2,440			-2,805			-4,199		
Relative total loss to base case	0.81			0.86			0.99			1.48		

Figure 2. Projection results from the bio-economic model in which the total minimum effort level is varied.



12. What is an appropriate effort threshold

Factsheet: What is an appropriate effort threshold?

Sean Pascoe and Tom Kompas

CSIRO and University of Melbourne

Introduction

The current bioeconomic model incorporates a minimum fishing effort aimed at ensuring the fleet remains economically viable in each year. The use of 2777 days for each fleet (5554 days total) as a minimum effort level dates back to the initial model runs from 2009, where it was first introduced as a constraint. In the 2022 stock assessment, the use of this minimum resulted in a recommended TAE hi8gher than the observed level of fishing effort in the previous year, raising concerns about its validity as the constraints became binding and influenced the model outcomes. The aim of this factsheet is to explain where the threshold values used in the model came from, and what might be a more appropriate value for future modelling work.

Where does the current model threshold effort come from?

The first reference to imposing a minimum effort level for the fishery was in the minutes of the May 2008 RAG meeting, which stated: "*The 2009 effort increase will be taken as an increase in days fished; with an increase in days to be calculated using the bio-economic model with a new minimum value of half the 2007 tiger prawn effort and an 8% efficiency increase.*" This applied to all tiger prawns, not just browns.

The 2007 tiger prawn effort was 5142 days; min=0.5*5142*1.08=2777. This was built into the original (2009) bioeconomic model as a minimum of 2777 days each for browns and grooved, and has since become embedded as the base case. This gives a total minimum level of fishing effort of 5554 days, allocated equally between the two fishing activities (i.e., the brown and grooved "fleets").

This was modified slightly in the 2012 harvest strategy, which stated "*Providing the limit reference point is not exceeded, nominal effort for the fleet in any one year can not be less than 1.08 times the nominal effort targeted at brown tiger prawns in 2007.*" (Page 17) This suggests that the minimum only applies to browns. There is no mention of a minimum for grooved. The effort on browns in 2007 was 1185 days: min=1185*1.08=1280 days. However, the combined 5554 days was maintained in the model and split equally between the two fishing activities.

What are the alternatives? A "back of the envelope" analysis

We looked at the economic data provided by NPFI over the last five years, covering the years 2017 to 2021 inclusive (2022 data are not yet available). Using these data, we were able to split out the revenue and variable costs associated with the tiger and banana prawn fisheries. We assumed all "other species" revenue was associated with tiger prawns, along with endeavours.

As fixed costs are fixed (by definition), we were able to estimate how much these were covered by the banana prawn fishery alone, and how much net income needs to be generated by the tiger

Factsheet: What is an appropriate effort threshold?

Sean Pascoe and Tom Kompas

CSIRO and University of Melbourne

Introduction

The current bioeconomic model incorporates a minimum fishing effort aimed at ensuring the fleet remains economically viable in each year. The use of 2777 days for each fleet (5554 days total) as a minimum effort level dates back to the initial model runs from 2009, where it was first introduced as a constraint. In the 2022 stock assessment, the use of this minimum resulted in a recommended TAE hi8gher than the observed level of fishing effort in the previous year, raising concerns about its validity as the constraints became binding and influenced the model outcomes. The aim of this factsheet is to explain where the threshold values used in the model came from, and what might be a more appropriate value for future modelling work.

Where does the current model threshold effort come from?

The first reference to imposing a minimum effort level for the fishery was in the minutes of the May 2008 RAG meeting, which stated: "*The 2009 effort increase will be taken as an increase in days fished; with an increase in days to be calculated using the bio-economic model with a new minimum value of half the 2007 tiger prawn effort and an 8% efficiency increase*." This applied to all tiger prawns, not just browns.

The 2007 tiger prawn effort was 5142 days; min=0.5*5142*1.08=2777. This was built into the original (2009) bioeconomic model as a minimum of 2777 days each for browns and grooved, and has since become embedded as the base case. This gives a total minimum level of fishing effort of 5554 days, allocated equally between the two fishing activities (i.e., the brown and grooved "fleets").

This was modified slightly in the 2012 harvest strategy, which stated "*Providing the limit reference point is not exceeded, nominal effort for the fleet in any one year can not be less than 1.08 times the nominal effort targeted at brown tiger prawns in 2007*." (Page 17) This suggests that the minimum only applies to browns. There is no mention of a minimum for grooved. The effort on browns in 2007 was 1185 days: min=1185*1.08=1280 days. However, the combined 5554 days was maintained in the model and split equally between the two fishing activities.

What are the alternatives? A "back of the envelope" analysis

We looked at the economic data provided by NPFI over the last five years, covering the years 2017 to 2021 inclusive (2022 data are not yet available). Using these data, we were able to split out the revenue and variable costs associated with the tiger and banana prawn fisheries. We assumed all "other species" revenue was associated with tiger prawns, along with endeavours.

As fixed costs are fixed (by definition), we were able to estimate how much these were covered by the banana prawn fishery alone, and how much net income needs to be generated by the tiger prawn fishery to at least break even. The resultant estimate of how much tiger prawn (and associated species) net revenue (revenue less variable costs) is required to at least reach a zero level of profits is shown in Table 1.

Table 1. Summarised economic data from the NPFI surveys 2017-2021, average per boat.

	2017	2018	2019	2020	2021
Banana prawn revenue	$1,586,172	$1,342,080	$1,278,572	$837,579	$1,251,853
Banana prawn variable costs	$658,038	$606,279	$663,277	$387,982	$489,592
Total fixed costs	$728,855	$812,120	$799,087	$978,491	$889,783
Profit if zero tiger income	$199,279	-$76,318	-$183,792	-$528,894	-$127,522
Tiger prawn revenue[a]	$1,199,542	$1,030,968	$1,116,585	$956,037	$579,920
Tiger prawn variable costs	$455,687.40	$424,690.68	$525,219.19	$588,810.14	$422,859.94
Net revenue tiger prawn	$743,854.82	$606,277.07	$591,365.80	$367,226.70	$157,060.06
Average days fished[b]	94	106	110	104	90
Net revenue per day	$7,908.50	$5,744.61	$5,379.81	$3,543.48	$1,750.72
Number of days required to break even (average per boat)	0	13	34	149	73
Fishery level days	0	691	1776	7761	3788

a) Include endeavours and other prawn revenue; b) based on total fishery effort divided by 52 boats

In four of the five years, tiger prawn net revenue was required for the average boat to break even. This was highly correlated with the level of banana prawn revenue (Figure 1) – in a good year (e.g., 2017), banana prawn revenue was sufficient on its own to cover total fixed costs as well as the variable costs associated with the banana prawn fishing activity.

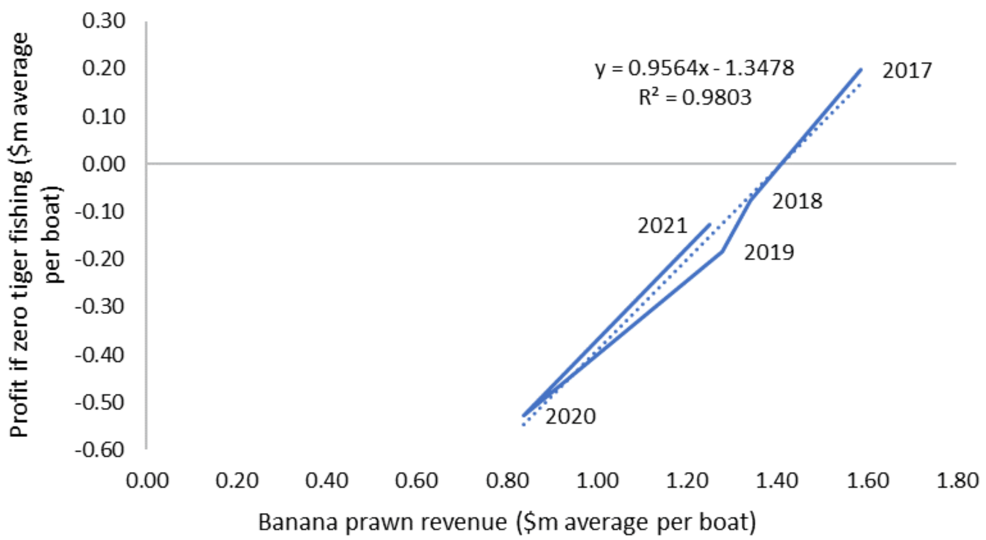


Figure 1. Average vessel profit if tiger prawn revenue was zero.

The average net revenue per day fishing in the tiger fishery (revenue minus variable costs) was estimated from the data. From this, the number of days required to achieve this level of net revenue needed to break even was estimated. In most years, this was less than the default minimum total level of effort imposed in the model (5554 days) (Figure 2). In 2020, however, a higher level of fishing effort would have been required (the vessels on average made a loss in 2020).

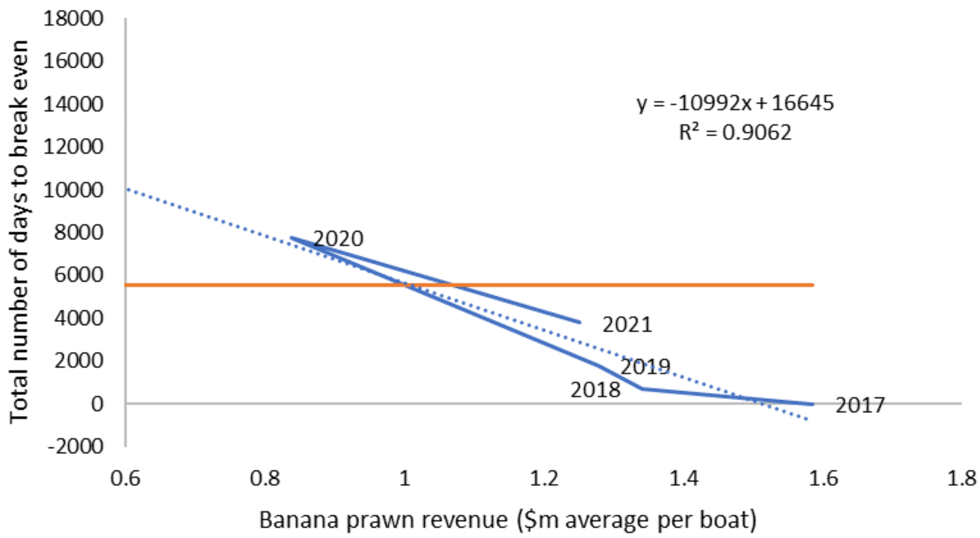


Figure 2. Number of tiger prawn fishery days required to break even.

The years 2019 and 2021 both had a similar level of banana prawn revenue. Fuel prices were higher in 2021, resulting in a smaller net revenue per day fished and consequently a higher number of days to break even. This suggests that an appropriate threshold level of effort is going to be a function of banana prawn catches, tiger and banana prawn prices and fuel prices. Ideally, a dynamic threshold effort level would be imposed, but in practice, these drivers will not be known in advance for future years.

From the 2012 harvest strategy, a minimum constraint on browns of 1280 days, and an equivalent value for grooved, results in a total effort level of 2560 days. This is roughly midway between the 2019 and 2020 values, both of which were roughly "average" banana prawn years, but with differing fuel and prawn prices.

Caveats

The analysis undertaken here is very preliminary and includes assumptions that may not be valid.

- The analysis assumes that revenues and variable costs are both linearly related to days fished. More than likely, catch rates would decline as the season progressed, so marginal revenue is more likely to decrease with increasing number of days. Similarly, costs may increase as the prawns become harder to find.
- Conversely, the marginal net revenue is likely to be higher at the start of the season (for the same reasons as above), so the threshold effort level may in fact be lower than suggested in the simple analysis.
- The analysis is based on an "average" boat. With any distribution, some vessels will make a profit at the average "break even" point and others will make a loss. The distribution of winners and losers at each level of fishing effort has not been considered.
- The impacts of the threshold level of effort on future stock sizes has also not been taken into account. A higher threshold may result in the bioeconomic model predicting a higher immediate profit level but a lower flow of profits over time. Ideally the threshold value should consider these trade-offs in addition to very short-term measures of profits.

Where to from here?

The results of the simple analysis suggest that there is unlikely to be a threshold effort level that will be appropriate in all circumstances. From the limited analysis, the value depends on the banana prawn season as well as prawn and fuel prices. Ideally, a more detailed analysis is required using more years of data and also considering the role of input and output prices. For the bioeconomic model, estimates of how prices may move over the near future is already included, so could be used to modify the threshold effort level in the model also.

The potential set of threshold values also need to be tested using the bioeconomic model to determine their longer-term implications. As noted above, achieving a higher short-term profit may be at the expense of a lower flow of profits into the future.

13. Data factsheet summary of inputs and timeline for the NPF stock assessment analyses

Data Factsheet summary of inputs and timeline for the NPF stock assessment analyses

Roy Deng, Margaret Miller, Trevor Hutton, Chris Moeseneder, Sean Pascoe, Eva Plagányi, Judy Upston, Rob Kenyon, Tonya van der Velde, Anthea Donovan, Shijie Zhou and André Punt

CSIRO

Introduction

The NPF is a complex multispecies fishery such that the analyses and models used to support its management draw on a wide range of data inputs, including both fishery-dependent and fishery-independent sources. In addition, there are also a number of non-biological data inputs that are considered important, such as economic data and vessel efficiency. Here we provide a brief overview of the different data sources, their use and timing, as well as a historical timeline of changes in data availability through the history of the fishery.

Data sources

Economic data from roughly two thirds of the fleet are collated late in each calendar year (November-December) by NPFI. Data are collected at the individual boat level (Figure 1). These data are collated by an external contactor and then presented as an average per boat. Five key economic cost parameters are derived from these data for use in the model: (fuel cost per day $/day; repairs and maintenance $/day; marketing, packaging etc $/kg; crew share (%); annual vessel costs (fixed costs), $/vessel). Capital costs ($/vessel) are derived from ABARES surveys as these data are not collected in the NPFI survey. The annual vessel costs and capital costs are apportioned to the tiger prawn fishery based on the revenue share of tiger prawns since 2004-05 (averaged over all years). Economic depreciation (% of capital value) is based on the results of a previous CSIRO study (Zhou et al. 2013). The opportunity cost of capital (% of capital cost) is equal to the discount rate agreed with the RAG at an earlier meeting (5%).

Price data for tiger and endeavour prawns are also derived from the NPFI survey data (average $/kg). Prices for tiger prawns are scaled to reflect different prices by size class based on information provided by Industry relating to the 2014 fishing season (and not subsequently updated).

Vessel gear information is collated at the same time and sent to a gear consultant specialist that applies a gear analysis to obtain a measure of performance by each vessel (prawn trawl performance model – PTPM estimate of swept area in metres^2/sec) (Figure 1).

Data Factsheet summary of inputs and timeline for the NPF stock assessment analyses

Roy Deng, Margaret Miller, Trevor Hutton, Chris Moeseneder, Sean Pascoe, Eva Plagányi, Judy Upston, Rob Kenyon, Tonya van der Velde, Anthea Donovan, Shijie Zhou and André Punt

CSIRO

Introduction

The NPF is a complex multispecies fishery such that the analyses and models used to support its management draw on a wide range of data inputs, including both fishery-dependent and fishery-independent sources. In addition, there are also a number of non-biological data inputs that are considered important, such as economic data and vessel efficiency. Here we provide a brief overview of the different data sources, their use and timing, as well as a historical timeline of changes in data availability through the history of the fishery.

Data sources

Economic data from roughly two thirds of the fleet are collated late in each calendar year (November-December) by NPFI. Data are collected at the individual boat level (Figure 1). These data are collated by an external contactor and then presented as an average per boat. Five key economic cost parameters are derived from these data for use in the model: (fuel cost per day $/day; repairs and maintenance $/day; marketing, packaging etc $/kg; crew share (%); annual vessel costs (fixed costs), $/vessel). Capital costs ($/vessel) are derived from ABARES surveys as these data are not collected in the NPFI survey. The annual vessel costs and capital costs are apportioned to the tiger prawn fishery based on the revenue share of tiger prawns since 2004-05 (averaged over all years). Economic depreciation (% of capital value) is based on the results of a previous CSIRO study (Zhou et al. 2013). The opportunity cost of capital (% of capital cost) is equal to the discount rate agreed with the RAG at an earlier meeting (5%).

Price data for tiger and endeavour prawns are also derived from the NPFI survey data (average $/kg). Prices for tiger prawns are scaled to reflect different prices by size class based on information provided by Industry relating to the 2014 fishing season (and not subsequently updated).

Vessel gear information is collated at the same time and sent to a gear consultant specialist that applies a gear analysis to obtain a measure of performance by each vessel (prawn trawl performance model – PTPM estimate of swept area in metres^2/sec) (Figure 1).

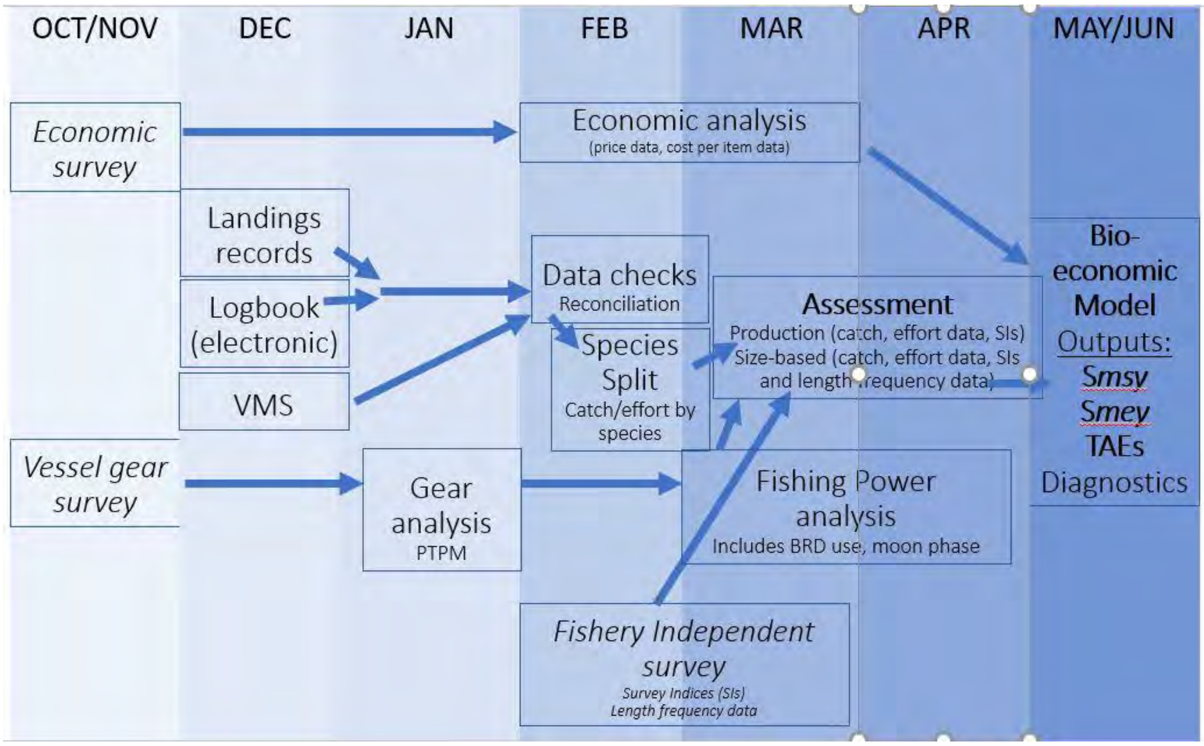


Figure 1. The flow of data from surveys and other sources during the assessment process

The PTPM estimate (which equates to swept area per vessel), is inputted into the fishing power analysis so as to adjust the year-on-year CPUE estimates from the fleet in the assessment model. At the end of the calendar year, landing records are reconciled and checked against logbook data. Later, these data are further checked against the VMS data (Figure 1). Only when all these checks have been performed is the final clean set of catch records included in the species split model. The species split model spatially allocates catch and effort per species to apportion logbook data which are included in the assessment attributed to prawn species (Figure 1). In addition, the species-specific survey indices from the fishery independent NPF surveys are included (conducted in late Feb – March and June-July). The assessment model outputs feed into the bio-economic model as inputs.

Catch data are available from the beginning of the fishery (1970) (Figure 2). Other stock assessment input data include abundance indices from the adult spawning survey (Survey_JUL) which are available from 2002 (except 2010 and every second year since and including 2014) and the recruitment survey which has been conducted every year since 2003 (Survey_FEB) (Figure 2). Length-frequency data associated with all these fishery independent surveys are thus available from 2002. Tag-recapture data are available for 1983-1984 (Figure2). Data that are inputted into the species split model are available for 1976-1992, 1994, 1996-1998, and 2002-2022 (see species split factsheet). Gear data are here defined as the data that are inputted in the prawn trawl performance model, and these are available since 2008. Economic data (where no hindcast data are used) are available since the 2005 financial year (Figure 2).

References

Zhou, S.., Pascoe, S., Dowling, N., Haddon, M., Klaer, N., Smith, T., Thebaud, O., Larcombe, J., Vieira, S. 2013. Quantitatively defining biological and economic reference points in data poor fisheries. Canberra: CSIRO. csiro:EP132319. https://doi.org/10.4225/08/585038ddcb3e5

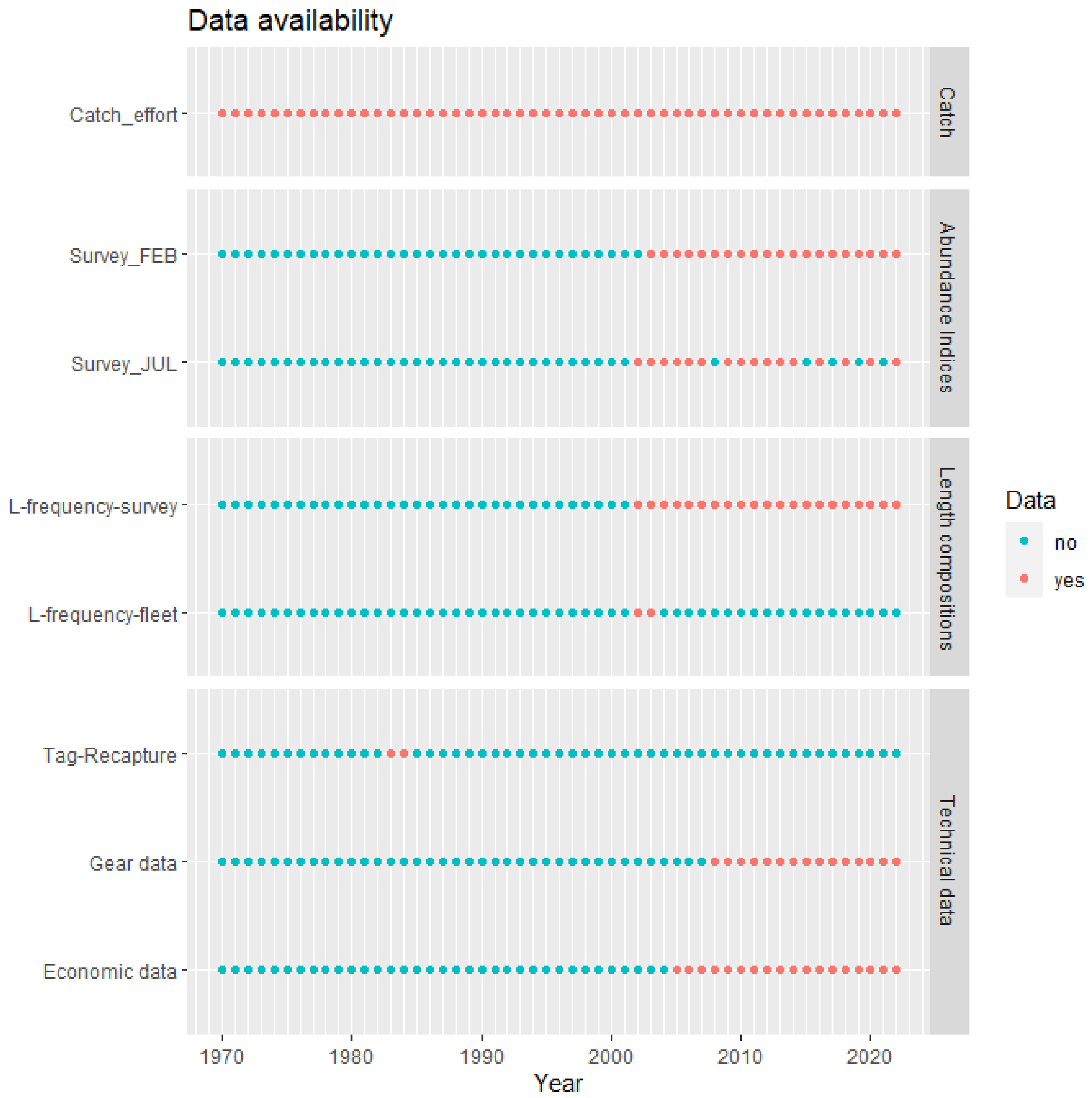
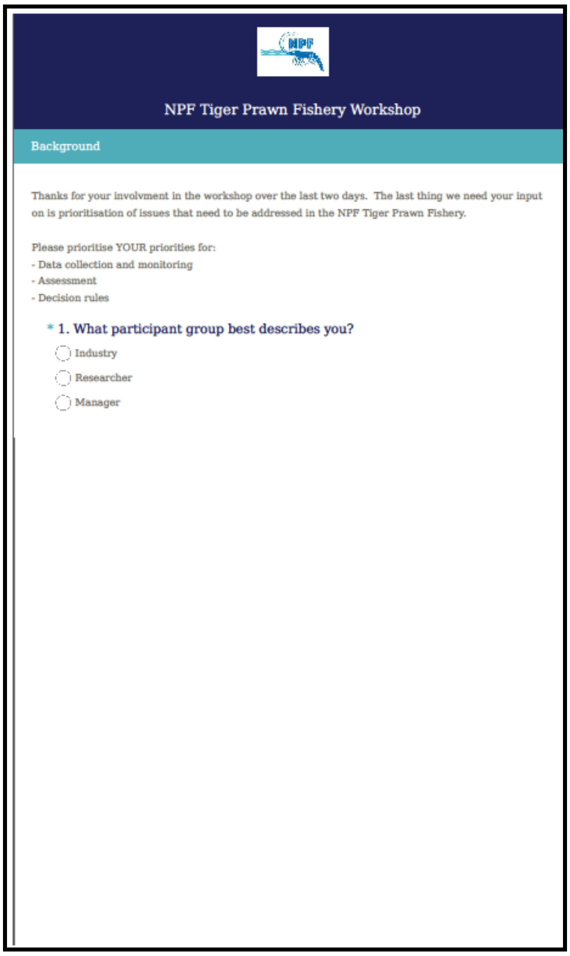


Figure 2. The available data of different types over the history of the fishery

Appendix D: During-workshop survey

1. During-workshop survey



NPF Tiger Prawn Fishery Workshop

Background

Thanks for your involvment in the workshop over the last two days. The last thing we need your input on is prioritisation of issues that need to be addressed in the NPF Tiger Prawn Fishery.

Please prioritise YOUR priorities for:
- Data collection and monitoring
- Assessment
- Decision rules

* 1. What participant group best describes you?

- Industry
- Researcher
- Manager

NPF Tiger Prawn Fishery Workshop

Background

Thanks for your involvment in the workshop over the last two days. The last thing we need your input on is prioritisation of issues that need to be addressed in the NPF Tiger Prawn Fishery.

Please prioritise YOUR priorities for:
- Data collection and monitoring
- Assessment
- Decision rules

* 1. What participant group best describes you?

- ◯ Industry
- ◯ Researcher
- ◯ Manager

NPF Tiger Prawn Fishery Workshop

Data collection and monitoring Priorities

* 2. Data collection and monitoring

☐	Fishing power inputs	☐ N/A
☐	Biological parameter that change over time	☐ N/A
☐	Physical data oceanography, river flows, climate, etc	☐ N/A
☐	Biological: ecosystems (habitats / food / predators	☐ N/A
☐	Other	☐ N/A

3. Any comments on data and monitoring?

NPF Tiger Prawn Fishery Workshop

Assessment Priorities

* 4. Assessment

Fishing power model	☐ N/A
Economic modification	☐ N/A
Inclusion of climate change, SOI etc	☐ N/A
Inclusion of spatial indicators	☐ N/A
Feasibility of spatially-based assessment	☐ N/A
Catchability	☐ N/A
Other	☐ N/A

5. Any comments on Assessment?

NPF Tiger Prawn Fishery Workshop

Decision Rule Priorities

* 6. Decision Rules

[ ]	Effort Threshold	☐ N/A
[ ]	Other effort controls - seasons	☐ N/A
[ ]	Other effort controls - closures	☐ N/A
[ ]	Other	☐ N/A

7. Any comments on Decision Rules?

[ ]

NPF Tiger Prawn Fishery Workshop

GENERAL COMMENTS

* 8. How would you rate the content of the workshop

- Very satisfied
- Satisfied
- Neither satisfied nor dissatisfied
- Dissatisfied
- Very dissatisfied

* 9. How would you rate the process of the workshop

- Very satisfied
- Satisfied
- Neither satisfied nor dissatisfied
- Dissatisfied
- Very dissatisfied

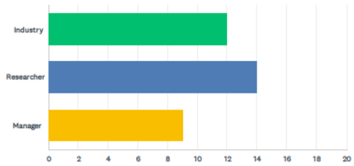
10. Do you have other comments, questions or concerns regarding the NPF Tiger Prawn Fishery management or stock assessment you would like to raise for consideration at the workshop?

2. During-workshop survey results

NPF Tiger Prawn Fishery Workshop

Q1 What participant group best describes you?

Answered: 35 Skipped: 0

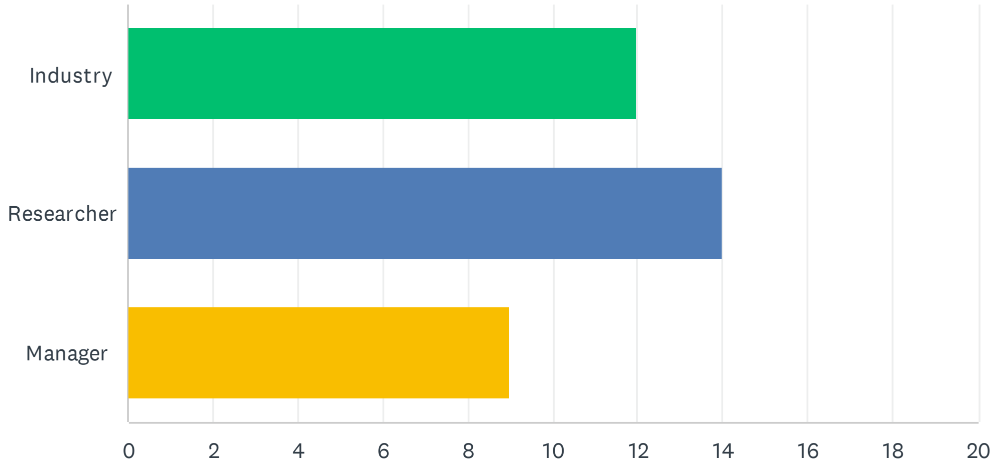


ANSWER CHOICES	RESPONSES	
Industry	34.29%	12
Researcher	40.00%	14
Manager	25.71%	9
TOTAL		35

1 / 10

Q1 What participant group best describes you?

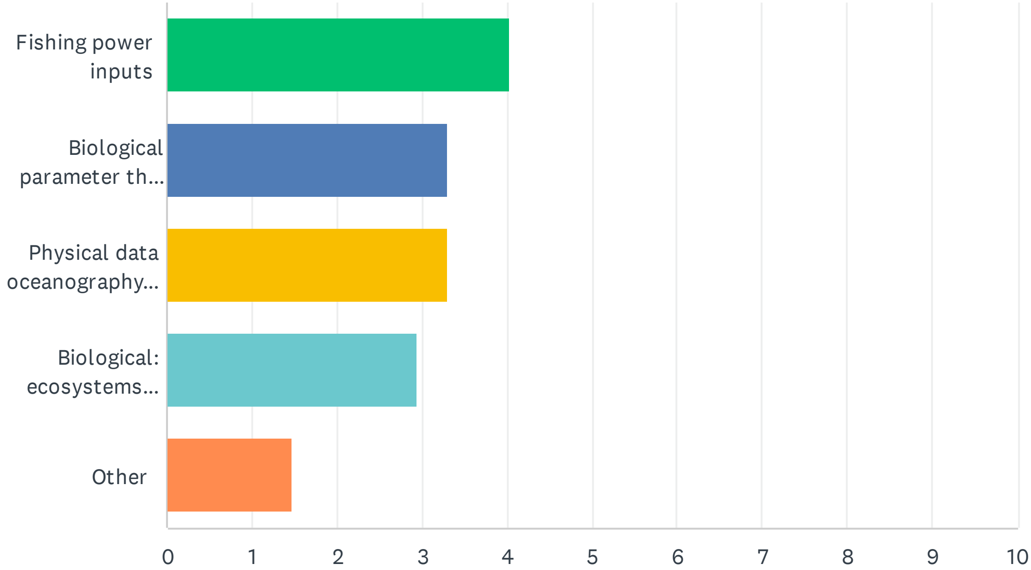
Answered: 35 Skipped: 0



ANSWER CHOICES	RESPONSES	
Industry	34.29%	12
Researcher	40.00%	14
Manager	25.71%	9
TOTAL		35

Q2 Data collection and monitoring

Answered: 35 Skipped: 0



	1	2	3	4	5	N/A	TOTAL	SCORE
Fishing power inputs	57.14% 20	11.43% 4	8.57% 3	22.86% 8	0.00% 0	0.00% 0	35	4.03
Biological parameter that change over time	14.29% 5	34.29% 12	22.86% 8	25.71% 9	2.86% 1	0.00% 0	35	3.31
Physical data oceanography, river flows, climate, etc	14.29% 5	28.57% 10	31.43% 11	25.71% 9	0.00% 0	0.00% 0	35	3.31
Biological: ecosystems (habitats / food / predators	11.43% 4	20.00% 7	31.43% 11	25.71% 9	11.43% 4	0.00% 0	35	2.94
Other	2.86% 1	5.71% 2	5.71% 2	0.00% 0	68.57% 24	17.14% 6	35	1.48

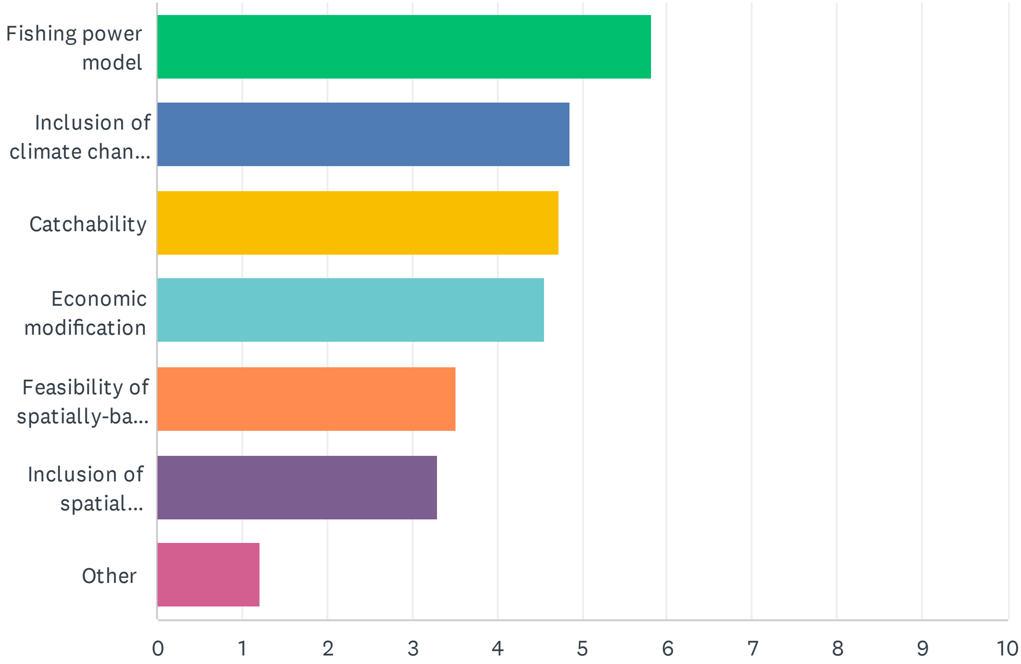
Q3 Any comments on data and monitoring?

Answered: 15 Skipped: 20

#	RESPONSES	DATE
1	Explore further fishery independent data	2/24/2023 3:37 PM
2	Look for opportunities to collect data easily and cheaply that is PERTINENT	2/24/2023 3:37 PM
3	None	2/24/2023 3:36 PM
4	Fishing power as top priority may change after reviewing assessment inputs/weighting	2/24/2023 3:36 PM
5	Kevin. Exlude	2/24/2023 3:35 PM
6	Review update economic components	2/24/2023 3:35 PM
7	Changes are currently being considered for fishing power so hold until these are complete before undertaking any further review or work on the current fishing power model	2/24/2023 3:35 PM
8	The environment drives the fishery so much that understanding this variability is the highest priority	2/24/2023 3:35 PM
9	Prioritise key data through use of models	2/24/2023 3:35 PM
10	Physical data will become more important over time, and collaborations that improve these monitoring systems need to be forged asap	2/24/2023 3:35 PM
11	Nil	2/24/2023 3:33 PM
12	Economic data	2/24/2023 3:33 PM
13	Good bang for the buck	2/24/2023 3:33 PM
14	Ik	2/24/2023 3:21 PM
15	Ik	2/24/2023 3:17 PM

Q4 Assessment

Answered: 35 Skipped: 0



	1	2	3	4	5	6	7	N/A	TOTAL	SCORE
Fishing power model	60.00% 21	14.29% 5	0.00% 0	11.43% 4	5.71% 2	5.71% 2	2.86% 1	0.00% 0	35	5.83
Inclusion of climate change, SOI etc	22.86% 8	20.00% 7	8.57% 3	28.57% 10	11.43% 4	5.71% 2	2.86% 1	0.00% 0	35	4.86
Catchability	11.43% 4	22.86% 8	34.29% 12	8.57% 3	5.71% 2	17.14% 6	0.00% 0	0.00% 0	35	4.74
Economic modification	2.86% 1	28.57% 10	28.57% 10	20.00% 7	2.86% 1	17.14% 6	0.00% 0	0.00% 0	35	4.57
Feasibility of spatially-based assessment	2.86% 1	11.43% 4	14.29% 5	17.14% 6	17.14% 6	34.29% 12	2.86% 1	0.00% 0	35	3.51
Inclusion of spatial indicators	0.00% 0	2.86% 1	14.29% 5	11.43% 4	57.14% 20	11.43% 4	2.86% 1	0.00% 0	35	3.31
Other	0.00% 0	0.00% 0	0.00% 0	2.86% 1	0.00% 0	8.57% 3	68.57% 24	20.00% 7	35	1.21

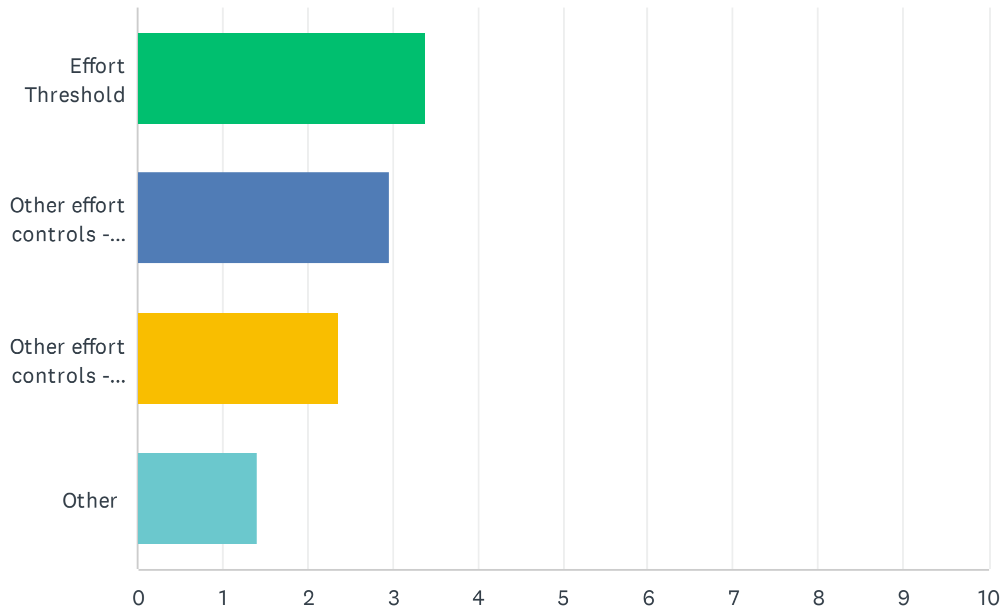
Q5 Any comments on Assessment?

Answered: 7 Skipped: 28

#	RESPONSES	DATE
1	Explore down-weighting CPUE in the assessment	2/24/2023 3:39 PM
2	As per previous re fishing power	2/24/2023 3:37 PM
3	Review existing data that have not been used.	2/24/2023 3:37 PM
4	Higher weighting on the FIS	2/24/2023 3:36 PM
5	Nil	2/24/2023 3:35 PM
6	I have included q in fishing power	2/24/2023 3:34 PM
7	Ik	2/24/2023 3:22 PM

Q6 Decision Rules

Answered: 35 Skipped: 0



	1	2	3	4	N/A	TOTAL	SCORE
Effort Threshold	62.86% 22	17.14% 6	17.14% 6	2.86% 1	0.00% 0	35	3.40
Other effort controls - seasons	25.71% 9	48.57% 17	22.86% 8	2.86% 1	0.00% 0	35	2.97
Other effort controls - closures	8.57% 3	25.71% 9	51.43% 18	8.57% 3	5.71% 2	35	2.36
Other	2.86% 1	8.57% 3	8.57% 3	62.86% 22	17.14% 6	35	1.41

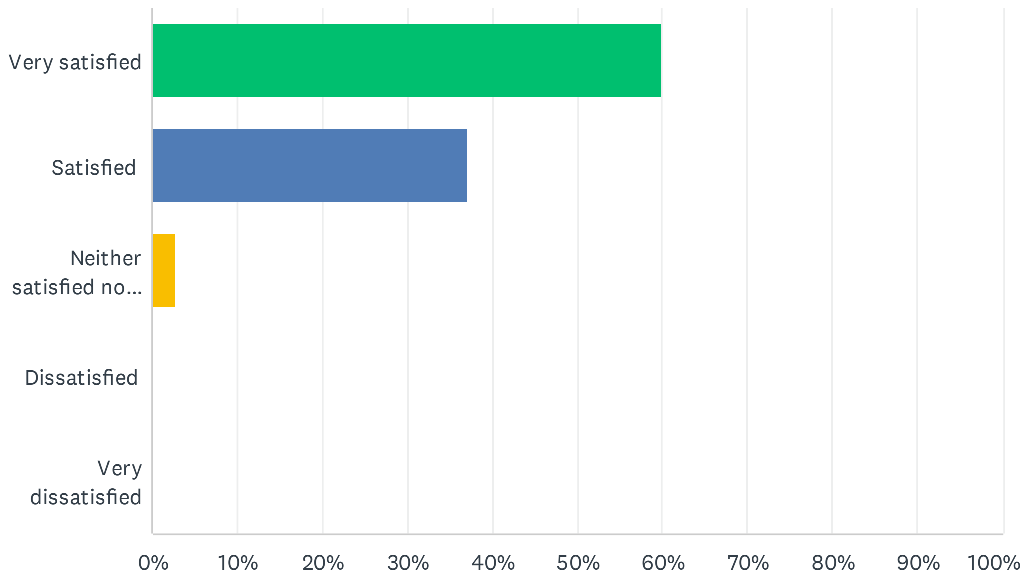
Q7 Any comments on Decision Rules?

Answered: 11 Skipped: 24

#	RESPONSES	DATE
1	Consider catch rate triggers for different purposes	2/24/2023 3:40 PM
2	Trigger limits	2/24/2023 3:39 PM
3	Stop using BRD.	2/24/2023 3:38 PM
4	Have in season indicators to allow flexibility to take advantage of variable seasons	2/24/2023 3:38 PM
5	in season triggers	2/24/2023 3:37 PM
6	Other = triggers	2/24/2023 3:36 PM
7	In season catch triggers	2/24/2023 3:35 PM
8	Catch trigger review	2/24/2023 3:35 PM
9	Gotta look at fleet size	2/24/2023 3:35 PM
10	Ik	2/24/2023 3:22 PM
11	Ik	2/24/2023 3:18 PM

Q8 How would you rate the content of the workshop

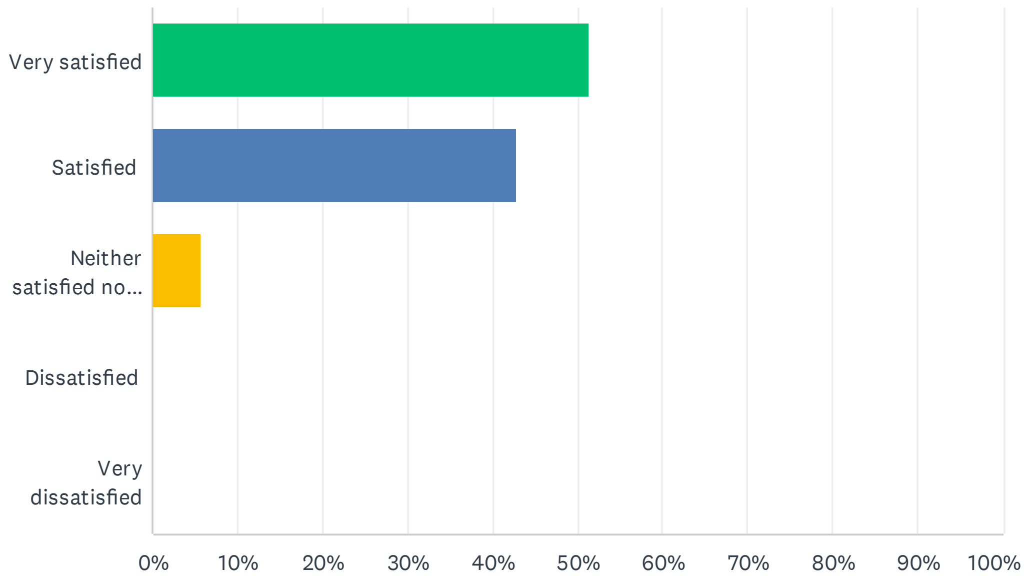
Answered: 35 Skipped: 0



ANSWER CHOICES	RESPONSES	
Very satisfied	60.00%	21
Satisfied	37.14%	13
Neither satisfied nor dissatisfied	2.86%	1
Dissatisfied	0.00%	0
Very dissatisfied	0.00%	0
TOTAL		35

Q9 How would you rate the process of the workshop

Answered: 35   Skipped: 0



ANSWER CHOICES	RESPONSES	
Very satisfied	51.43%	18
Satisfied	42.86%	15
Neither satisfied nor dissatisfied	5.71%	2
Dissatisfied	0.00%	0
Very dissatisfied	0.00%	0
TOTAL		35

Q10 Do you have other comments, questions or concerns regarding the NPF Tiger Prawn Fishery management or stock assessment you would like to raise for consideration at the workshop?

Answered: 8   Skipped: 27

#	RESPONSES	DATE
1	Well done team	2/24/2023 3:40 PM
2	More focus on understanding climate impacts than fine tuning the model	2/24/2023 3:39 PM
3	Parallel with improved science and yield estimates, it will be important to adjust management framework to suit changes.	2/24/2023 3:38 PM
4	When can we meet again?	2/24/2023 3:37 PM
5	Should be done more frequently.	2/24/2023 3:36 PM
6	Thanks	2/24/2023 3:36 PM
7	Pray for rain	2/24/2023 3:35 PM
8	Blah	2/24/2023 3:18 PM

Appendix E: Working Group Reports

Table 2: Summary of key discussions/outcomes from each Working Group

Working Group	Summary
1	The working group discussions on Day 1 (considering the results of pre-workshop survey among other things), noted the following: • Fishing Power – impact since 2010 has been dramatic, there is uncertainty in the calculation of fishing power and how it has fed into the assessment. Needs some communication from the RAG. • Basic biological information has remained the same for the last 40 years (since the 1980s) – particularly growth, movement, spawning cycle and recruitment – but this may have changed particularly given the changing environmental factors, and it is unclear what the implications of this would be on the outputs of the model. • Short-term look at climate variability – MICE model / environmental report card – similar to biological information need to ensure what the implications are on the outputs of the model and the costs. Key Priorities identified on Day 2 included: 1. Fishing power and catchability (low cost, feasible and high value), a review of the fishing power is currently underway. 2. Update the economics package and minimum effort threshold (low cost and feasible). 3. Climate variability – two phases to work moving forward. First, in the short term, a retrospective analysis of the data using the MICE model; and secondly, in the long term, understanding that an improve the TAE calculation ranking re cost, feasibility? Other conclusions/comments provided: • The use of biological data was not included in the top three priorities due to the expense. However, in the longer-term such data is important. • It may be possible to rely on the independent survey program, with 20 years of available data, rather than relying on fishery dependent data including fishing power or catch rates. • Fleet size should be looked at, actual profitability and environmental variability, and should be addressed.

Working Group	Summary

2	The working group discussions on Day 1 (considering the results of pre-workshop survey among other things) noted the following:
	
	• Fishing power needs to be reviewed as it seems to be too high currently.
	• Climate and environmental drivers are regarded as important in this fishery, with room for a lot of exploration. There was general agreement that it is not the action of the fishery impacting the stock. A better understanding of these drivers could allow the development of a tool for predictions in the fishery to allow more flexibility to respond in good or poor years, including spatial differences across the fishery. In addition, it could enhance the demonstrable sustainability of the fishery (what changes are attributable to the fishery and what to environmental changes).
	• Effort threshold – this needs to be set at an appropriate level that takes into account economic considerations as well as biological.
	• Consideration of improvements to the model to ensure the model fits the reality in the fishery, including:
	    ○ The interactions between the two banana prawn fisheries and tiger prawn fishery.
	    ○ Fisher behaviour and expertise over each year and in recent years (i.e., the last five years).
	• Could industry assist in an industry-based program to collect biological data to reduce expense?
	
	Key Priorities identified on Day 2 included:
	
	1. A review of fishing power and catchability is important.
	2. Minimum effort threshold is not correct and requires a review with different options explored to get a better representative threshold.
	3. Biological data – it is likely that the parameters have changed as the data has aged. Noting that, the stock assessment model should be tested to gauge the importance of this on the outputs of the model.
	4. Effort controls – for the tiger prawn season there is only one trigger being used based on a multiple prawn species catch rate, if triggered this closes the fishery. However, the use of other prawn species in the catch rate trigger could be artificially keeping the season open. Consideration should be given to use additional triggers, including a prawn size-based trigger.
	
	Other conclusions/comments provided:
	
	• While not in the listed priorities, the impact of the environment and climate is very important.
	• There is a need to ensure that there is a clear benefit in moving to spatial management, as operators adjust their fishing behaviour based on their catch in various regions.

<table>
<tr><th>Working Group</th><th>Summary</th></tr>
<tr><td>3</td><td>
The working group discussions on Day 1 (considering the results of pre-workshop survey among other things), noted the following:

Potential change to the seasonal closures with an option to open later rather than close early, potentially in line with the moon phase.
Impacts of localised depletion – resulting from pulse fishing in areas.
The calculated fishing power needs to be reviewed as its too high, additionally it may not be capturing all changes including,

Automatic Radar Plotting Aid (ARPA)
Increased communication between crew/skippers in the last five years.

Make most out of skipper data, including information of coral spawning, jellyfish and water temperature and wind information.

Key Priorities identified on Day 2 included:

A better understanding of the influence of different environmental factors feeding into the stock assessment (MICE model), e.g., can knowledge be linked to abundance and catches. There could be increased collection of knowledge/data from available platforms (including industry) and other methods to collect long term and ensure better usage of that data to build knowledge and lessen uncertainty.
Biological data (including natural mortality etc.) is important as the biological parameters are likely to have changed since the 1980s/90s and could have a significant influence on the outputs of the model.
Inclusion of spatial indicators is important. However, it is unclear currently how these could be implemented in a management sense.
Economic data such as fuel costs are considered on a day-to-day basis by industry and are being shared in an informal way.
Fishing power needs to be reviewed, however before we can provide advice on the importance of reviewing fishing, there needs better communication on how that data is used and what it is. However, if it’s decided not to use fishing power in the analysis then perfecting it (fishing power model) is not important.

Other conclusions/comments provided:

It’s important to ensure that there is flexibility in management arrangements, increasing flexibility will become more important if environmental conditions continue to become more variable.
Potential use of fishery information to better understand the fishery and how it’s operating. Additionally, skippers/boats could also collect environmental data.

</td></tr>
</table>

<table>
<tr><th>Working Group</th><th>Summary</th></tr>
<tr><td>4</td><td>
The working group discussions on Day 1 (considering the results of pre-workshop survey among other things) noted the following:

Stock Sustainability – there is some linkage with overfishing but there may be other factors affecting stock sustainability. This is an important/critical issue noting the further discussion on improving the model to better understand stock dynamics.
Economics and cost of fishing is an important consideration in the fishery particularly important given Commonwealth objectives of targeting MEY.
Climate and environmental change are important with a need to identify the impacts of these.
Several aspects of the current model need to be improved including:

Fishing Power – the growth in fishing power does not seem to represent reality of technological and other improvements
Minimum Effort Threshold – there is a disconnect between the output of the model and what the fleet is able to achieve
The NPF is a data rich fishery and should be used to full advantage
Environmental conditions that could be driving tiger prawn populations, with a need to analyse historical environmental events against favourable and unfavourable years.

The use of historical data to predict for the next season is flawed. Implementing in-season data inputs would ensure contemporaneous conditions are considered for management. This includes both economic data (where there is a high variability in fuel costs and prawn prices), catch rates (noting that operators focus on fishing during the season) and environmental data.
In unusual years, when the TAE is out of kilter, NPF industry have adjusted fishing operations to take this into account, for example will change locations when the catch rate is low.

Key Priorities identified on Day 2 included:

A review of fishing power – looking at inputs to the model and the model itself to see if fishing power is still required in the assessment. Catchability is also an important priority and equal with fishing power in requiring review.
Environmental drivers are important in terms of adjusting to climate change/ trophic changes but also in terms of providing a better indicator of stock status and forecasting productivity (contingent on the MICE). Need to understand the environment’s impact on the fishery spatially, even if the intent is not necessarily to manage the fishery spatially. A better understanding is required of which indicators are genuinely linked to tiger prawn stock dynamics and then look at monitoring these into the future.
Effort limit threshold – in terms of a break-even point, the objective of the threshold is important from an industry/business certainty perspective although as part of economic work we need to consider how this is implemented.
Reworking of the economic components of the model (noting more clarity is required on what this entails and NPRAG need to further consider the risks/benefits).
Retrospective examination of the stock model to try and link to environmental factors.

</td></tr>
</table>

<table>
<tr><th>Working Group</th><th>Summary</th></tr>
<tr><td></td><td>
6. Decision rules around effort controls should be reviewed:
  ○ Season opening and closing dates to ensure they are optimal for the fishery needs
  ○ The purpose of and need for fishery closures
  ○ The 350kg/day trigger decision rule for the early closure of the tiger season.

Other conclusions/comments provided:

• An update of the old biological data is important, although currently a lower priority due to the significant cost investment. To reduce the cost, which indices the models are most sensitive should be prioritised.
• The benefits of spatial model are currently a lower priority compared to other assessment/data collection priorities that have been identified (e.g., environmental drivers). Overall, there may be benefits but this requires further consideration and analysis.
• Weighting of model inputs requires review – the surveys are quite indicative of what will happen in the season on the water and the weighting associated with FIS needs to be further considered along with the weighting of model inputs to determine if they are right.
• The need for simplicity vs realism in the models should be explored, noting that simple models use strong assumptions whereas complex models use fewer assumptions and more closely represents reality. If proceed with including environmental information in the model, it will become inherently more complex.
</td></tr>
<tr><td>5</td><td>
The working group discussions on Day 1 (considering the results of pre-workshop survey among other things), noted the following:

• Only a small portion of fishery costs are due to the assessment. There are significant costs in keeping the fleet operating at a company level. Many of these costs are not included in the stock assessment and estimates of MEY.
• While the bioeconomic model was important and was about profits and sustainability, there should be more focus on sustainability – less on economics. The smaller size of industry now may have decreased the importance of economic analysis with resources including research potentially better directed to emerging challenges–climate/environmental changes (broadly interpreted to include environmental, climate, trophic, habitat).
• Key risks for the fishery include:
  ○ Climate/environmental change – there is significant risk of not understanding impact of changes, and the degree of the changes, on target species.
  ○ Everything in the fishery is ageing – assets, including people. Fishery is well managed with good supporting data and well-established trust relationships between management, scientists and industry. However, when new people come in (industry, managers, scientists) inadequate handover leading to loss of corporate knowledge. There are risks to the fishery as a result of aging infrastructure (assets, community, hardware)
</td></tr>
</table>

Working Group	Summary

	as well as a need to consider succession planning due to the imminent departure of industry members to ensure that corporate knowledge is retained (which is one of the most valuable assets is the knowledge in industry). Additionally, the handover between AFMA managers of some of the historical reasons/rationale behind management measures needs to improve.
	
	Key Priorities identified on Day 2 included:
	
	1. Fishing power model
	    o Fishing power inputs could be done in short term with current information.
	    o Assessment of fishing power made in 2010 is unlikely to be relevant to the 2023 fleet.
	2. Understanding the impacts of Climate Change – impacts on recruitment, changes in fishing patterns, with information required at the relevant spatial and temporal scale to support analysis.
	    o Need to distinguish these impacts/risks between strategic (longer-term impacts that can feed into stock assessments) and tactical (make in-season fishing decisions more efficient).
	    o Discussion about matching the types of environmental changes/events that industry sees on-water with availability of data on the identified issue – potential to target scientific research using partnerships with third-party agencies (e.g. BoM).
	    o Discussion about habitat impacts caused by weather events – cyclones, storms – that have medium to longer term impacts on stocks.
	    o Change over time could impact the validity of the stock assessment including biology, habitat, trophic levels, fishery interactions and climate change.
	    o Biology including mortality, growth and migratory pathways of prawns (information is currently based on very old studies). This could affect the assessment and whether the decline in the stock assessment is indicating a declining population or it is a change in prawn availability.
	3. Catchability – together with fishing power this will provide the basis for estimating fishing mortality.
	4. Spatial indicators with clear view a feasibility approach required before any consideration of inclusion in assessment.
	    o Industry raised some concerns with this, with an initial step to apply the endeavour prawn assessment (which is spatial) to tiger prawns. There may be a way to easily investigate the need and feasibility of a more complex spatial model.
	5. Economics – undertaking work to improve the economic components of the model would be relatively cheap and straight forward.
	6. Effort threshold.
	7. Development of effort controls other than TAE.

Working Group	Summary
	Other conclusions/comments provided: • Social licence impacts might have become greater still. Need to be cognisant of First Nation Peoples' sea country and changes to Marine Protected Areas. Need to ensure that First Nations people are involved in the process. • Bycatch utilisation – potential opportunity for economic development? • Variability in tiger prawns – are the prawns there but not being found or are they varying in abundance? • Changes to the trophic system and habitat, especially competition and predation on prawns. Fishery's impact on the balance of the ecosystem.