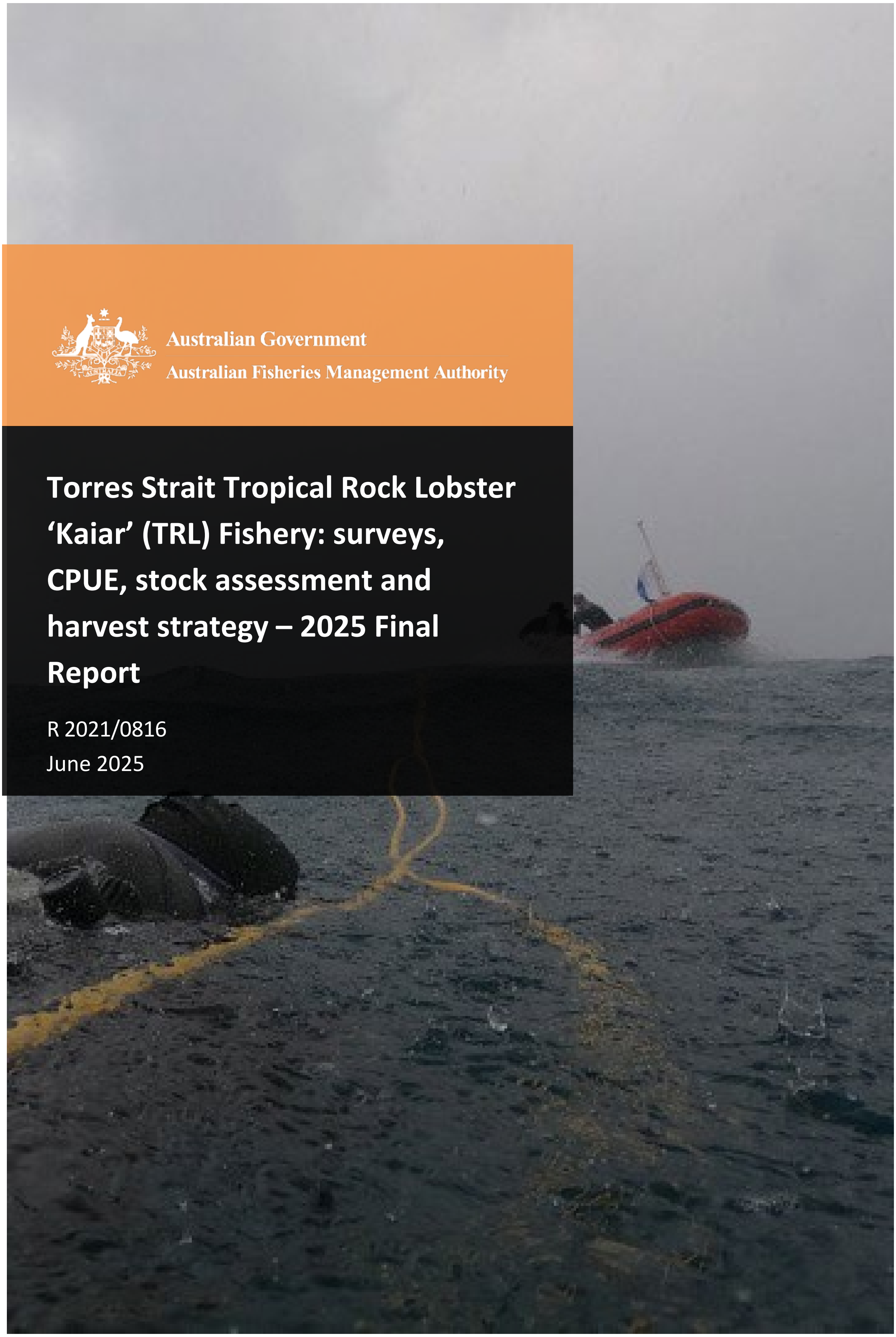

Australian Government
Australian Fisheries Management Authority

Torres Strait Tropical Rock Lobster 'Kaiar' (TRL) Fishery: surveys, CPUE, stock assessment and harvest strategy – 2025 Final Report

R 2021/0816
June 2025

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AFMA Project No. 2021/0816: Torres Strait Tropical Rock Lobster survey, stock assessment and harvest strategy

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Executive Summary

Background

The Torres Strait tropical rock lobster 'Kaiar' *Panulirus ornatus* (TRL) fishery has traditional, economic and social significance, hence there is a need to ensure the long-term biological sustainability of the stock through appropriate management decisions supported by research. The fishery is shared with Papua New Guinea (PNG) and is biologically connected to a lesser extent with stocks in northern Queensland. However, TRL has a broad distribution across the Indian and Pacific Oceans, including the eastern coast of Africa, Australia, Vietnam, China and as far north as southern Japan. Recent genomics research reveals that although these are all the same species, there are distinct genetic differences between lobsters from northern Australia and populations in South-East Asia, West Australia and the central and western Indian Ocean. The northeastern Australian population includes Torres Strait, Papua New Guinea and the Queensland East Coast, with these populations self-seeded due to strong retention in the Coral Sea gyre.

Freediving and hookah (surface supply air) are the preferred method to hand-collect TRL. As the fishing grounds are shallow (<25 m), the stock and recruitment levels are monitored using fishery-independent dive surveys. The Torres Strait TRL survey is currently the longest running fishery-independent dive survey for any marine resource globally and is a key input to a robust harvest strategy that sets quotas based on regular updates in stock recruitment. The survey also monitors key habitats such as seagrass and corals, which underpin the rich regional biodiversity and productivity. CSIRO's stock assessments show that the Torres Strait *P. ornatus* fishery varies naturally around levels close to the virgin levels, making this amongst the most precautionary and best-managed fisheries globally. The fishery also has a very low ecological footprint and is culturally very important.

Catches and market issues

Over the period of 1989-2024, the combined annual catch of the Australian and PNG Torres Strait fisheries has averaged 633 tons. However, over the past 5 years the average annual catch has reduced to 384 tonnes due to ongoing market access issues. TRL contributes substantially to employment and economic opportunities in northern coastal regions, and Torres Strait in particular. The supply chain and market access challenges facing this fishery have therefore been considered as part of related research as well as in aspects summarised in this report.

The 2024 fishing season combined catch recorded by the Traditional Inhabitant Boat (TIB) and Transferable Vessel Holder (TVH) sectors was 200.2 tonnes as TIB and TVH caught 107.7 and 92.5 tonnes respectively. After extrapolating the PNG catch to account for October to November, the total reported PNG catch for the 2024 fishing season was 154 tonnes. The total 2023-2024 TRL catch from all sectors (TIB, TVH, PNG) was 354.2 tonnes, which was 67% of the TAC. This is one of the lowest catches on record to date. The 2024 TVH sector fishing effort was 452 tender-days and TIB sector was 1,659 days fished which equates to a 60.9% and 31.8% decrease, respectively, relative to the previous season.

Standardised catch rates

The nominal catch rates for both TIB and TVH sectors increased but increases were significant for the TVH sector during the 2024 season. The record low effort level for both sectors may have biased the nominal CPUE, and both the TIB and TVH catch per unit effort (CPUE) data series are standardised before being input to the empirical Harvest Control Rule (eHCR). The default standardised models are the “Int-1” model for the TVH series and “Seller” model for the TIB series as described in this report.

Scientific surveys

The stock comprises mainly three age classes, recently settled (6 months old, termed 0yr), recruiting (average 1.5 years old, termed 1yr) and fished (average 2.5 years old, termed 2yr). Annual fishery-independent monitoring of the TRL population has been conducted since 1989 and provide long-term information on the relative abundance of recruiting (age 1+ years) lobsters. The surveys provide key model input data to assess current fishery status and forecast stock biomass. In addition, these data inform the empirical Harvest Control Rule (eHCR) that has been developed for TRL to calculate the Recommended Biological Catch (RBC) each year.

In 2024, the CSIRO team conducted successful dive surveys of 77 sites between the 4th and the 16th of November. In total, 391 TRL were observed and categorized into three age classes: 0+, 1+ and 2+ years. As in previous surveys, most of the TRL observed in 2024 (n=361) were from the Age 1+ cohort. Age 2+ TRL were rarely observed (n=6) as most have emigrated from Torres Strait during August/September to undertake the annual breeding migration. The number of Age 0+ lobsters (n=22) observed during the 2024 survey were significantly lower (6 times) compared to the high numbers observed in 2023 and about half of those observed in 2021 and 2022.

The Age 1+ abundance index for 2024 was the highest pre-season point estimate on record, well above the long-term average for the pre-season surveys (2005-2023). The highest index was recorded at the South-East, followed by Warraber-Bridge and Reef Edge. Similar to 2021-23, Age 1+ index at TI_Bridge was the lowest. The 2024 results for the Age 1+ (point estimate) abundance index was around or above average in all sites except TI Bridge. The large standard error recorded for all regions except Mabuaig and TI Bridge reflects the high variability in counts between sites within these regions.

Monitoring habitat and environmental variables under a changing climate

In recent years, there have been environmental anomalies in the Torres Strait region, and monitoring habitat variables could help in understanding how these affect TRL distribution. The seabed habitat monitoring program has provided one of the longest time series records in Torres Strait, offering valuable insights for future climate change research related to fisheries in the region. High water temperatures can have both direct and indirect (via habitats and food webs) impacts on the TRL fishery.

Given changing climate conditions across northern Australia, this project also reviewed previously established morphometric relationships for TRL, with the aim also of advancing understanding of spatial variability in growth rates. Carapace length and total weight measurements were thus collected from TRL catch samples in 2023, and compared with existing length-weight relationships. No significant differences were found but there were not enough samples across the year and from different locations to reliably make a conclusion about spatial differences in length-weight relationships.

Revision of the empirical harvest control rule (eHCR)

In December 2019, the TRL fishery transitioned from annual stock assessments to using an eHCR to inform the Recommended Biological Catch (RBC). The eHCR uses the average catch over the past five years, or the TAC, as a multiplier to inform the RBC. However, catches over the past five years have been low relative to the TAC due to a number of external factors affecting the fishery. As these factors were outside the range of impacts for which the eHCR was tested, the RAG has recommended in the past substituting these catches with the fishery global TAC in the average catch multiplier in the eHCR but noted that it would be preferable to replace this *ad hoc* approach with a revised formally-tested new eHCR.

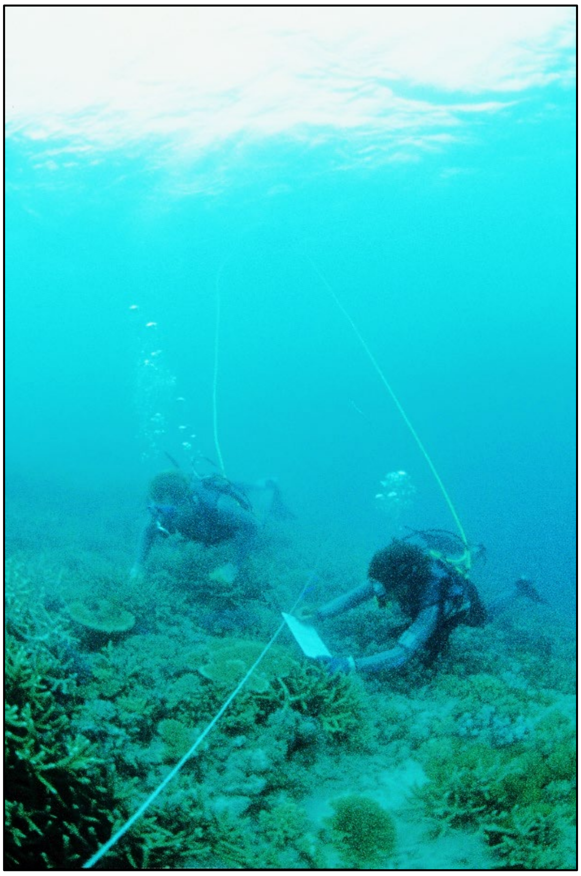
As part of revising the Harvest Strategy (HS) to select a preferred revised eHCR, CSIRO developed a number of alternative kinds of rules that incorporated feedback received. The versions considered were those tuned to meet the HS objectives (e.g., keep the TRL/ 'Kaiar' population fluctuating about the (precautionary) target reference level with very low risk of fishing causing the population to decrease to the limit reference level). The rules were tested by CSIRO using Management Strategy Evaluation (MSE) in combination with a set of four alternative operating models with different parameter settings, different levels and types of uncertainties and climate change impacts, and assuming considerable natural variability.

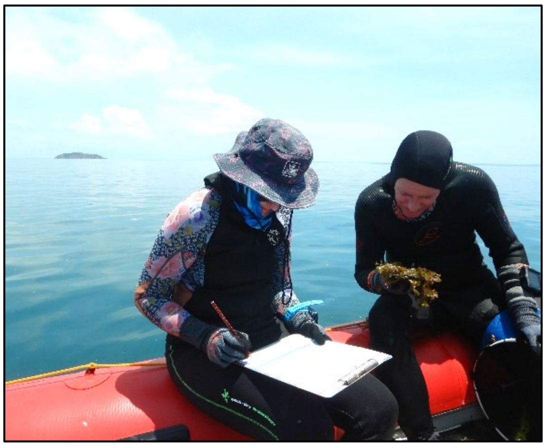
The TRLRAG and TRLWG focussed on comparisons between three types of rules in particular, referred to as the Turtle, Seahorse and Dolphin rules to help capture key features of each. As no consensus was reached at the December 2024 meetings, the decision as to which rule to apply to set the 2024/25 TRL TAC was passed to the PZJA. They agreed to using the midpoint of the outputs from each of the Seahorse and Dolphin rules, which resulted in setting a total TAC (all sectors) of 688 t for the 2024/2025 fishing season, but they also encouraged selecting a preferred rule for longer term implementation. CSIRO have therefore added an additional rule, termed the Osprey Rule, which is an MSE-tested variant of the above rules that is tuned to yield the PZJA-recommended TAC for the 2024/25 season.

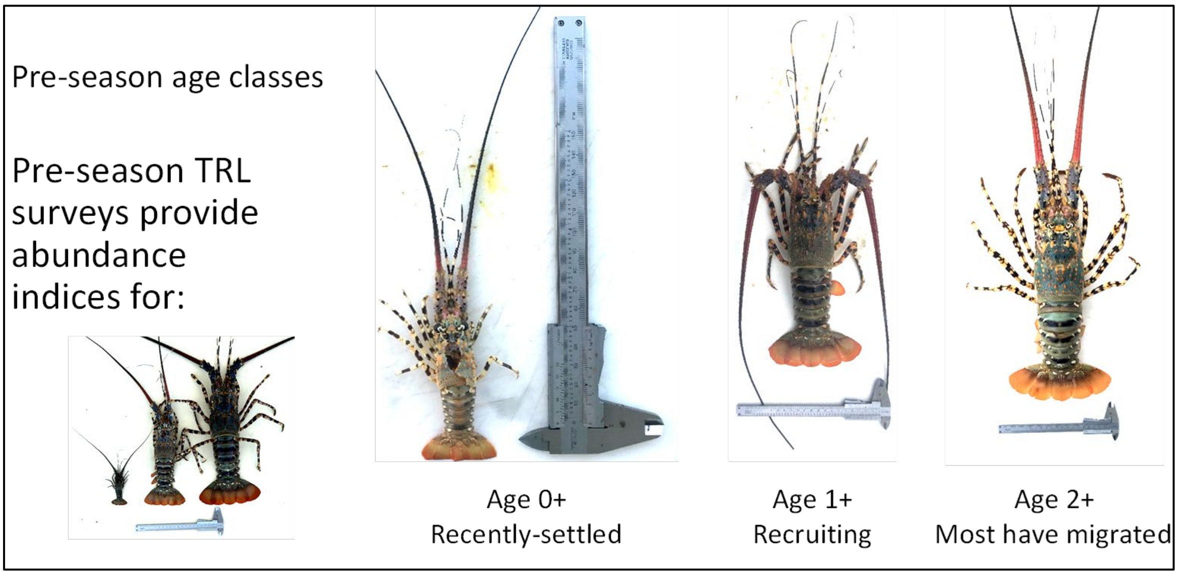
Integrated and bespoke stock assessment

In December 2024, CSIRO conducted an update of the bespoke TRL stock assessment, with the outcomes accepted by TRLRAG38. The integrated statistical population model included the latest (November 2024) Pre-season survey results, the catch total for 2024 and updates to the commercial standardised CPUE (TVH & TIB) data series. The model results indicate that the TRL spawning biomass is at about 84% of the 1973 reference (B_0) level, which is well above the agreed target reference point of B_{65} under the harvest strategy. The target reference point is deliberately conservative to allow for non-commercial take of TRL in support of traditional practices and livelihoods in the Torres Strait.

Based on the stock assessment, the TRL spawning biomass is estimated to have remained above the target reference level during the past six years, having recovered from the lower levels estimated over the period 2017 and 2018, possibly in response to low catches and favourable environmental conditions. The 2024 commercially available biomass estimate (i.e., the lobsters that are available to be caught by the fishery) of 4044 t was about 76 % of the long-term average (1989-2023). However, the model predictions for 2025 indicate this will increase to approximately 130% of the long-term average. Consequently, catch rates in 2025 are predicted to be good although catches may not correspondingly be above average given external factors (e.g. market access) influencing the fishery.







Source: CSIRO

Non-Technical Summary

The Torres Strait tropical rock lobster (TRL) ‘Kaiar’ fishery is important economically as well as culturally to Torres Strait Islanders and supports a non-Islander commercial sector. TRL is shared with Papua New Guinea (PNG) whereas the Queensland East Coast fishery is managed separately. Given the significant importance of Kaiar, fishers and managers need to understand how many Kaiar there are in the region and how many can be caught to keep the population healthy (called target reference points) to ensure future generations can continue to fish them. Ongoing Kaiar research in Torres Strait has led to a good understanding of when there should be concern if the Kaiar population decreases to unacceptably low levels (called limit reference points) that need to be avoided. Scientists, managers and fishers have now agreed in the harvest strategy on what process should be followed if we get close to low levels.

In addition to collecting catch data from fishers (called fishery-dependent data), CSIRO have also been doing annual dive surveys (called fishery-independent data collection) to collect data on Kaiar and their surrounding habitat since 1989. These surveys have been jointly funded by AFMA and CSIRO. During the surveys CSIRO divers count the numbers of Kaiar and note their sizes. These counts are used to estimate Kaiar population size and inform estimates of how many can be caught sustainably in the coming fishing season. In addition, these data are essential inputs to an empirical Harvest Control Rule (eHCR) that has been developed for TRL to calculate the Recommended Biological Catch (RBC). During 2021-2023, the CSIRO dive team included a TIB fisher (Mr Tony Salam) to assist with the Kaiar survey. The survey team also collected environmental and habitat data.

The 2023-24 fishing season catch of 354t was one of the lowest catches recorded to date. During the November 2024 survey, a total of 391 Kaiar were observed and as in previous surveys, age 1+ lobsters comprised the majority of the lobsters observed. Age 2+ lobsters were rarely observed, as most fished lobsters emigrate from Torres Strait during August/September to undertake the breeding migration. Age 0+ lobster numbers were lower than average, suggesting that there is currently not a strong indication of good numbers of Kaiar settling to support the fishery in the following fishing season.

In 2024, the Age 1+ abundance index was the highest recorded since the pre-season survey started in 2005 and well above the long-term average. The abundance index for Age 1+ lobster in 2023 indicates that recruitment was generally widespread across the Torres Strait areas surveyed, with all areas above average, except for Mabuiag and TI Bridge. A revised stock assessment was used to check the status of the Kaiar population, which suggested that the population is currently at a healthy level relative to past reference levels and that fishing effort is low relative to target levels.

The TRLRAG/WG have sought advice on revisions to the empirical Harvest Control Rule (eHCR) under the TRL Harvest Strategy in response to ongoing external circumstances that have been impacting the RAG’s ability to apply the eHCR when providing advice on a Recommended Biological Catch (RBC).

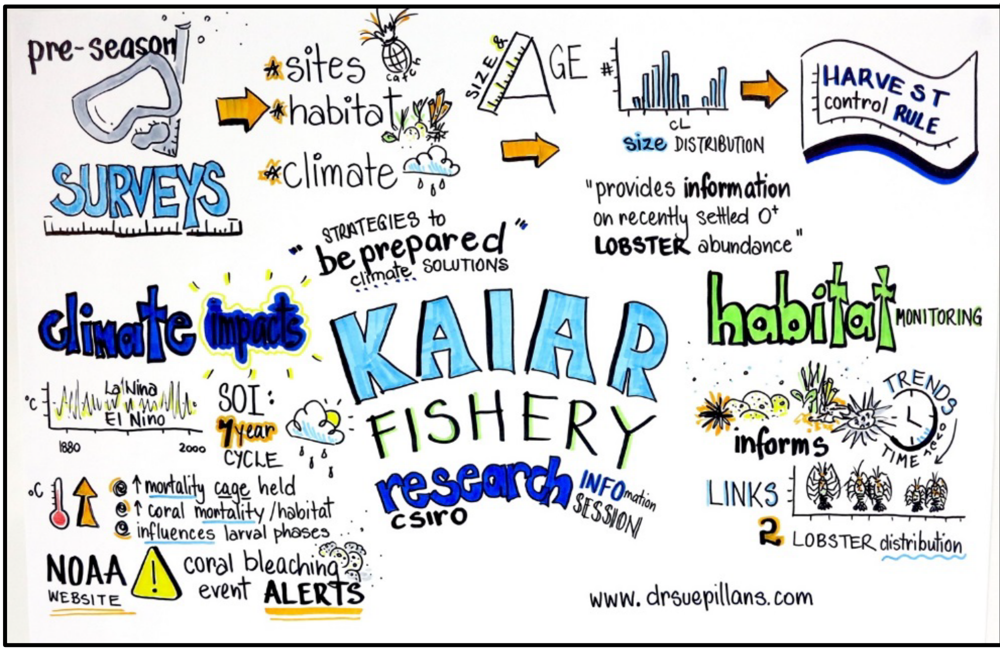
It is considered best practise to review and revise harvest strategies every five years or so, and hence it is also timely to revise the current harvest control rule. This allows an opportunity to better account for market and other external factors that have impacted the fishery in the past few years, in different

ways to conditions when the current rule was first implemented. In addition, as our understanding of the impacts of climate change improves, it is important to use this information in testing any new harvest control rule to ensure it has as good a chance as possible to maintain stock sustainability even under a changing climate.

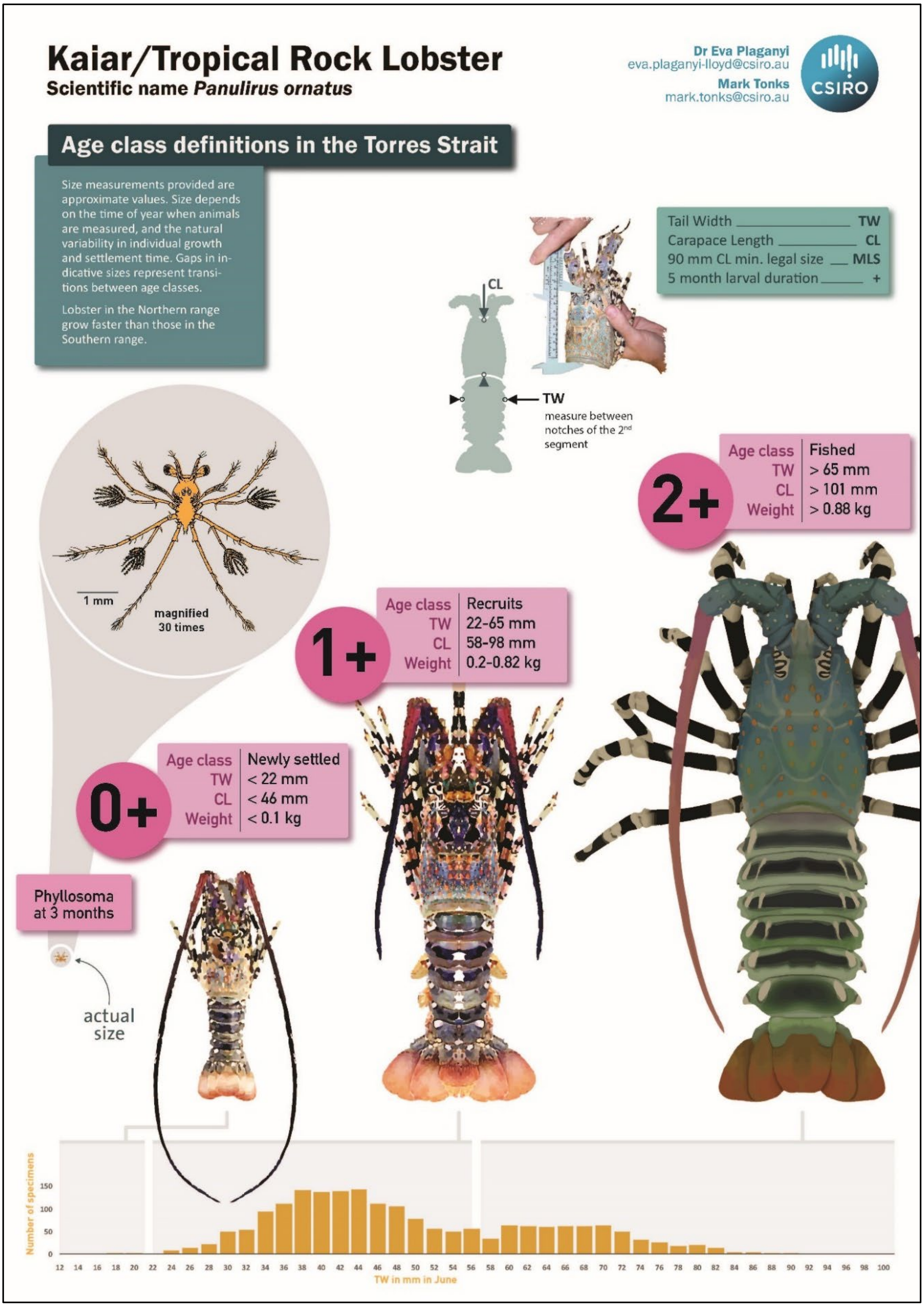
Revising the harvest control rule is time consuming and requires considerable analysis and computer simulations using Management Strategy Evaluation to support checking and comparing how well proposed changes to the harvest control rule perform in meeting objectives. Feedback from Traditional Owners and stakeholders is also incorporated, and everyone can consider the trade-offs between different rules, to collectively support choosing a revised harvest control rule that satisfactorily achieves the management objectives agreed on for the Kaiar fishery.

The lower-than-expected total catches from 2019 to 2024 were agreed by TRLRAG participants to be due to market factors and not because of low lobster abundance. The TRLRAG and TRLWG focussed on comparisons between three new types of rules developed by CSIRO. These were named the Turtle, Seahorse and Dolphin rules to help capture key features of each and non-technical summaries and comparisons of the rules have been shared with participants. As no consensus was reached at the December 2024 meetings, the decision as to which rule to apply to set the 2024/25 TRL TAC was passed to the PZJA. They agreed to using the midpoint of the outputs from each of the Seahorse and Dolphin rules, which resulted in setting a total TAC (all sectors) of 688t for the 2024/2025 fishing season, but they also encouraged selecting a preferred rule for longer term implementation.

See also Appendix A. Non-Technical Chapter Summaries



Visual story of the Kaiar Fishery CSIRO research information session held with the TRL community on Thursday Island in November 2016 explaining the fisheries science (Graphic by Dr Sue Pillans, www.drsuepillans.com)


Kaiar/Tropical Rock Lobster
Scientific name Panulirus ornatus
Dr Eva Plaganyi
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Mark Tonks
mark.tonks@csiro.au
CSIRO
Age class definitions in the Torres Strait
Size measurements provided are approximate values. Size depends on the time of year when animals are measured, and the natural variability in individual growth and settlement time. Gaps in indicative sizes represent transitions between age classes.
Lobster in the Northern range grow faster than those in the Southern range.
Tail Width — TW
Carapace Length — CL
90 mm CL min. legal size — MLS
5 month larval duration — +
CL
TW
measure between notches of the 2nd segment
2+
Age class | Fished
TW | > 65 mm
CL | > 101 mm
Weight | > 0.88 kg
1 mm
magnified 30 times
1+
Age class | Recruits
TW | 22-65 mm
CL | 58-98 mm
Weight | 0.2-0.82 kg
0+
Age class | Newly settled
TW | < 22 mm
CL | < 46 mm
Weight | < 0.1 kg
Phyllosoma at 3 months
actual size
Number of specimens
0 50 100 150
12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90 92 94 96 98 100
TW in mm in June

Glossary

0+/1+/2+	Age-classes (years) of newly settled, recruits, and fished TRL respectively
AFMA	Australian Fisheries Management Authority
CPUE	Catch Per Unit Effort
CSIRO	Commonwealth Scientific and Industrial Research Agency
eHCR	Empirical Harvest Control Rule
HCR	Harvest Control Rule
HS	Harvest Strategy
MSE	Management Strategy Evaluation
RBC	Recommended Biological Catch
TAC	Total Allowable Catch
TIB	Traditional Inhabitant Boat sector
TRL	Tropical Rock Lobster (kaiar) *Panulirus ornatus*
TS	Torres Strait (Zenadth Kes)
TSSAC	Torres Strait Scientific Advisory Committee
TVH	Transferrable Vessel Holder (Licence)
TRL RAG	Tropical Rock Lobster Research Advisory Group
TRL WG	Tropical Rock Lobster Working Group
PNG	Papua New Guinea
PZJA	Protected Zone Joint Authority

Acknowledgements

CSIRO acknowledges the Traditional Owners of the land, sea and waters, of the area that we live and work on across Australia. In particular, we would like to acknowledge the Traditional Owners of Torres Strait, namely the Guda Maluilgal, Kemer Kemer Meriam, Kulkalgal, Kaurareg and Maluligal peoples. We acknowledge their continuing connection to their culture and we pay our respects to their Elders past and present.

Thank you to all TRLRAG and TRLWG members and observers for constructive comments and feedback on all aspects of this research. Big esso to Torres Strait traditional owners for hosting our survey and research meetings on western Zenadth Kes land and sea. Thank you to all TRL RAG members and observers for constructive comments and feedback on all aspects of this research.

We wish to sincerely thank the master (Rob Benn) and crew (Anita Benn and Gracie Dean) of the Wild Blue and Mr Tony Salam for excellent assistance in all aspects of the pre-season dive survey in Torres Strait, and in logistic support. Thanks to AFMA and fishery participants for providing fishery data and to PNG NFA for providing catch summaries.

We thank staff of M.G. Kailis Pty Ltd for providing size data from commercial catches for over a decade. Staff at Pearl Island Seafoods (Thursday Island) kindly volunteered to assist in collecting carapace length and total weight measurements for morphometric analyses.

We thank Darren Dennis, Mick Haywood and Rob Campbell for their previous contributions to the survey and analyses. A special thank you to Marjo Roos for editing and report formatting support, and to Pia Bessell-Browne and Ashley Williams for their role as CSIRO internal reviewers.

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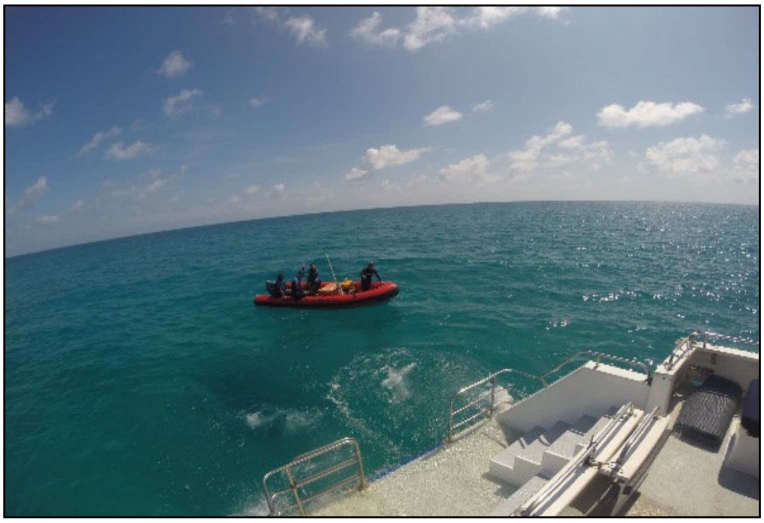


1. Torres Strait Rock Lobster Fishery – Summary of the Catch and Effort Data Pertaining to the 2024 Fishing Season (Dec-2023 to Sep-2024)

Roy Deng, Denham Parker, Steven Edgar, Éva Plagányi, Laura Blamey, Nicole Murphy, Leo Dutra, Kinam Salee, and Mark Tonks

1.1 Summary

In the fishing season 2024 (period of Dec 2023 to Sep 2024), combined catch recorded by the TIB and TVH sectors was 200.2 tonnes, which represents a 19.3% decrease from last season and equates to about 55.9% of the quota for that year. TIB and TVH caught 107.7 and 92.5 tonnes, respectively, representing a 16.9% and 21.9% decrease from the previous season. The Australian sector catches represent 45.4% and 76.4% of the allocations for the TIB and TVH sectors, respectively. PNG 2024 catch data were provided for Dec 2023 as 0.08 tonnes and Jan to Sep 2024 totals 120.6 tonnes. After extrapolation for late season catch plus the adjustment of implementing a hookah ban from 15 Nov 2024 to 31 March 2025, the estimated PNG total season catch was 154 tonnes. The 2024 TVH sector fishing effort was 452 tender-days and TIB sector was 1,659 days fished which equates to a 60.9% and 31.8% decrease, respectively, relative to the previous season.

1.2 Introduction

This chapter provides a summary of the catch and effort data pertaining to the Torres Strait Tropical Rock Lobster (TSTRL) fishery during the 2024 fishing season. (Note, a fishing season begins on 1st December each year and extends through to 30th September the following year).

1.3 Catch Summary

The catch summary in Table 1 is updated with 2024 season data for TSTRL. The TIB sector data are mainly updated from TDB02 - the Torres Strait Catch Disposal Record (CDR) and TVH data are updated mainly from TRL04 and ELOGS - the Torres Strait Tropical Rock Lobster Fishery Daily Fishing Log. PNG data are provided by PNG NFA via AFMA.

The 2024 fishing season combined catch recorded by the TIB and TVH sectors was 200.2 tonnes (rounded) which represents a 19.3% decrease from last season and equates to about 55.9% of the quota for that year. TIB and TVH caught 107.7 and 92.5 tonnes respectively, representing a 16.9% and 21.9% decrease from the previous season. The Australian sector catches represent 45.4% and 76.4% of the allocations for the TIB and TVH sectors respectively.

The PNG TRL catch data are provided annually up until September each year, and hence a pre-agreed method is used to extrapolate the data to obtain a total catch estimate for the current year to represent the period December (of previous year) to November (current year). The method involves using the available catch data over January to September to calculate an average monthly catch which is then substituted for the "missing/forthcoming" months. This means that once data updates are provided each year, it is also necessary to retrospectively update the PNG catch total from the previous year.

The 2023 season total PNG catch estimate was 36t, based on data provided to October 2023 totalling 30t. The 2023 PNG total catch has been revised upwards based on updated catch totals provided by PNG. This yields a total PNG catch for 2023 of 109.9 t. Hence the retrospectively adjusted total TRL catch from all sectors (TIB, TVH, PNG) for 2023 was 358.0t which equates to 68.7% of the 2023 TAC. We note that the total catch used in the 2023 calculations was 277.2t which was 46.3% of the TAC and hence a considerable under-estimate.

PNG 2024 catch data were provided for Dec 2023 as 0.08t and Jan to Sep 2024 totals 120.6t. The PRELIMINARY total of 141.5t shown (Table 1) for use in analyses is an extrapolated value based on the method as used previously, i.e., substituting the average catch from Jan-Sept for the remaining months. However, we received a copy of a notice that PNG were implementing a hookah ban from 15 Nov 2024 to 31 March 2025. As for the Australian sector hookah bans, this does not mean zero catches given free diving, and hence for simplicity we simply here that 10% of the usual catch will be caught via free diving over this period. We note that data on the relative proportions of free diving versus hookah diving would improve these estimates. Assuming full compliance with the hookah ban on fishing, we therefore assume that for the second half of November, the catch is 10% of half an average month's catch, i.e., 0.1 x 0.5 x 13.4t. This suggests a total PNG catch estimate from Dec 2023 to November 2024 of 141.5t taken from catches inside and outside the TSPZ in the PNG jurisdiction (Table 1). In addition, we note from the AFMA catch report to be tabled at the forthcoming TRLRAG, a reported PNG catch allocation within Australian waters during 2024 of 12.493 t which needs to be added to the PNG total, yielding a total catch of 154t.

Based on these estimates, the total TRL catch from all sectors (TIB, TVH, PNG) for 2024 becomes 354t which equates to 66.8% of the 2024 TAC (which was 530t).

Please refer to the following table for summaries of catch:

- Table 1.1 for the annual catch for TSTRL shown by fishing season (Dec-Sept for each year)

At the time of preparing catch summaries for TRLRAG and for input to the eHCR and stock assessment, these were the best estimates available of the PNG catch. We note however that subsequent correspondence confirmed that PNG had implemented a total fishery closure (not just hookah ban) and hence that catches were zero over that period. In addition, at the time of writing this report, updated information was received from PNG that they had revised the PNG catch and discovered some discrepancies, indicating that the overcatch of the TAC as previously reported (around 120 tonnes) was not as severe as previously thought. The revised catch update from NFA for the 2024 catches and the revised total reported catch is thus 107 tonnes, which will need to be taken into account in future analyses, noting also that catch totals correspond in the analyses to the fishing season which starts in December of each year.

Table 1.1. Total annual catch (in tonnes) for each of the sectors as indicated.

SEASON	TIB	TVH	PNG DIVERS	PNG TRAWL	TS TOTAL
2001	52.0	79.9	173.0	5.4	310.3
2002	68.0	147.2	327.0	42.8	585.0
2003	123.0	358.8	211.0	5.4	698.2
2004	210.4	481.0	182.0	0.0	873.4
2005	367.6	549.0	228.0	0.0	1144.6
2006	140.5	135.4	142.0	0.0	417.9
2007	268.7	268.6	228.0	0.0	765.3
2008	185.7	100.4	221.0	0.0	507.1
2009	147.8	91.1	161.4	0.0	400.3
2010	140.0	282.6	292.8	0.0	715.4
2011	199.1	503.5	165.0	0.0	867.6
2012	142.4	387.3	173.7	0.0	703.4
2013	142.5	361.7	108.3	0.0	612.5
2014	198.8	273.2	151.4	109.8	733.2
2015	202.6	152.7	235.7	0.0	591.0
2016	267.1	243.0	248.0	0	758.1
2017	111.6	166.3	113.0	0	390.9
2018	127.4	134.1	156.4	0	417.9
2019	260.6	156.1	167.0	0	583.7
2020	216.3	143.2	126.4	0	485.9
2021	127.6	116.3	97.0	0	340.9
2022	150.1	139.7	88.8	0	378.6
2023	129.6	118.5	109.9	0	358.0
2024	107.7	92.5	12.5+ 141.5*	0	354.2
Mean of last 5 years	146.3	122.0	115.2	0.0	383.5

* Note: see text for details re PNG 2024 catch estimate and 2023 catch total updates

1.4 Effort Summary and Nominal CPUE

The effort summary in Table 1.2 is updated from the same data sources as the catch summary. The effort unit for TVH is tender-shot day and TIB is crew day fished, adjusted from the original data source.

The 2024 TVH sector fishing effort was 452 tender-days and TIB sector was 1,659 days fished which equates to a 60.9% and 31.8% decrease, respectively, relative to the previous season.
The nominal catch rates for both TIB and TVH sectors increased but increases were significant for the TVH sector during the 2024 season. However, the record low effort level for both sectors, can be

expected to substantially bias the nominal CPUE, hence also why a standardised index is preferred (see Chapter 7 and Chapter 8).

Summaries of the effort data and CPUE data are provided in the following figures and tables:

- Table 1.2 for the annual effort for TVH and TIB sector
- Figure 1.1 for TIB and TVH annual effort trajectories
- Figure 1.2 for TIB and TVH annual nominal CPUE trajectories

Table 1.2. Effort for TVH (tender-shot days) and TIB (days fished).

SEASON	TVH	TIB
2004	5235	4823
2005	4393	8606
2006	2435	4791
2007	2869	7099
2008	1211	5787
2009	1308	4859
2010	2368	3715
2011	2668	3457
2012	2380	2330
2013	3008	288
2014	2910	2925
2015	2683	3217
2016	2654	2932
2017	2515	3100
2018	1506	3537
2019	1911	4530
2020	1267	2742
2021	1621	2962
2022	1352	3296
2023	1156	2433
2024	452	1659

Figure 1.1. TIB and TVH annual effort trajectories.

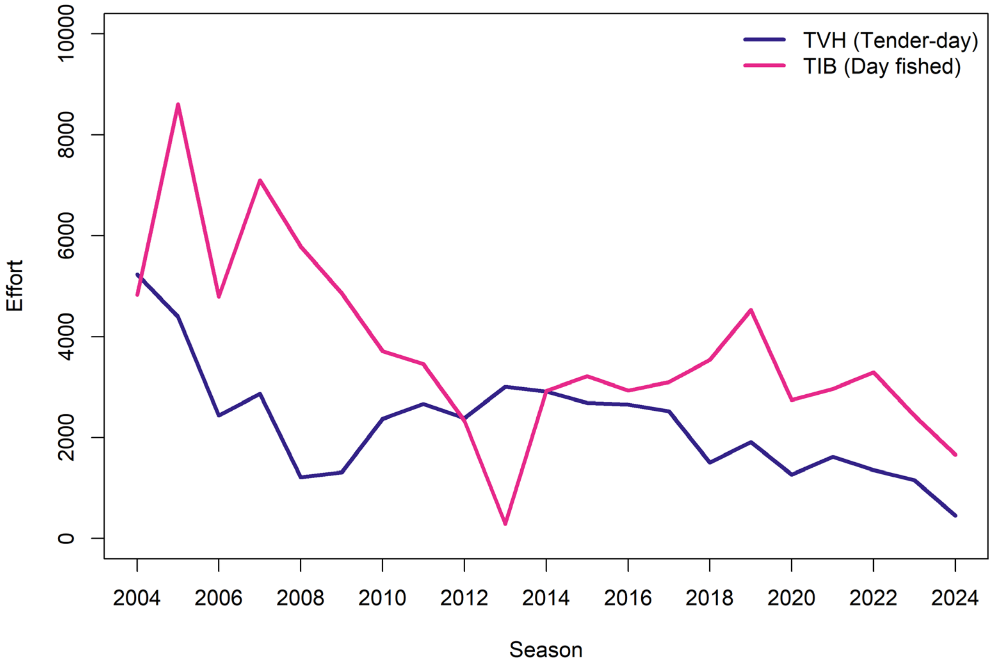
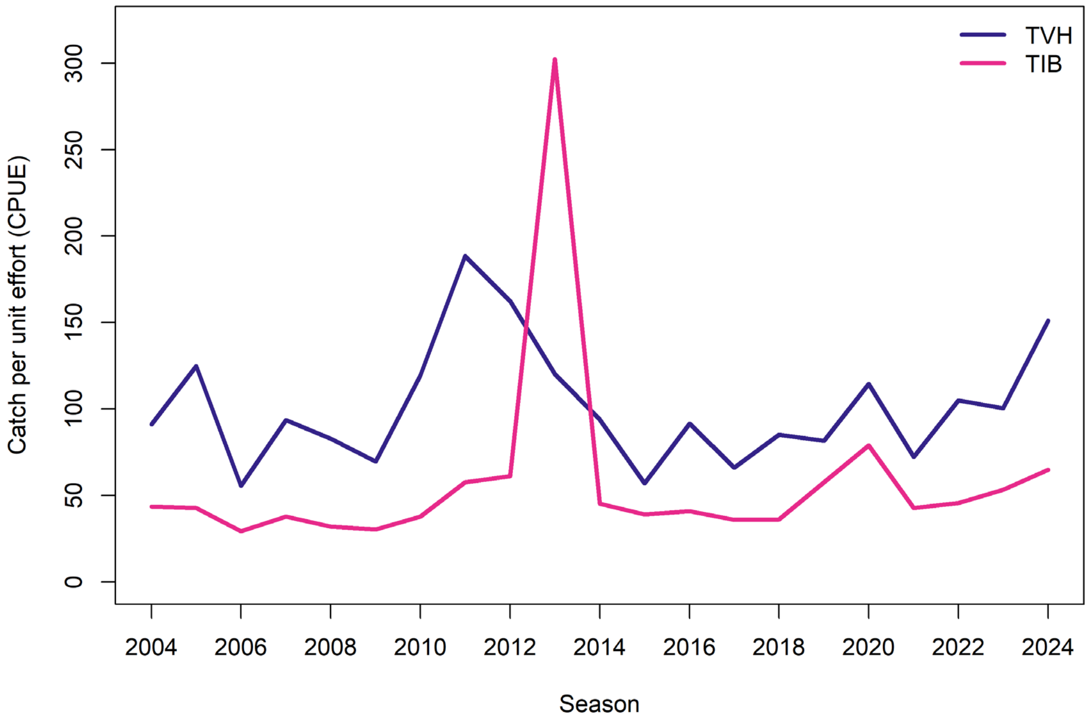


Figure 1.2. TIB and TVH annual nominal CPUE trajectories.



2. Torres Strait Tropical Rock Lobster 2024 Pre-Season Population Survey

Leo Dutra, Nicole Murphy, Steven Edgar, Kinam Salee, Mark Tonks, Roy Deng, Laura Blamey, Denham Parker, and Éva Plagányi

2.1 Summary

The 2024 yearly Torres Strait Tropical Rock Lobster (TRL) survey was the 36th – among the longest monitoring program in the world. The survey team completed a total of 77 sites, collecting data to calculate abundance indices for three age classes: Age 0+ (recently settled lobsters), Age 1+ (recruiting lobsters) and Age 2+ (mature adults). The CSIRO team used the standard 2000m2 belt transect method (2 divers per site each scanning 2m by 500m). A new abundance index (Ref2024) was proposed after review of stratum and incorporating data from three sites consistently surveyed over the past five years. Average transect distance was 442m (88% of the average total distant swam), which ensures a non-significant impact on the calculation of the Age1+ index. The survey recorded 391 TRL, with 162 lobsters measured for tail width (TW) and sex determination. Males constituted 51% and females 49% of the measured lobsters. As in previous years, Age 1+ lobsters were the predominant age class observed (n=363) and showed the highest pre-season point estimate on record. Age 0+ abundance index point estimate showed a significant decrease from 2023 and previous years; it is the second lowest since 2005, only above 2017. Not unexpected, counts of Age 2+ were low because at the time of the survey most had emigrated to breed. Survey results highlight year-to-year variability in spatial distribution of TRL in the region.

2.2 Introduction

The 2024 Tropical Rock Lobster (TRL) Pre-season survey was conducted between the 4th and the 16th of November 2024. The CSIRO TRL dive survey team included Leo Dutra (science leader), Nicole Murphy (survey leader), Kinam Salee, Steven Edgar (dive coordinator) and Mark Tonks who completed 77 survey sites, starting at site N150 and following an anticlockwise direction (Figure 2.1). CSIRO used the tender “CHRIS B” to conduct the dives, supported by the mothership “Wild Blue” (Rob Benn Holdings) (Figure 2.2).

Winds during the 13-day survey ranged between 15-25 knots (Figure 2.3) and underwater visibility averaged around 4m (range 1-10m). In 2024, the survey started during neap tides, with weak currents in the first half of the survey, shifting to stronger spring tidal flow in the second half. Conditions allowed for a good visual census and collection of TRL.

Figure 2.1. Map of western Torres Strait showing the sites surveyed during the 2024 TRL pre-season survey. *The yellow dots and corresponding numbers are site identifiers for the survey.*

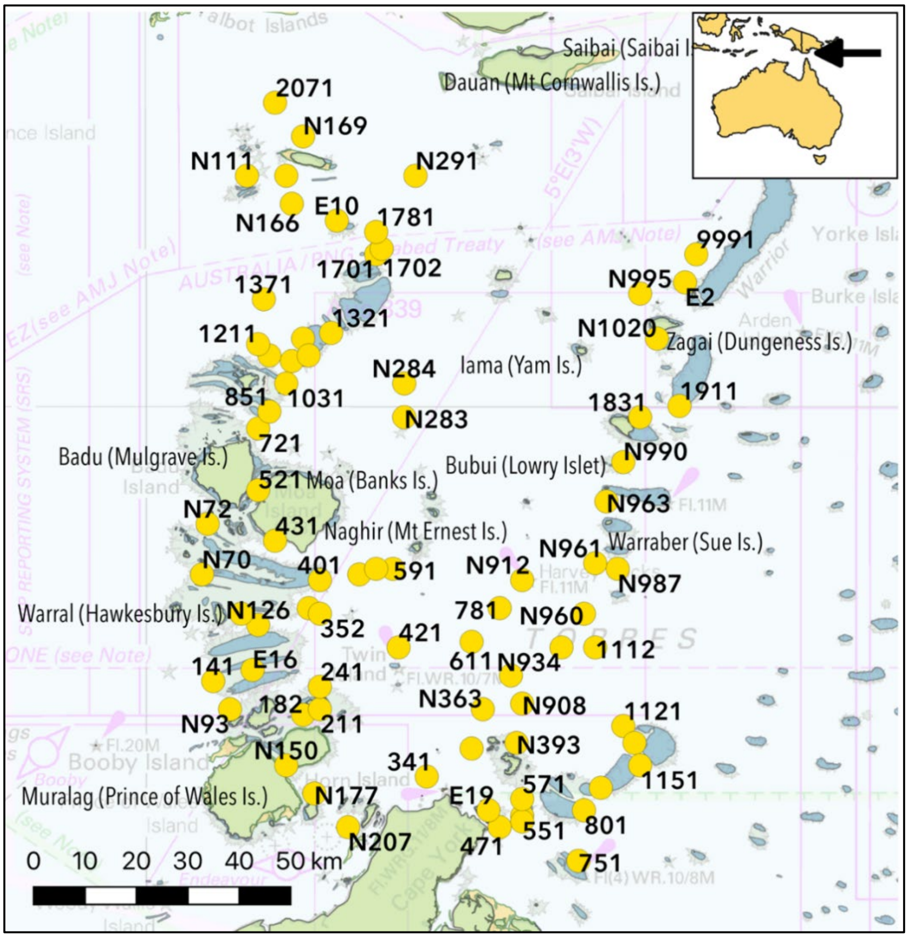


Figure 2.2. Boats used during the 2024 pre-season survey: Mothership "Wild Blue" (left) and tender "Chris B" (right) were used to support the dives.

Figure 2.3. Prevailing weather conditions during the 2024 TRL pre-season survey were windy (15-25 knots) and mostly cloudy.

Three research permits were required to conduct research associated with 2024 TRL population surveys. These included:

- Protected Zone Joint Authority Permit
    - Collect no more than 430 lobster per survey within the area of Australian Jurisdiction in the Torres Strait Tropical Rock Lobster Fishery
- Queensland General Fisheries Permit
    - Collect no more than 430 lobsters in tidal waters east of longitude 142˚ 31´ 49˝ east and north of latitude 14˚ south
- Great Barrier Reef Marine Park Authority Permit
    - Collect no more than 35 juvenile lobster in total (≤90mm carapace length) per year from 7 sites from within the Great Barrier Reef Marine Park Zone (; sites E19, 471, 541, 551, 571, 751, 801), and
    - Collect no more than 5 juvenile lobster per site per year from within the Great Barrier Reef Marine Park Zone

2.3 Methods

2.3.1 Site Survey

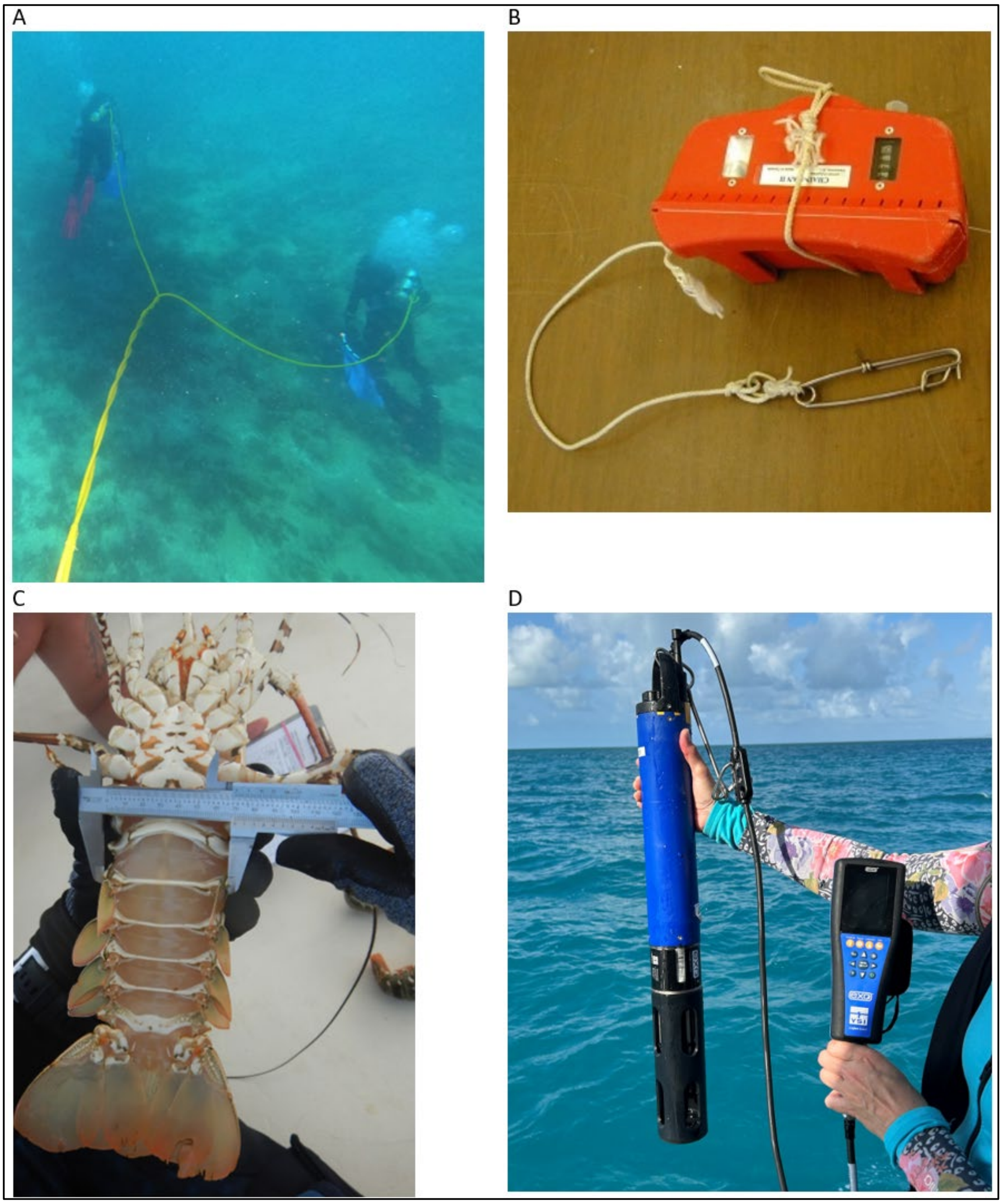
The CSIRO dive team used the standard 2000m^2 belt transect method (2 divers per site each scanning 2m by 500m following currents; Figure 2.4A) with transect distance measured using a Chainman® device (Figure 2.4B). Divers follow the no decompression limits set by the Australian scientific diving code (AS2299.2). Dive depths recorded in previous surveys are used to inform the dive plan (Appendix B), noting variations in depth due to times of tides and direction swam require extra attention in adhering to dive standards. As a result, when dive time limits are reached before completion of the full 500m transects – often due to a lack of tidal current and depth – observed lobster counts are standardised to an area of 2000m^2. At the completion of each transect the divers record the following data in data sheets (Appendix C):

- The number of TRL caught per age-class
- The number and age-class of those observed but not caught
- Depth
- Visibility
- Current speed
- Distance and direction swum from site co-ordinate
- Habitat and substrate characteristics of the site

Representative samples of TRL were caught and measured (tail width, TW; Figure 2.4C) to provide fishery-independent size-frequency data. Since 2019, temperature and depth profiles were measured at sites using a small Van Essen CTD Diver logger attached to a diver's harness. Since 2021, additional water column data (chlorophyll, depth, fluorescent dissolved organic matter, conductivity, dissolved oxygen, salinity, turbidity, total suspended solids, total dissolved solids, pH and temperature) were collected (up to 25m deep) using a hand-held sounder (Xylem - YSI EXO2 Multiparameter water quality sonde) deployed from the mothership 'Wild Blue' (Figure 2.4D).

In addition, other species of interest (i.e., pearl oyster (*Pinctada maxima*), crown-of-thorns starfish (*Acanthaster planci*) and holothurian species (e.g., *Stichopus herrmanni*)) were counted and the habitat is characterised using estimated percent cover for the various substrate and biota types (sand, mud, hard substrate (consolidated rubble, limestone pavement, boulders), seagrass, algae, sponges, whips and live coral). The presence of bleached coral was also recorded, where applicable. These data were recorded onto data sheets (Appendix C), which also include the direction and distance swum from start coordinate.

Figure 2.4. Picture of (A) CSIRO Divers sampling a standard 500m x 4m belt transect, (B) the Chainman® device used to measure transect length, (C) tail width measurement of caught tropical rock lobster, and (D) the hand-held sounder (Xylem - YSI EXO2 Multiparameter water quality sonde) used to collect additional water column data during the survey.



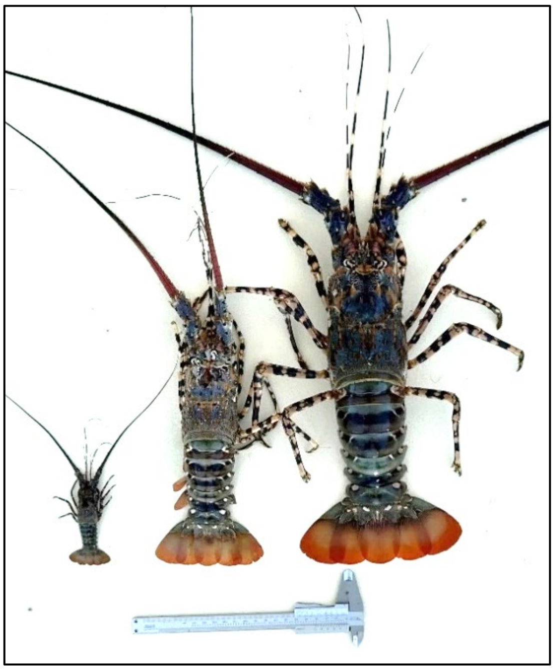
2.3.2 Survey Data Analysis

Upon completion of the transect dives, completed data sheets were entered into the project's relational database and verified for accuracy prior to analysis. An abundance index was calculated for each stratum and the entire survey area for three age classes (Figure 2.5):

- Age 0+ (recently settled lobsters)
- Age 1+ (recruiting lobsters)
- Age 2+ (adults)

Following the 2024 survey, data analyses were presented at TRLRAG meetings held in December 2024.

Figure 2.5. Tropical Rock Lobster age classes (left to right): Age 0+, or recently settled lobsters; Age 1+, or recruiting lobsters, and Age 2+ lobsters (adults).



2.3.2.1 History of Survey

Since the first TRL survey in 1989, the survey design and method have been modified to accommodate advances in technology, new knowledge generated through the project and financial and the safety issues (e.g., Australian Standard for Scientific Divers (AS2299.2)). The history of changes in the survey design is summarised as follows:

- The 1989 benchmark survey aimed to provide data for stock assessment and to monitor annual variation of the lobster stock. It applied a stratified survey method, deploying 542 transects (paired transects per site) in 7 weeks, rope and time swam to estimate transect area, and radar position fixes and multiple compass bearings to locate sites (Pitcher *et al.* 1992b, 1992a; Pitcher *et al.* 1997).
- Between 1989 and 2001 abbreviated fixed site surveys aimed to determine the relative abundance of the recruiting and fished year-classes (Ages 1+ and 2+ respectively), using a subset of benchmark survey (82 transects in 41 sites) deployed in June-July each year.

- In 1992 the survey design incorporated GPS coordinates to locate sites. This allowed the first recording of distance swum to compare with the timed swim data (Ye *et al.* 2004; Ye *et al.* 2005).
- The availability of the ®Chainman device in 1996 and subsequently in 1998-2001, enabled accurate measurements of the distance swam (transect length) underwater. The combined data of transect distance and time swam allowed the conversion of the abundance data from timed swim to measured transect (500 m by 4 m) records. This standardisation enabled comparisons across years (Ye et al., 2004).
- In the second benchmark survey (2002) the location and stratum of each site was reviewed by incorporating extensive seabed habitat data, obtained by CSIRO between 1989-2001. Also, the 2002 survey used only one transect at each selected location to increase the spread of transects in the survey area (Ye *et al.* 2004).
- The sampling strata areas of the 2004-2005 annual survey were modified from the 2002 design to include updated seabed habitat information, with nine strata sampled in 2004 and eight in 2005. The 2005 pre-season survey design was modified to estimate relative abundances with higher precision (Ye *et al.* 2007).
- Abbreviated pre-season surveys, conducted in November, were introduced in 2008 with the aim of calculating abundance indices for recruiting Age 1+ lobsters. The pre-season surveys also calculated abundance index for recently settled Age 0+ lobsters. Age 2+ lobsters continue to be monitored, but at the time of the pre-season survey most have already emigrated to spawn.
- In 2005-2008 additional sites were added to increase precision of Age 1+ abundance index with 130 sites surveyed.
- Between 2014-2024 the number of sites surveyed was reduced to 77 due to financial constraints, and after having considered cost-benefit analyses that also accounted for survey precision (Dennis *et al.* 2015).
- In 2024, CSIRO reviewed the stratum areas and incorporated data from sites N283, N284 and N912, which have been consistently collected in the last 5 years, into the calculation of the abundance index for Mid-Year Only (MYO) sites, creating the Ref.2024 index.

2.3.2.2 Steps to Calculate Abundance Index per Age Class

Step 1: Correcting count of lobsters to represent complete transects

The total count of lobsters (*N*) per age class is the total number of lobsters (including those that were caught and those that were only observed) counted for a complete transect of 500m in length and 4m in width, covering an area of 2,000m^2. For cases where transects needed to be stopped before reaching the complete length of 500m (i.e., so-called partial transects, such as due to a combination of bottom time constraints and diving conditions), the total number of lobsters counted was scaled using Equation 1:

Equation 1

$$N_{(Age_i)} = (c_{Age_i} + m_{Age_i}) \times \frac{2{,}000}{T_l \times T_w}$$

Where:

N: lobster count

Age_i: age class *i*
c_{Age_i}: number of lobsters of age class *i* caught (sum of counts from 2 divers on paired transect)
m_{Age_i}: number of lobsters age class *i* observed but not caught (sum of counts from 2 divers on paired transect)
T_l: transect length
T_w: transect width

Step 2: Standardising lobster count per transect based on survey date

Within the Torres Strait survey area, the abundance of lobsters within each age class varies throughout the year due to migration and life cycle (including mortality, emigration, and settlements). Because the survey is not conducted on the same days each year, consistent with past analyses, each lobster count per transect was standardised based on the survey date (calendar day) to enable comparison across years and seasons (i.e., mid-year and pre-season). This step applies mortality rates adjusted to the day of the transect data collection relative to a reference day in order to standardise comparisons across years.

The date-standardised lobster count per age class represents the count of lobsters per age class estimated for June 30th of that year over a complete transect calculated using Equations 2, 3, and 4:

Equation 2 $$Nc_{Age0+} = e^{1.15*\left(\frac{cd-180}{365}\right)} * N_{Age0+}$$

Equation 3 $$Nc_{Age1+} = e^{1.15*\left(\frac{cd-180}{365}\right)} * N_{Age1+}$$

Equation 4 $$Nc_{Age2+} = e^{0.81*\left(\frac{cd-180}{365}\right)} * N_{Age2+}$$

Where:
Nc: lobster count adjusted for calendar day
cd: calendar day

For standardising purposes, the 1+ and 0+ age-specific annual mortality rate is set at 1.15 and the emigration/mortality rate for 2+ lobsters at 0.81 yr^{-1}, based on the original estimates derived by Pitcher et al. (1997). Given the rapid growth and mortality/emigration of these lobsters, this approach helps standardise for inter-annual differences in the timing of Preseason surveys, such as when conducted at the start or end of November in any year.

Step 3: Calculating the Abundance Index per Stratum

The abundance index per stratum and age class represents the average density of lobsters per transect area (2,000m^2) and is calculated as the mean of all corrected lobster counts per age class (*Nc*, Equations 2-4) per stratum.

Table 2.1. Surface area and proportional area (to the entire survey area) of each stratum surveyed.

This information was used to calculate the Ref.2024 abundance index.

Stratum	Surface area (m^2)	Proportional survey area incl. Buru	Proportional survey area excl. Buru
BURU	1,689x10^6	0.194	0
MABUIAG	1,394 x10^6	0.160	0.199
KIRCALDIE_RUBBLE	960 x10^6	0.110	0.137
TI_BRIDGE	2,924 x10^6	0.336	0.417
WARRABER_BRIDGE	744 x10^6	0.086	0.106
SOUTH-EAST	893 x10^6	0.103	0.127
REEF EDGE	93 x10^6	0.011	0.013

Step 4: Calculating the Abundance Index for the Entire Survey Area for Different Scenarios

As the seven strata differ in surface area (Table 2.1), the yearly abundance index for the entire survey area was calculated by summing the stratum-specific indices, each weighted according to its proportional area (Table 2.1) using Equation 5:

Equation 5 $$I_{(age)} = \sum_i p_i \times I_i^{(age)}$$

where:

$I_{(age)}$: Abundance index for the entire survey area per age class

$I_i^{(age)}$: Abundance index for stratum *i* per age class

p_i: Area of stratum *i* as a proportion of entire survey area (Table 2.1)

In 2024, the following scenarios were used to calculate the TRL abundance index for the entire survey area:

1. All sites surveyed: index uses all (77) sites surveyed with revised stratum surface areas (Table 2.1).
2. All sites excluding Buru (Ex. Buru): index uses all sites excluding the sites in the Buru stratum with revised stratum surface areas (Table 2.1). This index has been reported to compare the sensitivities of the index without the Buru stratum.
3. Mid-Year Only (MYO) sites: index uses 74 sites commonly surveyed during mid-year surveys. The index utilises the common sites across mid-year survey (longer time series since 1989; not currently conducted) and pre-season surveys that started in 2008._
4. Reference 2024 sites (Ref2024): index uses all 77 sites surveyed during each of the last 4 years with revised stratum surface areas (Table 2.1).

2.4 2024 TRL Survey Results

A total of 77 sites were surveyed in 2024. Divers aim to complete the full transect length at each site but occasionally transects were shorter than 500m due to bottom time limits of dive tables and weak currents. The average distance swam per site in 2024 was 442m, or 88% of the transect distance (Table 2.2), the lowest point since 2014 (not shown). Partial transects are common during the survey. Testing and analysis presented at TRLRAG35 (AFMA 2023) showed that the overall transect length recorded in 2024 is within the range that do not cause a significant impact on the calculation of Age1+ index. The lower-than-expected average distance swam in 2024 was due to a combination of deep dives (with short bottom time limits), weak currents and high number of TRL observed and speared, especially on the Eastern side of the survey area, which slowed down the completion of transects.

Table 2.2. Total survey distance swam since 2020.

	2020	2021	2022	2023	2024
Average distance swam per site (m)	475	495	485	480	442
Percentage of total distance swam	95%	99%	97%	96%	88%

In the 2024, survey a total of 391 TRL were observed and categorized into three age classes, compared to a total of 309 counted in 2023, 266 in 2022 and 356 in 2021 (Table 2.4). Despite the lowest average distance swam recorded, the 2024 survey registered the third largest absolute counts of Age 1+ lobster in the 74 Mid-Year Only (MYO) sites, only below counts recorded in 2014-2015 (Table 2.3). Of these, 162 were measured (TW) and their sex determined (Table 2.4). Males comprised 51% of the TRL measured (n=82) and females 49% (n=80) (Table 2.5). The sex ratio in 2024 was similar to previous years with a more or less even sex distribution.

Table 2.3. Counts of TRL across the mid-year only (MYO) sites since 2005.

YEAR	N-Sites	Age-0+	Age-1+	Age-2+	Total
2005	68	165	167	20	352
2006	71	55	268	3	326
2007	72	60	264	18	342
2008	73	96	151	6	253
2014	72	131	295	11	437
2015	73	76	459	17	552
2016	73	87	138	15	240
2017	74	19	153	4	176
2018	73	52	225	5	282
2019	74	92	337	4	433
2020	74	101	216	7	324
2021	74	45	304	4	353
2022	74	50	201	11	262
2023	74	126	174	7	307
2024	74	22	358	6	386

As in previous surveys, most of the TRL observed in 2024 (n=363) were from the Age 1+ cohort. Age 2+ TRL were rarely observed (n=6) as most have emigrated from Torres Strait during August/September to undertake the annual breeding migration. The number of Age 0+ lobsters (n=22) observed during the 2024 survey were significantly lower (6 times) compared to the high counts in 2023 and about half of those observed in 2021 and 2022 (Table 2.4).

Table 2.4. Comparison of TRL numbers per age class observed from 2020 to 2024 pre-season surveys.

Age	2020	2021	2022	2023	2024
0+	101	45	50	126	22
1+	225	307	205	176	363
2+	7	4	11	7	6
Total	333	356	266	309	391

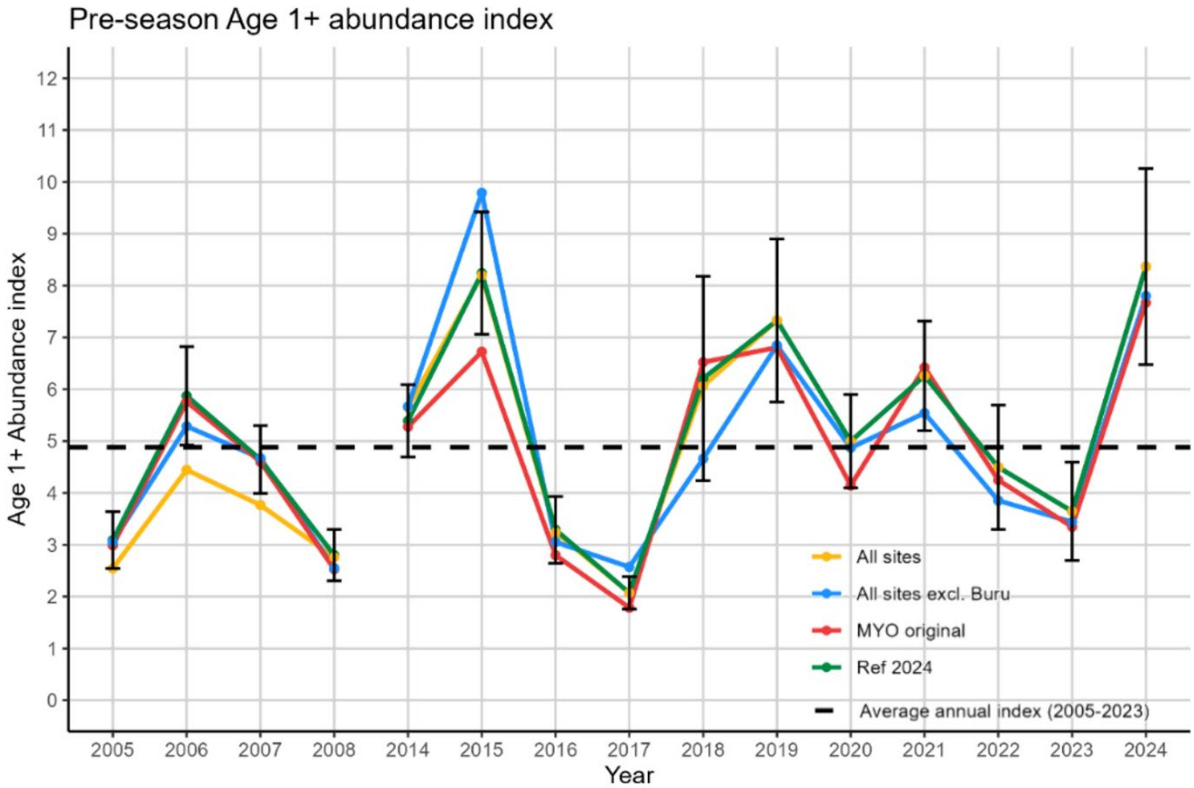
Table 2.5. Comparison of sex ratios across surveys.

Sex	2020	2021	2022	2023	2024
Female	99 (55%)	79 (45%)	63 (51%)	58 (44%)	80 (49%)
Male	80 (45%)	95 (55%)	61 (49%)	74 (56%)	82 (51%)
Total	179	174	124	132	162

2.4.1 Age 1+ TRL Lobsters

In 2024, the Age 1+ abundance index for the Ref2024 sites (green line in Figure 2.6) was the highest pre-season point estimate on record, well above the long-term average for the pre-season surveys (2005-2023) shown by dashed black line. The 2024 survey index variance was higher compared to those for 2020-23 surveys, and similar variability observed in the 2018-19 surveys, also with high point estimates.

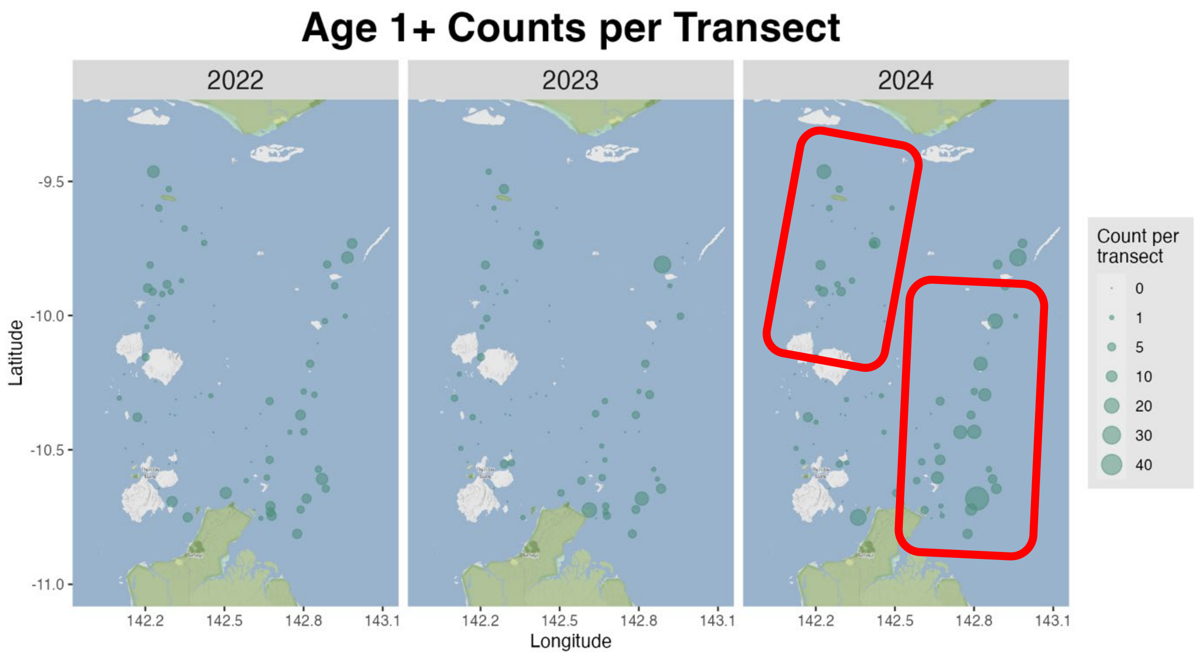
Figure 2.6. Torres Strait TRL (P. ornatus) Age 1+ abundance index (2024) shown for a number of alternative scenarios as indicated. *Standard errors for Ref2024 sites are shown as vertical bars. The long-term average for the pre-season*



surveys (2005-2023) is indicated by the horizontal black dashed line.

Age 1+ TRL in 2024 had a similar spatial distribution compared to 2022-23. However, counts (sizes of circles in Figure 2.7) were significantly higher compared to previous years. Historically, the eastern side of the surveyed area shows higher density (number TRL per transect) of Age 1+ TRL (Figure 2.8) and 2024 followed this trend. The only exception was 2018, when Age 1+ TRL density was higher on the western side of the survey area. The red squares in Figure 2.7 show the areas where counts were significantly higher in 2024 compared to previous 2 surveys. Still, changes in spatial distribution over time and space are natural occurrences (sizes of circles changes from year to year and within each year and changes in density between the West and East sectors and sites). As in the previous two years, the counts of Age 1+ TRL in the southeast region remained high (Figure 2.7).

Figure 2.7. Torres Strait TRL (P. ornatus) Age 1+ counts per transect across all sites surveyed in 2022 to 2024 (n=77). *The red boxes show representative areas for the survey, where numbers (sizes of circles) were significantly higher than observed during the 2022 and 2023 survey years (i.e., fewer or smaller circles).*



The abundance index for Age 1+ TRL across the survey regions (strata) in 2024 (Figure 2.9) indicates that recruitment to the fishery is generally widespread across the different regions surveyed. The highest recruitment was recorded in the South-East stratum, followed by Warraber-Bridge and Reef Edge (Figure 2.9). Similar to 2021-23, recruitment at TI_Bridge was the lowest (Figure 2.9 and Figure 2.10). The 2024 results for the Age 1+ (point estimate) abundance index was around or above average in all sites except TI Bridge. The large standard error recorded for all regions except Mabuaig and TI Bridge reflects the high variability in counts between sites within these regions (Figure 2.10B).

The indices of TI Bridge and Mabuiag are generally below the historical average (Figure 2.10; 13 years out of 15 and 9 out of 15 years for TI Bridge and Mabuiag, respectively – data not shown). Low indices observed at these regions are potentially due to habitat differences and possibly varying currents and settlement, the latter could possibly explain low counts in Kirkaldie Rubble in 2023. In 2024 and 2023 counts for Age 1+ TRL were more variable within Warraber Bridge and Reef Edge regions compared to 2021-22 (higher standard errors shown in Figure 2.9B). This again shows high variability in survey counts across regions and years.

Figure 2.8. Torres Strait TRL (P. ornatus) Age 1+ density (#TRL per transect) for 2014-24 across the western and eastern regions of the surveyed area (W = West; E = East).

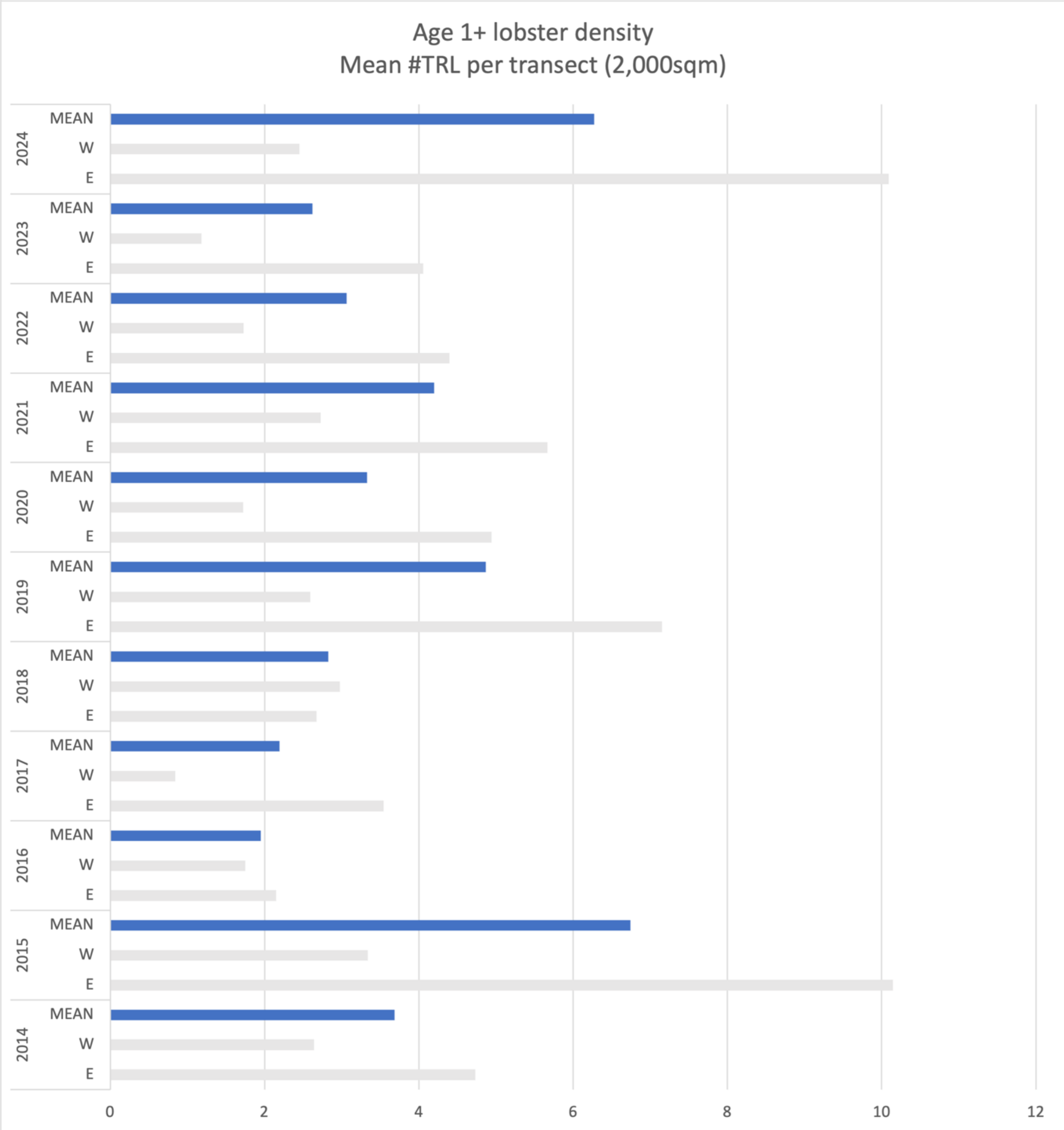


Figure 2.9. (A) The western Torres Strait showing strata (regions) sampled during the annual Torres Strait TRL (P. ornatus) surveys. (B) The Torres Strait TRL 2024 Age 1+ abundance index and standard errors by regions (stratum). *The black dashed line indicates the mean abundance index for the period between 2005 and 2023. Note that the 'Reef Edge' stratum is not shown on the map as this stratum consists of sites distributed across the survey area, including 1321, 9991, E10, E16, E19 and E2.*

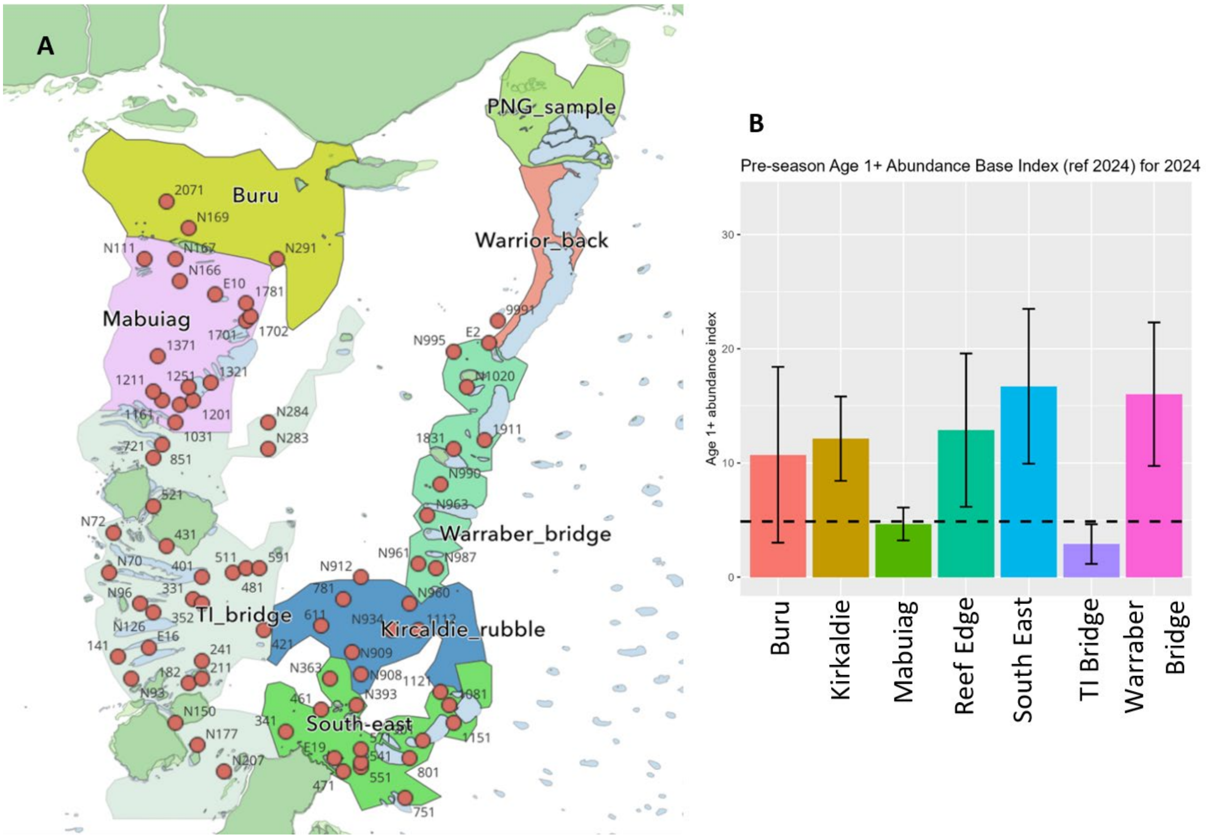
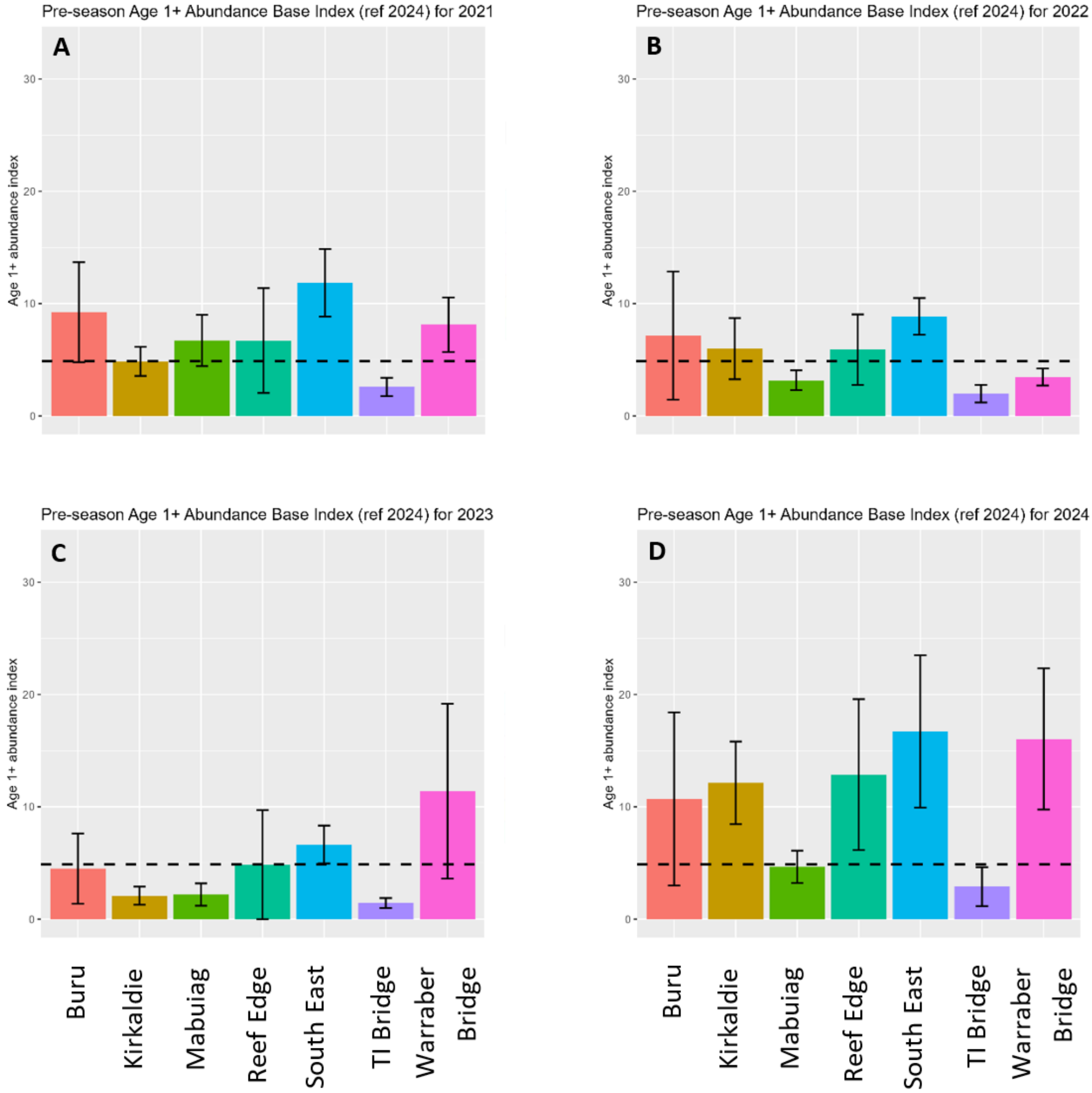


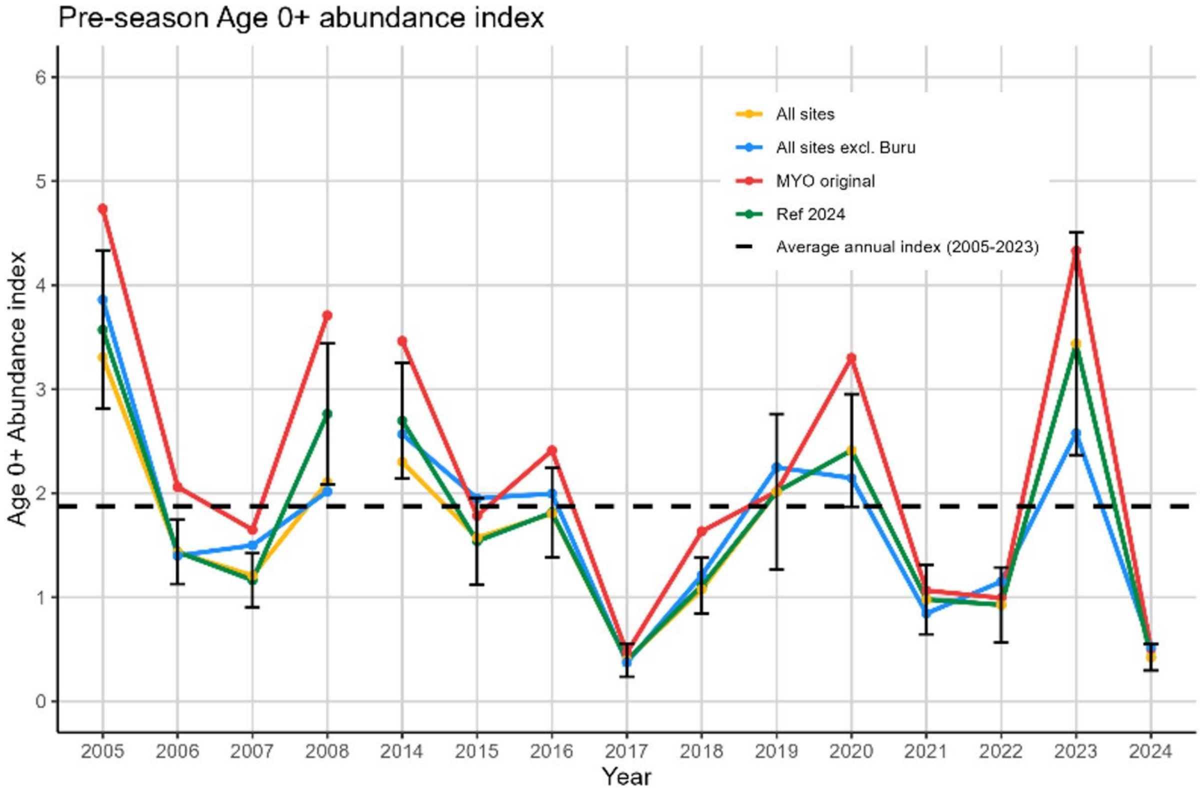
Figure 2.10. Torres Strait TRL (P. ornatus) Age 1+ abundance indices (and standard errors) across years and strata. *The black dashed line represents the mean abundance index for the period between 2005-2023 for Mid-Year Only (MYO) sites.*



2.4.2 Age 0+ TRL Lobsters

In 2024, the Age 0+ abundance index point estimate showed a significant decrease from 2023 and previous years. In fact, the index is the second lowest since 2005, only above 2017 (Figure 2.11). As opposed to the Age 1+ lobsters, which tend to be more abundant on the Eastern side of the survey area, the Age 0+ TRL typically settle in the west (Figure 2.12 and Figure 2.13). In 2024, over 2 times more Age 0+ TRL settled on the western side (mostly around Mabuiag and TI Bridge), compared to the east (Figure 2.12, Figure 2.13, and Figure 2.14).

Figure 2.11. Torres Strait TRL (P. ornatus) Age 0+ abundance indices (and standard errors) across years. *The red dashed line represents the mean abundance index for the period between 2005-2023 for Mid-Year Only (MYO) sites.*



In 2024, the survey team observed Age 0+ TRL in all regions but Kirkaldie and Buru (Figure 2.14). All regions showed a below-average index where Age 0+ lobsters settled mostly in the Reef Edge region (across the survey area) and in the West in Mabuiag and TI Bridge.

In the East, counts are normally lower compared to the West (Figure 2.12 and Figure 2.13), where they settled in Warraber Bridge and South-East to a lesser extent (Figure 2.14).

Historically, Age 0+ TRL were observed in Mabuiag in all pre-season surveys (indicated in Figure 2.15 but full data now shown). Counts in South-East, Buru, Reef Edge and Warraber Bridge are also consistent, but more variable across the years, with Age 0+ observed in 10 out of 15 survey years (South East and Buru) and 13 out of 15 for Warraber Bridge (data not shown). Age 0+ lobsters are rarely observed in Kirkaldie. In fact, none have been observed in Kirkaldie in the last 4 survey years; they were observed in this region in only 6 out of 15 survey years (data not shown). Survey results show year to year variability in spatial distribution of where TRL settle, with a steep downward trend in 2024 from high counts in 2023 (Figure 2.11).

Figure 2.12. Torres Strait TRL (P. ornatus) Age 0+ densities (#TRL per transect) for the western and eastern regions of the surveyed area from 2014 to 2024 (W = West; E = East).

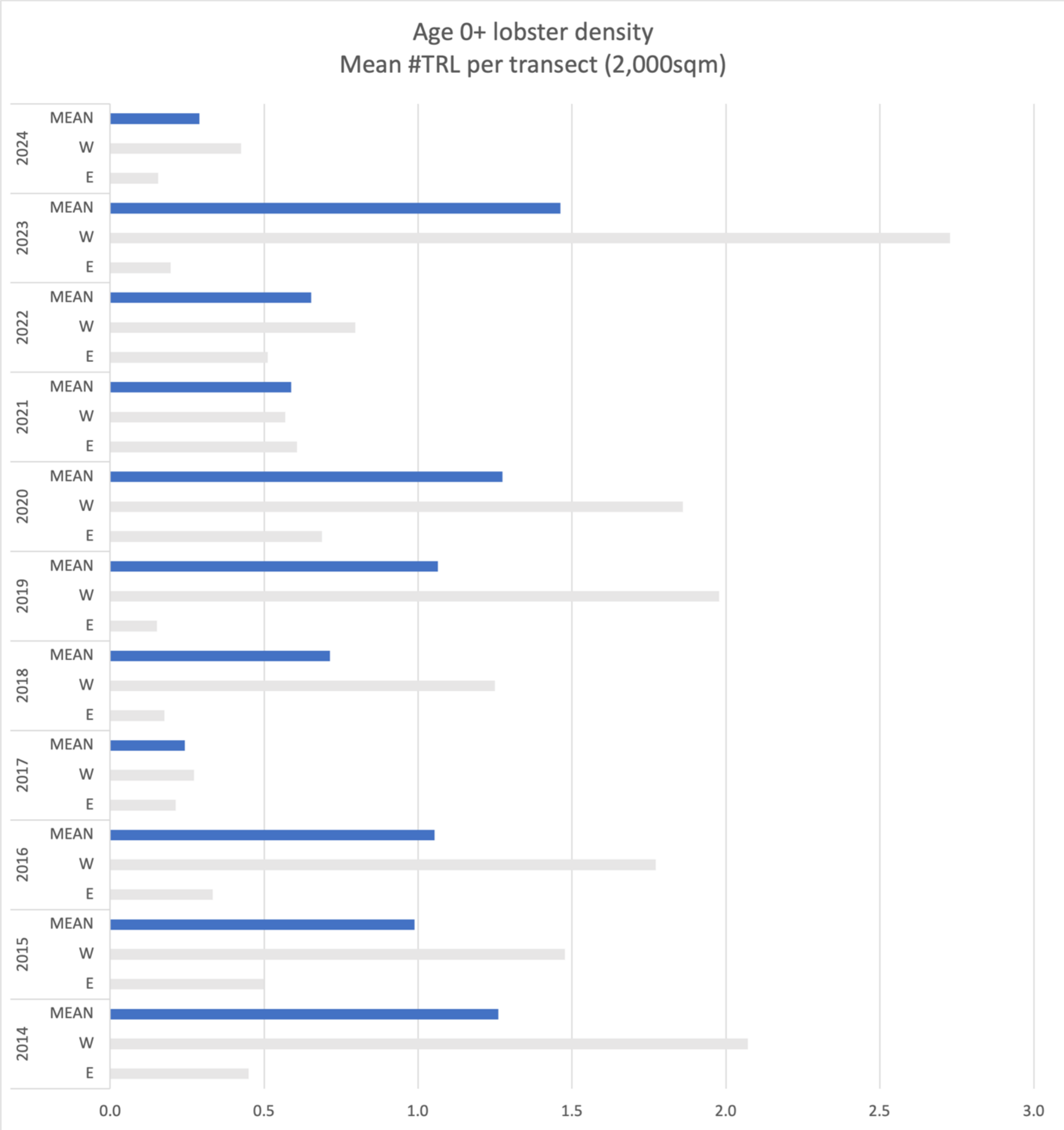


Figure 2.13. Torres Strait TRL (P. ornatus) Age 0+ counts per transect for all sites surveyed in 2022 to 2024 (n=77).

The red box shows a representative area for the survey, where numbers were significant lower compared to 2022 and 2023 survey years (i.e., less or smaller circles).

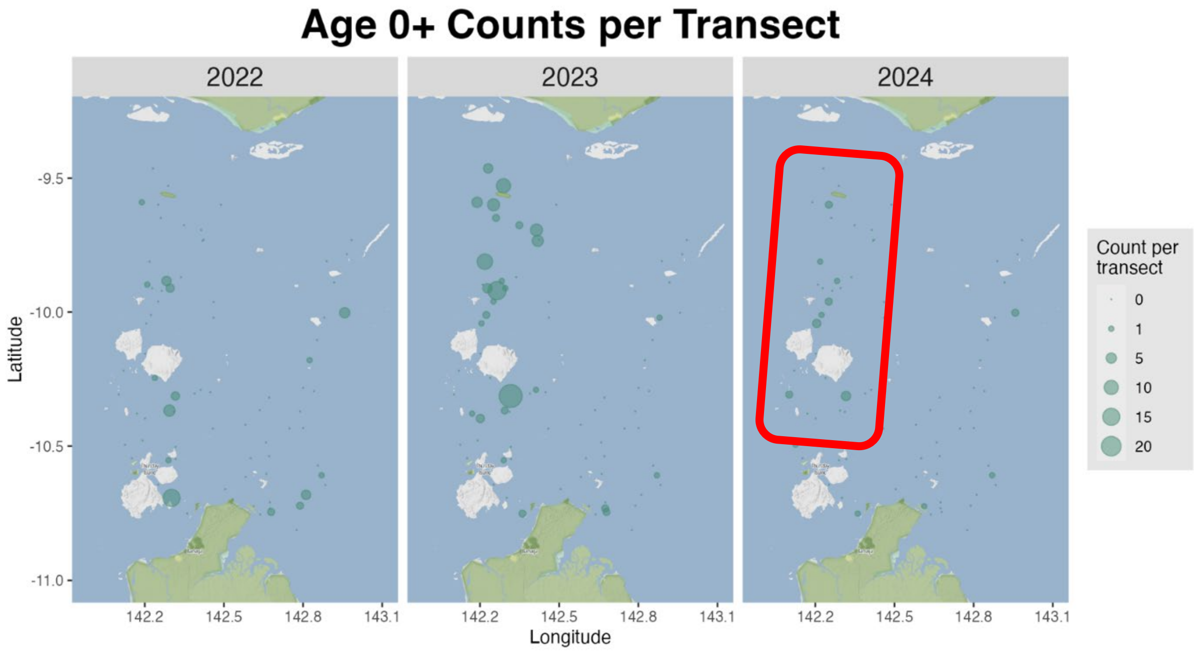


Figure 2.14. (A) The western Torres Strait showing regions (strata) sampled during the annual Torres Strait TRL (P. ornatus) surveys. (B) The Torres Strait TRL 2024 Age 0+ abundance index and standard errors by stratum. *The black dashed line indicates the mean abundance index for period between 2005 and 2023. Note that the 'Reef Edge' stratum is not shown on the map as this stratum consists of sites distributed across the survey area, including 1321, 9991, E10, E16, E19 and E2.*

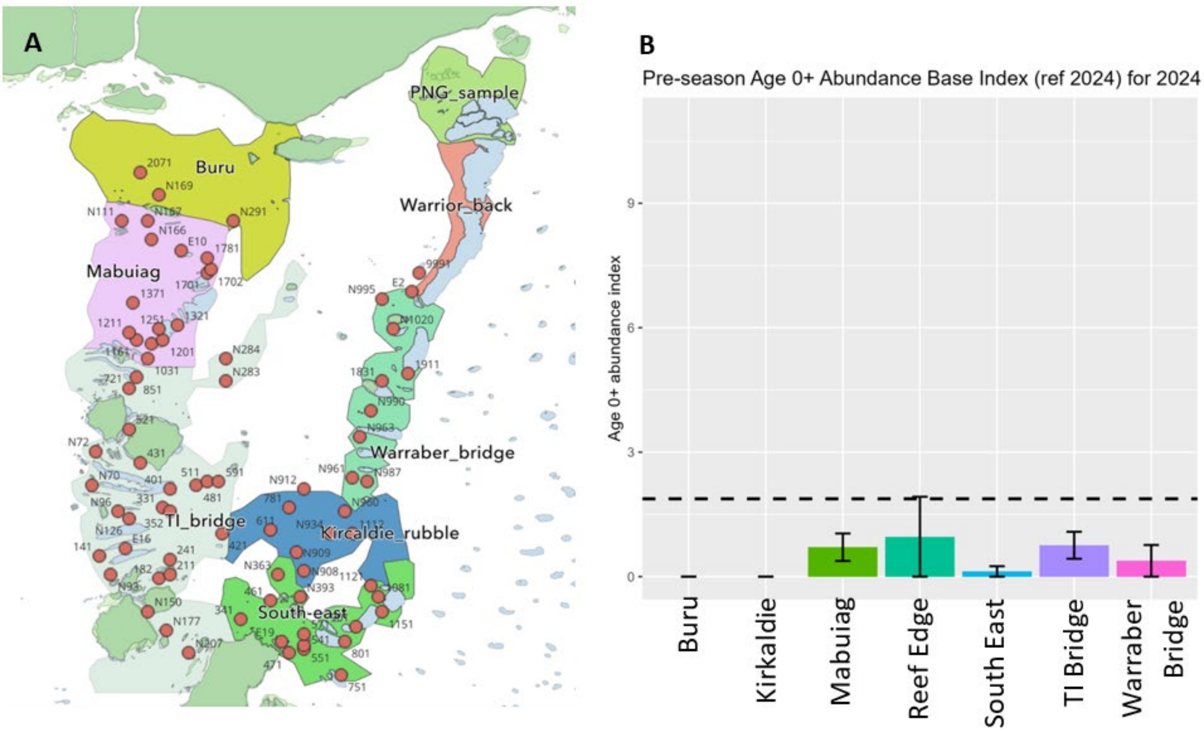
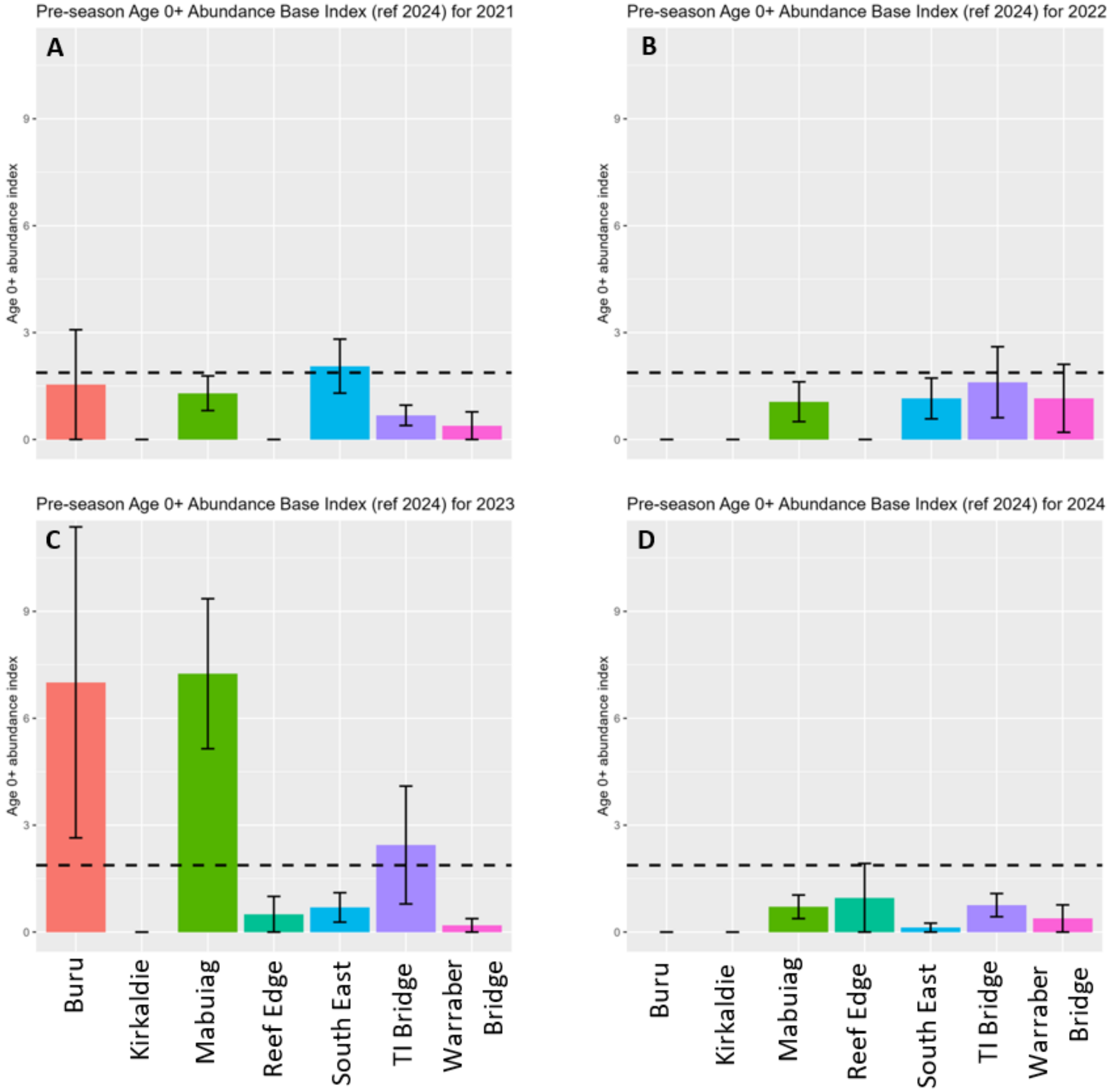


Figure 2.15. Torres Strait TRL (P. ornatus) Age 0+ abundance indices (and standard errors) across years and strata. *The black dashed line represents the mean abundance index for the period between 2005-2023 for Mid-Year Only*



(MYO) sites.

2.5 Conclusions

A total of 77 sites were surveyed in 2024, although rough weather meant that the average transect distance swum was 442m or 88% of the total transect. However, based on earlier analyses presented at TRLRAG35 (AFMA, 2023), this was within the range that does not cause a significant impact on the calculations of the Age1+ index.

In total, 391 TRL were observed and 162 were measured (TW) and their sex determined, finding a roughly even sex ratio. As previously, Age 1+ TRL comprised the majority of TRL observed in 2024 as most Age 2+ TRL have emigrated from Torres Strait in August/September to undertake the annual breeding migration.

In 2024, CSIRO reviewed strata and incorporated data from 3 sites that have been consistently surveyed in the last 5 years: N283, N284 and N912. A new abundance index (Ref2024) which incorporated these sites into the MYO index was proposed and accepted by the TRLRAG.

The Age 1+ abundance index for 2024 was the highest pre-season point estimate on record for Ref2024, well above the long-term average for the pre-season surveys (2005-2023). The highest index was recorded at the South-East, followed by Warraber-Bridge and Reef Edge. Similar to 2021-23, Age 1+ index at TI_Bridge was the lowest. The 2024 results for the Age 1+ (point estimate) abundance index was around or above average in all sites except TI Bridge. The large standard error recorded for all regions (except Mabuaig and TI Bridge) reflects the high variability in counts between sites within these regions.

The Age 0+ abundance index point estimate was decreased relative to 2023 and previous years. In 2024, Age 0+ TRL were again more commonly observed on the western side of the surveyed area, with over twice as many lobsters compared to the east.

These results further corroborate that there is year to year variability in spatial distribution where TRL settle in Torres Strait (see also TRL Spatial Variability).

3. Monitoring of Torres Strait Seabed Habitat

Nicole Murphy, Leo Dutra, Steven Edgar, Kinam Salee, Mark Tonks and Éva Plagányi

3.1 Summary

Tropical Rock Lobster (TRL; *Panulirus ornatus*) use different habitats during their life cycle. Monitoring seabed habitats over time are important because physico-chemical water characteristics interact with one another and cause synergistic effects on TRL growth, reproduction and survival. Qualitative seabed habitat data have been recorded alongside TRL abundance data since 1989, providing valuable insights into changes. Key habitat insights for the most recent survey include - in 2023, algae cover increased to the highest level since 2017 and stayed at similar levels in 2024. There was less hard substrate in 2024 in comparison to 2023, but the reduction in hard substrate between these years is not notable. Live coral cover has been increasing from the lowest estimate in 2018 with an upward trend until 2024, when it reached its highest estimate for all pre-season surveys. In 2024, sand cover estimate was similar to 2023, slightly higher than 2022 and similar to the lowest levels seen in 2015. Seagrass cover has been increasing and in 2024, seagrass cover was the highest level since 2019.

3.2 Introduction

Tropical Rock Lobster (TRL; *Panulirus ornatus*) use different habitats during their life cycle. For example, juveniles are observed in seagrass beds, adults walk over bare sand and hide in coral reefs. Monitoring seabed habitats and physio-chemical water characteristics over time are important because they can interact with one another and cause synergistic effects on TRL growth, reproduction and survival (Dennis *et al.* 2013; Norman-López *et al.* 2013; Green *et al.* 2014). These interactions are complex and direct cause-effect relationships are difficult to detect, despite obvious influence of some environmental factors (e.g., water temperature affecting growth and moulting) and habitats (e.g., seagrass and coral reef providing protection) for lobster settlement, growth and survival. For this reason, qualitative seabed habitat data have been recorded alongside key TRL abundance data (see methods in Section 2.3.1) since 1989, providing valuable insights into changes and major influencing factors. Examples being, the 1991-1993 seagrass dieback event which impacted the TRL population in north-west Torres Strait (Long *et al.* 1997), higher abundances of TRL (age 1+) found in areas where seagrass cover is >17% (Plagányi *et al.* 2018a) and sand incursions found to cause habitat destruction, seagrass die backs and reduced TRL abundance (Plagányi *et al.* 2016a).

Habitat data include percentage cover for types of abiotic and biotic substrate categories, such as unconsolidated substates (mud, sand, rubble) and consolidated hard substrates (pavement), as well as biota (live coral - including bleaching, seagrass and algae). Habitat information has been collected during mid-year surveys from 1994-2014 and 2018, and for pre-season surveys from 2005-2008, and 2014-2024. The number of sites surveyed prior to 2015 was around 130, with surveys since 2015 at around 75 sites. There are 66 common sites across all pre-season survey years. Additional sites were surveyed in Papua New Guinea waters during the 2006 and 2007 pre-season surveys, which have not been repeated since then. Data recorded during mid-year surveys (1994-2014) have provided the longest continuous time series of 21 years, which are useful for identifying habitat trends for the survey area. Over more recent years, pre-season survey data offer a continuous annual time series of 10 years in which trends (2014-2024) for the 66 common sites are presented in this report.

3.3 Trend Summary for Pre-Season Survey Seabed Habitat Composition

A comparison of mean percentage cover for unconsolidated and consolidated substrate categories, for all pre-season surveys (n=15; Figure 3.1) indicates the following trends:

- Mean algal cover of around 15 percent between 2005-2008 followed by a small decline observed in 2014 (~12 percent). An increase to about 20 percent was observed in 2015 and algae cover was relatively steady (around 15-20 percent) between 2015 and 2019. In 2020 there was a sharp notable decline in algal cover to about 10 percent; the lowest point estimate recorded for all pre-season surveys. Algae cover increased to 15 percent in 2021 and decreased again to a bit over 10 percent in 2022. In 2023, algae cover increased to the highest level since 2017 at around 20 percent and stayed at similar levels in 2024.

- Coral bleaching was detected at very low rates (~0.15 percent) in 2016 but not observed in other years.

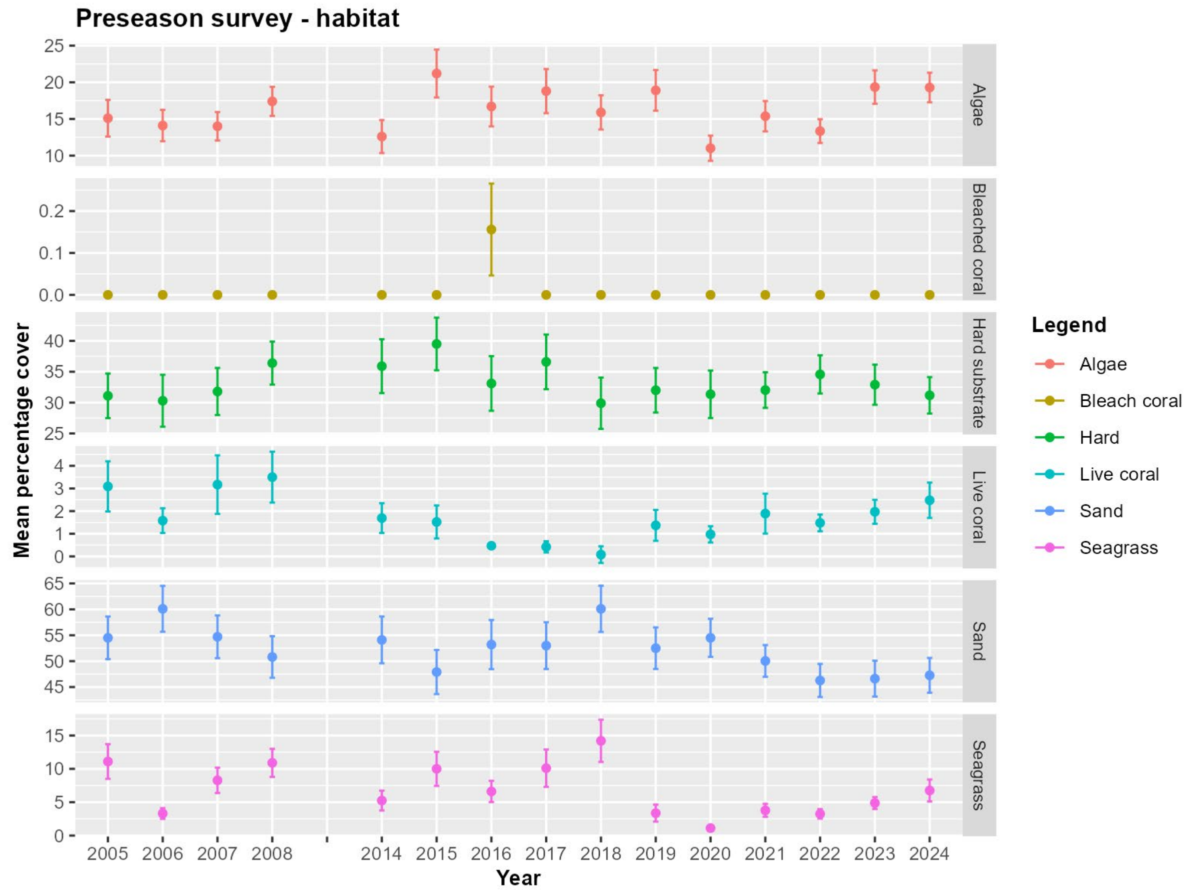
- Hard substrate (combined consolidated rubble and limestone pavement) cover is consistent at around 30-40 percent throughout the pre-season survey period, although it appears the years 2005-2007 and 2018-2021 and 2023 (point estimate and error bars) were closer to 30 percent and years 2008 and 2014-2017 and 2022 were slightly higher. There was less hard substrate in 2024 in comparison to 2023, but the reduction in hard substrate between these years is not notable.

- Historically, live coral cover is relatively low at survey sites varying between 1-4 percent. Average live coral cover (and variability) was higher during the period between 2005-2008 compared to the period between 2014-2022; the latter period also shows less variability in live coral cover in individual years. The period between 2014-2022 shows an initial declining trend (2014-2018) in live coral cover, followed by a recovery (but still variable) in 2019. Since then, live coral cover has been increasing from the lowest point estimate in 2018 with an upward trend until 2024, when it reached its highest point estimate for all pre-season surveys.

- Sand movement is dynamic due to strong tidal currents in the region. Fishers report sand incursions into sites, which are sometimes also captured during the survey. The data show variability in sand cover with point estimates ranging from ~50 to 60 percent throughout the pre-season survey period. A decreasing trend was observed between 2005-2008, an increasing trend of point estimates from 2014-2018 and steady decline from 2019-2022. In 2024, sand cover point estimate was similar to 2023; slightly higher than 2022 and similar to the lowest levels seen in 2015.

- Seagrass cover is highly variable, with noticeable low cover (<5 percent) in 2006 and for the period between 2019 and 2022. From 2006-2008 and 2014-2018 there was a notable (approximately 3-fold) increase in the seagrass cover point estimate, and a noticeable decline in 2019. In 2020, seagrass cover was the lowest point estimate for the 15 pre-season surveys. Since then, seagrass cover has been increasing. In 2024, seagrass cover was the highest level since 2019.

Figure 3.1. Mean percent covers of abiotic and biotic categories recorded during pre-season surveys in Torres Strait during 2005-2008 and 2014-2024 (error bars = 1 standard error).



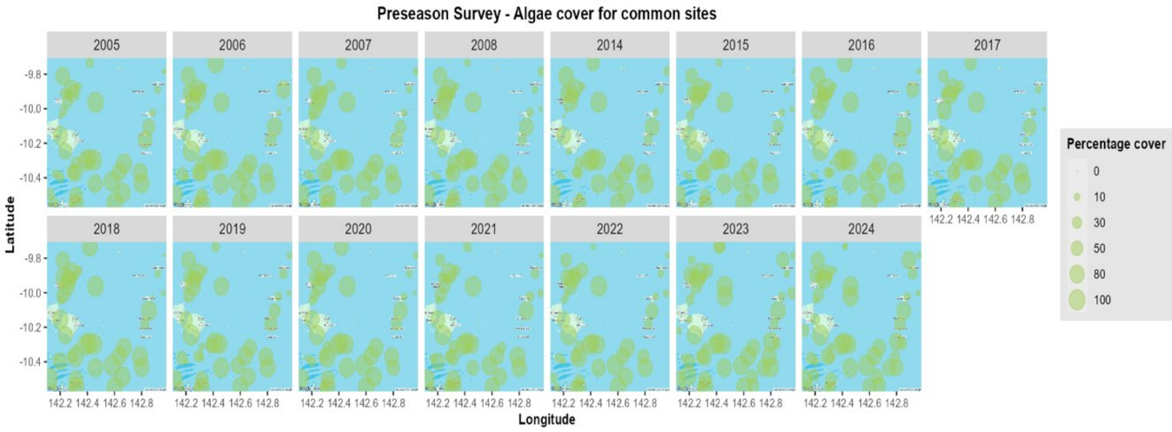
3.4 Habitat Distribution Through Time (2005-2020): Inter-Site Variation

The results presented here are based on the analyses of 66 common survey sites.

3.4.1 Algae

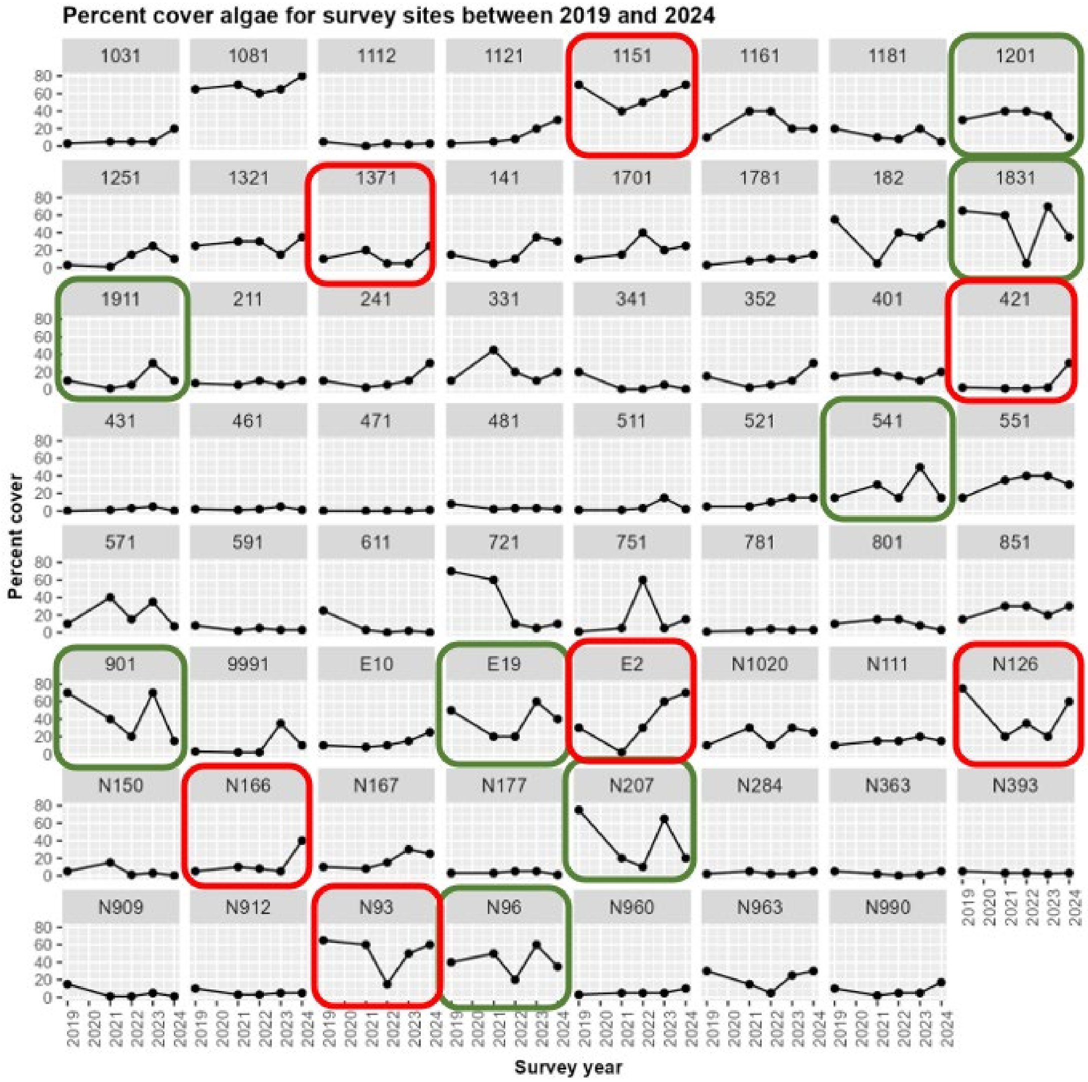
The percentage cover of algae is consistent across sites throughout the years, ranging from 15-20 percent (Figure 3.2). In 2015, algae cover reached its maximum point estimate (slightly over 20 percent) with lowest levels observed in 2014 and 2020 (Figure 3.1); with the latter showing the lowest cover recorded for all pre-season surveys, with a 10 percent difference from the highest cover recorded in 2015. Algae cover increased ~5 percent in 2021 from 2020, decreased (~3 percent) between 2021 and 2022, and increased ~5 percent in 2023 to the second highest level. In 2024, algae cover was at similar levels to 2023 (Figure 3.1 and Figure 3.2).

Figure 3.2. Total percent cover (rescaled so the maximum so the maximum observed value = 100%) of algae recorded during pre-season surveys in Torres Strait during 2005-2008; 2014-2021 (66 common sites shown).



Recent trends between 2021 and 2024 show notable (>40 percent difference in point estimates) decreases (green squares; Figure 3.3) in algae cover observed for sites 1201, 1831, 1911, 541, 901, E19, N207 and N96, with strong increases (i.e., >20-30 percent difference in point estimates) found for sites 1151, 1371, 421, E2, N126, N166 and N93 (red squares; Figure 3.3), noting variability across the time period of analyses (2019 to 2024).

Figure 3.3. Percent cover for algae for survey sites recorded by survey divers for 63 common sites between 2019 to 2024.

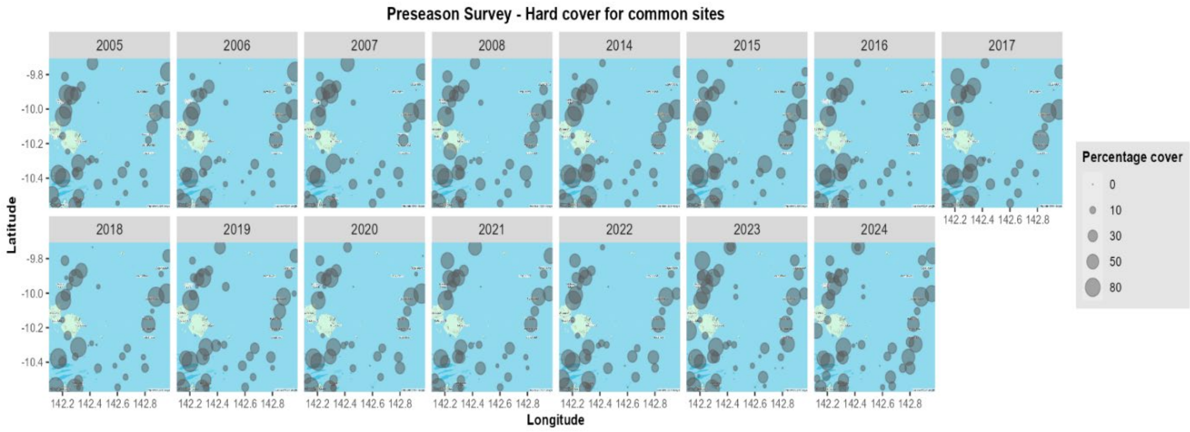


The green squares show sites where there were strong decreases (>40 percent difference) between survey years and the red squares strong increases (>40 percent difference) between survey years.

3.4.2 Hard Substrate (Combined Consolidated Rubble and Limestone Pavement)

The general distribution of hard substrate over the survey area was relatively consistent across years with little changes across the survey sites (Figure 3.1 and Figure 3.4).

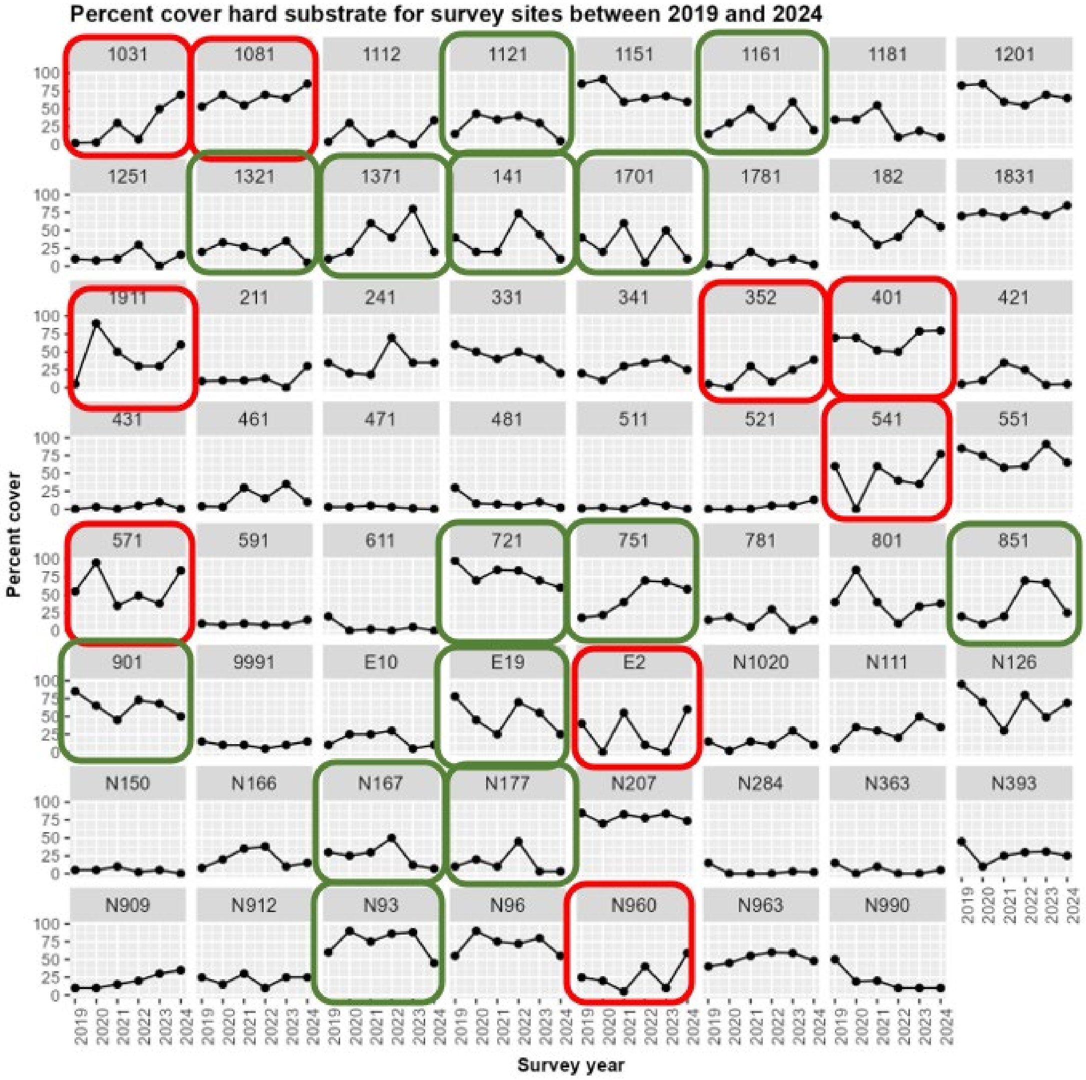
Figure 3.4. Total percent cover (rescaled so the maximum so the maximum observed value = 100%) of hard substrate recorded during pre-season surveys in Torres Strait during 2005-2008 and 2014-2024 (showing 66



common sites).

Between 2021 and 2024, notable decreases in hard substrate (>25 percent difference in point estimates) cover were found for sites 1121, 1161, 141, 1701, 1321, 1371, 1421, 721, 751, 851, 901, E19, N167, N177 and N93 (green squares; Figure 3.5), with notable increases (>25 percent difference in point estimates) observed for sites 1031, 1081, 1911, 352, 401, 541, 571, E2 and N960 (red squares; Figure 3.5), despite variability across the time period of analyses (2019 to 2024).

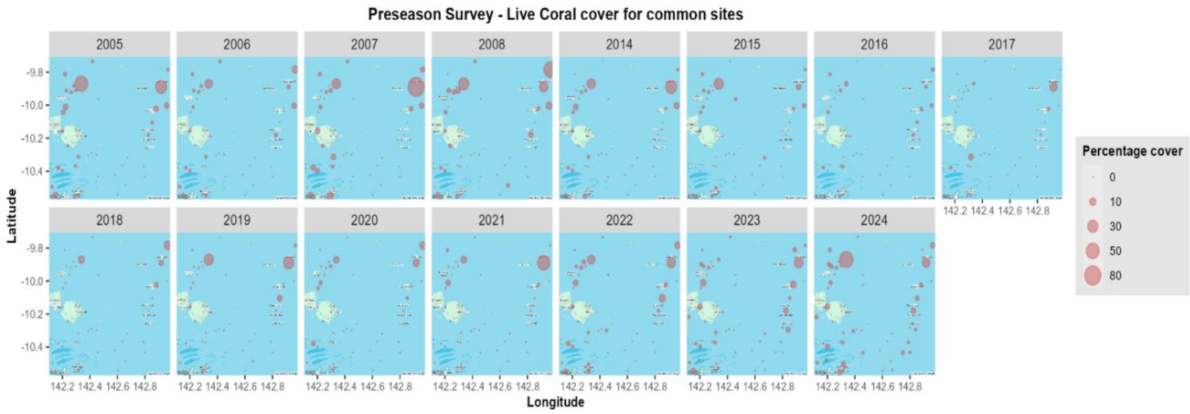
Figure 3.5. Percent cover for hard substrate for survey sites recorded by survey divers for 63 common sites between 2019 to 2024.



3.4.3 Live Coral

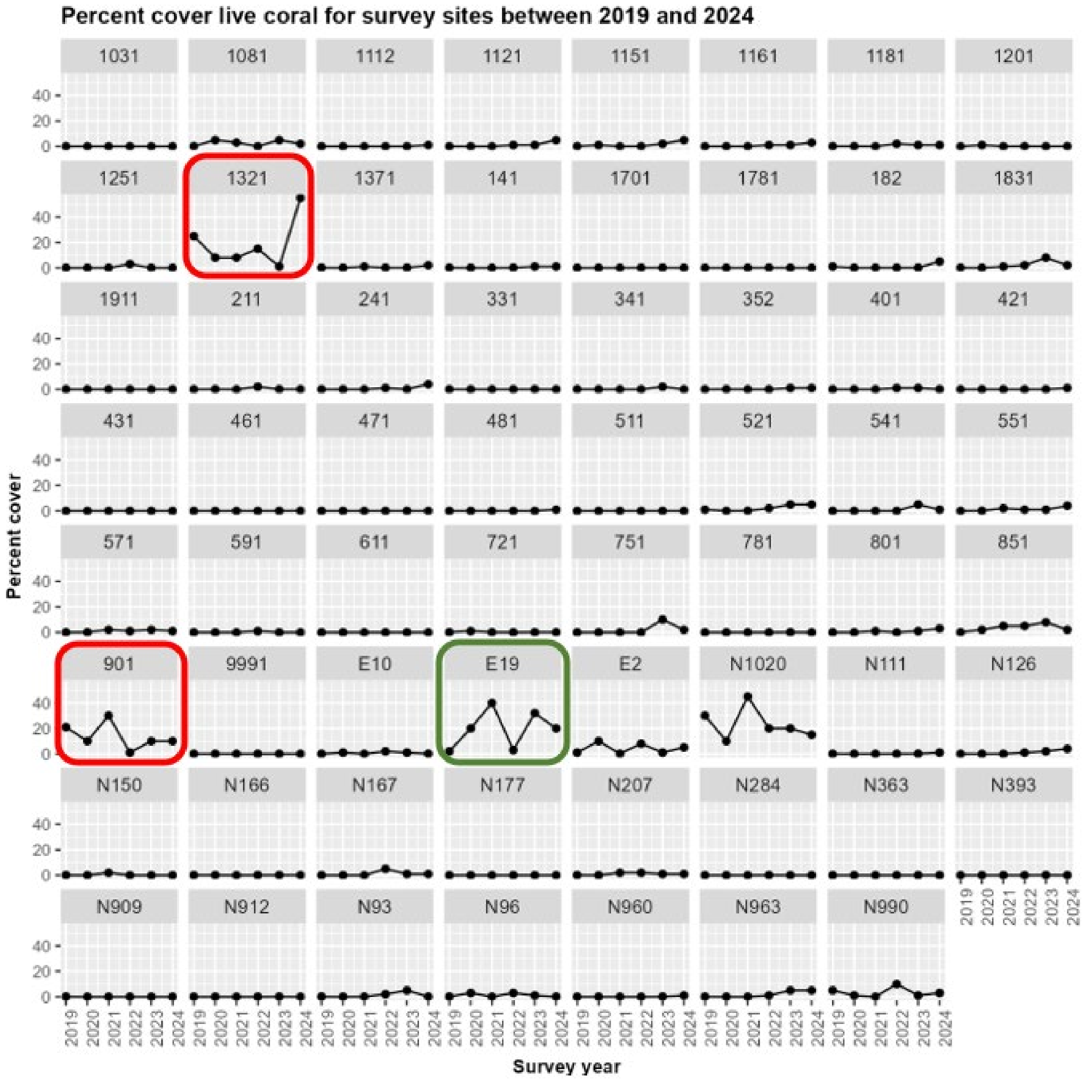
Live coral cover is low and variable across years (Figure 3.1) and sites (Figure 3.6) although point estimates of live coral cover show a declining trend since its peak (3.5%) in 2008. Interestingly the decreases in live coral cover seem to be more pronounced in the western side of the survey area (Figure 3.6). Percentage cover point estimates were consistent at around 1% from 2016-2020. From 2018 to 2022, although still variable, point estimates show an increase from its lowest point. Live coral cover in 2022 is lower comparing to 2021, decreasing about 0.5%. In 2023, live coral cover increased about 2% from 2020 to the highest levels since 2018, though still low in comparison to 2008. In 2024, live coral cover increased another ~0.5% from 2023 and was at the third highest level since 2007 (Figure 3.1 and Figure 3.6).

Figure 3.6. Total percent cover (rescaled so the maximum so the maximum observed value = 100%) of live coral recorded during pre-season surveys in Torres Strait during 2005-2008; 2014-2024 (66 common sites shown).



Between 2021 and 2024 there was notable decreases (>10-20 percent difference in point estimates; coral cover has been multiplied by 10) of live coral cover found for site E19 (green squares; Figure 3.7), with notable increases (>10-20 percent difference in point estimates; coral cover has been multiplied by 10) of live coral cover for sites 1321 and 901 (red squares; Figure 3.7), despite variability across the time period of analyses (2019 to 2024) for some sites e.g., E2 and N1020.

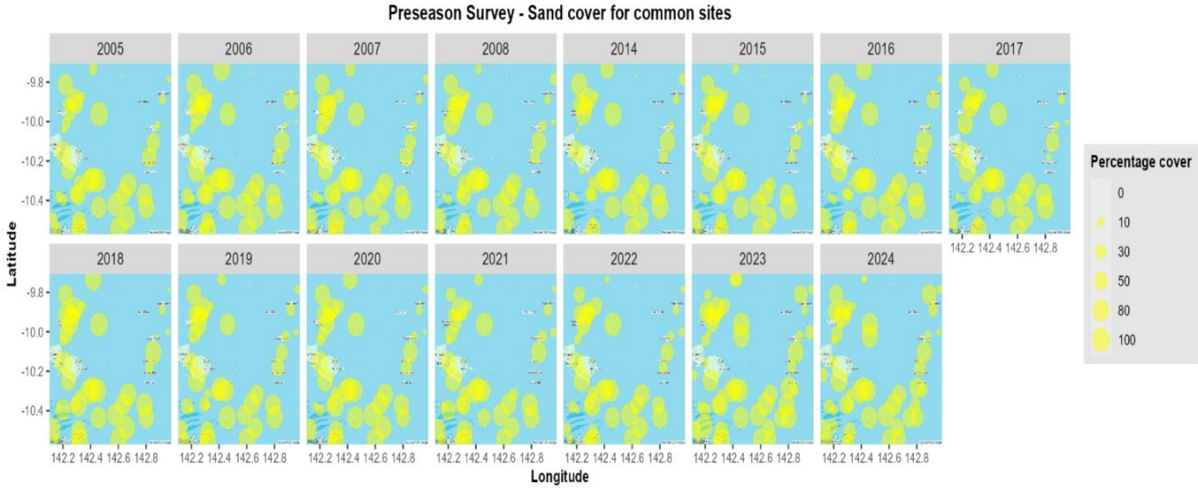
Figure 3.7. Percent cover live coral for survey sites recorded by survey divers for 63 common sites between 2019 to 2024.



3.4.4 Sand

The distribution of sand within the survey area appears relatively consistent across years for the 66 common sites that allow for comparison (Figure 3.1 and Figure 3.8).

Figure 3.8. Total percent cover (rescaled so the maximum so the maximum observed value = 100%) of sand recorded during pre-season surveys in Torres Strait during 2005-2008 and 2014-2024 (showing 66 common sites).



Changes in sand cover may be associated with the movement of the sand across Torres Strait due to strong currents. As part of the survey, the team have been recording sites with potential sand incursions, which are then discussed during the RAG. In 2020, a sand incursion was noted for site 611 and fishers reported in the TRLRAG that fine white sand was covering biota on a wide scale (TRLRAG, 2020). No sand incursion was noted in 2021 (site 611 was not surveyed). In 2022, new sand incursions were recorded for sites 352, N169, N111 and 1112. In 2023, there was a continued sand incursion for site 352 (towards transect end), and new sand incursion for sites 471 (a site with historically high sand cover in previous survey years) and N990. For 2024, sand incursions were noted for sites 1112, N283, 591, and 211 and continued sand incursions for 471 and N990 (Table 3.1).

Strong tidal flows cause localised incursions of sand on the survey sites, covering established habitat. This is consistent with observations from fishers (TRLRAG, 2020). During the 2018 survey, sand incursions were observed by divers at sites 341, N195, N284 (Table 1). In the 2019 survey, two of these sites were re-sampled (341, N284), and sand cover declined for both sites (from 69% to 60%, and from 97% to 80% respectively) (Table 3.1, Figure 3.9). In 2020, site N284 was surveyed again and sand cover increased to 97% and decreased slightly in 2021 to 58% for site 341 and to 95% for site N284, which shows that sand movement is quite dynamic across the survey area. In 2022, the previous sand incursion recorded for site 611 in 2020, was found to be at similar values (from 100% to 99%), with sites 341 and N284 recording similar values to 2021 (Table 3.1, Figure 3.9). In 2023, sand cover for sites 341, N169 and N111 (from 2022) were found to have noticeably decreased (Table 3.1, Figure 3.9). In 2024, there was an increase in sand cover for sites 611, 341, N169 and N111 all showed increases, with N284, 1112 and N990 decreasing slightly (Table 3.1, Figure 3.9).

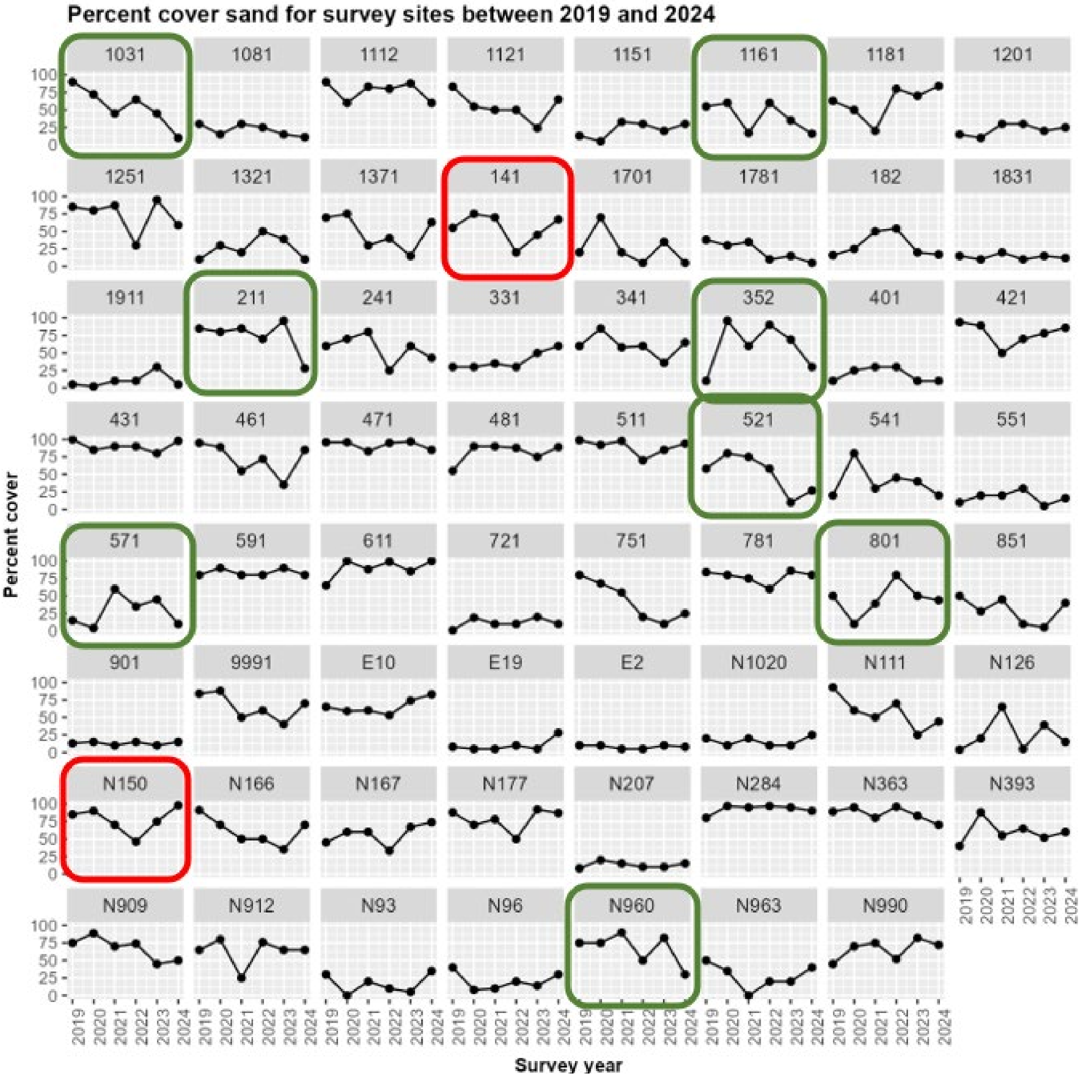
Table 3.1. Percent sand cover at sites where sand incursions were observed by survey divers from 2018 to 2024. *Note, '–' site not surveyed; sites where sand incursion was observed by divers in 2024 are marked with '*'.*

Site	2018	2019	2020	2021	2022	2023	2024
611	95	65	100	-	99	85	100
341	69	60	-	58	60	36	65
N284	97	80	97	95	97	95	90
352	20	10	96	60	90	69	90
N169	70	40	30	35	70	38	70
N111	80	93	60	50	70	25	70
1112	80	90	60	83	50	88	83*
471	99	96	96	83	95	97	83
N990	87	45	70	75	52	82	74
N283	90	95	-	85	80	90	92*
591	99	80	90	80	80	90	80*
211	95	85	80	85	70	96	28*

On average, observed sand cover increased by 2-3% between 2019 and 2020 (but note strong variation across survey sites) and decreased 5% between 2020 and 2021 (Figure 3.1). Sand cover was similar for 2022, 2023 and 2024.

Between 2021 and 2024 strong (>25 percent difference in point estimates) decreases in sand cover were observed for sites 1031, 1161, 211, 352, 521, 571, 801 and N960 (green squares; Figure 3.9), with strong increases found for sites 141 and N150 (red squares; Figure 3.9), despite variability across the time period of analyses (2019 to 2024).

Figure 3.9. Percent cover of sand for survey sites recorded by survey divers for 63 common sites between 2019 to 2024.

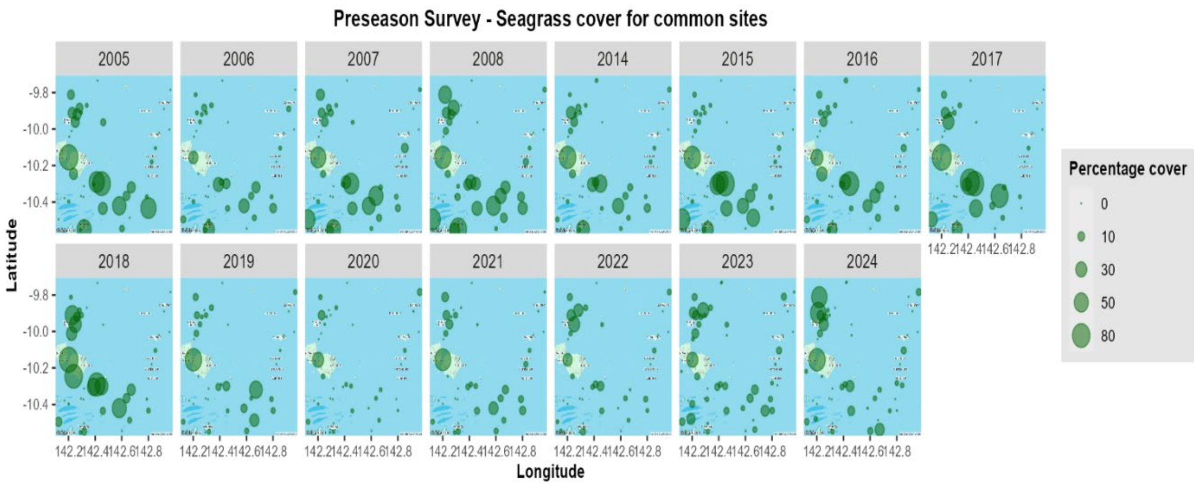


Anecdotal reports of substantial sand incursions by fishers are not always detected in the standard survey results, as these events occur on variable spatial and temporal scales. For example, in 2015 fishers reported large sand incursions, however the overall percentage sand cover from the pre-season survey that year was one of the lowest reported (Figure 3.1). As survey data are limited to a single annual snapshot, observations for dynamic habitat variables such as sand, also rely on complementary anecdotal reports from fishers.

3.4.5 Seagrass

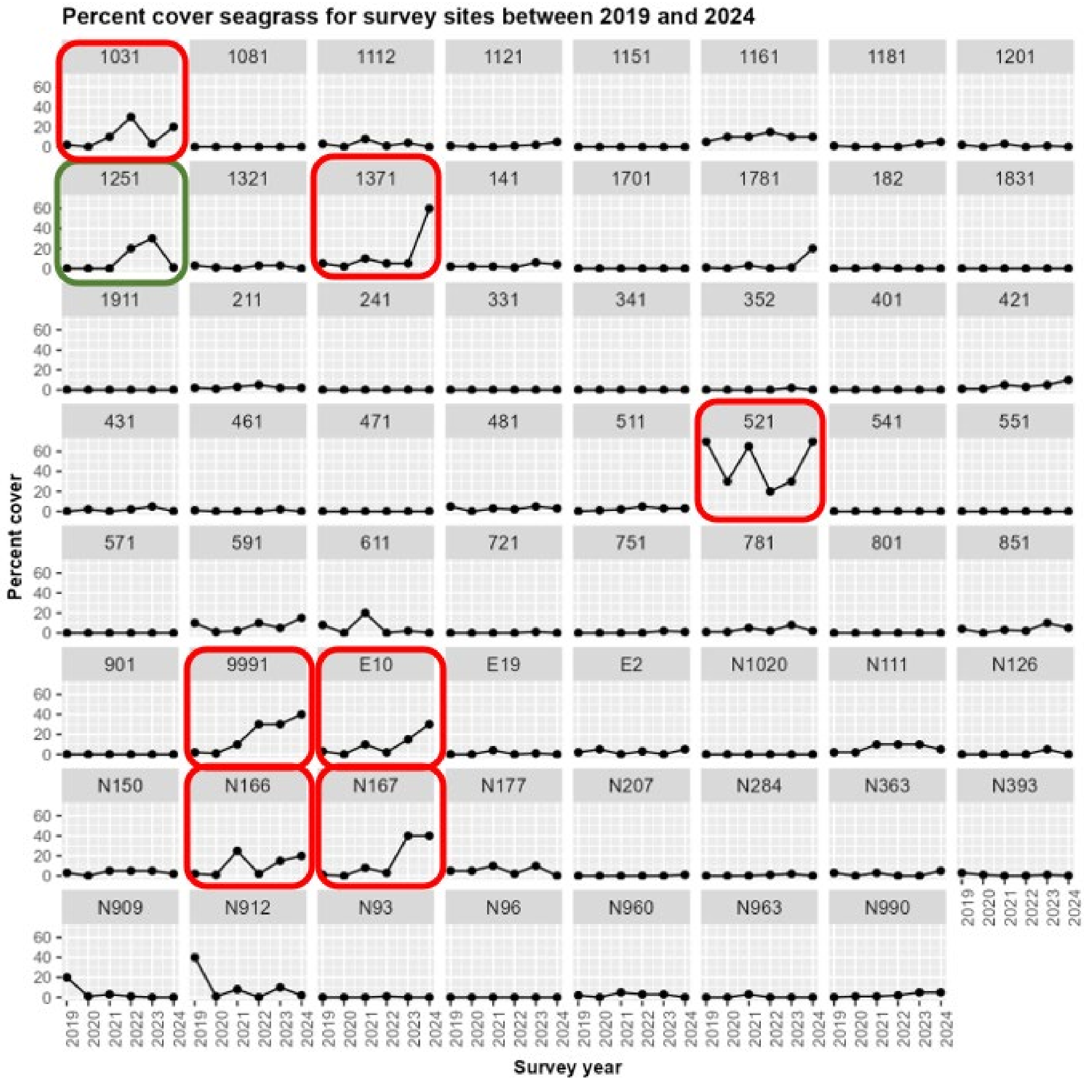
In contrast to sand and hard substrates, the distribution of seagrass over survey years is more variable both in space and time (Figure 3.1 and Figure 3.10). In 2006 and 2014, a notable decrease in the point estimate for seagrass cover was observed. Between 2006 to 2008, and 2014 to 2018, there was an increasing trend in seagrass cover, with noticeable declines in 2014, 2019 and 2020 (small size of circles in Figure 3.10). In 2019, the decrease in seagrass cover was more evident in the north-west (between Mabuiag and Turnagain Islands) and south-western regions compared to 2018. In 2020, seagrass had declined even further, to the lowest point estimate recorded for surveys, compared to previous historical lows in 2006 and 2014. In 2021, seagrass cover point estimate increased ~3 percent compared to 2020, however in 2022 the point estimate of seagrass cover decreased again to approximately 2 percent, but this was not notable (still within variability from 2021 survey; Figure 3.1). In 2023, seagrass cover point estimate was at the highest levels since 2019 (though still low), increasing ~2% from 2022. For 2024, seagrass cover again increased another ~2% from 2023 and was at the highest level since 2019 (Figure 3.1 and Figure 3.10).

Figure 3.10. Total percent cover (rescaled so the maximum so the maximum observed value = 100%) of seagrass recorded during pre-season surveys in Torres Strait during 2005-2008; 2014-2024 (66 common sites shown).



Between 2022 and 2024 notable decreases (>10-20 percent difference in point estimates) in seagrass cover were observed for site 1251 (green squares; Figure 3.11), with strong increases (>25 percent difference in point estimates) found for sites 1031, 1371, 521, 9991, E10, N166 and N167 (red squares; Figure 3.11). Small increases in seagrass cover in 2024 were observed in sites 1781, 421 and 591, compared to 2023. This has contributed to the overall improvement on seagrass cover in 2024.

Figure 3.11. Percent cover seagrass for survey sites recorded by survey diver for 63 common sites between 2018 to 2024.



3.5 Conclusions

The importance and influence of environmental change on the Torres Strait TRL population has been emphasized by both TIB and TVH sectors at several TRLRAG meetings where it has been noted that lobster catch-rates often correlate with favourable seabed habitat; principally cover of pearl and mussel (‘busted shells; *Pinctata margaretifa*) shells. It is therefore important to quantify seabed habitat and associated abiotic factors that influence lobster growth and mortality, in case these variables improve the ability to predict the size of the highly variable annual recruiting year-class.

In addition, there has been a number of anomalous environmental changes over recent years and monitoring of habitat variables can help explain changes in TRL distribution (e.g., 2015 changes in lobster abundance were partly attributed to sand incursions) and also serve as a baseline for monitoring habitat changes under climate change. Data from the seabed habitat monitoring program provides one of the longest time series on record for Torres Strait and directly informs both past (e.g., (Fulton *et al.* 2018; Plagányi *et al.* 2018a; Dutra *et al.* 2020) and future climate change work for fisheries in Torres Strait.

In 2020, the continuing decline in seagrass abundance was of concern because of dramatic declines in TRL abundance were previously associated with declines in seagrass cover (Long *et al.* 1997). Anecdotal reports from industry stakeholders suggest there was an increase in dugong numbers in 2019 and this may be an impacting factor. Dugongs are known to move from areas where seagrass are in short supply and are thought to have moved to Torres Strait after seagrass cover declined around the Cape from floods in January 2019 (H. Marsh pers. comm.; (Preen and Marsh 1995; Sheppard *et al.* 2006). In 2021, seagrass cover has increased, and sand cover has decreased, which may partially explain the decline in seagrass cover in 2020, because the declines for both are somewhat proportional. In 2022, sand cover and seagrass cover both decreased, with a slight recovery for seagrass and similar cover for sand in 2023 and 2024, suggesting other environmental or biological factors are likely contributing to the decline in seagrass. This can be further investigated by undertaking exploratory analyses of survey data correlation with other physical variates to understand drivers involved.

In 2020, algae cover declined to the lowest point estimate recorded for pre-season surveys, decreasing from the 2019 (point) estimate of 10 percent, with the only corresponding increase for other dominant habitat being for sand at approximately 2 percent. In 2021, algae cover increased proportionally to a decrease in sand cover which is near its lowest levels seen in 2015. A further decrease for algae and sand cover was seen in 2022, also suggesting other environmental or biological factors are contributing to declines in algae. In 2024 (and 2023), algae cover increased ~7 percent to the third highest level since 2015 (with sand cover at similar levels to 2022). As algae is a dominant and widespread biota, previous lower levels are of concern as this can potentially be linked to changes in physio-chemical drivers (e.g., temperature, salinity and nutrients) and impact ecosystems. Elucidating potential contributing factors for the 2023 and 2024 increase (from 2022), is also important to understand with respect to system dynamics and the environment.

Ongoing collection of environmental baseline data is important for understanding potential cause-effect relationships of changes in physio-chemical variables on ecosystems and species. In support of this, sea water temperature measurements have been collected from 2019 to 2024, with some initial analyses undertaken and presented in Chapter 4. Expansion of the collection of other relevant physical parameters e.g., dissolved oxygen and pH is of high importance in future surveys to investigate the correlation of ecosystem drivers for the TRL fishery habitat, as well as local and wide scale dynamics. Further research to analyse trends in the habitat data as well as ecosystem dependencies and responses to habitat changes is ongoing (Murphy et al. in prep).

4. Water Temperature and Habitat Correlation

Nicole Murphy, Leo Dutra, Steven Edgar, Kinam Salee, Mark Tonks, and Éva Plagányi

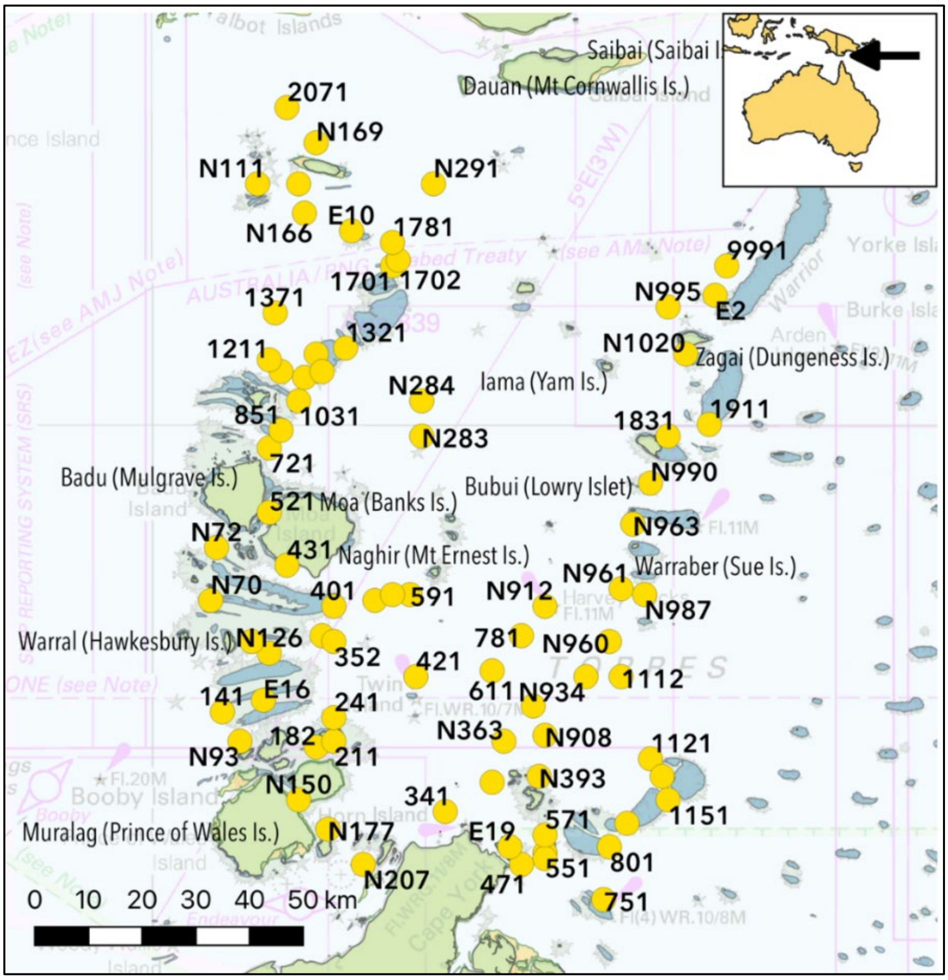
4.1 Summary

From 2019 to 2024, a logger has been deployed by divers during the Torres Strait TRL surveys, allowing for real-time continuous data collection of water level (depth) by autonomously measuring conductivity, pressure and temperature. These data are important to monitor as high water temperatures may have direct and indirect (via habitats and food webs) negative impacts on the TRL fishery. TFurther comparisons show little difference in water temperature across geographical quadrants for survey years, suggesting that the waters of Torres Strait are well mixed. Mean temperature values for the logger show similar trends to Sea Surface Temperature (NOAA) records.

4.2 Introduction

From 2019 to 2024, a Van Essen CTD-Diver Water Level & Conductivity Logger has been deployed by divers during the Torres Strait TRL surveys. The CTD-Diver logger is attached to the dive harness of one of the divers, allowing for real-time continuous data collection of water level (depth) and autonomously measures conductivity, pressure and temperature. Measurements were recorded for all survey sampling sites, with depth varying from 0-25 m (Figure 4.1).

Figure 4.1. Survey sites sampled by divers using the CTD diver logger for 2019 to 2024 survey years.



4.3 Summary of Results (2019 to 2024)

For all sampling sites across all survey years (2019 to 2024), sea water temperature varied by ~0.5°C in the first 5m of the water column (Figure 4.2). This was expected because the CTD data logger automatically activates at around 1m depth, at the top layer of the water column (which absorbs heat) resulting in variation in temperature. Variability at this top layer is likely to be a result of sensor acclimatation. In 2021, variability for surface water ranged between ~0.5-2°C, with less variation – between ~0.5-1°C for 2022 and 2023, and increasing ~1°C in 2024 (Figure 4.2).

The water temperature data across sites (coloured dots represent real time temperature recording data) shows that in November (when the surveys are conducted) the water is well mixed with no stratification (Figure 4.2). From 2019 to 2021, mean sea water temperatures increased by approximately a 1°C across all sites and years (noting low variability in measurements), and was also consistent at deeper depths (20 m - 25 m) (Table 4.1; Figure 4.2) suggesting the water column is well mixed (i.e., no stratification). Also, temperatures are lower at deeper sites indicating shallow waters are warmer. For 2021 and 2022, water temperatures were the highest with less variation of water temperature in 2022 (between 29.5 - 30.5ºC) compared to 2021, when temperatures varied between

29 and 31°C (Table 4.1; Figure 4.2). In 2023, mean water temperature declined and was similar to 2019 (consistent to depths up to 25 m deep), showing a ~2°C drop in temperature from the previous 2 years (Table 4.1; Figure 4.2). Water temperature increased 1°C in 2024 (from 2023), being the third highest across the six years of data collection (Table 4.1; Figure 4.2).

Table 4.1. Mean temperature (◦C) for CTD diver logger measurements (combining all TRL sampling sites) for 2019 to 2024 survey years (Standard Error (SE) = 1).

Year	Mean temperature	SE
2019	27.82	0.01
2020	28.90	0.01
2021	29.84	0.04
2022	29.75	0.01
2023	27.46	0.01
2024	28.47	0.01

Figure 4.2. CTD diver logger comparisons of temperature (◦C) for TRL sampling sites for 2019 to 2024 survey years (coloured dots represent real time temperature recording data across different days and sites).

Temperature data (starting at 1 m depth) for survey years (2019-2024) were split into area quadrants of grouped survey sites: North East (NE), North West (NW), South East (SE) and South West (SW) for the surveyed region (Figure 4.3). The data shows that there is little difference in water temperature across the quadrants in each survey year, suggesting that the waters of Torres Strait are well mixed. The differences are probably due to water depth and geographical conditions (e.g., sites located at shallower waters in reefs, compared to sites at deep waters).

In 2019, the mean water temperature for each quadrant was 27.77°C NE, 27.39°C SE, 27.94°C SW and 28.29°C NW (Table 4.2). There was little variation between the NE and SE quadrants, with warmer water (~0.5°C difference) seen in the SW compared to the SE (Figure 4.3).

In 2020, the mean water temperature for each quadrant was 29.08°C NE, 28.68°C SE, 28.77°C SW, 29.20°C NW (Table 4.2). Water temperatures differed ~0.5°C for the NE and SE quadrants, with the SW and NW also differing by ~0.5°C (Figure 4.3).

In 2021, the mean water temperature for each quadrant was 29.86°C NE, 29.56°C SE, 29.54°C SW and 30.38°C NW (Table 4.2). Water temperatures were similar for the NE, NW and the SE, with the SW showing a ~0.6°C difference from other quadrants (Figure 4.3).

In 2022, the mean water temperature for each quadrant was 29.91°C NE, 29.69°C SE, 27.94°C SW and 28.29°C NW (Table 4.2). Temperatures were similar for the NE, NW, SE and SW, varying up to ~0.3°C between quadrants (Figure 4.3).

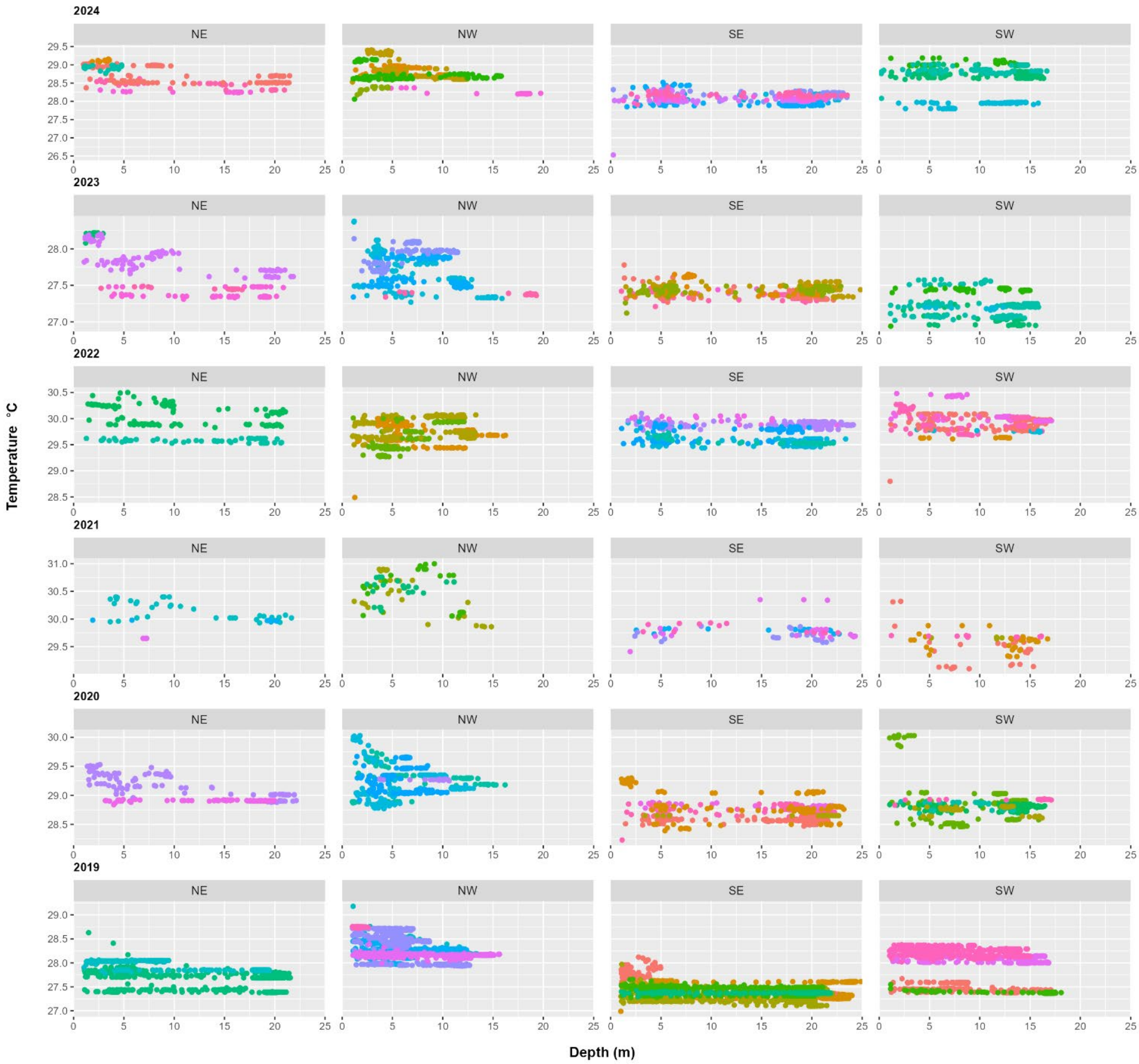
In 2023, the mean water temperature for each quadrant was 27.66°C NE, 27.36°C SE, 27.19°C SW and 27.69°C NW (Table 4.2). Temperatures were similar for the NE and NW quadrants, and there was ~0.5°C variability for the SE and SW (Figure 4.3).

For 2024, the mean water temperature for each quadrant was 28.61°C NE, 28.07°C SE, 28.64°C SW and 28.69°C NW (Table 4.2). Temperatures were similar for the NE and NW quadrants, and there was ~0.5°C variability for the SE and SW (Figure 4.3).

Table 4.2. Mean temperature (◦C) for CTD diver logger measurements, separated into area quadrants for TRL sampling sites, for survey years (Standard Error (SE) = 1).

Year	Quadrant	Mean temperature	SE
2019	NE	27.77	0.01
	NW	28.29	0.00
	SE	27.39	0.00
	SW	27.94	0.01
2020	NE	29.08	0.02
	NW	29.20	0.02
	SE	28.68	0.01
	SW	28.77	0.01
2021	NE	29.86	0.08
	NW	30.38	0.08
	SE	29.56	0.05
	SW	29.54	0.08
2022	NE	29.91	0.03
	NW	29.67	0.02
	SE	29.69	0.01
	SW	29.84	0.02
2023	NE	27.66	0.03
	NW	27.69	0.02
	SE	27.36	0.01
	SW	27.19	0.01
2024	NE	28.61	0.02
	NW	28.69	0.02
	SE	28.07	0.01
	SW	28.64	0.02

Figure 4.3. CTD diver logger comparisons of temperature (◦C) and depth (m) (starting at 1 m), for TRL sampling sites split into area quadrants for the NE (North East), NW (North West), SE (South East) and SW (South West) for 2019 to 2024 survey years (coloured dots represent real time temperature recording data for different days and sites).



Sea Surface Temperature (SST) records (NOAA, 2018) for the November (overall) mean for Torres Strait, were plotted against mean percent cover for seagrass (important juvenile TRL habitat), for TRL pre-season surveys from 2014 to 2024 (Table 4.3; Figure 4.4). A poor (non-significant) correlation is suggested between SST and seagrass cover (R^2=0.0329; Figure 4.4). In 2019, there were low SST values and low seagrass cover, with SST then increasing until 2022 (and decreasing in 2023) and seagrass remaining at low levels until 2022 (and increasing in 2023 and 2024) (Figure 4.5).

Further work is needed to investigate relationships between physical parameters such as SST (noting SST data is collected continuously and possible temperature effects may not directly relate to the same survey year) and the important lobster habitat of seagrass (possible time lag in response of seagrass to SST), which is likely to be influenced by a combination of parameters and environmental events.

Table 4.3. Mean November temperatures (◦C) for Sea Surface Temperature (SST) for Torres Strait, for 2014 to 2023 survey years (Standard Error (SE) = 1) (SST; source = NOAA, 2018).

Year	Mean temperature	SE
2014	27.48	0.08
2015	27.88	0.11
2016	28.58	0.07
2017	28.31	0.05
2018	28.31	0.10
2019	27.55	0.05
2020	28.38	0.04
2021	29.27	0.08
2022	29.71	0.05
2023	27.74	0.09
2024	27.91	0.08

Figure 4.4. Relationship for Torres Strait Sea Surface Temperature (SST; November mean) and mean percent seagrass cover, for 2014 to 2024 TRL survey years (regression parameter values shown) (SST; source = (NOAA, 2018)).

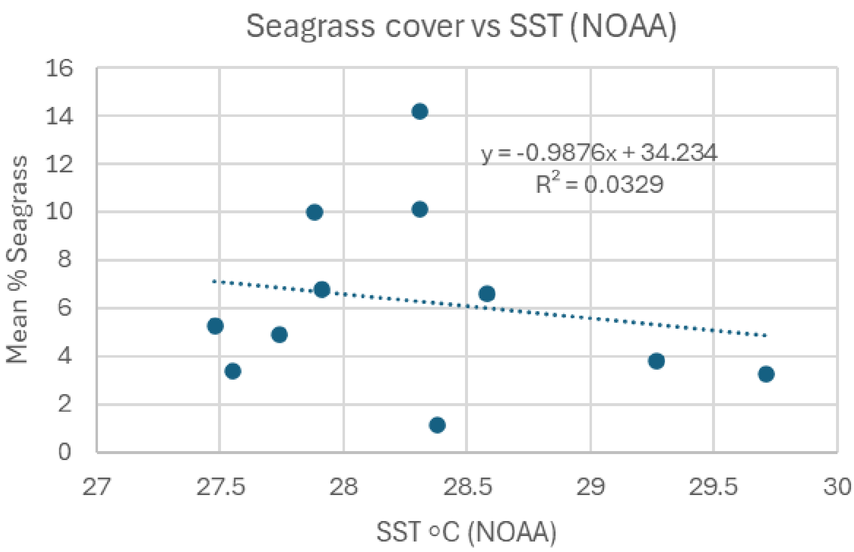
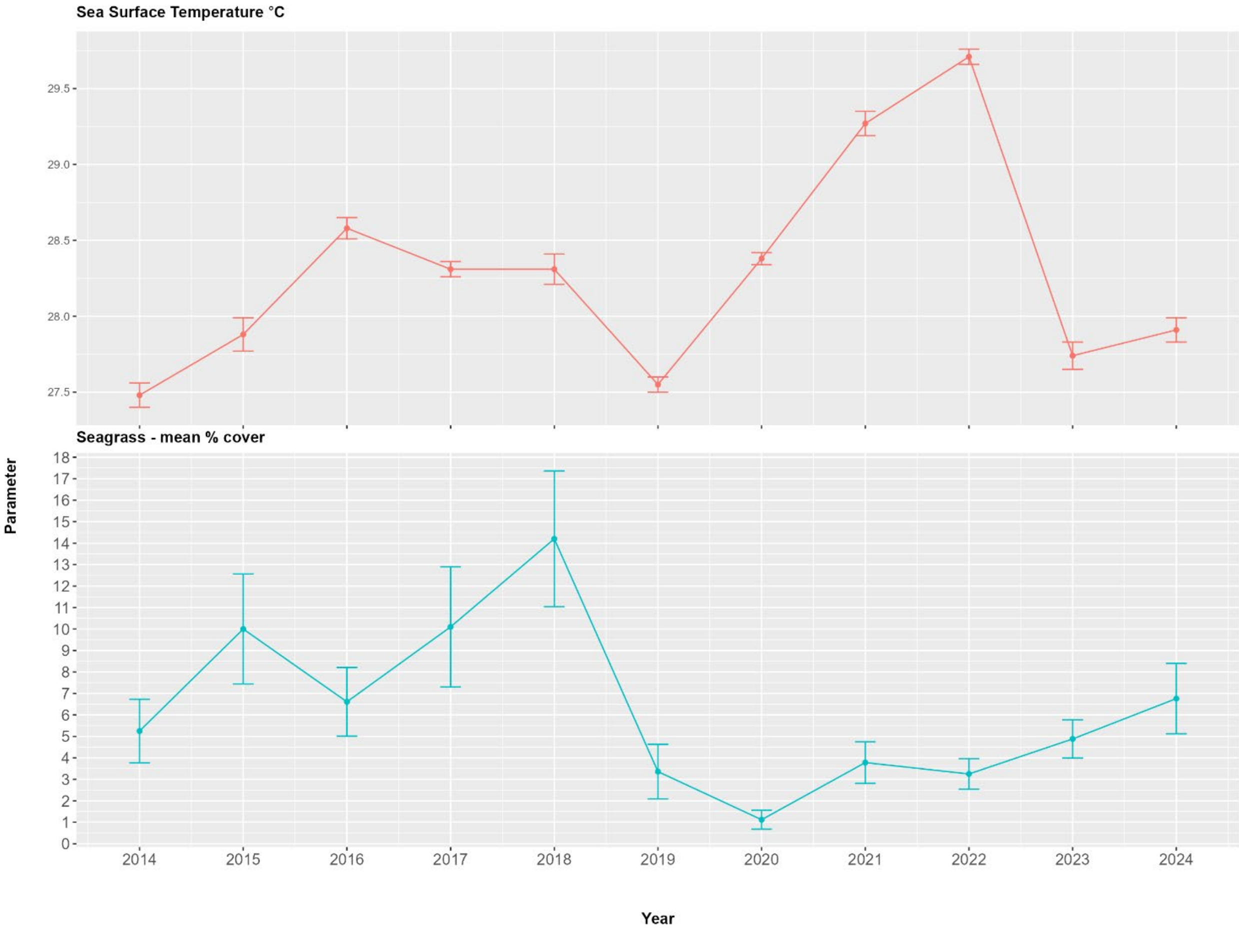


Figure 4.5. Mean percent cover for seagrass and Torres Strait Sea Surface Temperature (SST ◦C; November mean), for 2014 to 2024 TRL survey years (SST source = (NOAA, 2018).



As shown below (Figure 4.6 and Figure 4.7), mean temperature values for the CTD data logger for survey years 2019 to 2021 show a similar trend to NOAA SST records, i.e., a rising trend in water temperatures for this period (Figure 4.5). For 2022, a slight temperature decrease was found for CTD data logger values and a slight temperature increase was recorded for SST, (Figure 4.6 and Figure 4.7). In 2023, SST and CTD decreased, showing close correlation (R^2=0.8802) and both values increased in 2024 (Figure 4.7).

Figure 4.6. Relationship for Torres Strait Sea Surface Temperature (SST ◦C; November mean) and mean CTD diver logger temperature (◦C), for 2014 to 2024 TRL survey years (regression parameter values shown) (SST; source = NOAA, 2018).

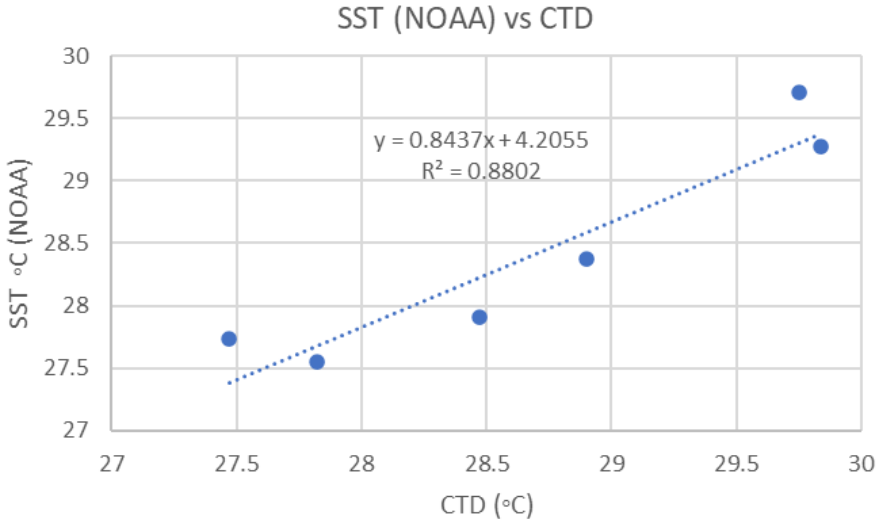


Figure 4.7. Torres Strait Sea Surface Temperature (SST ◦C; November mean) and mean CTD-Diver logger temperature (◦C), for 2014 to 2024 TRL survey years (SST source = NOAA, 2018).

4.4 Conclusions

The data show that mean water temperatures in 2024 were higher than the previous year (2023) (Table 4.1; Figure 4.2). Temperatures for 2022 were similar (and/or slightly lower) to 2021, with temperatures in 2021 higher when compared to 2020 and 2019 (Table 4.1).

High water temperatures may have direct and indirect (via habitats and food webs) negative impacts on the TRL fishery and are of concern if there is an ongoing trend, especially of increasing temperature because previous modelling work suggests negative impacts on lobster mortality when temperatures are above 29°C (Plagányi *et al.* 2019b). In 2021 and 2022, temperature values for both SST and CTD Diver logger were found to be above 29°C (Table 4.1; Table 4.3). It is possible that previous declines in seagrass, algae and coral may be attributable to direct (negative) impacts of higher water temperatures on species and habitats across the survey years (whole of ecosystem effect). These impacts can also act in combination with other local scale drivers, such as sand incursions and seagrass decline, plus need to consider related impacts of dugong herbivory.

Future work is needed to investigate the biotic and abiotic causes of the change in seabed habitats, including changes in water quality parameters and potential grazing pressure from dugongs. Further analyses are also investigating historical sea water temperature data (where available), as well as further investigation of SST data set types (and other physio-chemical parameters) and how they relate to Torres Strait. These aspects are being investigated further as part of the TRL stock assessment modelling as well as modelling conducted as part of the Torres Strait climate change project.

5. Pre-Season Survey Size Distribution

Denham Parker, Leo Dutra, Nicole Murphy, Steven Edgar, Kinam Salee, Roy Deng, and Éva Plagányi

5.1 Summary

This chapter comprises a summary of size (tail width) distributions for Torres Strait tropical rock lobsters based on observations from independent research surveys during the Pre-season (November/December) survey, with emphasis on the 2024 and recent survey years.

There were 162 lobsters measured in the 2024 pre-season survey, which is marginally higher than in recent years (132 in 2023; 124 in 2022). There was a notable difference in the distribution of lobster measured, with substantially more lobster measured in the South (115) compared to the North (47). For comparison, in 2023 a total of 64 lobsters were measured from the South and 68 lobsters from the North. The spatial distribution of the survey covered 77 locations, but lobsters were only measured from 40 of these locations. The 2024 lobster sex ratio was marginally skewed toward males (1.025 males/females).

5.2 Methods

The research survey data collection methods are outlined in Chapter 3 of this report. The survey size results are depicted with a combination of descriptive statistics, histograms and kernel density estimates which were produced in the R statistical software R version 4.2.2 (R Development Core Team 2020).

5.3 Results

The number of TS rock lobsters observed and measured each survey and year, by area and location, are reported in Table 5.1. The 2024 tail width frequency distribution of TS lobster (Figure 5.1) comprised mostly of recruiting lobsters with an approximate size range of 40-70mm tail width (TW). The modal size of 1+ lobster in 2024 was comparable to most other pre-season surveys, however, compared to previous years, there was a low proportion of recently settled lobsters (i.e., <40mm TW) (Figure 5.2 and Figure 5.3). This increased the 2024 mean lobster TW to 51.8mm from a relatively low mean of 42.3mm in 2023; the latter being the result of a higher proportion of recently settled lobsters sampled during the 2023 survey (Figure 5.3).

The density distributions of TS rock lobster tail width, by sex and years (since 2020), sampled in Pre-season surveys are shown in Figure 5.4.

Figure 5.1. Length frequency distribution of tropical rock lobster (Panulirus ornatus) sampled during the 2024 pre-season surveys in Torres Strait. *Note: 90mm CL ≈ 60 mm tail width, which is the minimum size for all commercially caught lobsters).*

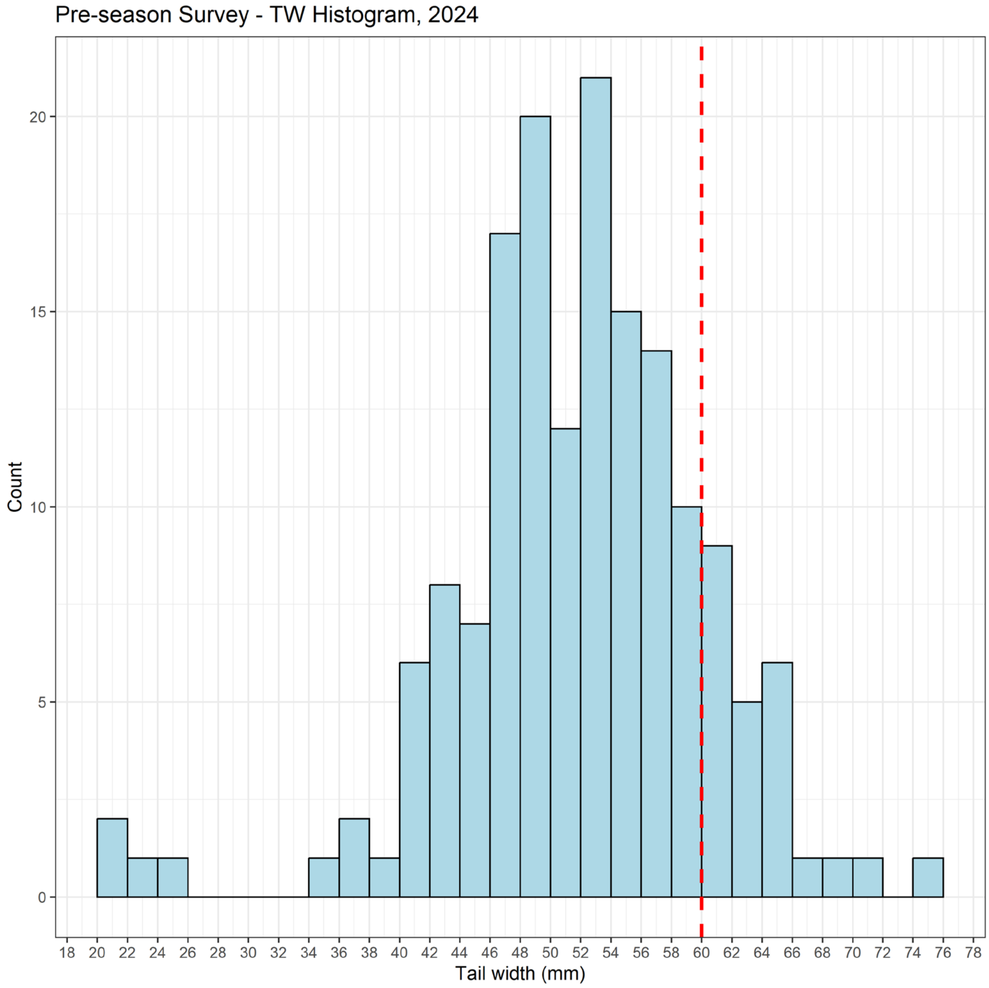


Figure 5.2. Kernel Density Estimate (KDE) of tropical rock lobster (Panulirus ornatus) tail width sampled during pre-season surveys in Torres Strait. *The red line represents the KDE for the 2024 pre-season survey sample. The black dashed line is the combined (average) KDE for pre-season surveys across all years, and the grey shaded area represents one standard error either side of the combined model.*

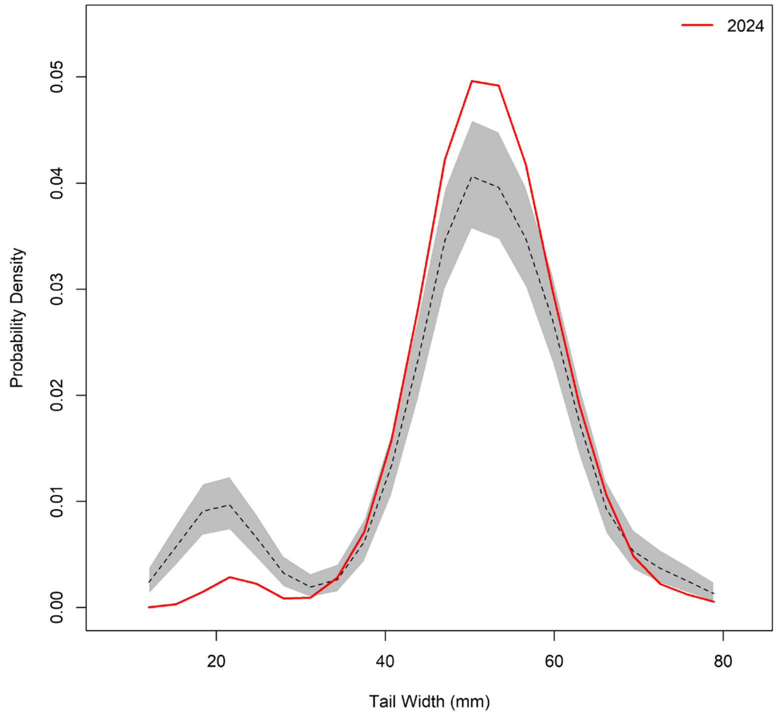


Figure 5.3. Kernel Density Estimate (KDE) of tropical rock lobster (Panulirus ornatus) tail width sampled during the previous three pre-season surveys (2022 - 2024) in Torres Strait. *The black dashed line is the combined (average) KDE for pre-season surveys across all years, and the grey shaded area represents one standard error either side of the combined model.*

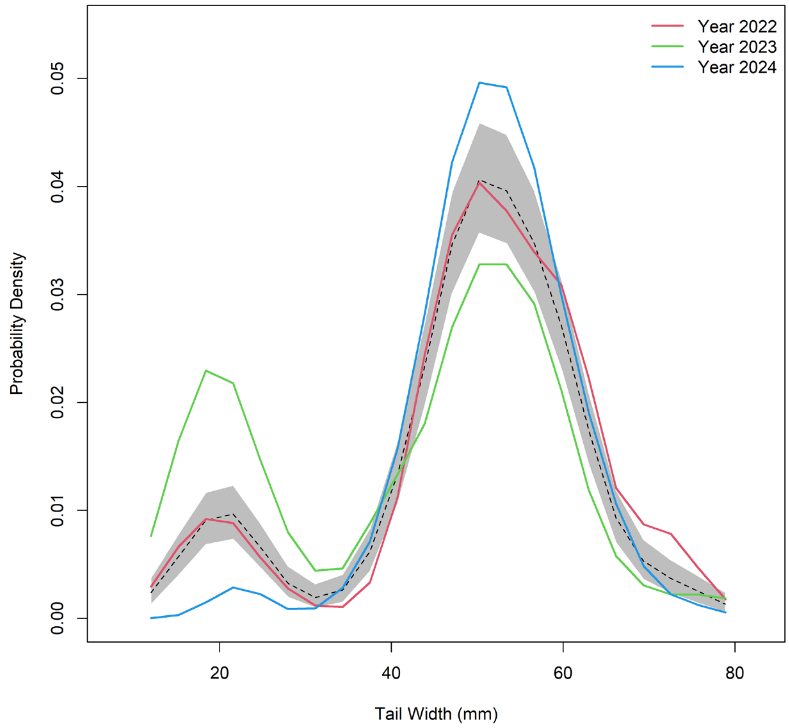
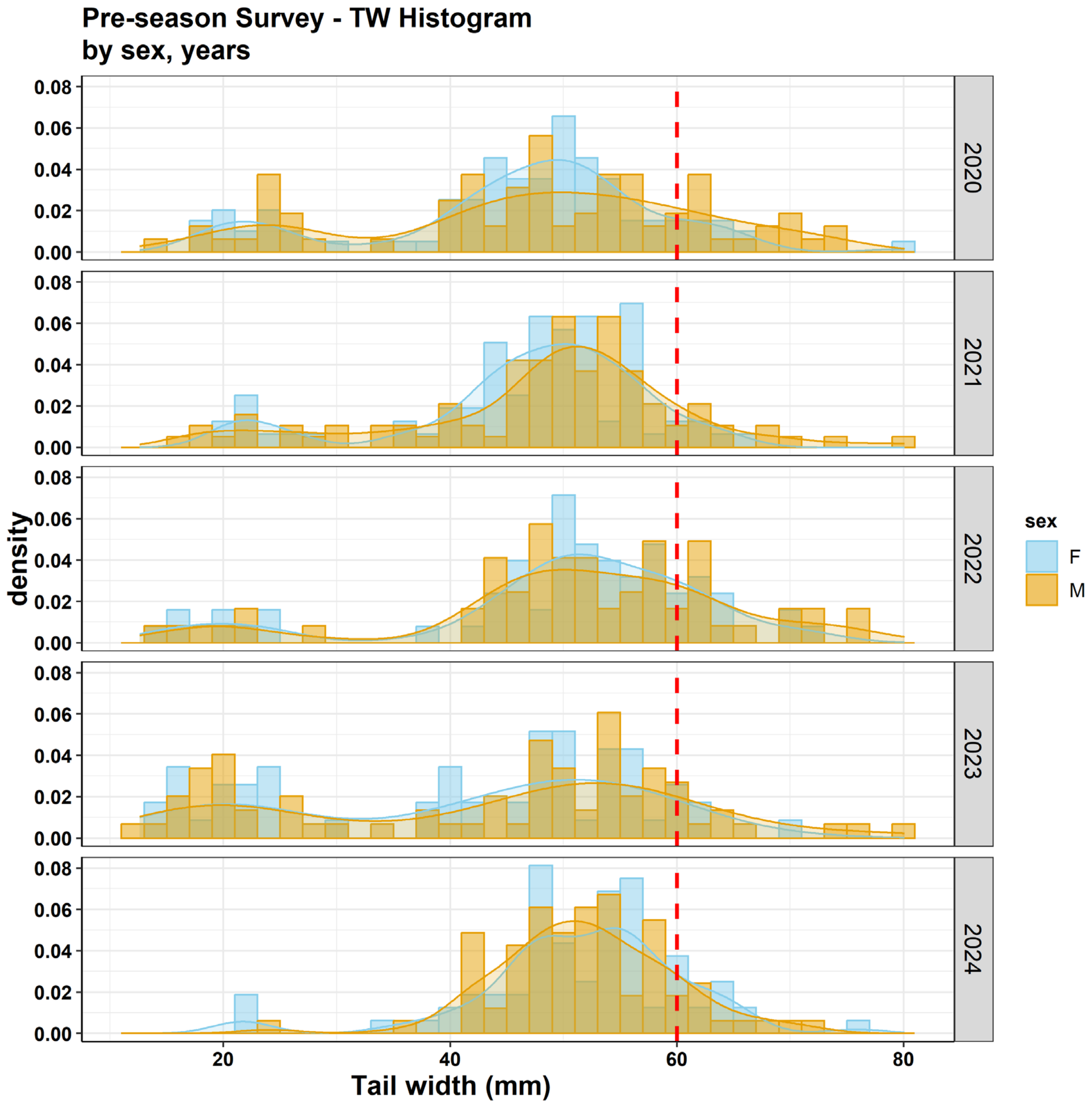


Table 5.1. The number of TS rock lobsters measured each Survey and Year, by area (North or South). *In addition, the observed sex ratio, the number of locations at which lobsters were measured and total number of locations surveyed are indicated.*

Year	Survey	Number of lobster	Sex ratio (M/F)	Number of lobster (North)	Number of lobster (South)	Number of locations with lobster	Number of locations surveyed
1989	Mid	816	0.99	125	691	73	542
1990	Mid	521	1.02	193	328	81	100
1991	Mid	655	0.89	248	407	84	100
1992	Mid	851	0.91	212	639	83	100
1993	Mid	334	1.06	77	257	67	100
1994	Mid	599	0.9	205	394	80	100
1995	Mid	458	0.97	165	293	69	100
1996	Mid	367	0.92	137	230	73	82
1997	Mid	457	1.18	227	230	67	82
1998	Mid	386	0.88	213	173	108	215
1999	Mid	375	0.88	132	243	56	82
2000	Mid	231	1.18	112	119	50	82
2001	Mid	148	0.97	28	120	48	82
2002	Mid	271	0.63	71	200	52	375
2003	Mid	499	0.91	286	213	94	158
2004	Mid	340	0.88	123	217	77	117
2005	Mid	232	0.85	72	160	54	86
2005	Pre	302	1.15	100	202	84	154
2006	Mid	303	1.19	68	235	56	80
2006	Pre	395	1.08	175	220	105	189
2007	Mid	339	0.99	130	209	78	106
2007	Pre	327	1.20	101	226	95	188
2008	Mid	207	0.95	59	148	56	103
2008	Pre	216	0.88	97	119	72	148
2009	Mid	238	0.92	114	124	56	74
2010	Mid	342	0.76	117	225	55	74
2011	Mid	380	0.90	109	271	61	73
2012	Mid	333	1.03	183	150	55	77
2013	Mid	173	1.16	73	100	41	74
2014	Mid	283	1.02	104	179	56	74
2014	Pre	436	1.12	146	209	92	130
2015	Pre	440	0.87	54	386	56	78
2016	Pre	130	0.69	52	78	49	77
2017	Pre	109	0.76	8	101	36	77
2018	Mid	178	1.14	74	104	52	78
2018	Pre	171	0.99	77	94	57	82
2019	Pre	249	0.83	82	167	58	77
2020	Pre	179	0.81	59	120	53	76
2021	Pre	174	1.21	58	116	51	77
2022	Pre	124	0.97	48	76	45	77
2023	Pre	132	1.27	68	64	45	77
2024	Pre	162	1.03	47	115	40	77

Figure 5.4. Histogram (density distributions) of tropical rock lobster (Panulirus ornatus) tail width (by sex), sampled during the previous five pre-season surveys in Torres Strait (2020-2024). *The red dashed line represents legal size (Males 90mm CL ≈ 60 mm tail width).*



Note: The y-axis is probability density. Density scales the height of the bars so that the sum of their areas equals 1. This is helpful for comparing plots, and as a starting point for exploring density distributions (by visualising how the tail width observations are distributed).

6. Commercial Catch Length Frequency Analysis

Denham Parker, Roy Deng, Leo Dutra, Steven Edgar, and Éva Plagányi

6.1 Summary

Since 2001, monthly commercial size data has been recorded at the M.G. Kailis lobster processing factory in Cairns. Sampling continued in 2024, and this chapter describes the distribution of size data across years, months, and sex, with emphasis on the 2024 and recent years.

6.2 Methods

Each month, the sex and total weight of 200 randomly selected lobster were recorded from Torres Strait caught processing batches. The data were sent to CSIRO and converted from individual total lobster weight to carapace length using the morphometric relationship applied to both sexes (Dennis et al., 2009):

$$Total\ lobster\ weight = 0.00258 \times (Carapace\ length^{2.76014})$$

The survey size results are depicted with a combination of descriptive statics, histograms and kernel density estimates which were produced in the R statistical software R version 4.2.2 (R Development Core Team 2020).

6.3 Results

Length frequency plots were generated for Torres Strait commercial catch by number (Figure 6.1) and by proportion of total observations (Figure 6.2). The monthly length frequency plots, by sex, show that early season catches (February/March) comprised larger male lobsters in general, including the most recent 2024 sample. This is to be expected as a portion of the male population remain in Torres Strait while most females migrate in August/September the previous year. The migratory pattern is also reflected in the monthly size distribution (Figure 6.5).

The size distribution of lobster in 2024 was comparable previous years, except that there were a higher proportion of individuals in the 90 -120mm carapace length range (Figure 6.3). There is a marked difference in sex-specific size distribution with a higher proportion of females in the 80-120mm carapace length range and males are more prevalent above 120mm carapace length (Figure 6.4).

Figure 6.1. Monthly length frequency (count) by sex from commercial catch data for tropical rock lobsters (Panulirus ornatus) processed for fishing seasons 2001-2024 combined in Torres Strait (left panel) and 2024 fishing season (right panel).

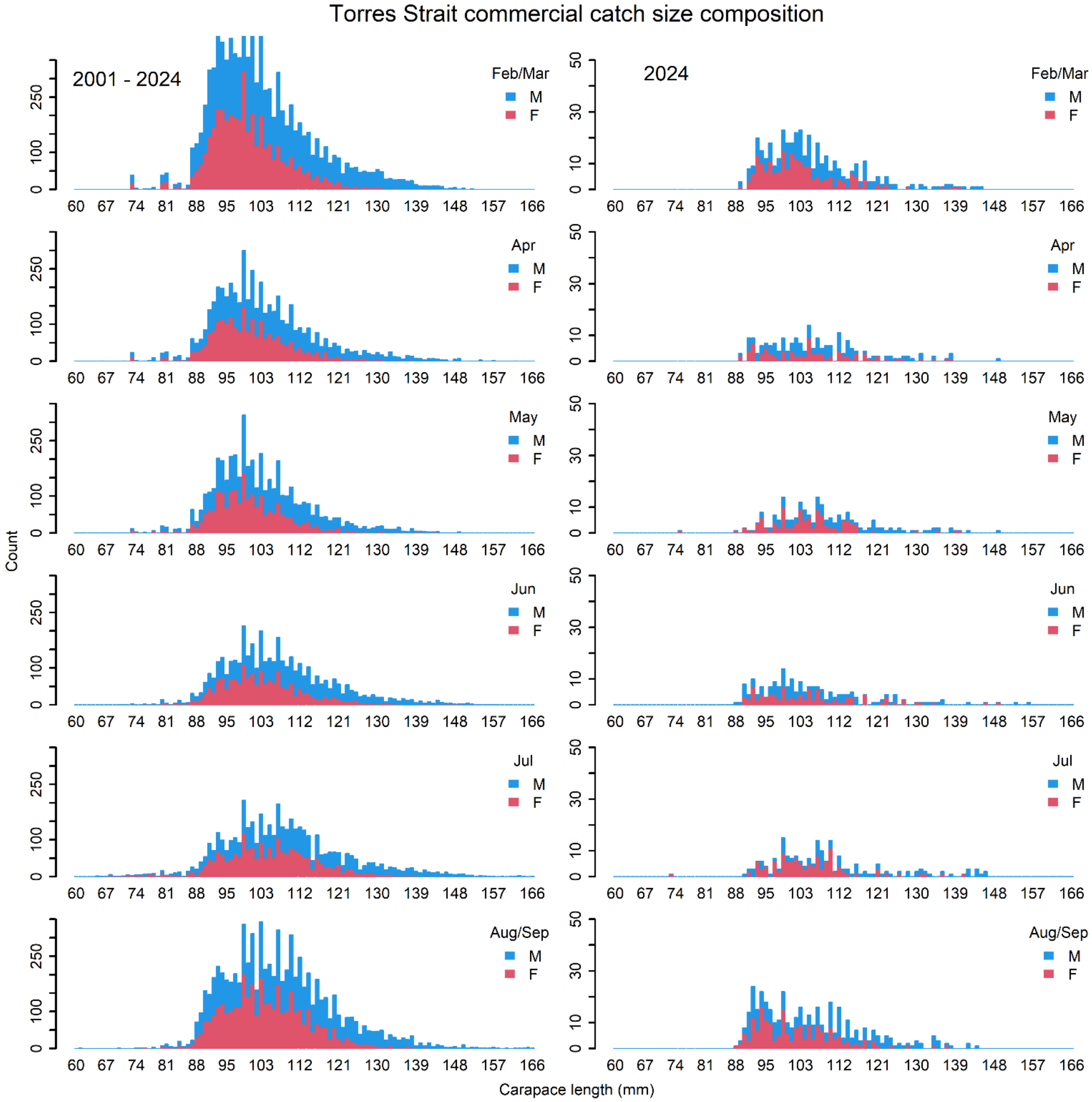


Figure 6.2. Monthly length frequency (proportion) by sex from commercial catch data for tropical rock lobsters (Panulirus ornatus) processed for fishing seasons 2001-2024 combined in Torres Strait (left panel) and 2024 fishing season (right panel).

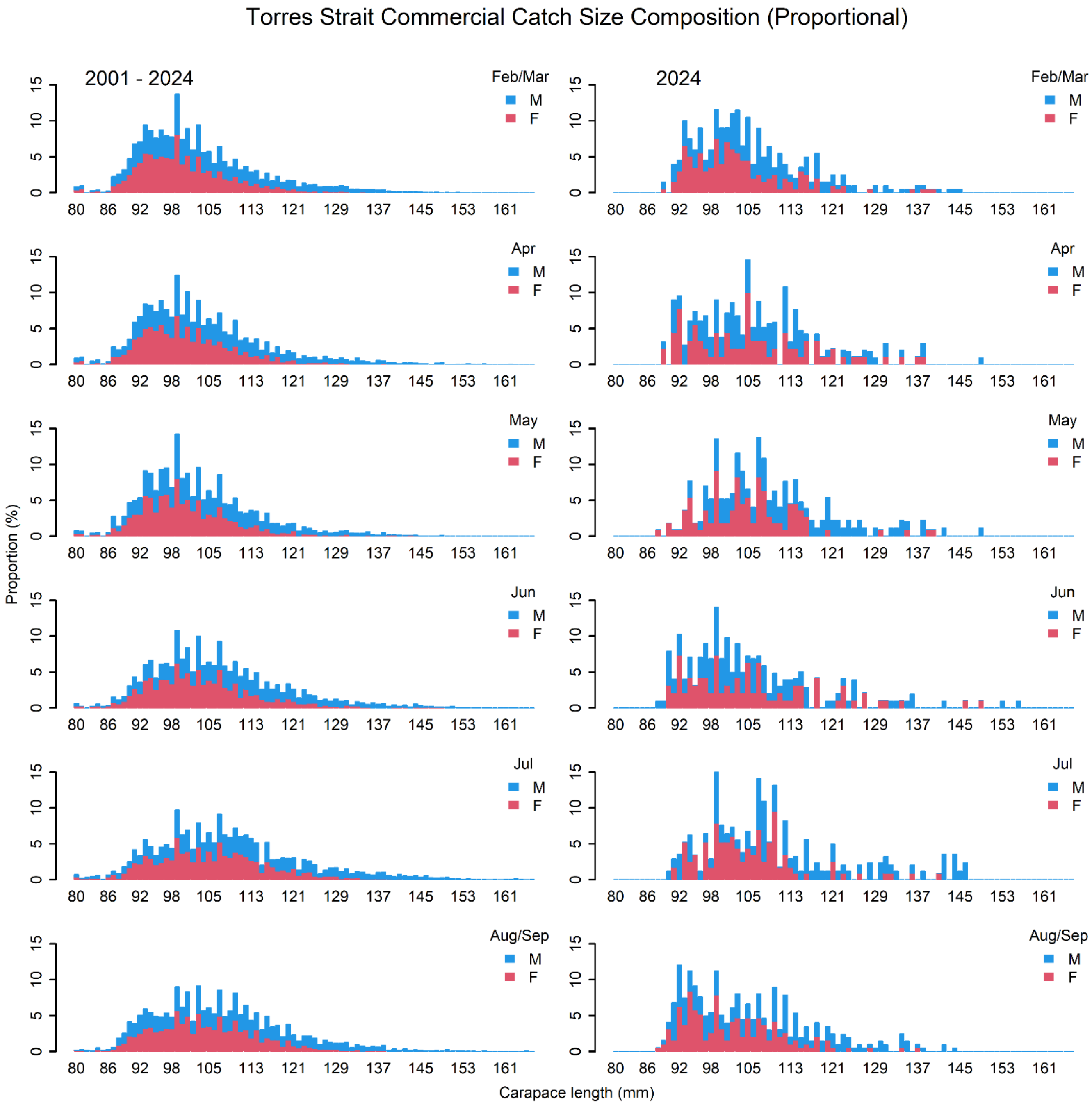


Figure 6.3. Kernel Density Estimate (KDE) of tropical rock lobster (Panulirus ornatus) carapace length from commercial catch data. *The red line represents the KDE for the 2024 samples. The black dashed line is the combined (average) KDE across all years, and the grey shaded area represents one standard error either side of the combined model.*

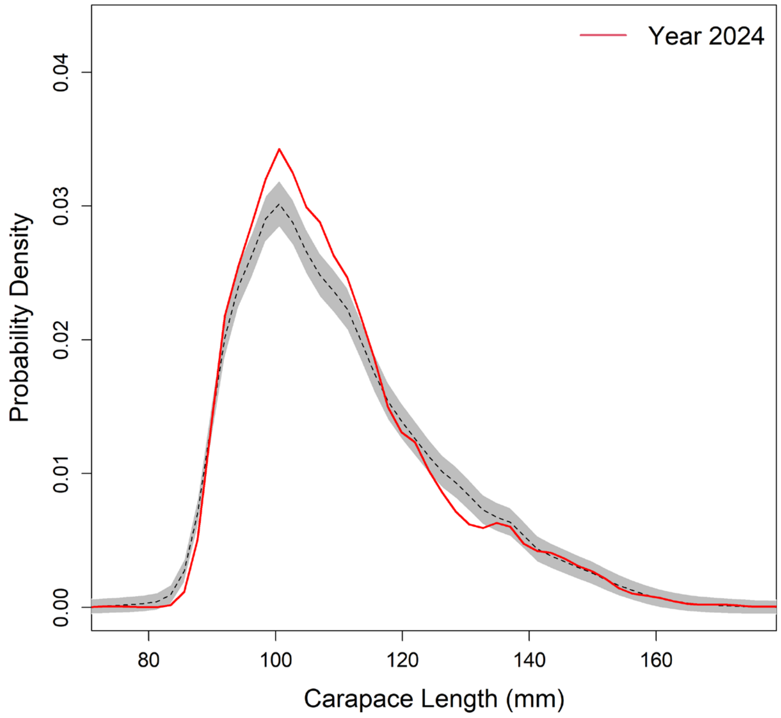


Figure 6.4. Sex-specific density distribution of tropical rock lobster (Panulirus ornatus) carapace length from commercial catch data for 2024. *The red area represents females and the blue area males.*

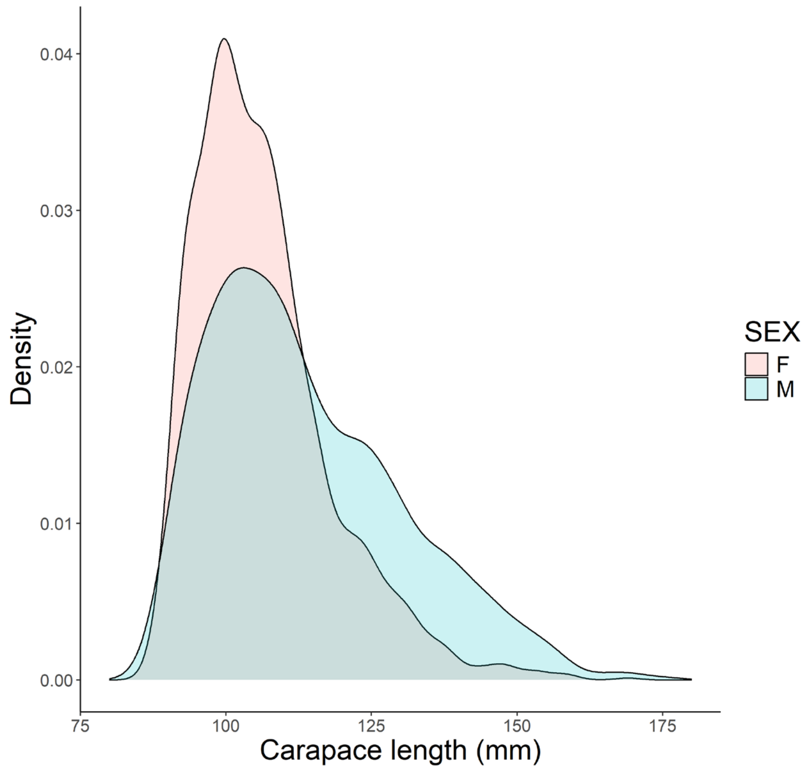
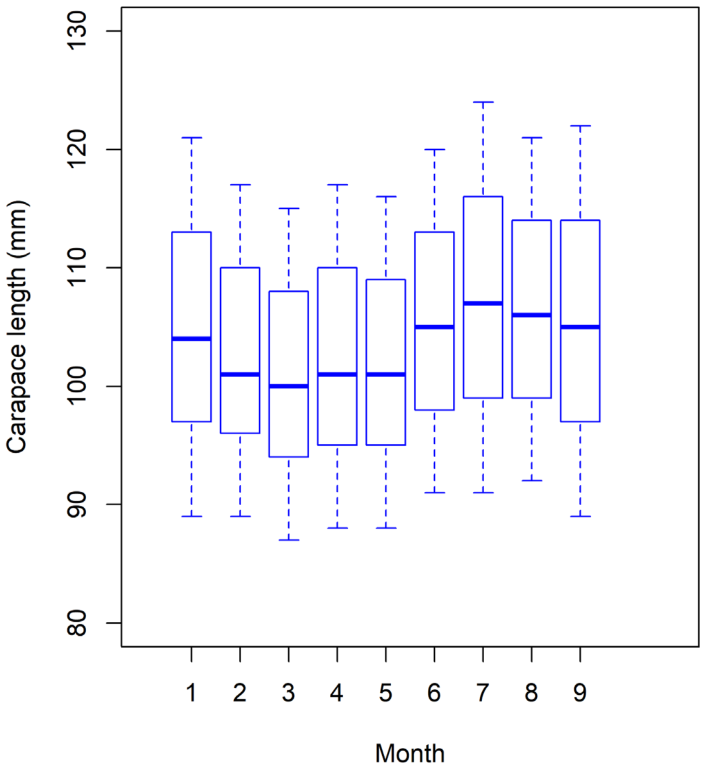


Figure 6.5. Monthly carapace length distribution of tropical rock lobster (Panulirus ornatus) carapace length from commercial catch data for the period 2001-2024.



7. Use of TVH Logbook Data to Construct an Annual Abundance Index for Torres Strait Rock Lobster – 2024 Update

Denham Parker, Roy Deng, Steven Edgar, Éva Plagányi, Laura Blamey, Nicole Murphy, Leo Dutra, and Kinam Salee

7.1 Summary

The Torres Strait Tropical Rock Lobster Fishery's Daily Fishing Log dataset, which spans over 30 years (1994-2024) and includes over 100,000 catch records, was analysed to assess the relative abundance of lobsters in different areas, seasons, and fishing methods. General Linear Models (GLMs) were applied to the data to produce standardized catch-per-unit-effort (CPUE) indices. Three models with varying levels of interaction between *Season*, *Month*, and *Area* were tested. The results showed annual fluctuations in lobster abundance with no clear trend across the timeseries, although certain variables like vessel and area had a substantial impact on CPUE estimates. The 2024 CPUE values were notably lower than the nominal index, but overall, the abundance index varied around the long-term mean.

7.2 TVH Data

The Torres Strait Tropical Rock Lobster Fishery Daily Fishing Log (TRL04) was used to record the catches taken in the TVH sector of the Torres Strait Tropical Rock Lobster fishery. Logbook data obtained from AFMA consists of over 100,000 individual catch records for the TVH rock-lobster fishery for the 30 years from 1994 to 2024. For each vessel-day there can be multiple shots (up to 4) with each shot consisting of up to 8 tenders. Each tender has a catch recorded by diving method (hookah, free, or unknown) and the catch is recorded by processed form (whole, tailed or unknown). The data were aggregated so that each record refers to the rock-lobster catch for a unique vessel-day, shot, tender and diving method. This gave 78,233 records.

The distribution of these 78,233 catch records was analysed by season and month, diving method, processed state of catch and area. The analysis was limited to the 8 months between February and September, the other months had minimal effort recorded and were omitted (see Campbell et al., 2019, 2021 for details). Similarly, the analysis was also limited to those records with a known MSE-area (i.e., areas designated A0 and A99 were excluded). MSE-areas 201 and 202 were combined and designated as area 101 (to provide a better data coverage), and area 401 (GBR) was also excluded.

7.3 Method

As in previous years, several different General Linear Models (GLMs) were used for analysing the data to obtain a standardised index of stock abundance in each year. The GLM methods applied were the same as those previously applied, the full technical details provided in (Campbell *et al.* 2019b; Campbell *et al.* 2021b; Plagányi *et al.* 2022).

The GLM models include:

7.3.1 Main Effects Model

To explore the impact of each main effect included in the GLM, the first set of analyses was based on the following model where no interactions between main effects were included:

<u>Model-1: Main effect:</u>

CPUE = *Intercept + Season + Month + Area + Vessel + 'Fishing-Method'*
+ Proportion of Catch Landed as Tails
+ Southern Oscillation Index (SOI) + Moon-Phase
/ distribution = gamma, link = log

Where:

a) *Season* has 30 levels: 1994-2024
b) *Month* has 8 levels: February–September
c) *Area* has 10 levels (Table 3 in (Campbell *et al.* 2021b))
d) *Vessel* has 51 levels (Figure 9 in (Campbell *et al.* 2021b))
e) *Fishing-Method* has 3 levels: (1) Hookah, (2) Free Diving, (3) Unknown
f) *Proportion*-Tails has 5 levels: (1) <20%, (2) 20-40%, (3) 40-60%, (4) 60-80%, (5) ≥80%
g) *SOI* is the monthly value of the Southern Oscillation Index
h) *Moon-Phase* has 30 levels: the number of days after the last full moon

The models are fitted using the R package "mgcv" (Wood and Wood 2015; Wood 2017). All effects were fitted as categorical effects, except for SOI, which was fitted as a continuous smooth effect using cubic regression splines. A log-gamma distribution was assumed for the distribution of CPUE values. The annual index of abundance was determined using the method described in the next section.

The simple structure of this Main Effects model ignores possible interactions and assumes that the influence of each level of a given main effect is the same across all other combinations of the other main effects. For example, the relative influence of each Month is assumed to be the same across all Seasons and Areas, and similarly the relative influence of each Area is the same across all combinations of Month and Season. Whilst these assumptions may to some extent approximate reality, there may be instances where some assumptions are not fulfilled. For example, there appears to be a degree of inter-annual spatial variation, with catch rates varying in different areas across seasons. We attempt to model such variation in the "Interaction models" described below.

As shown in Campbell (2004) a notable imbalance of observations across the spatial-temporal strata used for calculating the abundance index can result in bias. Given the data are fishery-dependent, we overcome unequal sample distribution by weighting observations when fitting the data to the GLM. Each observation was weighted so that the sum of observation weights was equal across all Season-Month-Area strata. Additionally, to account for these weights when assessing the annual influence of each main effect, the sum of weights for all observations within each level was used, rather than simply counting observations.

7.3.2 Interactions Models

A second set of analyses was undertaken to explore whether the inclusion of interactions between the main spatial-temporal effects improved the model fit to the data. Specifically, the following three models were examined:

<u>Model-2: Int-1:</u>

CPUE = *Intercept + Season + Month + Month * Area*
+ Vessel + 'Fishing-Method' + 'Proportion-Tails' + SOI + Moon
/ distribution = gamma, link = log

<u>Model-3: Int-2:</u>

CPUE = *Intercept + Season * Month + Season * Area + Month * Area*
+ Vessel + 'Fishing-Method' + 'Proportion-Tails' + SOI + Moon
/ distribution = gamma, link = log

<u>Model-4: Int-3:</u>

CPUE = *Intercept + Season * Month * Area*
+ Vessel + 'Fishing-Method' + 'Proportion-Tails' + SOI + Moon
/ distribution = gamma, link = log

Where * indicates an interaction between the main effects. Interactions were included to capture scenarios where the resource distribution across areas and months varies by season.

In previous years, results from a more complex model ("Model-4: Int-3") incorporating a three-way interaction between *Season, Month*, and *Area* was presented. However, attempts to fit this model to the current dataset did not result in convergence, likely due to insufficient data to support such a complex interaction structure.

Using results from each GLM, an annual abundance index was constructed using the standardised CPUE based on the main effects of *Season*, *Month* and *Area*. In total, there were 2,400 strata (30 seasons x 8 months x 10 areas). The standardised CPUE for each stratum was taken as an index of lobster density, which was integrated across the month and area strata to generate an overall abundance index for each fishing season. Finally, a relative annual abundance index (B_y) was calculated by scaling the indices so that their mean across all seasons equalled 1.

7.4 Results of Annual Abundance Indices

The relative abundance indices based on each of the four GLM models are listed and displayed in Table 7.1 and Figure 7.1, respectively. Relative to the nominal index, the standardised indices follow similar patterns but exhibit greater variability, particularly in the first half of the time-series (prior to 2014). The 2024 standardised CPUE values for all models are lower than the nominal index. Overall, the annual relative CPUE index fluctuates around the long-term mean of 1, without displaying a clear directional trend over the time series.

The annual effect (e.g., *Season*) is the most influential variable and accounts for 59.6% of the model's ability to explain the data. *Vessel* is the second most influential variable in the main effects standardisation model and accounts for 28.3% of the model's ability to explain the data (Table 7.2). The influence of *Vessel* is likely twofold; (1) variation in fishing efficiency between vessels operating within the same season and (2) the (expected) increase in the relative fishing power of vessels over time. The relative influence of the *Vessel* effect is seen to be greatest towards the start and end of the time- series and explains the divergence seen between the nominal and standardised indices at these times. *Area* also explains a reasonable proportion of variation in the CPUE observations (5%), indicating spatial variability in lobster densities (Table 7.2). *Moon-phase* is the next most important variable and explains 2.7% of the variability in the CPUE data. However, the annual influence of *Moon-phase* across the entire period is seen to be negligible, because the proportion of fishing during each level of *Moon-phase* is likely to have remained unchanged over time (likely being relatively equal each season).

Figure 7.2 demonstrates the seasonal variation in the nominal CPUE. The figure shows some differences in nominal CPUE when using tender-set as effort from the record of all tenders and set fishing 0.5-12 hours in 2024. The 2024 logbook data have many records with "hours_fished" values bigger than 12 hours which rarely appeared prior to 2024. This indicates there are some big differences introduced into the logbook system in 2024. By analysing these records with "hours_fished" values larger than 12, they appeared to all be from "tender" bigger than 2 and it seems the values reported are the sum of each tender hour value which is inconsistent with the existing method. The plot here for the tenders CPUE are using revised "hours_fished" values which are the average the values by tenders. The CPUE in kilograms per fished hour tracks the same trends as the former type CPUE.

Figure 7.3 shows the equivalent CPUE to those of Figure 7.2 in monthly variation, and with a focus on Season 2024. It indicates that in Feb, CPUE starts high, then drops to the lowest value and peaks between April and May, eventually dropping again in July when the quota runs out. Although there are some differences among the CPUEs from all tenders and the subsets of 0.5-12 hours and fishing hours, they all show similar trends.

Figure 7.4 shows the seasonal CPUE from all tender records for each of the months.

Figure 7.5 shows the seasonal CPUE from all tender records for each of the Areas.

Table 7.1. Relative abundance indices based on standardised CPUE data for the TVH fishery. *Note, each index is scaled so that the mean of the index over all years is equal to 1. The model "Int-1" has previously been adopted by the TRLRAG as the default for input to the eHCR.*

Models	Main Effs	cpue = season month area method tails vessel soi			
	Int-1 (Int-M*A)	cpue = season month*area method tails vessel soi			
	Int-2 (S*M+S*A+M*A)	cpue = season*month season*area month*area method tails vessel soi			
Season	Nominal	Main-Effs	Int-1	Int-2	Mid-year Survey
94	0.89	1.46	1.45	1.23	1.03
95	0.86	1.42	1.39	1.32	1.76
96	0.93	1.04	1.04	1.47	0.91
97	1.01	1.20	1.19	1.09	0.79
98	1.06	1.13	1.12	2.06	1.05
99	0.71	0.67	0.67	0.70	0.35
00	0.60	0.70	0.69	0.76	0.47
01	0.43	0.44	0.43	0.38	0.18
02	0.70	0.68	0.67	0.45	0.64
03	1.09	1.05	1.04	0.76	1.71
04	1.10	1.16	1.16	1.02	1.24
05	1.54	1.48	1.48	1.24	1.60
06	0.67	0.69	0.69	0.49	0.59
07	1.11	0.98	0.98	0.85	1.20
08	0.84	0.86	0.87	1.04	0.71
09	0.61	0.65	0.65	0.61	0.90
10	1.24	1.13	1.16	1.14	1.01
11	2.06	1.77	1.77	2.12	1.71
12	1.58	1.40	1.41	1.09	1.11
13	1.29	1.23	1.24	1.58	1.04
14	0.97	0.94	0.95	0.77	1.01
15	0.61	0.63	0.63	0.43	
16	1.17	1.10	1.11	1.45	
17	0.74	0.73	0.73	0.64	
18	0.88	0.70	0.70	0.57	0.58
19	1.04	0.92	0.93	0.64	
20	1.22	1.23	1.23	1.28	
21	0.77	0.68	0.68	0.82	
22	1.01	0.96	0.96	1.19	
23	1.00	1.05	1.06	0.99	
24	1.26	0.92	0.93	0.83	
Mean	1.00	1.00	1.00	1.00	1.00

Table 7.2. Model statistics for the main effects of the GLM applied to TVH data.

Fixed Effect	Residual Deviance	DF	Chi - Squared	Pr > ChiSq	% Deviance Explained
Intercept	37177	-	-	-	
Season	30296	30	6881	<0.0001	59.6
Month	30137	7	159	<0.0001	1.4
Area	29562	9	575	<0.0001	5.0
Fishing method	29507	2	55	<0.0001	0.5
Tails	29291	4	216	<0.0001	1.9
Vessel	26018	50	3272	<0.0001	28.3
Moon-Phase	25704	29	314	<0.0001	2.7
SOI	25643	1	62	<0.0001	0.5
SOI2	25642	1	0	0.7537	0.0
SOI3	25629	1	13	<0.0001	0.1

Figure 7.1. The seasonal abundance indices for the TVH sector of the Torres Strait rock lobster fishery based on the standardised CPUE from the Main-Effects and interaction models.

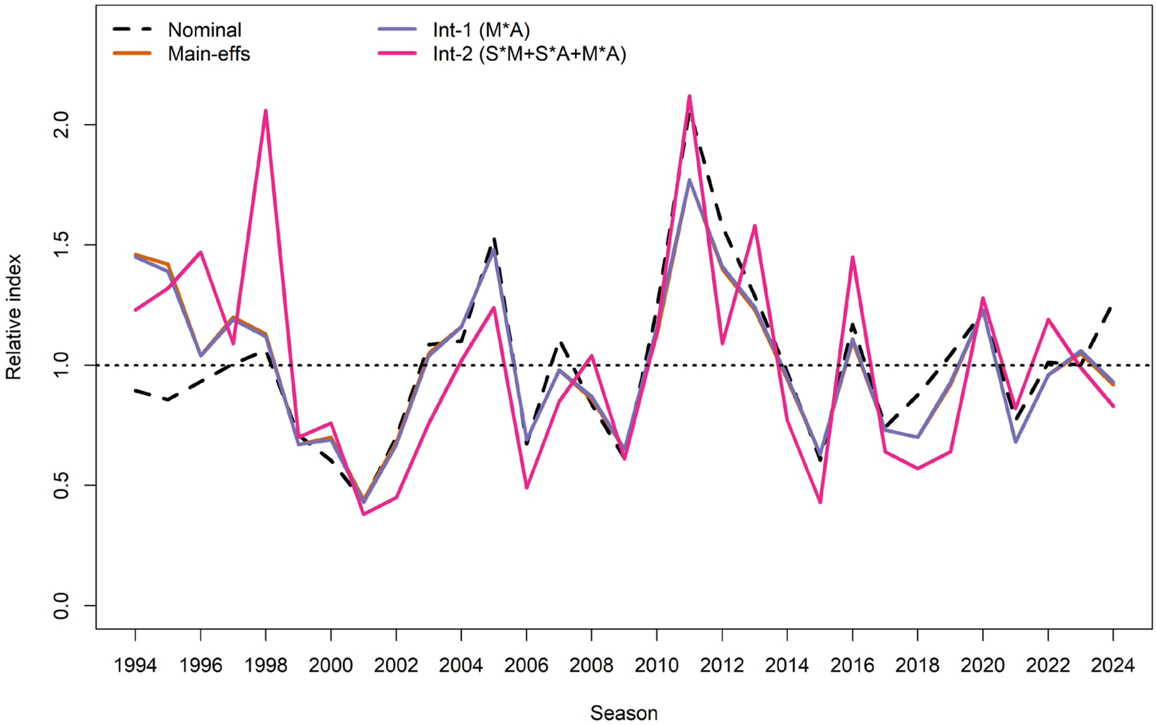


Figure 7.2. The alternative nominal TVH CPUE series (from 2004).

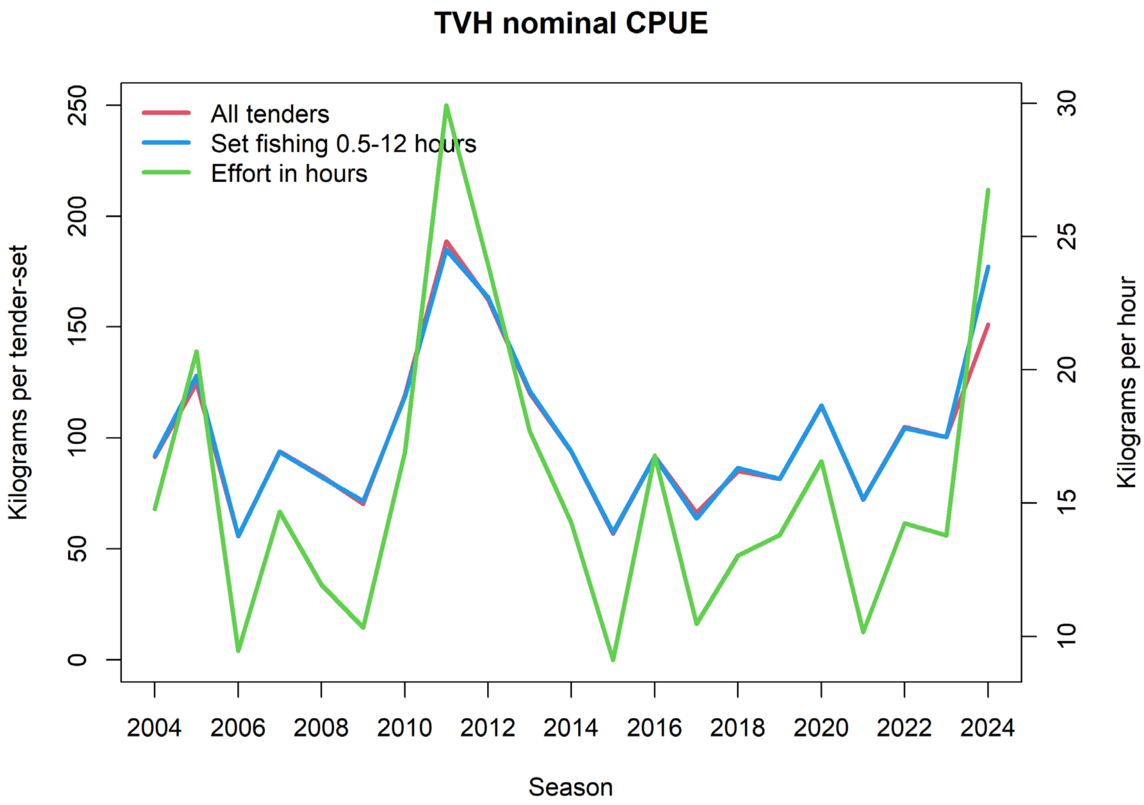


Figure 7.3. Season 2024 nominal TVH CPUE per month.

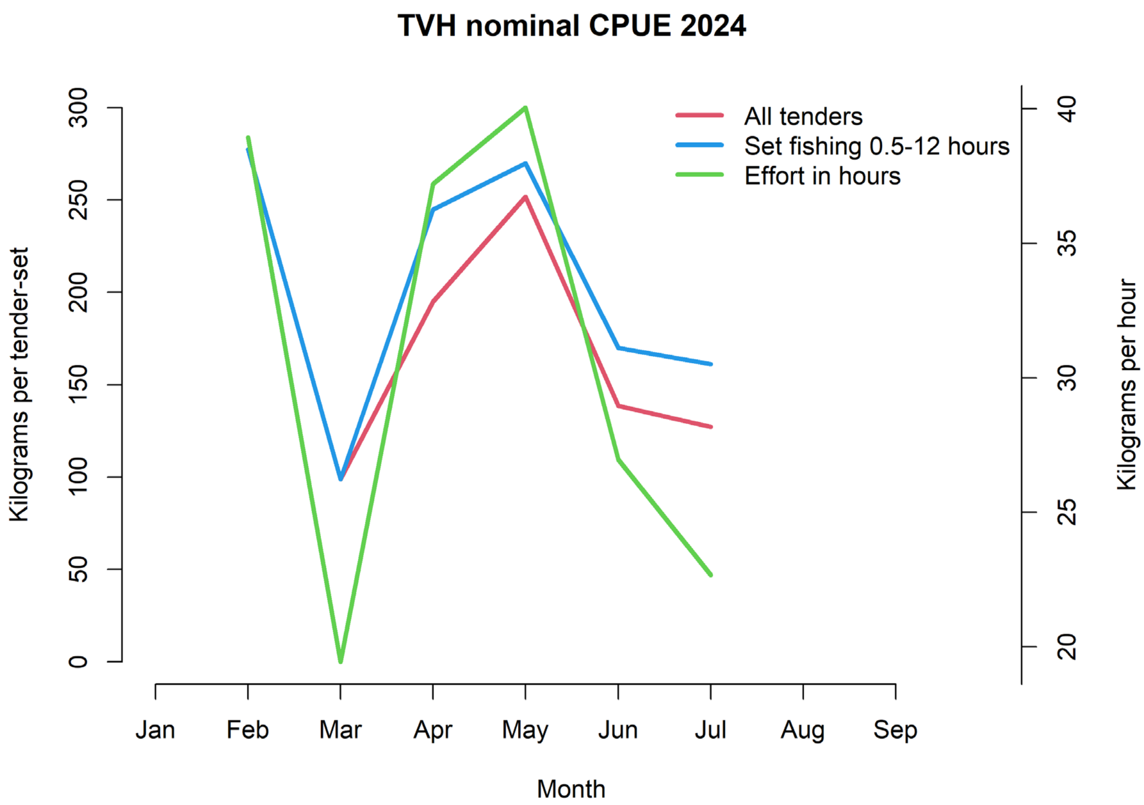


Figure 7.4. Monthly CPUE time series from nominal CPUE per month. *No plots for Dec and Jan due to the hookah gear closure period.*

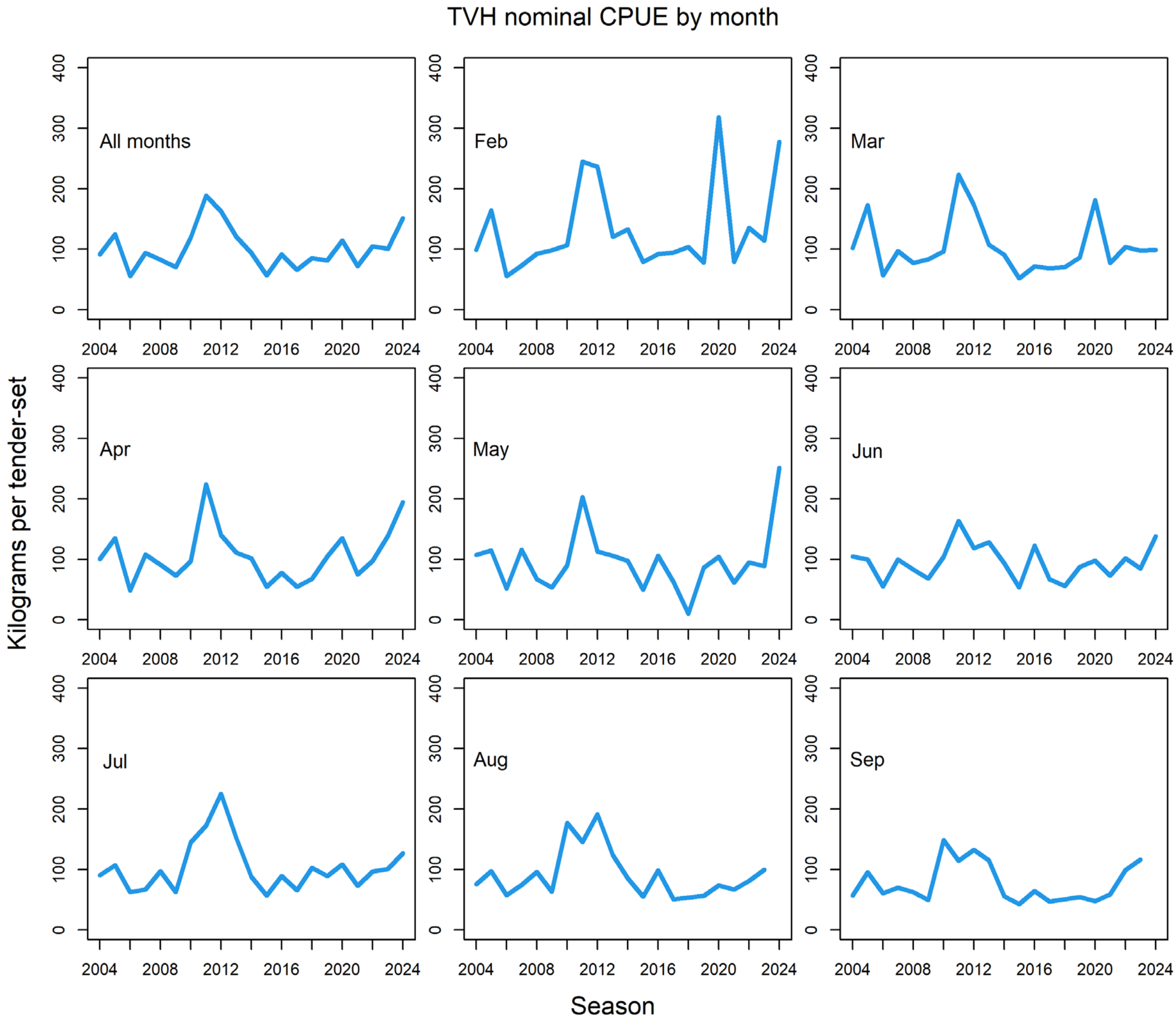
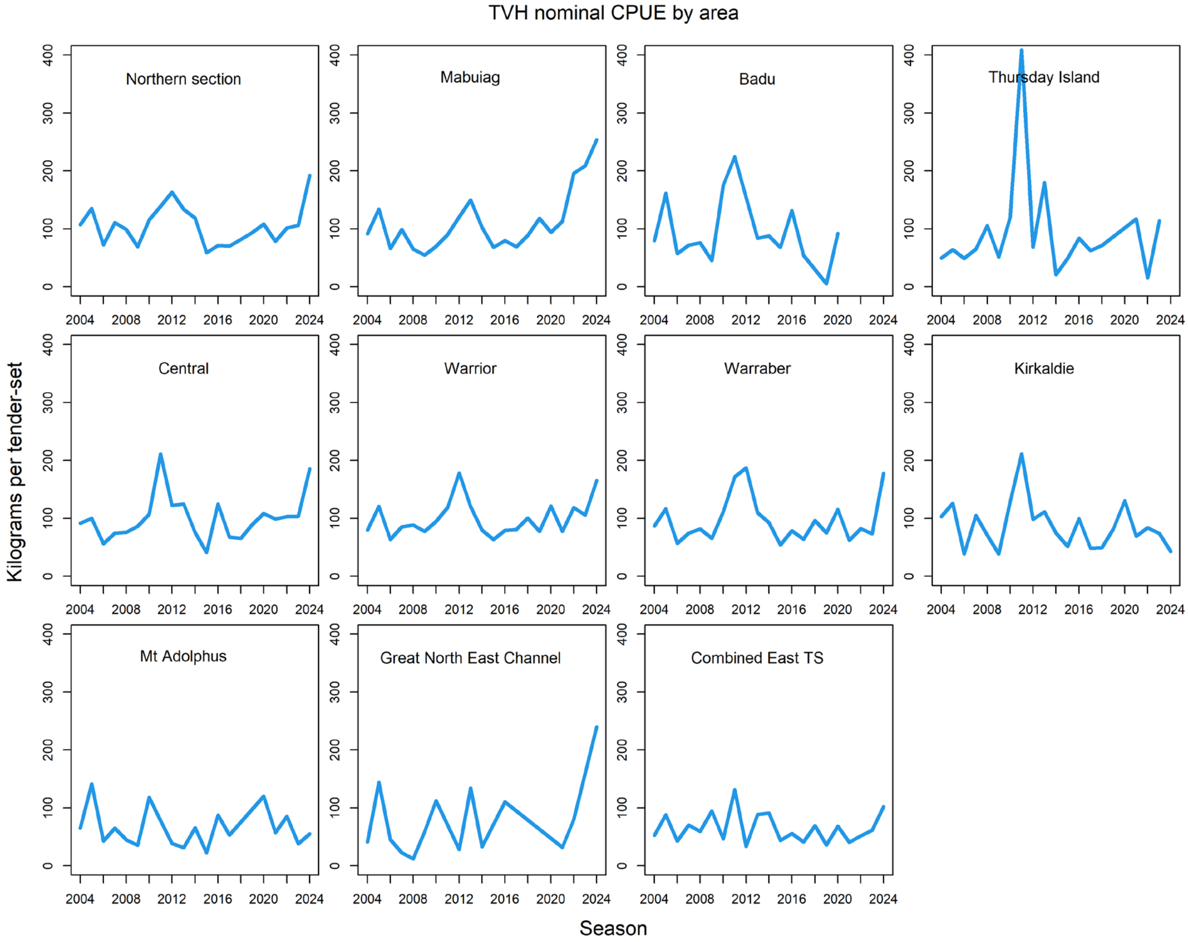


Figure 7.5. TVH CPUE time series from nominal CPUE per area.



8. Use of TIB Logbook Data to Construct an Annual Abundance Index for Torres Strait Rock Lobster – 2024 Update

Denham Parker, Roy Deng, Steven Edgar, Éva Plagányi, Laura Blamey, Nicole Murphy, Leo Dutra, and Kinam Salee

8.1 Summary

Catch data from the TIB sector of the Torres Strait Rock Lobster Fishery between 2004 and 2024 was analysed to assess the relative abundance of lobsters. The data were filtered to ensure accuracy, resulting in 44,374 valid Vessel-Day-Seller (VDS) records. General Linear Models (GLMs) were used to standardize catch rates (CPUE) and assess the impact of factors such as *Season, Month, Area, Fishing method,* and *Seller*. Results showed an increasing trend in standardised catch rates since 2015, with notable variability in recent seasons due to the increased influence of individual *Sellers* - fewer *Sellers* operated in 2024 (52) compared to 2023 (77) and previous years in general (353). The TIB data, while valuable, lacks some precision compared to the TVH sector and needs improvement in accuracy and completeness to be able to provide detailed abundance estimates.

8.2 Selection of TIB Data for CPUE Analysis

Considerable effort has gone into understanding the nature of both the TDB01, TDB02 Docket-Book and TRL04 Logbook data so as to identify the catch records that should be assigned to the TIB sector of the fishery. A full description of the approach and data-rules used to identify and remove these duplicate records from the Docket-Book data is described in Campbell and Pease (2017) and Campbell et al. (2021a) (summarised in the final report of Plagányi et al. (2022)). Each catch record in the TIB data is associated with a Record-No, and the structure of the Docket-Book would seem to indicate that there should be a unique Record-No for each vessel, date and seller-name. However, investigation of the data indicates that there are often multiple Record-Nos associated for a given vessel, date and seller-name. The reason for these multiple records remains unknown but may be due to incorrect recording of dates, etc.

In order to identify an appropriate data structure for analysis, we used the same procedure as previously to filter the data:

1. The TIB data was aggregated over vessel-symbol, date and seller-name. Where the vessel-symbol or seller-name was null these fields were set to ‘Unknown’. Data was limited to the seasons 2004 to 2024 resulting in a total of 68,919 aggregate Vessel-Day-Seller records (hence-forth known as VDS records).

2. Only those VDS records having a unique Record-No were selected for analysis. It was assumed that where the vessel or seller were unknown, that selection of only those GLM records having a unique Record-No limited the GLM records chosen to those associated with a single vessel and a single seller.
3. VDS records were also deleted where any of the number of fishers, the number of days fished, the number of methods, the area fished, and the Seller-Home were not unique or remained unknown (i.e., not recorded). Records associated with the TRL04 logbook or where the catch was zero were also deleted. This resulted in 51,677 VDS-records being retained.
4. Finally, VDS records were only retained where they satisfied the following criteria:
    a. the month was not October or November,
    b. the fishing method was either 'Hookah diving', 'Free diving', 'Lamp fishing' or some combination of these three methods (denoted 'Mixed'),
    c. the number of fishers was between 1 and 3,
    d. d. the number of days fished was between 1 and 9,
    e. the recorded catch weight was between 1kg and 500kg, Note, the distribution of catches is over-dispersed, with 0.54% of records having a catch greater than 500kg and 0.17% of records having a catch greater than 1000kg.

   The records for a few large vessels which were considered non-representative of the TIB fishing sector were also removed.
5. Finally, the records for the 2013 season were also deleted due to the small number of records for this season (72) compared to all other seasons (between 1,018 and 5,459). The small number for 2013 was because many of the fields on the TDB-01 Docket-Book that season were left blank.
6. This procedure resulted in 44,374 VDS records being selected for analysis.

8.3 Method

As in previous years, several different General Linear Models (GLMs) were adopted for analysing the data to obtain a standardised relative index of stock abundance in each year. Full technical details for the TIB CPUE standardisation process, including the data preparation, are provided (Campbell *et al.* 2019a; Campbell *et al.* 2021a; Plagányi *et al.* 2022).

General Linear Models (GLM) were fitted to the selected TIB data to standardise the CPUE to account for changes in the distribution of records across several main effects (e.g., *Season, Month, Area* and *Fishing-Method*). The measure of effort for the TIB data was taken to be days-fished. The catch rate associated with each GLM record was then defined to be the mean weight of lobsters caught per day-fished, i.e.:

$$CPUE = \frac{Whole\,Weight\ of\ landed\ lobsters}{Number\ of\ days\ fished}$$

In order to investigate the influence of the various effects on the catch rates and to help account for the possible misreporting of the Area fished on Docket-Book records (as noted by TSRL-RAG23 in May 2018), the following two models were fitted to the data described above. All GLMs were weighted as described in (Campbell *et al.* 2019a; Campbell *et al.* 2021a). The models are fitted using the R package "mgcv" (Wood and Wood 2015; Wood 2017).

8.3.1 Main Effects Model

To explore the impact of each main effect included in the GLM, the first set of analyses were based on the following model where no interactions between main effects were included:

<u>Model-1: Main effect:</u>

CPUE = *Intercept + Season + Month + Area-Fished + 'Fishing-Method'*
+ 'Proportion-Tails'
+ SOI + 'Moon-Phase'
/ distribution = gamma, link = log

Where:

a) *Season* has 19 levels: 2004-2012, 2014-2024
b) *Month* has 10 levels: December–to-September
c) *Area-Fished* corresponds to the *Seller-Home* and has 13 levels
d) *Fishing-Method* has 4 levels: (1) Hookah, (2) Free Diving, (3) Lamp Fishing, and (4) mixed methods
e) *Proportion-Tails* has 5 levels: (1) <20%, (2) 20-40%, (3) 40-60%, (4) 60-80%, and (5) ≥80%
f) *SOI* is the monthly value of the Southern Oscillation Index
g) *Moon-Phase* has 30 levels: the number of days after the last full moon

8.3.2 Interactions Models

A second set of analyses was undertaken to explore whether the inclusion of interactions between the main spatial-temporal effects improved the model fit to the data. Specifically, the following three models were examined:

<u>Model-2: Int-1:</u>

CPUE = *Intercept + Season + Month + Month * Area*
+ 'Fishing-Method' + 'Proportion-Tails' + SOI + Moon
/ distribution = gamma, link = log

<u>Model-3: Int-2:</u>

CPUE = *Intercept + Season * Month + Season * Area + Month * Area*
+ 'Fishing-Method' + 'Proportion-Tails' + SOI + Moon
/ distribution = gamma, link = log

Model-4: Int-3:

CPUE = *Intercept + Season * Month * Area*
+ 'Fishing-Method' + 'Proportion-Tails' + SOI + Moon
/ distribution = gamma, link = log

Where * indicates an interaction between the related effects. The inclusion in these interactions allows for the relative distribution of the resource between the different areas and months to be different between seasons.

A further set of models were run to include the "Seller" effect; this model has previously been adopted by the TRLRAG as the default for input to the eHCR. All effects were fitted as categorical effects, except for SOI, which was fitted as a continuous smooth effect using cubic regression splines. A log-gamma distribution was assumed for the distribution of CPUE values.

Using results from each GLM, an annual abundance index was constructed. The standardised CPUE for each stratum was taken as an index of lobster density, which was integrated across the *Month* strata to generate an overall abundance index for each fishing season. Finally, a relative annual abundance index (B_y) was calculated by scaling the indices so that their mean across all seasons equalled 1.

8.4 Results of Standardisation of Annual Abundance Indices

The seasonal abundance indices based on each of the four GLM models listed in the previous section are provided in Table 8.1 and Figure 8.1. Relative to the nominal index, each of the standardised indices displays substantive shifts, generally being lower than the nominal index over the first half of the time-series and higher than the nominal index during the second half (i.e., since 2012 to 2024). The nominal and standardised TIB CPUE suggest an increasing trend in catch rates since the 2015 season and all relative index values have been >1 since 2019. Notably, the 2024 standardised CPUE values for all models are lower than the nominal index.

Possible reasons for the observed increase in catch rates since 2015 can be investigated using the seasonal influence of each factor for the Main and Seller models. The most influential parameter is the *Seller* which accounted for 43.4% of the model's ability to explain variation in the CPUE data (Table 8.2). The influence of *Seller* effect has increased in recent seasons resulting in an increase in catch rates. This indicates that there has been an increase in the relative fishing efficiency of *Sellers* in recent seasons, which when accounted for in the standardisation model leads to a decrease in the standardised CPUE relative to the nominal values – it is important to note that 2024 is an exception to this as the nominal index is higher than standardised estimates derived from all of the models applied. This is likely due to fewer *Sellers* operating in 2024 (52) compared to 2023 (77) and previous years in general (353). Nonetheless, the influence of the *Seller* effect in recent seasons therefore explains the divergence seen between the standardised indices based on the Main and Seller models during this period.

Area is the second most influential parameter, accounting for 22.8% of the model's ability to explain variation in the data, followed by *Season* (14.1%), suggesting that the model is able to reasonably account for variation in CPUE observations across space and time (Table 8.2).

Given the importance of *Seller* as an explanatory variable, the model that incorporates this information, but without spatial-temporal interactions (i.e., Model "Seller") is considered the preferred model.

8.5 Concluding Remarks on TIB and TVH Abundance Indices

For the Torres Strait rock lobster fishery, there are currently two sources of catch and effort data, those for the TVH and TIB sectors. The TRL04 Logbook data from the TVH sector is believed to provide a relatively complete and good source of catch and effort data for this sector (e.g., Campbell et al. (2019a). Improvements in compliance to ensure that all fields in the Logbook are completed (e.g., area fished and hours fished) would improve the utility of these data. Also, a better recording of the locations of the fishing effort (i.e., at the tender level) would also improve the accuracy of the data for standardising catch rates.

The data for the TIB sector is less complete and the measure of effort (days fished) is less accurate and incomplete in many instances. There also remains problems with the way in which the area-fished in the TIB is recorded, and what is the correlation between what is recorded and where the fishing occurs. However, given the potential for this sector to grow in importance in future years there is a need to assess the utility of these data to provide a useful index of resource abundance.

The results presented above indicate that while the TIB-based indices have the potential to capture the major trends stock abundance, they likely lack the detail required to track finer inter-annual trends in abundance. There are several reasons for this outcome. In particular, the measures of catch and effort in the TIB data are coarser (trip-based) compared to the tender-hours based data for the TVH data. Indeed, for the TIB data it remains unknown how many hours per trip fishing occurred and whether there are differences between the different sellers and trends over the years. Effort needs to be placed on ensuring the completeness and accuracy of these data if they are to be used on a continuing basis.

Table 8.1. Relative abundance indices based on standardised CPUE data for the TIB fishery. *Note, each index is scaled so that the mean of the index over all years is equal to 1. The model "Seller" has previously been adopted by the TRLRAG as the default for input to the eHCR.*

Models		
	Main	ln(CPUE) = Season + Month + Method + Percent_Tails + SOI + Moon
	Int - M*A	ln(CPUE) = Season+ Month + Month*Area + Area + Method + Percent_Tails + SOI + Moon
	Seller	ln(CPUE) = Season + Month + Method + Percent_Tails + Seller + SOI + Moon
	Seller -Int M*A	ln(CPUE) = Season + Month +Month*Area + Area + Method + Percent_Tails + Seller + SOI + Moon
	Index scales so mean over all years = 1	

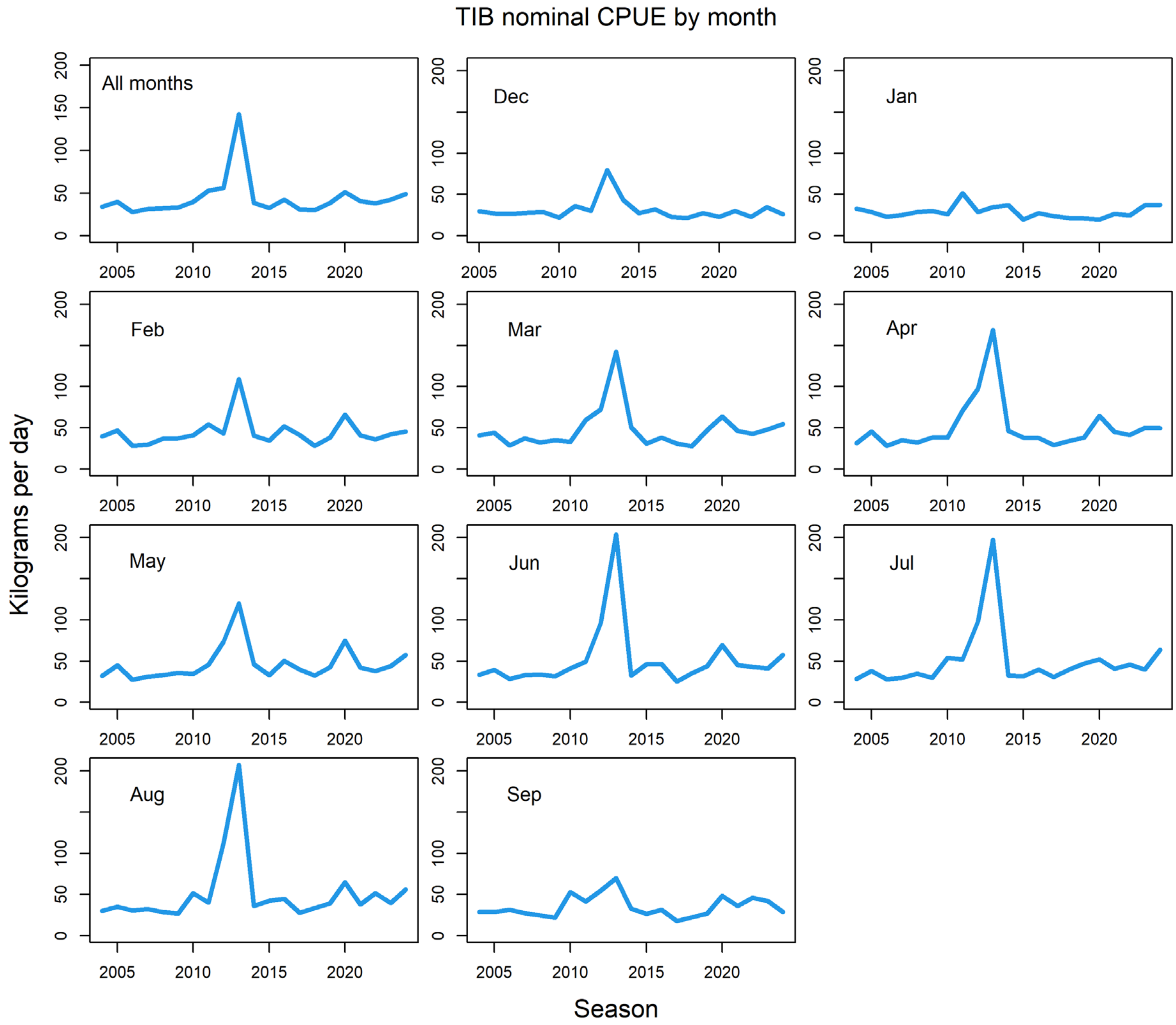
Season	Nominal	Main	Int - M*A	Seller	Seller Int-M*A
04	0.93	0.82	0.82	0.88	0.89
05	1.12	0.94	0.94	1.05	1.06
06	0.79	0.71	0.71	0.73	0.73
07	0.96	0.82	0.83	0.85	0.87
08	0.94	0.76	0.77	0.82	0.82
09	0.90	0.91	0.91	0.97	0.98
10	0.98	0.96	0.96	0.99	0.99
11	1.37	1.36	1.37	1.42	1.41
12	1.04	1.12	1.12	1.16	1.17
13					
14	1.00	0.91	0.91	0.94	0.93
15	0.67	0.76	0.75	0.81	0.79
16	1.06	1.05	1.05	1.03	1.02
17	0.76	0.95	0.95	0.88	0.89
18	0.75	0.81	0.81	0.77	0.78
19	0.98	1.20	1.18	1.06	1.06
20	1.35	1.33	1.35	1.19	1.19
21	0.97	1.12	1.12	1.04	1.04
22	0.97	0.97	0.97	1.04	1.03
23	1.18	1.33	1.31	1.25	1.23
24	1.27	1.17	1.17	1.13	1.12
Mean	1.00	1.00	1.00	1.00	1.00

Table 8.2. Model statistics for the main effects of the Seller Model applied to TIB data.

Main Effects	Residual Deviance	DF	Chi-Squared	Pr > ChiSq	% Deviance Explained
Intercept	29326	-	-	-	-
Season	27788	19	1538	<0.0001	14.1
Month	27320	9	467	<0.0001	4.3
Area	24832	12	2488	<0.0001	22.8
Method	24299	3	533	<0.0001	4.9
Tails	23488	4	811	<0.0001	7.4
Moon-phase	23199	29	289	<0.0001	2.7
Seller	18467	352	4732	<0.0001	43.4
SOI	18437	1	30	<0.0001	0.3
SOI2	18423	1	14	<0.0001	0.1
SOI3	18413	1	10	<0.0001	0.1

Figure 8.1. Relative indices of resource abundance based on each of the models fitted to the catch and effort data for the TIB fishery. *The nominal CPUE is also shown for comparison. The model "Seller" is the default series used for the eHCR.*

Figure 8.2. The monthly TIB CPUE nominal time series.



9. Revisiting Tropical Rock Lobster (*Panulirus ornatus*) Morphometric Conversion Ratios

Laura Blamey, Éva Plagányi, Kinam Salee, Denham Parker, and Roy Deng

9.1 Introduction

The effects of environmental change, particularly warming waters, have already been identified for a number of lobster stocks around the globe (Pecl *et al.* 2009; Caputi *et al.* 2010; Caputi *et al.* 2013; Boavida-Portugal *et al.* 2018; Klymasz-Swartz *et al.* 2019; McLeay *et al.* 2019; Shields 2019). These can include changes to lobster life history including recruitment, distribution, migration, growth, and size-at-maturity (see general review by (Caputi *et al.* 2013) as well as (Plagányi *et al.* 2011; Norman-López *et al.* 2013)).

Australia's oceans are warming and becoming more acidic (State of the Climate Report 2022; https://www.csiro.au/en/research/environmental-impacts/climate-change/State-of-the-Climate) and could have implications for life history parameters for a number of marine species including tropical rock lobster (TRL) *Panulirus ornatus*. Changes in growth or size at maturity have implications for fisheries management. Currently, rock lobsters that are caught by the Torres Strait TRL fishery are either measured or weighed and converted to other metrics such as size (and age) based on established morphometric conversion ratios (Table D.1 in Appendix D). These converted data are then used in a variety of analyses, such as length frequency analyses, splitting into age classes and for incorporation into the stock assessment model.

Morphometric conversion ratios for TRL were established nearly 20 years ago using data collected from the Torres Strait and from laboratory experiments at CSIRO Cleveland Marine Laboratories (Pitcher *et al.* 2005). These data were collected between the 1970s and 2003. Further work was undertaken in 2008 to assess size composition of catches and establish a live weight to tail weight conversion ratio for TRL (Table D.2 in Appendix D; (Dennis *et al.* 2009)). Given environmental changes taking place across northern Australia (Babcock *et al.* 2019), there is a need to revisit these conversion ratios to assess if any of these have changed. Moreover, recognising that lobster growth isn't uniform across Torres Strait, it would be helpful to have spatially resolved data on length-weight ratios. As an initial step to explore changes in morphometric conversion ratios, lobster size (carapace length) and total weight were collected from catch samples in the Torres Strait.

The aim of this chapter is to:

- revisit the carapace length:total weight relationship and see if it has changed over time
- explore spatially-resolved carapace length:total weight relationships from recent data

9.2 Method

9.2.1 Data Collection

In March 2023, CSIRO provided training and equipment to staff at Pearl Island Seafoods (Thursday Island) for them to assist in collecting carapace length and total weight measurements from randomly sampled lobsters received by the processing company. Where possible, sampling was undertaken each month between February and September 2023, with approximately 50 lobsters sampled from catches in one of that month's neap tides. Carapace length (mm), total weight (g), sex and location of catch were recorded on prepared data sheets (Appendix E) for each lobster sampled. Copies of the data sheets were then emailed to CSIRO.

9.2.2 Data Processing

Data were entered into a spreadsheet and checked and screened for inconsistencies. It was noted that measurements collected in April were less precise than measurements from other months, most likely due to a change to electronic callipers. Nonetheless these data were retained for analyses. Carapace length and total weight were measured for all lobsters except for lobsters sampled in May. In May, total weight and tail width (mm) were recorded. Given carapace length was not recorded in May, these data have been removed from the analyses.

9.2.3 Analysis

To compare the carapace length-total weight (CL-TOTWT) relationship from current (2023) samples with the original CL-TOTWT relationships based on historical data (Pitcher *et al.* 2005; Dennis *et al.* 2009), we first log-transformed the data and then fitted a linear model to the transformed length-weight data. We then ran an analysis of covariance (ANCOVA) to statistically test differences in the log-transformed carapace length-total weight (CL-TOTWT) relationships due to dataset (time period). The fitted length-weight models were then plotted using both the transformed (log-linear relationship) and untransformed (power relationship) data with back-transformed log-linear parameter estimates. All CL-TOTWT relationships presented in tables are done so using the back-transformed log-linear estimates.

Given the many samples that contributed to the Pitcher et al. (2005) dataset, including numerous small lobsters, we also then filtered the dataset and re-ran the ANCOVA using data in which CL ranged from 80-140 mm to match samples collected in 2023. For each relationship, a Student's t-test was used to test if there was a significant difference in *b* (the slope) from three (indication of isometric allometry). Only model results of analyses using the filtered data are shown.

Using the filtered data, we also compared CL-TOTWT relationships across decades in addition to the datasets. Given the numerous sample size from the 1970s in the Pitcher et al. (2005) dataset, we also then took 1000 random draws of sample size n = 180 to better align with sample sizes from other datasets and compared the slope of these data to other data sets from the 1990s, 2000s and 2020s.

Using data collected in 2023, we also explored spatially-resolved CL-TOTWT relationships. As above, we first log-transformed the data and then fitted a linear model to the transformed length-weight data. We then ran a three-way ANCOVA to statistically test differences in length-weight relationships due to sex or sex * location interactions. The fitted length-weight models were then plotted using the untransformed data and back transformed log-linear parameter estimates. All CL-TOTWT relationships presented in tables reflect the back-transformed log-linear estimates. For each CL-TOTWT relationship, a Student's t-test was used to test if there was a significant difference in b (the slope) from 3 (indication of isometric allometry).

All analyses and graphics were produced using R version 4.4.1.

9.3 Results

A total of 223 lobsters were measured in 2023 (39 % female and 61 % male) (Table 9.1). Measurements were collected in March, April, May, July, and August 2023. Sampled lobsters were caught from Thursday Island, Mabuiag, Warraber and Poruma (Coconut Island). There was less precision in the April measurements, possibly due to different callipers having been used. There was more precision in measurements from May, July and August when the processing facility switched to using electronic callipers. However, measurements taken in May included tail width measurements but not carapace length measurements. For this reason, measurements in May were removed from all analyses. Lobster carapace length ranged from 80 – 150.45 mm and total weight ranged from 630 – 2580g (0.63 – 2.58 kg).

Table 9.1. Number of female, male and total lobsters measured per month in 2023 and the associated sex ratio. *Samples from May were not included in the analyses given carapace length wasn't recorded.*

Month	Female	Male	Total	F:M Sex Ratio
March	15	35	50	30:70
April	11	13	24	46:54
May	19	31	50	38:62
July	23	28	53	43:57
August	18	30	48	38:62
Total	87	138	223	39:61

9.3.1 Length-Weight Relationships Over Time

When comparing the carapace length-total weight (CL-TOTWT) relationship from current (2023) samples with the original CL-TOTWT relationships based on historical data from Pitcher et al. (2005) and Dennis et al. (2009), we found a statistically significant difference in the slopes between the 2023 CL-TOTWT relationship and previous relationships (NewData2023 vs Dennis2009 $p = 0.0007$; Dennis2009 vs Pitcher2005 $p = 0.622$). However, this difference is not very apparent when plotted (Figure 9.1, Figure 9.2) and is unlikely to be biologically meaningful and could be due to different samples sizes and sizes of lobsters measured as seen in Figure 9.2.

Figure 9.1. Fitted carapace length- total weight relationships for three different data sets of lobsters sampled across the Torres Strait.

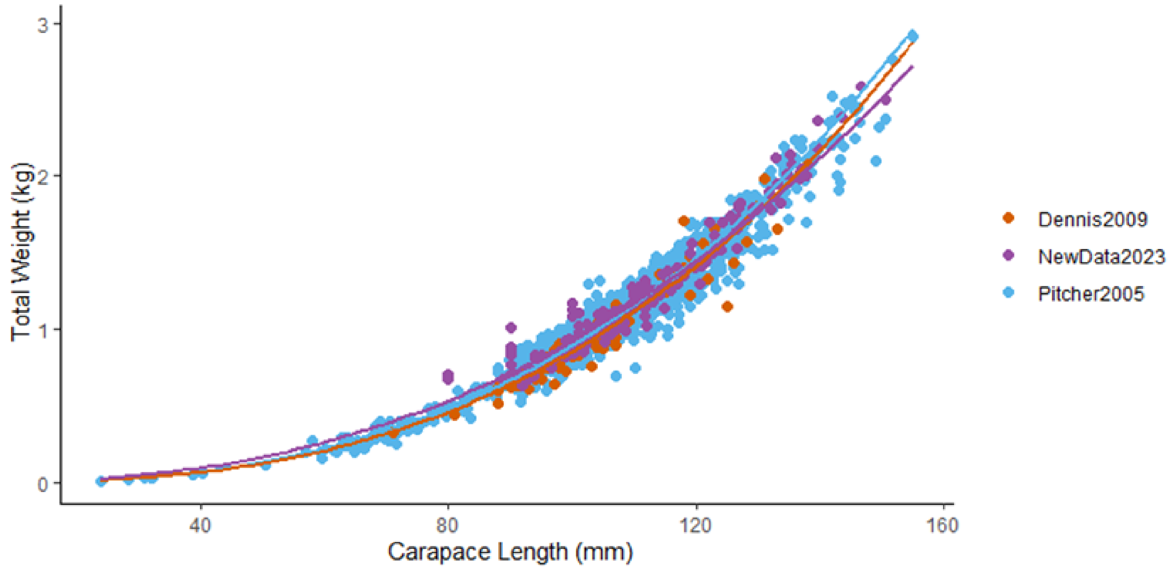
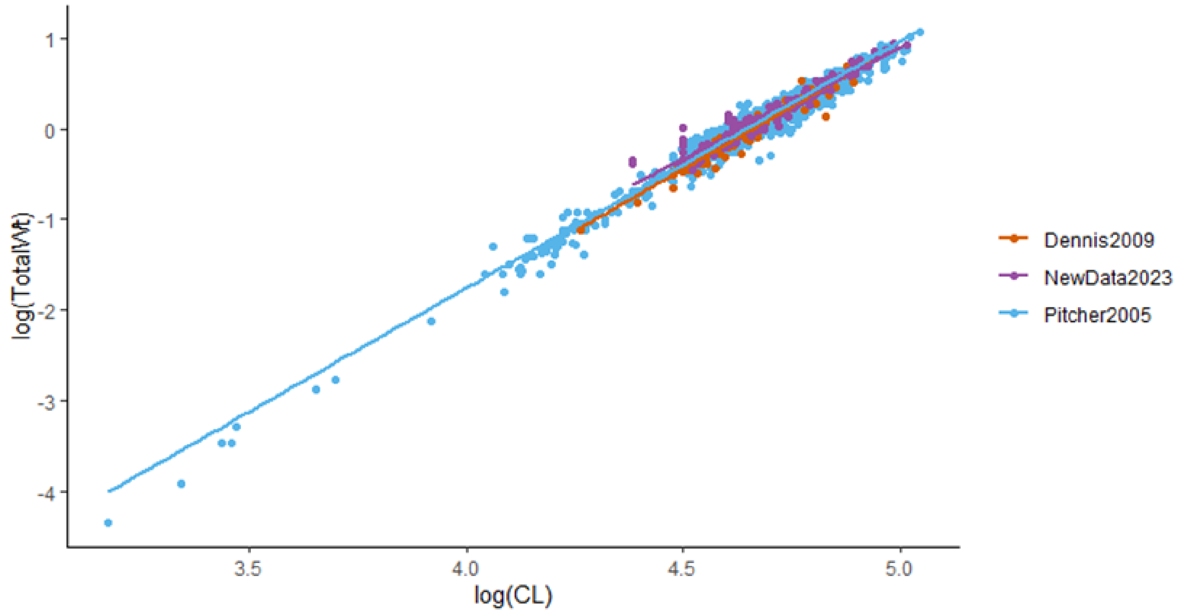


Figure 9.2. Fitted carapace length- total weight relationships using log-transformed data for three different data sets of lobsters sampled across the Torres Strait.



Using filtered datasets to ensure analyses focused on similar sizes ranges of lobsters (80-140 mm CL), we found no difference in the slopes of CL-TOTWT relationships between Pitcher et al. (2005) data and the lobsters measured in 2023 (Table 9.2, Table 9.3). We did find a statistical difference in the slope of the CL-TOTWT relationship between Dennis et al. (2009) and the other two datasets (Table 9.2), but this is unlikely to be biologically meaningful and relationships appeared similar when plotted (Figure 9.3). All slopes were significantly smaller than 3, indicating negative isometric allometry.

Figure 9.3. Fitted carapace length- total weight relationships using filtered data (80-140 mm CL) for three different data sets of lobsters sampled across the Torres Strait.

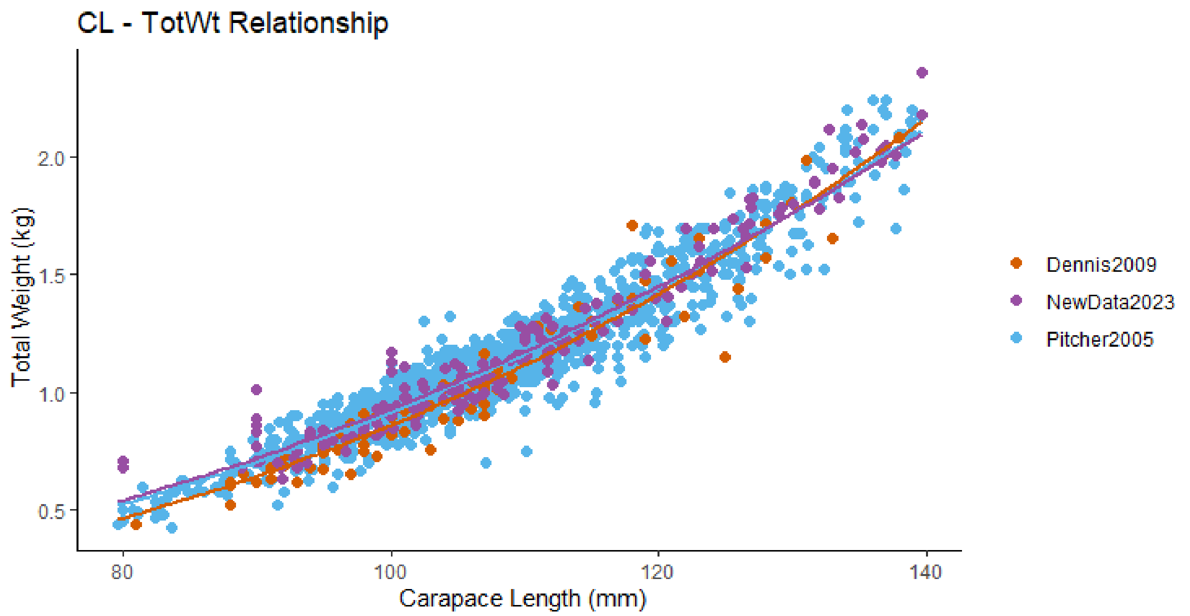


Table 9.2. Analysis of Covariance test for effects of carapace length and data set (time period) on total weight of lobsters. *Coefficient estimates are shown with standard error (SE) and associated t-value and p-value. P-values that are italicised indicate statistically significant effects.*

	Estimate	SE	t-value	P
Intercept (Dennis2009)	-12.792	0.346	-37.009	*<2e-16*
log(CL)	2.745	0.074	36.932	*<2e-16*
NewData2023	1.510	0.429	3.519	*0.0004*
Pitcher2005	1.204	0.363	3.321	*0.0009*
log(CL):NewData2023	-0.311	0.092	-3.377	*0.0007*
log(CL):Pitcher2005	-0.248	0.078	-3.178	*0.0015*

Table 9.3. Summary of the carapace length-total weight relationships and associated coefficient of variance (R^2) estimated from different datasets for male and female lobsters combined. *Probability of slope being significantly different from b = 3 (isometric relationship) also shown. Note that relationships were estimated using back transformed log-linear parameter estimates. Data were filtered to ensure similar sized lobsters for each dataset.*

Data Set	Sex	Relationship	CL Range	R^2	Departure from *b*=3
Pitcher et al. 2005	All	TOTWT = 0.0000093*(CL^2.497)	80-140	0.90	p<0.001
Dennis et al. 2009	All	TOTWT = 0.0000028*(CL^2.745)	80-140	0.94	p<0.001
New data 2023	All	TOTWT = 0.0000126*(CL^2.434)	80-140	0.92	p<0.001

We also compared the slopes of CL-TOTWT relationships from data collected across different decades and found no difference in the slopes of the relationships based on lobsters sampled in the 1970s and 2020s, and similarly no difference from lobsters sampled in the 1990s and 2000s. There was however a statistically significant difference in the slopes of CL-TOTWT relationships when comparing the

1970s-2020s data and 1990s-2000s data (Figure 9.4) with slopes from the 1970s-2020s samples estimated at around 2.4-2.5 and slopes from the 1990s-2000s at 2.8-2.9 (Table 9.3). All slopes were significantly smaller than 3, indicating negative allometry (Table 9.3).

Given the 1970s dataset had more than 1,100 samples, we also randomly subsampled 1000 times from that dataset and compared slopes of the CL-TOTWT relationships between the subsampled data and the 2020s data and found no difference (mean slope *b* of 1,000 subsamples from 1970s = 2.408 and slope *b* using 2023 data = 2.434).

Figure 9.4. Fitted carapace length - total weight relationships using filtered data (80-140 mm CL) for lobsters sampled across the Torres Strait over four different decades.

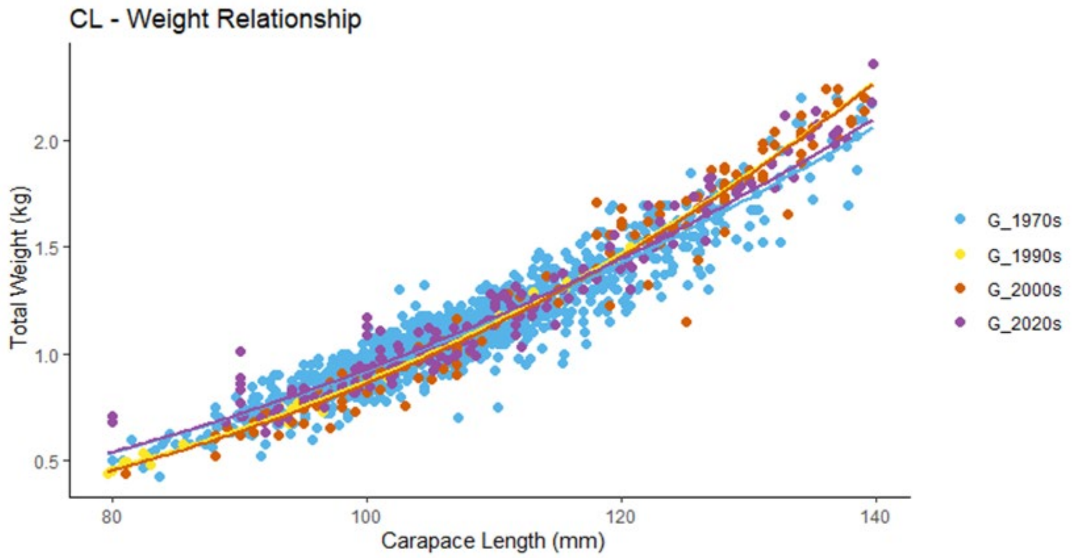


Table 9.4. Summary of the carapace length-total weight relationships and associated coefficient of variance (R^2) estimated from different decades of data for male and female lobsters combined. *Probability of slope being significantly different from b = 3 (isometric relationship) also shown. Note that relationships were estimated using back transformed log-linear parameter estimates. Data were filtered to ensure similar sized lobsters for each dataset.*

Data Set	Sex	Relationship	CL Range	R^2	Departure from *b*=3
1970s – Pitcher et al. 2005	All	TOTWT = 0.000014*(CL^2.409)	80-140	0.88	p<0.001
1990s – Pitcher et al. 2005	All	TOTWT = 0.0000018*(CL^2.848)	80-140	0.99	p=0.009
2000s – Pitcher et al. 2005 and Dennis et al. 2009	All	TOTWT = 0.0000015*(CL^2.886)	80-140	0.97	p=0.01
New data 2023	All	TOTWT = 0.0000126*(CL^2.434)	80-140	0.93	p<0.001

9.3.2 Length-Weight Relationships Across Region and Sex

A three-way ANCOVA model based on data collected in 2023 explained 94.6% of the variation in log total-weight (F = 255.3, p< 0.001). There was no evidence of differences in length-weight relationships due to sex or sex * location interactions (Table 9.4). Slopes of the CL-TOTWT relationships were similar for males (*b* =2.524) and females (*b* = 2.348) and both were significantly smaller than 3 indicating negative allometry (Table 9.4, Table 9.5). For each location, the slopes of the CL-TOTWT relationships were also significantly different from 3 (Table 9.5). For lobsters caught at Mabuiag, the CL-TOTWT relationships had a significantly different intercept and slope compared to other sites, with data suggesting that lobsters caught at Mabuiag are heavier at smaller sizes, but that weight increases more slowly with length compared to lobsters at Thursday Island and Poruma (Coconut Island) (Figure 9.6, Table 9.4, Table 9.5). However, samples for these regions were small (approx. 50-70) and collected across different months. Further samples are recommended before drawing any conclusions on whether these relationships are biologically different or before applying spatially resolved conversion ratios.

Table 9.5. Analysis of Covariance test for effects of carapace length, location and sex on total weight of lobsters. *Coefficient estimates are show with standard error (SE) and associated t-value and p-value. P-values that are italicised indicate statistically significant effects.*

	Estimate	SE	t-value	P
Intercept (Female, Coconut Island)	-11.865	1.186	-10.001	*<2e-16*
log(CL)	2.566	0.255	10.068	*<2e-16*
Mabuiag	3.039	1.375	2.209	*0.0286*
Thursday Island	-1.013	1.461	-0.694	0.489
Male	-0.742	1.368	-0.542	0.588
log(CL):Mabuiag	-0.665	0.296	-2.245	*0.026*
log(CL):Thursday Island	0.213	0.314	0.679	0.498
log(CL):Sex	0.150	0.292	0.514	0.608
Mabuiag:Male	-0.697	1.590	-0.439	0.662
Thursday Island:Male	0.954	1.692	0.564	0.574
log(CL):Mabuiag:Male	0.171	0.340	0.503	0.616
log(CL):Thursday Island:Male	-0.209	0.362	-0.577	0.564

Figure 9.5. Fitted carapace length- total weight relationships for male and female lobsters sampled across the Torres Strait in 2023.

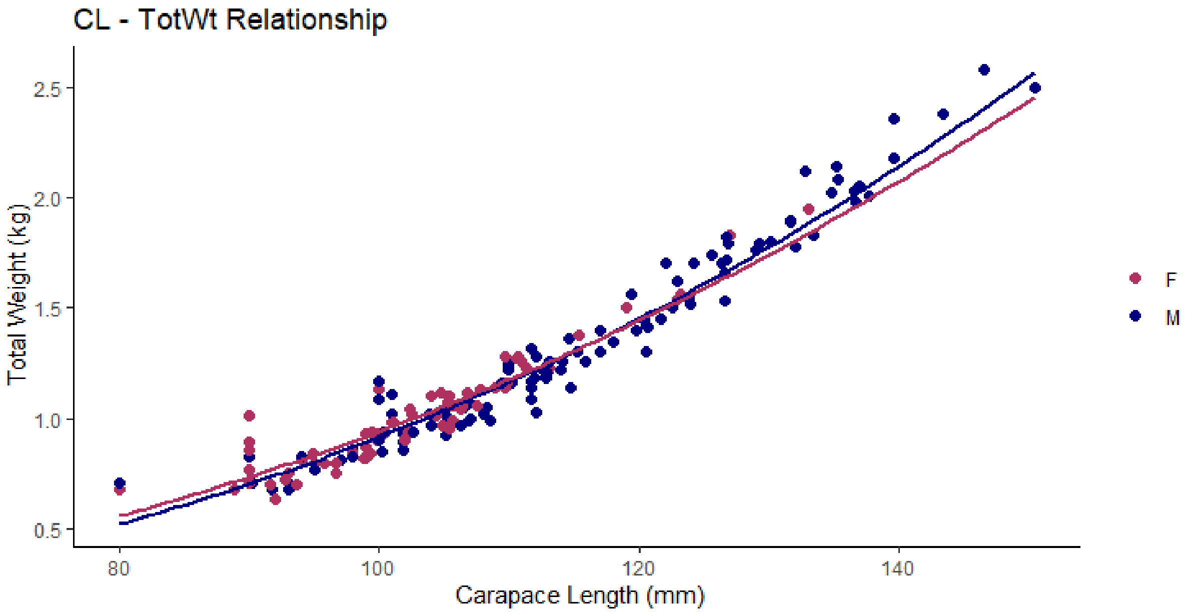


Figure 9.6. Fitted carapace length- total weight relationships for sampled lobsters from three different regions across the Torres Strait in 2023.

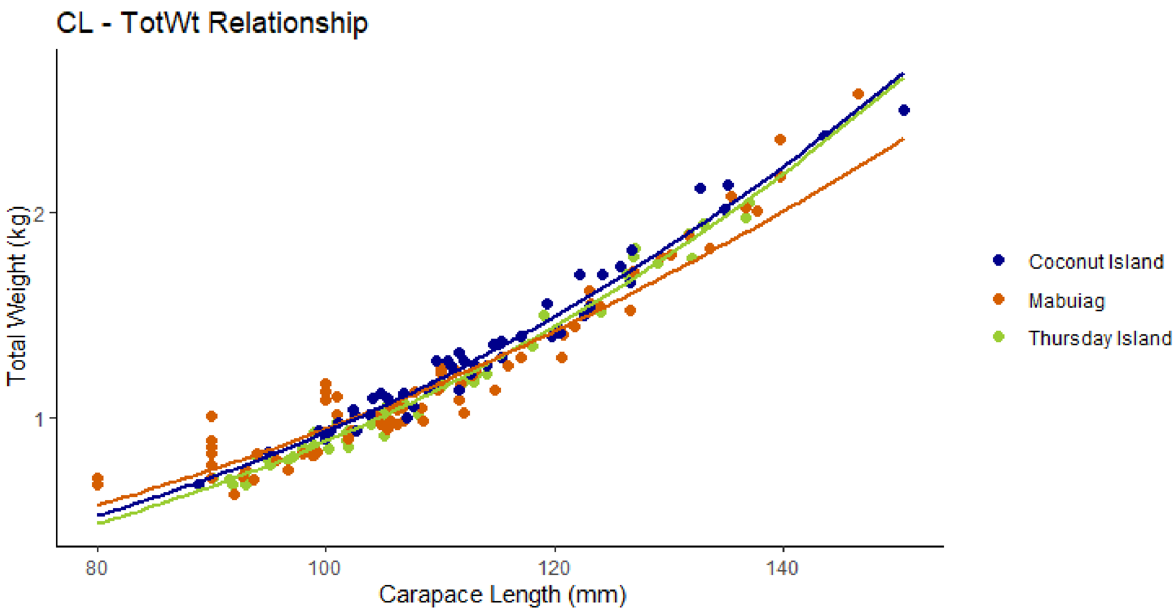


Table 9.6. Summary of the carapace length-total weight relationships and associated coefficient of variance (R^2) estimated using 2023 data from different regions and sex. *Probability of slope being significantly different from b = 3 (isometric relationship) also shown. Note that relationships were estimated using back transformed log-linear parameter estimates.*

Location	Sex	Relationship	CL Range	R^2	Departure from *b*=3
TS	All	TOTWT = 0.000012*(CL^2.450)	80-150	0.93	p<0.001
TS	M	TOTWT = 0.0000082*(CL^2.524)	80-150	0.94	p<0.001
TS	F	TOTWT = 0.000019*(CL^2.348)	80-150	0.85	p<0.001
Thursday Island	All	TOTWT = 0.0000037*(CL^2.692)	80-150	0.98	p<0.001
Mabuiag	All	TOTWT = 0.000032*(CL^2.236)	80-150	0.89	p<0.001
Poruma (Coconut Island)	All	TOTWT = 0.0000063*(CL^2.584)	80-150	0.97	p<0.001

9.4 Conclusions

Variability in length-weight relationships within species can be substantial, depending on the season, population, or environmental conditions (Froese 2006). These relationships can also differ across life-history stages e.g. for the Caribbean lobster *P. argus* (Martínez-Calderón *et al.* 2018).

We found that tropical rock lobster showed negative-allometric growth across time periods, locations and sex. Negative allometry suggests a decreasing growth rate in carapace length vs. weight and typically reflects a morphological change from an elongated body towards a wider, heavier body. Similar observations have been reported for other spiny lobsters e.g *P. argus* (Martínez-Calderón *et al.* 2018), *P. homarus* (Radhakrishnan *et al.* 2015) and the European lobster *Homarus gammarus* (Pavičić *et al.* 2021).

We did not find a difference in the original CL-TOTWT relationship by Pitcher et al. (2005) versus a CL-TOTWT relationship for lobsters caught in 2023, when data of the same carapace length range were analysed. However, we did find that the CL-TOTWT relationship for lobsters collected by (Dennis *et al.* 2009) was different to that of Pitcher et al. (2005) and this study. Similarly, when assessing these relationships across decades, we found that CL-TOTWT relationships for lobsters from the 1990s and 2000s were different from those based on lobsters from the 1970s and 2020s. Whether this is a true difference, and furthermore a biologically meaningful difference, is unknown. Further investigation into the data and environmental conditions during those periods could shed further light. It could be due to time of year the lobsters were caught, or location of where lobsters were caught, or prevailing environmental conditions at the time. These could be explored further in the future.

For lobsters caught in 2023, we found that the CL-TOTWT relationship did not differ between males and females, but it did differ between location. However, sample sizes were small, and samples were not collected evenly across the Torres Strait region or throughout the year. This was largely due to few processors being able to assist in the study but also due to reduced and sporadic catches given market conditions.

We recommend that the original CL-TOTWT relationship continue to be used when converting lobster weight to carapace length in ongoing assessment models. We do not recommend using a spatially resolved CL-TOTWT relationship from the 2023 data given limited and uneven sampling across the year and the Torres Strait region. Instead, we recommend further sampling be conducted over a few seasons and locations, possibly with help from an Observer program.

Source: CSIRO survey

10. Summary of Torres Strait TRL eHCR Implementation and Revision

Éva Plagányi, Roy Deng, and Laura Blamey

10.1 Summary

The Torres Strait tropical rock lobster *Panulirus ornatus* (TRL) fishery Harvest Strategy uses an empirical (data-based) Harvest Control Rule (eHCR) to rapidly provide a Recommended Biological Catch (RBC) based on the recent catches, survey abundance indices and Catch-Per-Unit-Effort (CPUE) from TIB and TVH sectors. The eHCR recommended catch is generally considered fairly robust across a number of alternative scenarios because it is based on medium-term (5 years) trends in all indices, plus the contributions of the trends in the CPUE indices (10% for each of the 2 CPUE indices) are small relative to the weight accorded to the fishery-independent survey. The eHCR is also designed to dampen variability in the TAC by focussing on 5-year trends in data.

However, since the 2021-22 fishing season, total TRL catch has been below the TAC due to a number of external factors affecting the fishery. As these factors were outside the range of impacts for which the eHCR was tested, as documented in TRLRAG32 and TRLRAG33 Meeting Records, the RAG recommended to substitute these anomalous catches with the fishery global TAC in the average catch multiplier in the eHCR. TRLRAG32 further recommended, as per ongoing work, that the eHCR be formally revised in future to account for these external impacts.

The 2023 default updated implementation of the eHCR used these substituted catches for the 2019-20, 2020-21 and 2021-22 seasons, together with the 2022-23 TAC of 521t and hence the average catch multiplier was 585t. Substituting into the eHCR formula together with the survey and CPUE information resulted in an RBC value of 530t for the 2023-24 season.

In 2024, the eHCR was revised and a number of alternative candidates considered as a basis for setting the TAC. The TRLRAG and TRLWG focussed on comparisons between three types of rules in particular, named the Turtle, Seahorse and Dolphin rules to help capture key features of each. As no consensus was reached at the December 2024 meetings, the decision as to which rule to apply to set the 2024/25 TRL TAC was passed to the PZJA. They advised using the midpoint of the outputs from each of the Seahorse and Dolphin rules, which resulted in setting a total TAC (all sectors) of 688t for the 2024-25 season, but they also encouraged selecting a preferred rule for longer term implementation. To assist the process going forward, CSIRO developed and added to the list of candidates a new rule, termed the Osprey rule, which gives the equivalent TAC for the current season and is thus an MSE-tested version of the PZJA compromise solution.

10.2 Introduction

The Torres Strait tropical rock lobster *Panulirus ornatus* (TRL) fishery is managed as a single stock and hence the assessment and management includes information from each of the three sectors: Australian TIB and TVH and the PNG sector which has a one-third share in the fishery (Plagányi et al., 2019). The stock comprises mainly three age classes, recently settled (6 months old, termed 0yr), recruiting (average 1.5 years old, termed 1yr) and fished (average 2.5 years old, termed 2yr). The TRL fishery Harvest Strategy uses an empirical (data-based) Harvest Control Rule (eHCR) to rapidly provide a Recommended Biological Catch (RBC) based on the recent catches, survey abundance indices and Catch-Per-Unit-Effort (CPUE) from TIB and TVH sectors.

The TRL Harvest Strategy is based on the Commonwealth Fisheries Harvest Strategy Policy and Guidelines, with best practice recommending that harvest strategies are to be reviewed every five years but may be reviewed earlier if necessary. In addition, Section 2.13 of the TRL Harvest Strategy provides guidance on when a review may be required earlier than 5 years, including relating to changing external drivers.

The 2022-23, 2021-22, 2020-2021, and 2019-2020 total catch were only around 53%, 62%, 55% and 84% respectively of the TAC (lower than the average proportion achieved historically) due to a number of external factors affecting the fishery. As these factors were outside the range of impacts for which the eHCR was tested, as documented in TRLRAG32 and TRLRAG33 Meeting Records, the RAG recommended to substitute these anomalous catches with the fishery global TAC in the average catch multiplier in the eHCR. TRLRAG32 further agreed, as per ongoing work, that the eHCR be formally revised to account for numerous external drivers, ongoing market and economic pressures that have impacted the fishery's performance.

The 2023 implementation of the eHCR thus once again used these substituted catches for the 2019-20, 2020-21 and 2021-22 seasons, together with the 2022-23 TAC of 521t and hence the average catch multiplier is 585t. Substituting into the eHCR formula together with the survey and CPUE information resulted in an RBC value of 530t for the 2023-24 season.

In 2024, the eHCR was revised and a number of alternative candidates considered as a basis for setting the TAC. The TRLRAG and TRLWG focussed on comparisons between three types of rules in particular, named the Turtle, Seahorse and Dolphin rules to help capture key features of each (see Appendix F for summary). As no consensus was reached at the December 2024 meetings, the decision as to which rule to apply to set the 2024/25 TRL TAC was passed to the PZJA. They advised using the midpoint of the outputs from each of the Seahorse and Dolphin rules, which resulted in setting a total TAC (all sectors) of 688t for the 2024-25 season, but they also encouraged selecting a preferred rule for longer term implementation. To assist the process going forward, CSIRO developed and added to the list of candidates a new rule, termed the Osprey rule (see Appendix F), which gives the equivalent TAC for the current season and is thus an MSE-tested version of the PZJA compromise solution.

The eHCR has been developed in close consultation with stakeholders at a number of meetings, including resource assessment groups (RAGs), fishery working groups and dedicated communication workshops. Effective communication was considered a high priority (see non-technical summary in Appendix F). For the same reason, eHCR candidates in the revised testing were given easy-identified names as described in Appendix F.

This document summarises MSE testing to inform options around revising the eHCR to ensure it addresses pre-specified objectives as well as the external factors as above.

The MSE testing extends on the earlier MSE analyses that informed choice and implementation of the current eHCR (Plagányi et al., 2018a) and is described more fully in (Plagányi et al., In review). As previously, the methods used to evaluate the eHCRs are consistent with the best practice guidelines outlined by Punt et al. (2016).

10.2.1 Empirical Versus Model-Based eHCR

Empirical or model-free approaches have many advantages in that they are simple to develop, easily understood by stakeholders and are computationally easier to implement (Rademeyer *et al.* 2007) plus are less expensive and require fewer resources to implement and review. They allow rapid testing of many simulations because they avoid iterative minimization routines that are required for fitting models to data (McAllister *et al.* 1999)). They can perform well if associated errors in abundance indicators are small (McAllister *et al.* 1999). It is well recognised that HCRs and models used as estimators in HCRs do not need to achieve a high degree of realism, but instead the objective should be to achieve good management performance (Cooke 1999).

For the TRL fishery, a fully empirical harvest control rule has the added advantage of not relying on more complex models which fishers and stakeholders may be sceptical about, may find hard to understand and may reduce the sense of ownership of an HCR because it no longer depends just on information and data (including their own CPUE data) that they are familiar with in a fishery. In addition, it provides greater transparency as can be shared on a simple spreadsheet.

A disadvantage of an empirical approach is that although it can move a resource in the desired direction, it doesn't inform on the level at which resource abundance will eventually equilibrate (Rademeyer et al., 2007). For TRL, this is addressed by running a stock assessment model every three years to inform on stock status (except when additional stock concerns are triggered). Periodic eHCR reviews can also be used to recalibrate an eHCR.

Another option is to develop a hybrid empirical and model-based rule. This was considered for TRL because it provides one solution to setting the multiplier or tuning parameter in the eHCR. The idea is that the slope change (i.e., the trend change) indicators could be used to adjust the RBC after multiplying by the assessment-RBC (noting assessment-RBC RBC_{mod} is not equivalent to the eHCR-TAC or RBC_{HCR}), where the RBC_{mod} is the most recent stock assessment-based RBC. However, as the stock assessment is only conducted every third year, and there may not be enough time to agree on a stock assessment before the RBC_{HCR} needs to be set, this means there will be up to a 4-year lag between when the RBC_{mod} multiplier term is first available and used in an eHCR calculation. In the years between stock assessments, the eHCR slope indicators can be considered simple 'proxies' for the stock assessment, but there remain a number of issues. Although this could work well for a longer-lived stock, it's problematic for a shorter-lived highly variable stock such as TRL. This is because there is little or no autocorrelation between recruitment in successive years. Hence, in the stock assessment year, the RBC_{mod} may be set very high or low depending on stock status at the time and has little or no relevance to the stock abundance level in the following years, so little justification to use it as a multiplier. A highly variable HCR could likely still work but would need careful calibration as may need to drop the RBC substantially from a high RBC_{mod} in some years or vice versa. Testing a rule of this type would also be computationally time-consuming as requires refitting the stock assessment model every three years in the MSE testing. An additional challenge is the need to increasingly consider replacing the stock assessment model with the climate-linked stock assessment model, and hence during this transition period, there is uncertainty around which is the most appropriate stock assessment model RBC to use in an HCR. There is also the added problem when using the stock assessments in harvest strategies of a process that in other fisheries has been termed 'model shopping' where stakeholders may select models or model runs that result in preferable TAC outcomes

Given that the TRL stock is managed in a highly precautionary manner and that the survey 1+ recruitment estimates suggest that the population fluctuates about some average value rather than trending longer-term up or down, use of a constant multiplier or tuning parameter was considered a plausible and reliable approach. Choice of plausible ranges for a multiplier for use and refinement in MSE testing were informed by considering long-term catch averages (i.e., demonstrated productivity of the stock) as well as the stock-assessment TACs that were output for each of years 2013-2019. The average of the RBC_{mod} was 644t with range 320-871t. A range of values was therefore tested to check whether the eHCR manages on average to maintain the stock fluctuating about the target level (which is successfully demonstrated). In the event that the stock starts exhibiting a downward trend or decline, the eHCR is designed to reduce catches and hence try and reverse a decline. Moreover, should the decline be steep, there are a number of safety measures built into the harvest strategy, such as a lower limit in the form of a Preseason Survey Trigger (PSST) that would trigger a review and, if necessary, an additional stock assessment or survey.

10.3 Management Objectives

The management objectives identified for the TRL fishery are as follows:

- maintain the stock at (on average), or return to, a target biomass point B_{TARG} equal to recent levels (2005-2015) that take account of the fact that the resource is shared and important for the traditional way of life and livelihood of traditional inhabitants and is at a level which is biologically and economically acceptable.
- maintain stocks above the limit biomass level (B_{LIM}), or an appropriate proxy (selected as half the B_{TARG} level), at least 90 per cent of the time.
- Implement rebuilding strategies, if the spawning stock biomass is assessed to fall below B_{LIM} in two successive years.

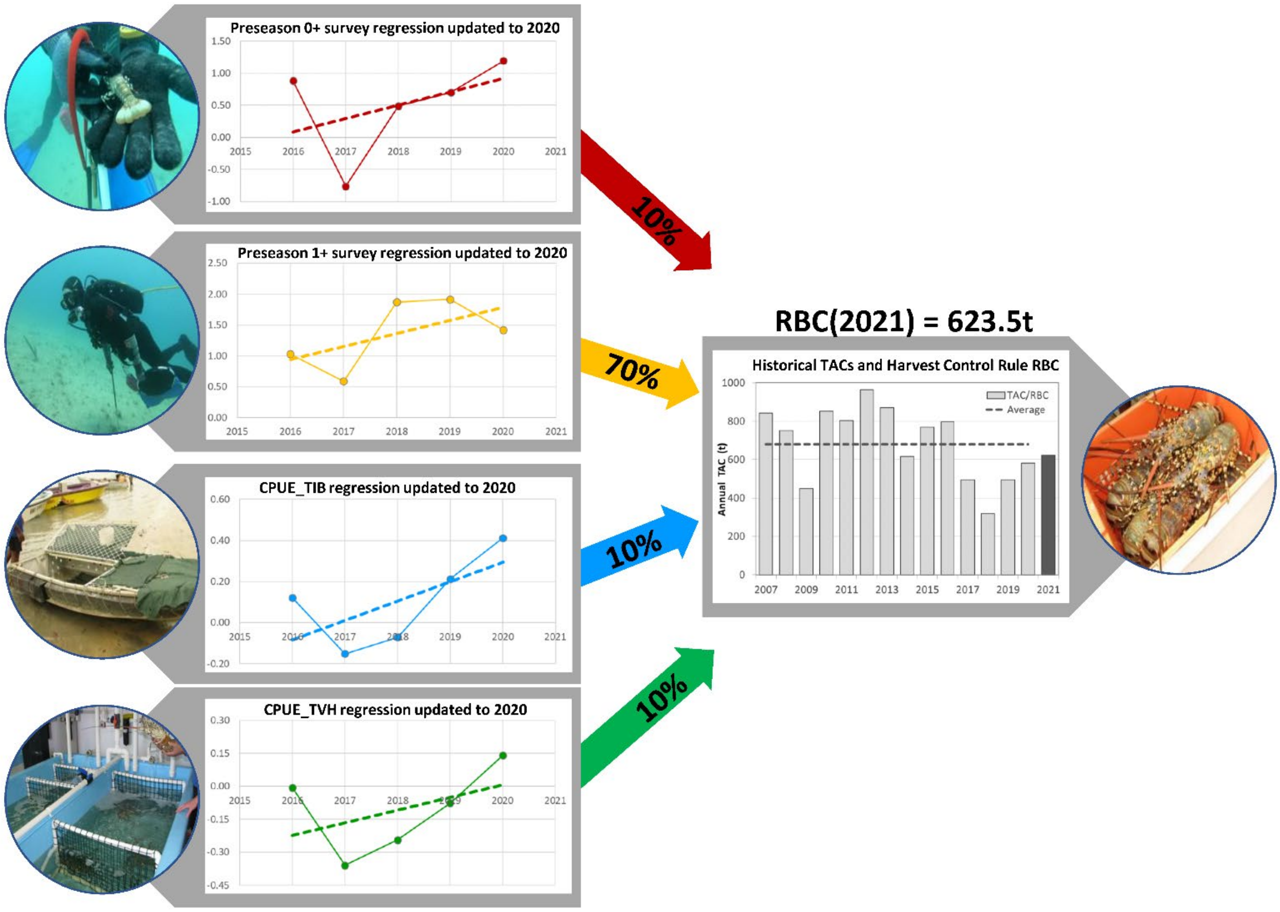
Candidate HCRs are evaluated as to their ability to maintain the resource as fluctuating about the target level and to ensure that they do not pose unacceptable risk to the spawning biomass. Quantifying the risk to the resource under alternative HCRs assists in the final selection of an HCR which meets the objectives of low risk of depleting the spawning biomass as well as ensuring that potential economic gains are not lost due to an overly conservative approach. Projected future catch rates for the TVH and TIB sectors are used as a proxy for economic performance, and an additional consideration relates to the inter-annual variability in catch. Stakeholders also expressed a preference for an upper limit to be set on the total annual catch to reduce biological risk.

10.4 eHCR Background

The eHCR formula outputs an RBC in December for the following year of fishing. This calculation is the multiple of the average catch over the last five years and a statistic which measures the relative performance of the fishery based on the following five data inputs (Figure 10.1): (1) Fishery-independent recruiting lobster (1+) standardised relative numbers; (2) Fishery-independent recently-settled lobster (0+) standardised relative numbers; (3) standardised CPUE for TIB sector; (4) standardised CPUE for TVH sector; and (5) total catch (TIB,TVH,PNG) (using data available up until end of October). Different weightings are applied to the four abundance indices included in the relative performance statistic used in the eHCR. These are based on extensive testing to compare performance of alternative weightings while also considering the information content and reliability of each series, as well as a preference expressed by the stakeholders to use a portfolio approach in determining the RBC (Plagányi et al., 2018a).

The fishery-independent Preseason 1+ index is the primary index and is most reliable and direct in terms of indexing the biomass of lobsters that will be available to be caught in the next fishing season. Hence, this index is assigned the highest weighting of 70%. The fishery-independent Preseason 0+ index provides an early indication of the following year's recruitment, whereas the CPUE indices aim to index the relative abundance of the large 2+ lobsters, the survivors of which will migrate out of the Torres Strait to spawning grounds to the East. Each of these three secondary indices (Survey 0+ and CPUE (TIB and TVH)) are assigned a weighting of 10% (30% total) in the eHCR formula.

Figure 10.1. Schematic summary of the empirical harvest control rule (eHCR) used to calculate the TRL (Tropical Rock Lobster) RBC (Recommended Biological Catch) (example shown for 2021 RBC) based on the CPUE (Catch Per Unit Effort) data from two fishery sectors, the scientific survey indices of two age classes, and the total average catch over the past five years (source Plagányi et al. 2021).



Simulation testing (Plagányi *et al.* 2016b) showed that the best approach is to use the slope of the trends in the secondary indices over the last five years' data (after first taking the natural logarithm of the data) for each of the abundance indices. This allows the RBC to be based on medium-term trends in abundance, rather than on just the current abundance.

Hence the HCR rule is as follows (see also Figure 10.1):

$$RBC_{y+1} = \left[0.7 \cdot \left(1 + s_y^{presurv,1}\right) + 0.1 \cdot \left(\left(1 + s_y^{presurv,0}\right) + \left(1 + s_y^{CPUE,TVH}\right) + \left(1 + s_y^{CPUE,TIB}\right)\right)\right] \cdot \bar{C}_{y-4,y} \quad (1)$$

Where

$\bar{C}_{y-4,y}$ is the average achieved catch during the past 5 years, including the current year i.e. from year y-4 to year y

$s_y^{presurv,1}$ is the slope of the (logarithms of the) fishery-independent survey 1yr abundance index, based on the 5 most recent values

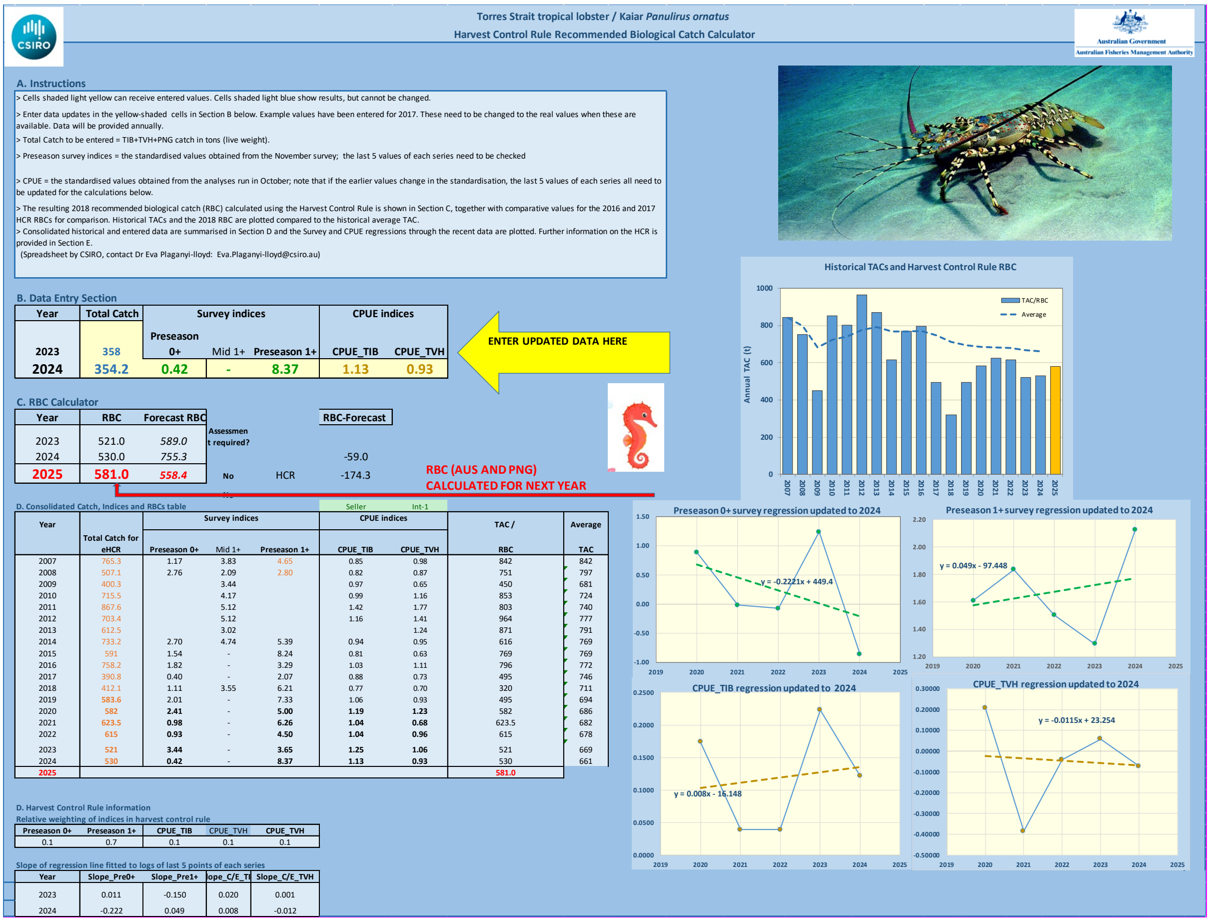
$s_y^{presurv,0}$ is the slope of the (logarithms of the) fishery-independent survey 0yr abundance index, based on the 5 most recent values

$s_y^{CPUE,TVH}, s_y^{CPUE,TIB}$ is the slope of the (logarithms of the) TVH and TIB CPUE abundance index, based on the 5 most recent values.

10.5 eHCR (Empirical Harvest Control Rule) Revision

The TRL fishery transitioned to using an empirical Harvest Control Rule (eHCR) to inform the Recommended Biological Catch (RBC) in December 2019, hence a stock assessment only needs to be conducted every three years unless the stock assessment is triggered by a decision rule. The eHCR used the latest available catch, CPUE and Pre-season survey data as summarised in Figure 10.2.

Figure 10.2. Summary of eHCR inputs in December 2024 showing the slopes of fitted regression lines to the log-transformed Preseason 0+ and 1+ indices, as well as the standardised CPUE data for the TIB (Seller model version) and TVH (Int-1 Model version) sectors. Example shown corresponds to the Seahorse eHCR candidate



The eHCR has been revised in 2024 as per methods described in Plagányi et al. (in review) and TRLRAG presentations. A number of alternative candidates were considered as summarised in Appendix F. For each HCR, there are a large number of performance statistics output for consideration by stakeholders. For all statistics, values shown are the median of the 800 replicates, together with the 75th and 25th percentiles (i.e., the rectangles encompass 50% of all outcomes for box and whisker plots) as well as the range of values excluding outliers (see Appendix F).

10.5.1 Pre-season Trigger Point

The TRL eHCR specifies that a stock assessment will be conducted every three years to rigorously assess stock status and productivity, and check that the eHCR is working as it is supposed to. As a stock assessment is only scheduled for every third year, action may not be taken quickly enough if the spawning biomass drops to very low levels, and hence an additional precaution has been built into the Harvest Strategy. Based on analysis of the historical pre-season and mid-year survey indices, a pre-season 1yr survey trigger point of 1.25 (average number of lobsters per survey transect and lower than any historically observed values) has been set, such that if this lower limit (LRP) is triggered in any year, then the required action is that a stock assessment be conducted in the following year.

This is similar to what is done in some other fisheries, such as decision rules for some of the New Zealand sub-stocks whereby a stock assessment is mandated if CPUE decreases below a specified base level (Bentley *et al.* 2005). If the stock assessment suggests that the spawning stock biomass is above the LRP, then the process continues as previously. However, if spawning biomass is assessed as below the LRP, then a stock assessment is again triggered in the following year. If the second stock assessment suggests the stock is above the LRP, then the process again continues as previously, but if the spawning biomass is below LRP (i.e., two consecutive years with spawning biomass below LRP), then the fishery is closed and appropriate action (e.g., implementing surveys, analysing size structure and environmental information) is put in place. In general, the eHCR is therefore applied every year unless the LRP is triggered in two consecutive years, or exceptional circumstances (de Moor *et al.* 2022) are invoked, such as when conditions observed are outside the bounds of the variability range during MSE testing.

The 2024 Age 1+ survey index was well above the survey trigger point (see Chapter 2).

10.6 Discussion

The TRL fishery transitioned in 2019 from using a traditional stock assessment approach to a formal harvest strategy framework and use of an eHCR. The harvest control rule is empirical, as it uses the data directly e.g., recent upward or downward trends in abundance indices are used directly as feedback and hence the RBC changes in the same direction.

Empirical Harvest Control Rules are now implemented in a number of fisheries globally, including for a number of lobster fisheries: Australia's southern rock lobster fishery (Punt *et al.* 2012), South African rock lobster (Johnston and Butterworth 2005), New Zealand rock lobster (Bentley *et al.* 2005; Miller and Breen 2010) and the Tristan da Cunha lobster fishery (Johnston and Butterworth 2013). Examples of other fisheries include South African hake (Rademeyer *et al.* 2008), anchovy and sardine (de Moor *et al.* 2011) and groundfish fisheries in British Columbia (Cox and Kronlund 2008). The eHCR for

Australia's southern lobster is based on the catch-rate for the most recent year and hence reacts quickly to changes in catch-rates (Punt *et al.* 2012).

The TRL stakeholders also expressed a preference to use a portfolio approach drawing on information from several data sources, including survey and CPUE data, albeit with more weight accorded to the most direct and accurate index, the 1yr survey index, compared with the pre-recruit 0yr index and the CPUE indices. The latter reflect the abundance of the large 2yr lobsters, the survivors of which mostly migrate out of the Torres Strait to breed such that only a very small proportion remain available to be fished in future (Dennis *et al.* 1992), but their spawning biomass index is an important consideration in terms of ensuring the future sustainability of the stock. There are examples of other Harvest Control Rules that use a combination of CPUE and fishery-independent survey information (e.g. Rademeyer *et al.* 2008) as well as pre-recruit (puerulus) indices (Bentley *et al.* 2005). The TRL eHCR rule is relatively data-rich compared with that applied to other lobster fisheries as the rule uses information from all the sources mentioned above. Harvest Control Rules may also include additional metrics such as size compositions and somatic growth rate (Johnston and Butterworth 2005; Plagányi *et al.* 2007), and these may be considered in future work.

Empirical HCRs are considered a defensible approach given that they have been shown to perform almost as well as model-based approaches (Rademeyer *et al.* 2007; Punt *et al.* 2012; Geromont and Butterworth 2015; Punt *et al.* 2016). Both model-based and empirical HCR's typically include free parameters that can be adjusted to tune their performance to achieve desired optimal trade-offs between performance statistics. Empirical harvest strategies have demonstrated the ability to achieve objectives such as reversing a decline in a population (Geromont and Butterworth 2015). However, they can suffer from a lack of information about the exact level of the resource, and hence additional analyses are required to determine what the status of the resource is relative to specified reference levels (Rademeyer *et al.* 2007). Some approaches use a 'target'-based rule whereby TAC adjustments are based on the magnitude of the difference between the recent CPUE and a target value (Johnston and Butterworth 2013). Compared with model-based HCRs, Rademeyer et al. (2007) and Butterworth (2008) suggest that empirical approaches can be easier to test and are often more easily understandable by stakeholders.

The eHCR has been extensively tested by simulation to provide appropriate trade-offs, taking into account a range of uncertainties and using methods that are now well established internationally (Dankel and Edwards 2016; Punt *et al.* 2016). The greatest advantages to adopting a eHCR approach are that (1) it can be applied quickly and easily to set a RBC in time for the start of the new fishing season; (2) it provides a transparent and easily understandable tool for stakeholders (e.g., the effect on the RBC of negative or positive decreases/increases in stock abundance indices can be readily seen, and a spreadsheet example is provided to stakeholders for this purpose); (3) it provides a sound basis for setting RBCs without compromising resource status; (4) it properly addresses concerns about scientific uncertainty through simulation testing to ensure that feedback secures reasonably robust performance across a range of plausible alternative resource dynamics; and (5) when tested using the MSE process, it empowers stakeholders by allowing them to transparently assess trade-offs between key performance measures and select the most favourable option taking into account a range of biological, economic, social and cultural considerations (Butterworth and Punt 1999; Plagányi *et al.* 2007; Rademeyer *et al.* 2007).

The TRL eHCR specifies that a stock assessment will be conducted every three years to rigorously assess stock status and productivity, and check that the eHCR is working as it is supposed to. As a stock assessment is only scheduled for every third year, action may not be taken quickly enough if the spawning biomass drops to very low levels, and hence an additional precaution has been built into the Harvest Strategy. Based on analysis of the historical pre-season and mid-year survey indices, a pre-season 1yr survey trigger point of 1.25 (average number of lobsters per survey transect and lower than any historically observed values) has been set, such that if this lower limit is triggered in any year, then the required action is that a stock assessment be conducted in the following year. This is similar to what is done in some other fisheries, such as decision rules for some of the New Zealand sub-stocks whereby a stock assessment is mandated if CPUE decreases below a specified base level (Bentley *et al.* 2005). If the stock assessment suggests that the spawning stock biomass is above the LRP, then the process continues as previously. However, if spawning biomass is assessed as below the LRP, then a stock assessment is again triggered in the following year. If the second stock assessment suggests the stock is above the LRP, then the process again continues as previously, but if the spawning biomass is below LRP (i.e., two consecutive years with spawning biomass below LRP), then the fishery is closed and appropriate action (e.g., implementing surveys, analysing size structure and environmental information) is put in place. In general, the eHCR is therefore applied every year unless the LRP is triggered in two consecutive years.

The current project is using MSE testing to refine the eHCR and exceptional circumstances rules (Plagányi *et al.* In review).

11. 2024 Stock Assessment of the Tropical Rock Lobster (*Panulirus ornatus*) Fishery in Torres Strait

Éva Plagányi, Roy Deng, Steven Edgar, Leo Dutra, Nicole Murphy, Denham Parker, Kinam Salee, Laura Blamey, Steph Brodie, and Mark Tonks

11.1 Summary

The Harvest Strategy for the Torres Strait tropical rock lobster *Panulirus ornatus* (TRL) specifies that the Integrated stock assessment model be run every three years (Plagányi *et al.* 2018b). The last update was based on the 2022 season data, but CSIRO conducted a stock assessment in December 2024 for reasons including:

a) It is useful work to support the Torres Strait Climate Change project;
b) It complemented some of the Management Strategy Evaluation testing;
c) The stock assessment is an essential component of ongoing high-level discussions relating to the export ban of *Panulirus ornatus* to help demonstrate that the Torres Strait TRL fishery is sustainably managed;
d) To support discussions on revising the eHCR; and
e) Concluding the current CSIRO project by providing an updated assessment before changing research providers.

The 2024 stock assessment model and results were considered and accepted by the December 2024 TRLRAG38. The model updates include the latest (Nov 2024) Pre-season survey results, the catch total for 2024 and updates to the commercial CPUE (TVH & TIB) data series. The model results indicate that the TRL spawning biomass is at about 84% of the 1973 reference (B_0) level, which is well above the agreed target reference point of B_{65} under the harvest strategy. The target reference point is deliberately conservative to allow for non-commercial take of TRL in support of traditional practices and livelihoods in the Torres Strait.

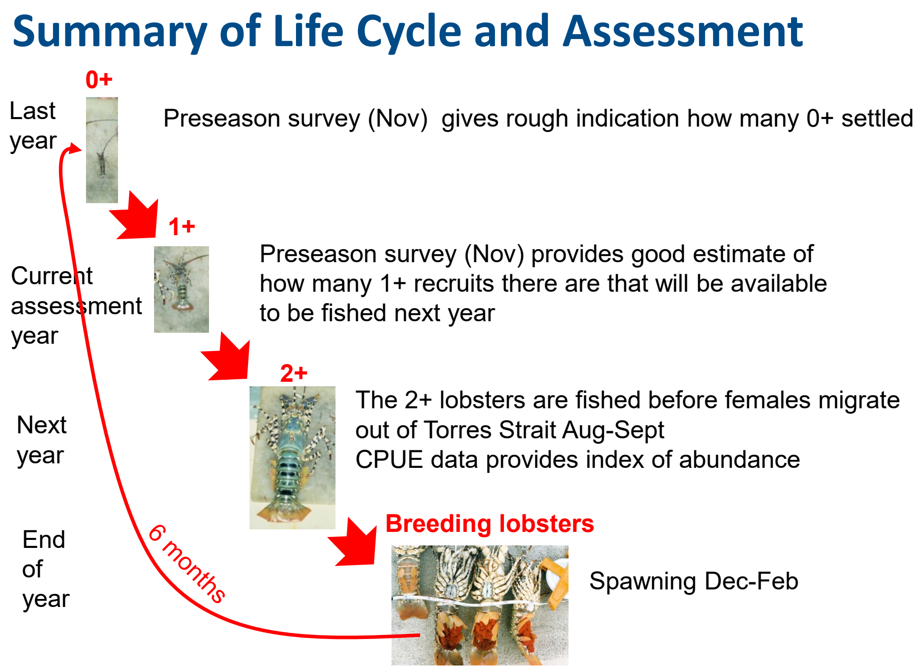
The model shows an excellent fit to the Pre-season survey 1+ index and is also fitted to the Mid-year survey series for past years, as well as the benchmark surveys. The model fits reasonably to the recent CPUE series for both sectors, and accounts for hyperstability. The Reference case model was fitted to the TVH CPUE Main Effects “Int1” option and the standardised “Seller” CPUE TIB series.

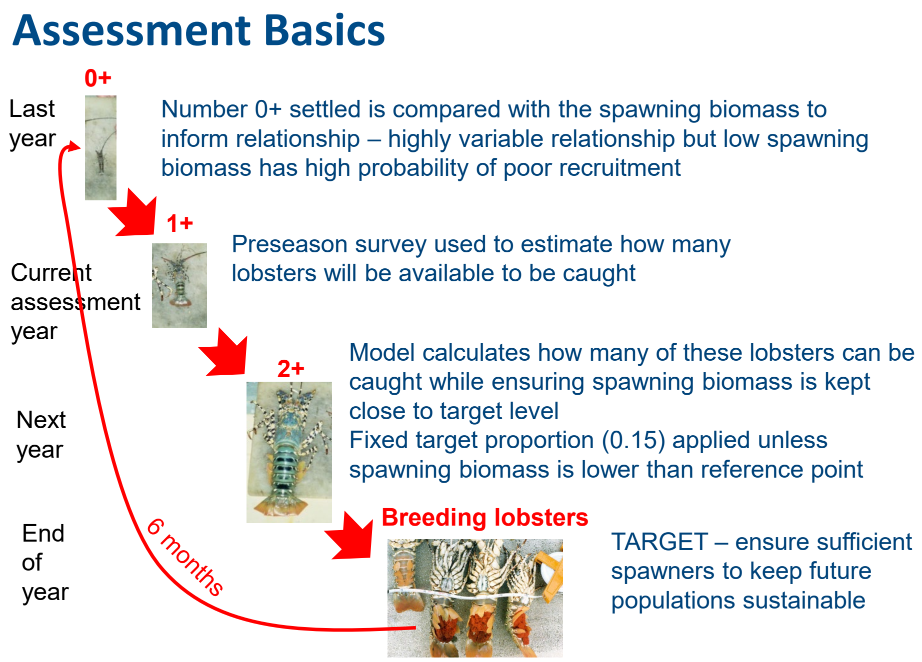
The TRL spawning biomass is estimated to have remained above the target reference level during the past six years, having recovered from the lower levels estimated over the period 2017 and 2018, plus possibly in response to low catches and favourable environmental conditions. The 2024 commercially available biomass estimate (i.e., the lobsters that are available to be caught by the fishery) of 4044t was about 76%of the long-term average (1989-2023). However, the model predictions for 2025 indicate this will increase to approximately 130% of the long-term average. Consequently, catch rates

in 2025 are predicted to be good although catches may not correspondingly be above average given external factors (e.g. market access) influencing the fishery.

The December 2024 Reference Case model suggests an RBC (2025) of 946 t [90% CI 592 – 1301 t]. The stock-assessment RBC for 2025 is thus expected to be much higher than the empirical Harvest Control Rule (eHCR) RBC because the latter rule is designed to dampen some of this inter-annual variability in TAC.

Schematic Summary of Method





11.2 Introduction

The Integrated stock assessment model (Plagányi *et al.* 2009) for the tropical rock lobster *Panulirus ornatus* (TRL) was developed in 2009 for the following reasons:

- the new model facilitates the move to a quota management system, in that it integrates all available information into a single framework to output an RBC;
- the new model addresses all of the concerns highlighted in a review of the previous stock assessment approach (Bentley 2006; Ye *et al.* 2006; Ye *et al.* 2007);
- the new model incorporates the Pre-Season survey data as well as CPUE data available from the TVH sector;
- the growth relationships used in the model were revised;
- the new model is of a form that could be used as an Operating Model in a Management Strategy Evaluation (MSE) framework, given that the need for a MSE to support the management of the TRL fishery was identified by the TRL RAG.

In addition, in response to review comments in 2012, the following changes are also implemented:

- there is no lower limit on the sigma parameter associated with fitting to the catch at age information;
- the fitting to the commercial catch-at-age information ignores the years when there are no true data;
- given there are catch-at-age data for the pre-1989 period, recruitment residuals are estimated for all years from 1985.

The model outputs a single RBC (with Confidence Interval) for the forthcoming fishing season, which is an integrated estimate that takes into account all available sources of information. The Integrated Model is a widely used approach for providing TAC advice with associated uncertainties. More formally, it is a Statistical Catch-at-Age Analysis (SCAA) (e.g., (Fournier and Archibald 1982)). This paper summarises the revised 2024 model assessment using the 2024 Pre-season survey data.

The revised Reference Case includes the following specifications (see Plagányi et al. (2020)):

- fitting to the CPUE data assuming a hyperstable relationship (with hyperstability parameter 0.75), and setting a lower bound of 0.15 (value selected by TRLRAG in 2013) to the variance associated with the CPUE data because it is less reliable than the survey data;
- increasing the stock recruit variance parameter from 0.3 to 0.5 to capture larger fluctuations in recruitment;
- estimating a different selectivity for the 1973-1988 period;
- using as the new Reference spawning biomass level the annual biomass of mature lobsters on 1 November each year i.e. at the start of the annual migration period;
- estimating the 2024 recruitment residual;
- the use of historical information to permit estimation of a large recruitment event that is known to have occurred in 1988, the year before the long-term surveys commenced. This is an important development as if this good recruitment is not accounted for in the model, the model tries to reconcile the subsequent dynamics by over-estimating the unfished stock size.

The TRLRAG have previously agreed to use the following specifications in the Reference Case model.

a) Fixed steepness h=0.7
b) Fixed hyperstability parameters for each CPUE series (TVH 0.75; TIB 0.5)
c) Mid-year survey index – after applying mixture model to separate age classes
d) Pre-season survey index – use as Reference MYO (mid-year only) series
e) CPUE TVH – Int-1 standardised series (and Int-3)
f) CPUE TIB – Seller standardised series

In past assessments, the model fit to the 2018 1+ Preseason survey data was not considered satisfactory, largely due to a conflict with the 0+ index for 2017 (Plagányi *et al.* 2022). However, the TRLRAG agreed that the 0+ index is likely to have been subject to substantial process error and thus not strictly comparable with other values because of anomalous changes that year in environmental factors possibly in turn changing population processes such as where and when juveniles settle. Additional work was therefore done to determine the most defensible approach for resolving the conflict in the model, with these analyses outlined in detail in previous reports (Plagányi et al. 2022). Additional analyses were also done to test for the effect of other factors (such as dive team composition and current strength) that may have influenced the index. Based on the updated analyses, the stock assessment model was updated, and this report summarises the updated results as a basis for informing management.

This document describes an update of the TRL stock assessment model using the results of the 2024 total catch, Pre-season survey conducted in November 2024 (see Chapter 2) and updated CPUE data for 2024 (see Chapters 7-8).

11.3 Methods

The model details are shown in Appendix G. Some background on the methods for estimating additional variance associated with the survey 0+ observations are provided in Appendix H. A summary of the methods used in the climate-linked version of the model are shown in Appendix I. Appendix J summarises previous work related to stock structure assumptions.

A summary of the input catch data is shown in Table 11.1. The historical Mid-year survey data are shown in Table 11.2. The latest November 2022 Pre-season survey Table 11.3 is included in the model. The commercial catch-at-age data are shown in Table 11.4.

The model uses the historical catch estimates. As done previously, the trawl catch has been separated from the other catches because of differences in the selectivity / targeting of the trawling sector which was focused predominantly on migrating 2+ lobsters. This is important because in the early years the trawling catch comprised 35 – 90% of the total TRL catch (Table 11.1). If trawling catches continue in future, then the model will need to similarly account for these separately to the total catch.

The TVH and TIB CPUE data input series have been revised and updated for the period 1989-2024 (Chapter 7, Chapter 8).

The model is fitted to additional historical information as described in Plagányi et al. (2012b). An adjustment has been made to the model to allow use of a separate selectivity function to be applied to the period 1973 to 1988, prior to the introduction of an MLS of 100mm TL in July 1988. The model already accounts for the subsequent size limit change to 115mm in 2002. Background information on the above specifications is given in Plagányi et al. (2012b) and this document.

The relationship between stock abundance and CPUE was explored and found to be better represented by a hyperstable relationship, than the assumption that CPUE is proportional to stock abundance (see e.g. Harley et al., (2001)). Based on additional sensitivity tests that were conducted, the Reference case model therefore uses a power curve with a hyperstability shape parameter of 0.75. This suggests that CPUE remains high while stock abundance declines. This is consistent also with results from considering an ecometric production function approach (Pascoe *et al.* 2013). In addition, the MSE and production function analyses (Plagányi *et al.* 2012a; Pascoe *et al.* 2013; Plagányi *et al.* 2013) suggested that the TIB CPUE relationship was characterized by a greater degree of hyperstability, and hence the Reference case model uses a power curve with a hyperstability shape parameter of 0.5, and sensitivity to alternative choices of this value were tested but don't have a large effect on model outputs.

11.4 Results

Observation and Process Error in the Torres Strait tropical lobster TRL stock 0+ survey index

The model estimated 13 additional variance parameters which significantly improved the fit. The A.V. parameter estimates and associated C.V.s are shown in Table 11.5.
Large process errors are estimated for the 2016, 2017, 2018, 2021 and 2022 0+ observations with a very small associated standard error. Results are consistent with the *a priori* expectation that the 2017 0+ survey would have the greatest amount of process error (see Table 1 in Plagányi et al., 2018b). For similar reasons, it was also hypothesized that the 2016 0+ survey would have large associated process error.

Table 11.1. Lobster catches (tonnes whole weight) landed in different jurisdictions from 1973 to 2024 with catches shown disaggregated by sector to the extent possible. *Catches comprised of both whole animals and tails have been converted into units of whole mass using the conversion ratio of 1kg tail=2.677 kg live. Note the 2024 PNG total catch is an extrapolated estimate as at the time of TRLRAG, data were available only for Jan to September 2024.*

SEASON	TIB	TVH	AUS_DIVERS	AUS_TRAWL	AUS-TOTAL	PNG_DIVERS	YULE_DIVERS	PNG-DIVERS TOTAL	PNG_TRAWL	PNG-TOTAL	Torres Strait TRL_TOTAL
1973			0.0	0	0	54	19	73	562.2	635.2	635.2
1974			0.0	0	0	75	83	158	107.1	265.1	265.1
1975			0.0	0	0	62	13	75	214.2	289.2	289.2
1976			0.0	0	0	48	0	48	262.3	310.3	310.3
1977			0.0	0	0	72	35	107	131.2	238.2	238.2
1978			296.1	0	296.1	43	3	46	187.4	233.4	529.5
1979			308.5	0	308.5	56	13	69	0	69	377.5
1980			328.4	21	349.4	94	3	97	588.9	685.9	1035.3
1981			495.1	131	626.1	96	3	99	262.3	361.3	987.4
1982			669.2	201	870.2	102	3	105	398.9	503.9	1374.1
1983			432.9	139	571.9	86	0	86	112.4	198.4	770.3
1984			330.9	8	338.9	86	0	86	29.4	115.4	454.3
1985			537.4	24	561.4	187	16	203	0	203	764.4
1986			890.6	21	911.6	198	62	260	0	260	1171.6
1987			622.0	0	622	128	54	182	0	182	804.0
1988			537.4	0	537.4	150.0	5	155.0	0.0	155.0	692.4
1989			651.0	0	651.0	211.0	24	235.0	0.0	235.0	886.0
1990			490.1	0	490.1	158.0	0	158.0	0.0	158.0	648.1
1991			444.1	0	444.1	168.0	0	168.0	0.0	168.0	612.1
1992			423.2	0	423.2	134.0	0	134.0	0.0	134.0	557.2
1993			505.7	0	505.7	166.0	0	166.0	0.0	166.0	671.7
1994		120.1	577.8	0	577.8	247.0	0	247.0	0.0	247.0	824.8
1995		87.0	556.9	0	556.9	257.0	0	257.0	0.0	257.0	813.9
1996		210.9	584.1	0	584.1	228.0	0	228.0	0.0	228.0	812.1
1997		271.4	653.1	0	653.1	241.0	0	241.0	0.0	241.0	894.1
1998		351.4	661.4	0	661.4	201.0	0	201.0	0.0	201.0	862.4
1999		93.6	409.6	0	409.6	163.0	0	163.0	0.0	163.0	572.6
2000		132.4	418.0	0	418.0	235.0	0	235.0	0.0	235.0	653.0
2001	52.0	79.9	131.9	0	131.9	173.0	0	173.0	5.4	178.4	310.3
2002	68.0	147.2	215.2	0	215.2	327.0	0	327.0	42.8	369.8	585.0
2003	123.0	358.8	481.8	0	481.8	211.0	0	211.0	5.4	216.4	698.2
2004	210.4	481.0	691.4	0	691.4	182.0	0	182.0	0.0	182.0	873.4
2005	367.6	549.0	916.6	0	916.6	228.0	0	228.0	0.0	228.0	1144.6
2006	140.5	135.4	275.9	0	275.9	142.0	0	142.0	0.0	142.0	417.9
2007	268.7	268.6	537.3	0	537.3	228.0	0	228.0	0.0	228.0	765.3
2008	185.7	100.4	286.1	0	286.1	221.0	0	221.0	0.0	221.0	507.1
2009	147.8	91.1	238.9	0	238.9	161.4	0	161.4	0.0	161.4	400.3
2010	140.0	282.6	422.6	0	422.6	292.8	0	292.8	0.0	292.8	715.4
2011	199.1	503.5	702.6	0	702.6	165.0	0	165.0	0.0	165.0	867.6
2012	142.4	387.3	529.7	0	529.7	173.7	0	173.7	0.0	173.7	703.4
2013	142.5	361.7	504.2	0	504.2	108.3	0	108.3	0.0	108.3	612.5
2014	198.8	273.2	472.0	0	472.0	151.4	0	151.4	109.8	261.2	733.2
2015	202.6	152.7	355.3	0	355.3	235.7	0	235.7	0.0	235.7	591.0
2016	267.1	243.0	510.1	0	510.1	248	0	248.0	0	248.0	758.1
2017	111.6	166.3	277.9	0	277.9	113	0	113.0	0	113.0	390.9
2018	127.4	134.1	261.5	0	261.5	156.4	0	156.4	0	156.4	417.9
2019	260.6	156.1	416.7	0	416.7	167	0	167.0	0	167.0	583.7
2020	216.3	143.2	359.5	0	359.5	126.4	0	126.4	0	126.4	485.9
2021	127.6	116.3	243.9	0	243.9	97	0	97.0	0	97.0	340.9
2022	150.1	139.7	289.8	0	289.8	88.8	0	88.8	0	88.8	378.6
2023	129.6	118.5	248.1	0	248.1	109.9	0	109.9	0	109.9	358.0
2024	107.7	92.5	200.2	0	200.2	154	0	154.0	0	154.0	354.2

Table 11.2. Mid-year survey data summary for the period 1989-2014 and 2018 (no 2019 mid-year survey). *The series depict standardised indices of relative abundance of each age class.*

Year	Annual	Transects	Age0	SE0	Age1	SE1	Age2	SE2
89	1989	40			1.663	0.243	2.427	0.305
90	1990	40			3.543	0.787	1.643	0.279
91	1991	40			3.953	0.542	1.502	0.343
92	1992	40			5.083	0.765	3.430	0.670
93	1993	37			2.343	0.490	0.774	0.328
94	1994	40			5.644	1.624	1.143	0.304
95	1995	40			3.497	0.591	1.825	0.944
96	1996	40			3.346	0.560	1.175	0.387
97	1997	40			3.970	0.673	1.018	0.248
98	1998	40			1.780	0.431	1.366	0.359
99	1999	40			3.493	0.894	0.467	0.242
00	2000	40			3.063	1.188	0.619	0.224
01	2001	40			1.235	0.246	0.236	0.093
02	2002	73			2.511	0.352	0.819	0.310
03	2003	43			2.829	0.521	2.175	0.640
04	2004	72			2.720	0.411	1.542	0.429
05	2005	71			1.194	0.181	1.957	0.686
06	2006	73	0.231	0.144	5.406	0.933	0.720	0.336
07	2007	70	0.011	0.008	3.833	1.100	1.621	0.536
08	2008	72	0.069	0.048	2.090	0.281	0.964	0.353
09	2009	68	0.034	0.025	3.438	0.523	1.263	0.373
10	2010	67	0.000	0.000	4.165	0.610	1.183	0.300
11	2011	65	0.000	0.000	5.124	0.812	2.243	0.466
12	2012	70	0.000	0.000	5.120	0.907	1.521	0.378
13	2013	66	0.000	0.000	3.024	0.556	1.455	0.454
14	2014	67	0.000	0.000	4.744	0.950	1.351	0.320
15								
16								
17								
18	2018	68	0.094	0.041	3.267	0.666	0.715	0.130

Table 11.3. Pre-season survey index (Midyear-Only (MYO) Sites) for the period 2005-2008 and 2014-2022. *The series depict standardised indices of relative abundance of each age class.*

Annual	Transects	Age0	SE0	Age1	SE1
2005	68	4.734	0.969	2.987	0.531
2006	71	2.061	0.492	5.759	1.248
2007	72	1.649	0.389	4.601	0.710
2008	73	3.709	0.95	2.528	0.421
2014	72	3.463	0.739	5.276	0.788
2015	73	1.783	0.46	6.724	1.005
2016	73	2.411	0.579	2.798	0.542
2017	74	0.468	0.174	1.801	0.276
2018	73	1.634	0.44	6.520	1.734
2019	74	2.016	0.68	6.808	1.425
2020	74	3.301	0.721	4.143	0.752
2021	74	1.065	0.306	6.421	1.108
2022	74	0.993	0.351	4.248	0.990

Table 11.4. Summary of commercial catch at age information from 1989 to 2022, with similar estimates for subsequent years.

	Percentage 1+	Percentage 2+
1989	5.98	94.02
1990	11.33	88.67
1991	25.39	74.61
1992	25.16	74.84
1993	21.29	78.71
1994	26.38	73.62
1995	23.91	76.09
1996	26.47	73.53
1997	28.63	71.37
1998	16.15	83.85
1999	31.25	68.75
2000	-	-
2001	-	-
2002	-	-
2003	-	-
2004	2.54	97.46
2005	1.19	98.81
2006	8.08	91.92
2007	1.55	98.45
2008	6.64	93.36
2009	0.6	99.4
2010	6.91	93.09
2011	1.02	98.98
2012	8.59	91.41
2013	5.8	94.2
2014	2.02	97.98
2015	1.82	98.18
2016	1.47	98.53
2017	1.85	98.15
2018	1.52	98.48
2019	3.64	96.36
2020	3.21	96.79
2021	3.99	96.01
2022	2.35	97.65

Table 11.5. Summary of model parameter estimates for (A) the December (Dec) 2024 Reference Case; (B) Dec2024 model testing sensitivity to revision of the survey MYO series and (C) comparison with Dec 2022 Reference Case, shown with Hessian-based 90% confidence intervals (CI). *Table shows estimates of the starting (1973) spawning biomass B^{sp}, the annual natural mortality rate (M), the stock-recruitment steepness parameter (h), selectivity (Sel) parameters for three time periods and the values of the CPUE-abduance hyperstability (hyps) parameters for the TVH and TIB sectors. As these are not climate-linked model versions, there are no estimates of the two parameters describing the relationship between Sea Surface Temperature (SST) and M. The exploitable biomass (Bexp) represents the biomass available to be fished. The negative log-likelihood contributions are shown from fitting to catch-at-age (CAA) data from the surveys and historical data, as well as fitting to the mid-year survey (Survey), benchmark surveys and Preseason surveys. The recruitment residual (RecRes) also contributes to the penalised log-likelihood function.*

	(A) Dec 2024 Reference Case			(B) Dec 2022 Reference Case		
Parameter	**Value**	**90% CI**		Value	90% CI	
B(1973)^{sp} (tons)	4399	3168	5630	4399	3162	5637
M	0.70	0.57	0.82	0.69	0.57	0.82
h	fixed 0.7			fixed 0.7		
Sel (age 1+) 1973-1988	0.42	0.23	0.60	0.42	0.23	0.60
Sel (age 1+) 1989-2001	0.17	0.15	0.19	0.17	0.15	0.19
Sel (age 1+) post2002	0.02	0.00	0.02	0.02	0.00	0.02
SST-M par1	-			-		
SST-M par2	-			-		
hyps(TIB)	fixed 0.5			fixed 0.5		
hyps(TVH)	fixed 0.75			fixed 0.75		
Model estimates and depletion statistics						
B(2024)^{sp} (tons)	3618	2337	4899	4305	2937	5673
RBC(2025) model	946	592	1301	497	293	702
RBCforecast(2026) model	664	485	843	637	465	808
Current Depletion (Nov) *B(2024)^{sp} / B(1973)sp*	0.84	0.60	1.08	1.04	0.78	1.31
Bexp(2024) (tons)	3957	2705	5210	4780	3357	6202
No. parameters estimated	59			55		
'-lnL:overall	**-235.20**			**-223.01**		
AIC	**-352.41**			**-336.01**		
Likelihood contributions		**Sigma**	**q**		**Sigma**	**q**
'-lnL:CAA	-85.23	0.04		-78.39	0.04	
'-lnL:CAAsurv	-20.31	from data		-20.32	from data	
-lnL:CAA historic	-15.92	0.15		-22.04	0.13	
-lnL:Survey Index 1+	-15.92	from data	3.970E-07	-1.634E+01	from data	3.963E-07
-lnL:Survey Index 2+	-15.59	from data	4.146E-07	-1.570E+01	from data	4.153E-07
-lnL:Survey benchmark	-3.14	from data		-3.132E+00	from data	
'-lnL:PRESEASON	-19.44	from data	9.055E-07	-1.553E+01	from data	8.625E-07
-lnL:PRESEASON 0+	-3.21	from data	1.582E-07	-5.198E+00	from data	2.223E-07
-lnL:CPUE (TVH)	-32.91	0.21	0.0019	-31.1653	0.2107	0.0019
-lnL:CPUE (TIB)	-26.15	0.16	0.0157	-23.4261	0.1651	0.0161
'-lnL:RecRes	8.74	0.33	input	8.22	0.50	input

11.4.1 Model fits

The fits of the updated Reference Case Model to all available data sources are shown in Figures 1 to 7. The starting number of lobsters is estimated and Figure 11.1 compares the benchmark survey (Ye et al., 2004) observed total lobster abundances in 1989 and 2002 with the corresponding model estimates. The Integrated model is fitted to the survey midyear index of abundance (in terms of total numbers of 1+ and 2+ lobsters) (Figure 11.2). The poor fit for the year (2014) of the series was because of a conflict with the more reliable and lower estimate that same year based on the Preseason survey. The observed and model-predicted proportions in each age class are compared in Figure 11.3.

The model fits to the catch at age data are adequate (Figure 11.4). The variability in the lobster age groups is well captured and the model reflects the post-2001 (increased size limit) decrease in the relative proportion of 1+ lobsters that are caught.

There were fifteen data points available from the Pre-season survey for the TRLRAG Reference Case, and the model was fitted to data on both 0+ and 1+ abundance, with a close fit evident for the 1+ (Figure 11.5). The fit is better for the 1+ age group than the 0+ age group, but incorporation of the latter assists in strengthening prediction of future lobster abundance, even given the fairly large uncertainty associated with these estimates.

Comparisons between CPUE data from the TVH sector (in kg per tender-day from 1994 to 2024) and corresponding model-predicted estimates are shown in Figure 11.6a (when fixing the lower bound of sigma at 0.15). Similarly, Figure 11.6b shows the fit to the standardised CPUE TIB data. The Reference Case assumes a hyperstable relationship between biomass and CPUE (TVH) as follows:

$$\left(\frac{C}{E}\right)_y^{TVH} = q_{TVH}\left(B_y^{ex}\right)^{0.75}$$

And similarly, for the TIB CPUE data:

$$\left(\frac{C}{E}\right)_y^{TIB} = q_{TIB}\left(B_y^{ex}\right)^{0.5}$$

Comparison between historical data and model estimates of the proportions of 1+ and 2+ lobsters in the catch is shown in Figure 11.7. The fit in the early years is reasonably good, with the later deviations in the fit partly a result of a slight conflict between these data and the catch at age data.

The fitted stock-recruit relationship from the Reference-case model version is shown in Figure 11.8, and the stock-recruit residuals are shown in Figure 11.9 from which it is clear that recruitment declined substantially during 2016-2017. There is considerable variation about the stock-recruit curve (as is expected), but nonetheless there is some support for an underlying stock-recruit relationship.

Figure 11.1. Comparison of benchmark survey observed lobster total abundance (with standard errors) and corresponding Revised Reference Case model-estimates of abundance.

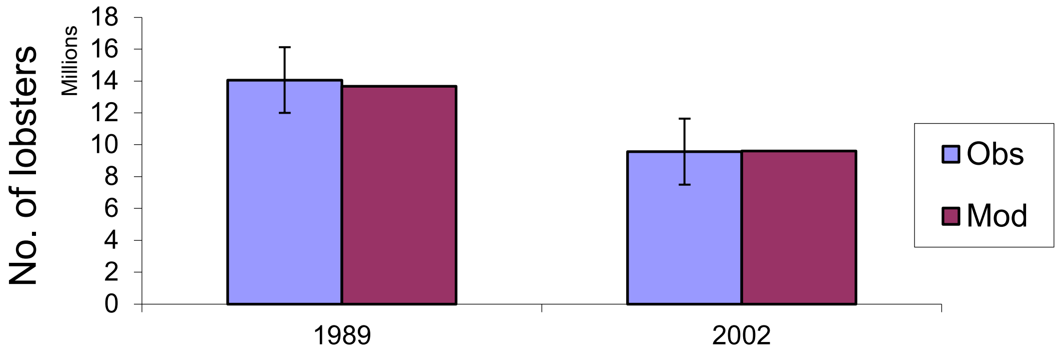
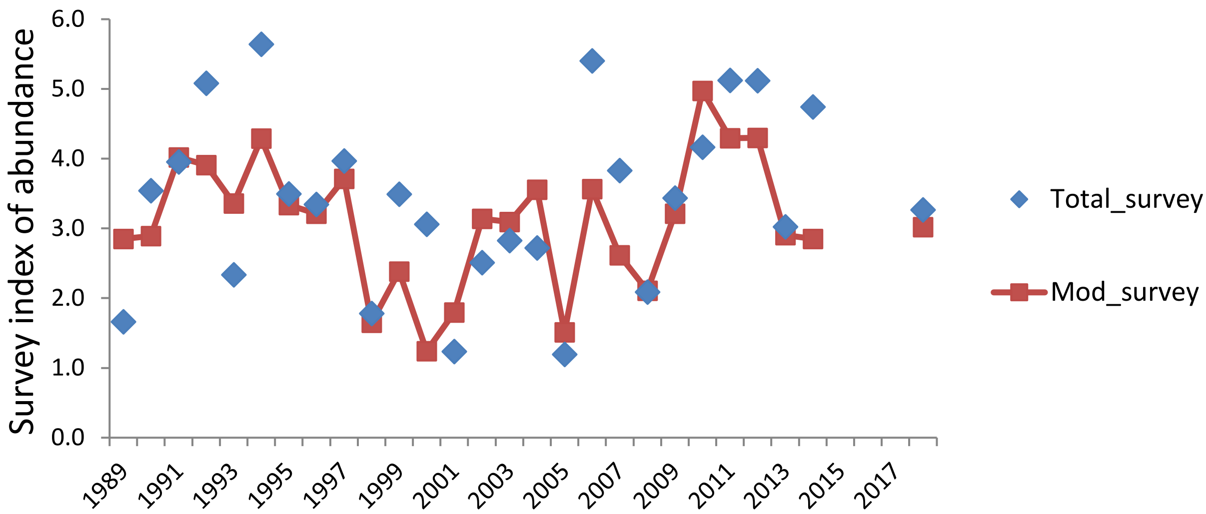


Figure 11.2. Comparison between survey midyear index of abundance (in terms of total numbers of 1+ and 2+



lobsters) compared with the corresponding model-estimated values for TRLRAG Reference Case.

Figure 11.3. Model estimates of the total annual number of lobsters in each age class, where the 1+ lobsters are those observed during the Pre-season survey, the 2+ lobsters are those targeted by the fishery and the Age 3 are the mature spawning animals.

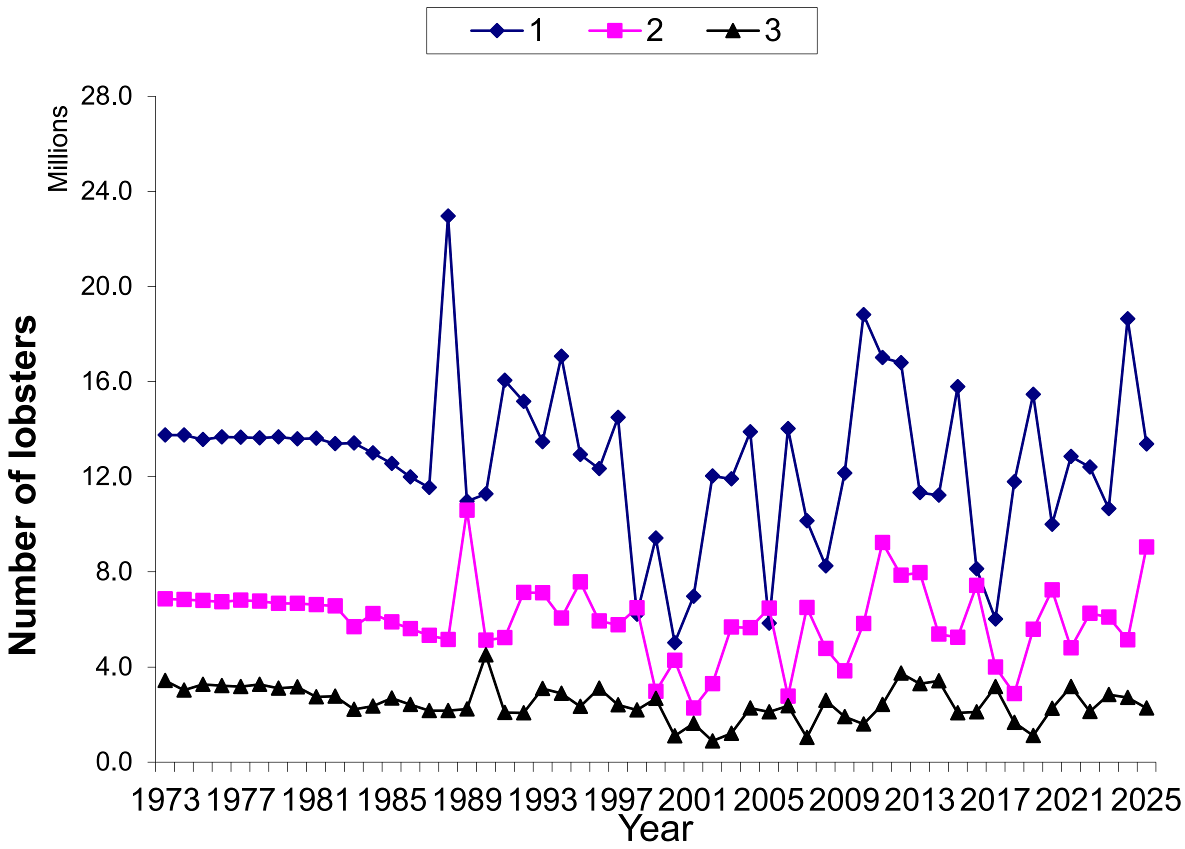
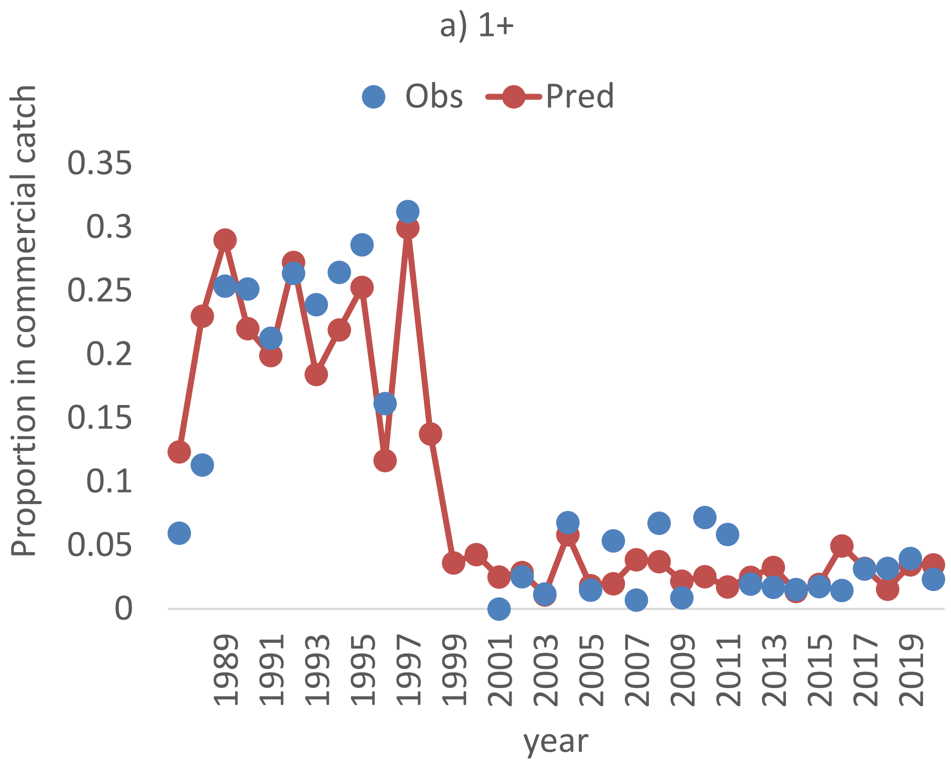


Figure 11.4. Comparison between available commercial catch-at-age data and corresponding model-predicted estimates for a) 1+ lobster and b) 2+ lobster.



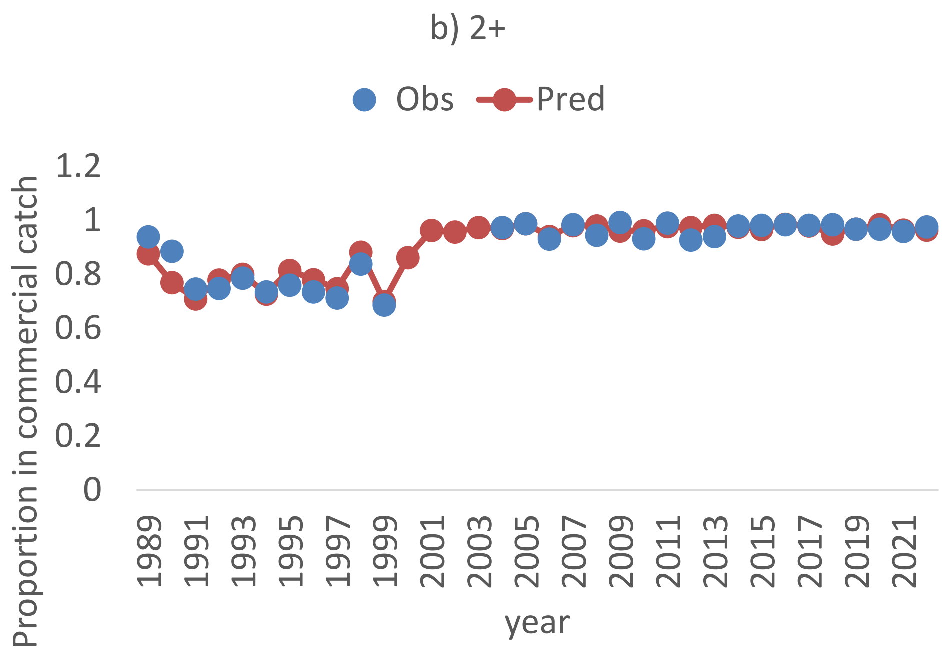
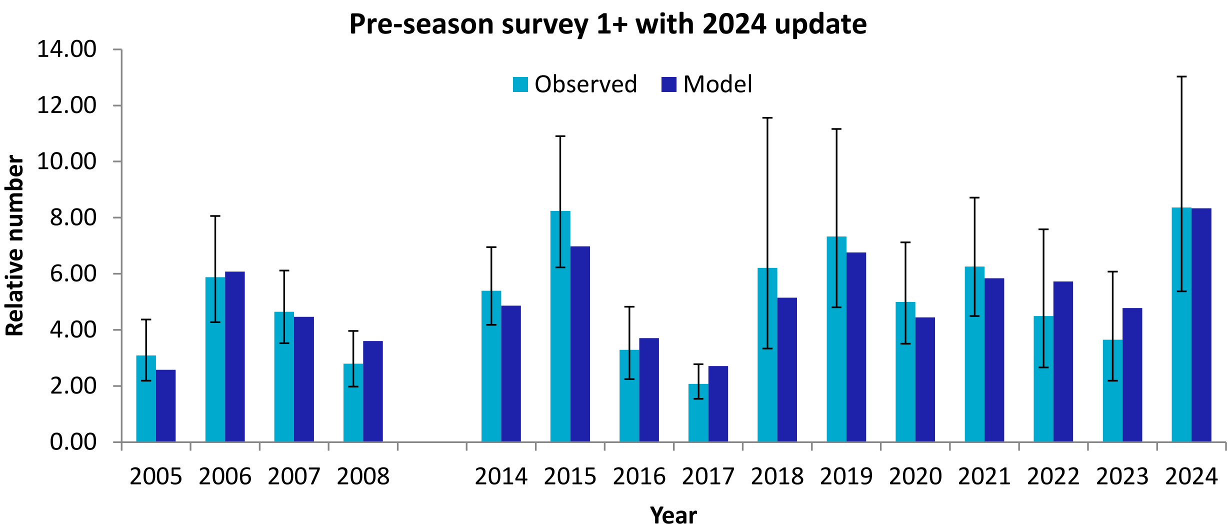


Figure 11.5.Comparison between observed Pre-season survey data (expressed in terms of number * 10^4) and corresponding (A) 1+ and (B) 0+ model-predicted estimates for TRLRAG Revised Reference Case which incorporates estimation of Additional Variance associated with each of the 0+ observations. *Note that in (B) the confidence intervals shown for the survey observations are based on the observed survey variance, but the model also estimates an annual additional 0+ survey variance to account for conflicts between the 0+ and following year 1+ survey observations, where as shown in (B) the 0+ were seen to under-estimate the later observed 1+ class in 2017, 2018, 2021 and 2022 in particular.*

(A)



(B)

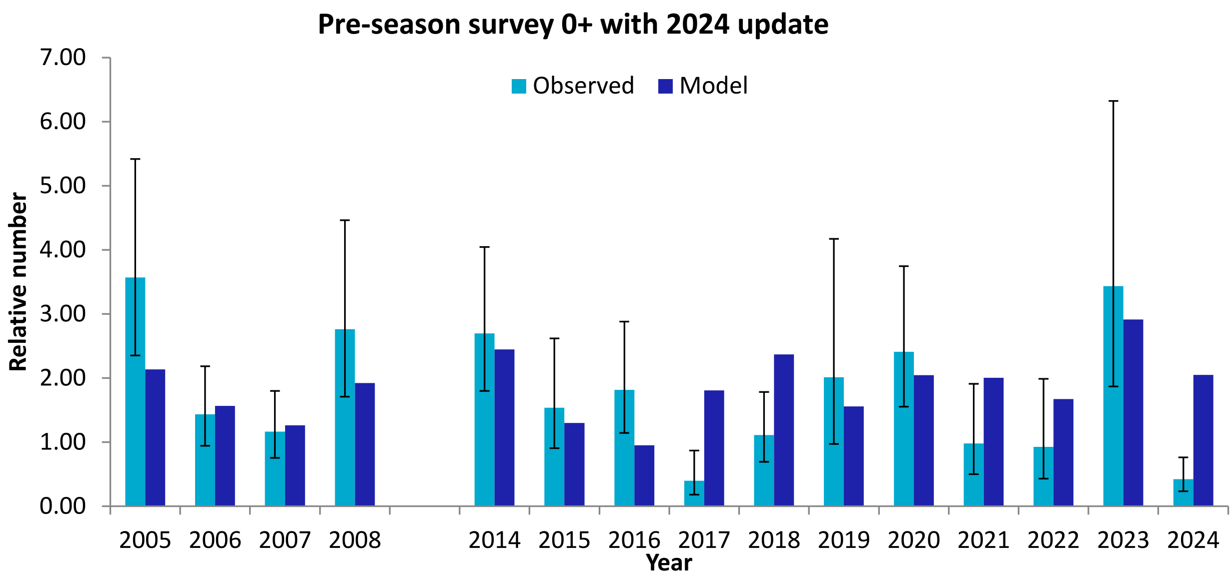
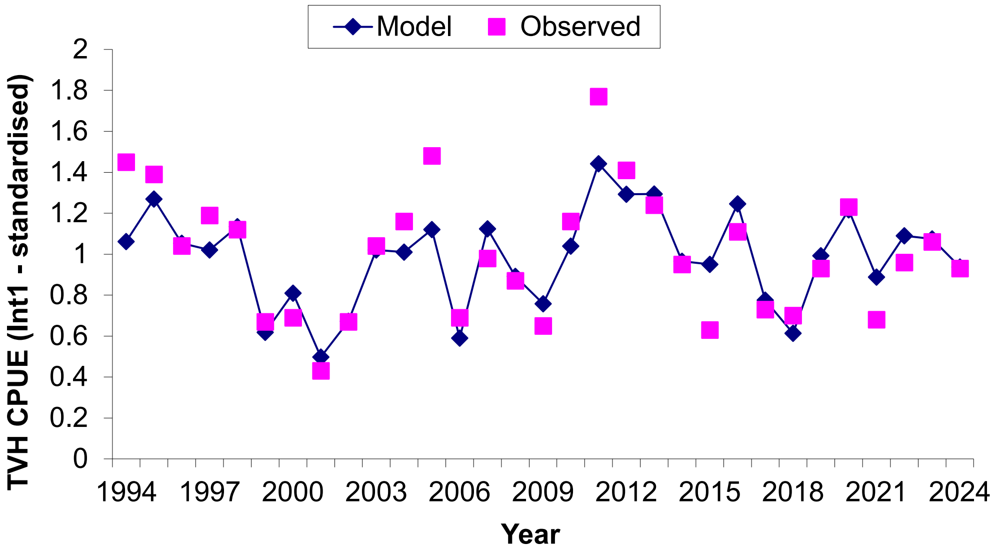


Figure 11.6. Comparison between CPUE data and corresponding model-predicted estimates. *The plots are respectively a) Reference-Case fit to CPUE standardised estimates from the TVH sector with lower bound for sigma set at 0.15, b) fit to TIB CPUE standardized estimates available from 2004-2024. A hyperstable relationship is assumed (with power shape parameter 0.75 and 0.5 respectively) between CPUE and exploitable biomass for the TVH and TIB sectors.*

a) FIT TO TVH CPUE (sigma lower bound = 0.15); Int1 MODEL



b) FIT TO TIB CPUE (sigma lower bound = 0.15); TIB Seller Model

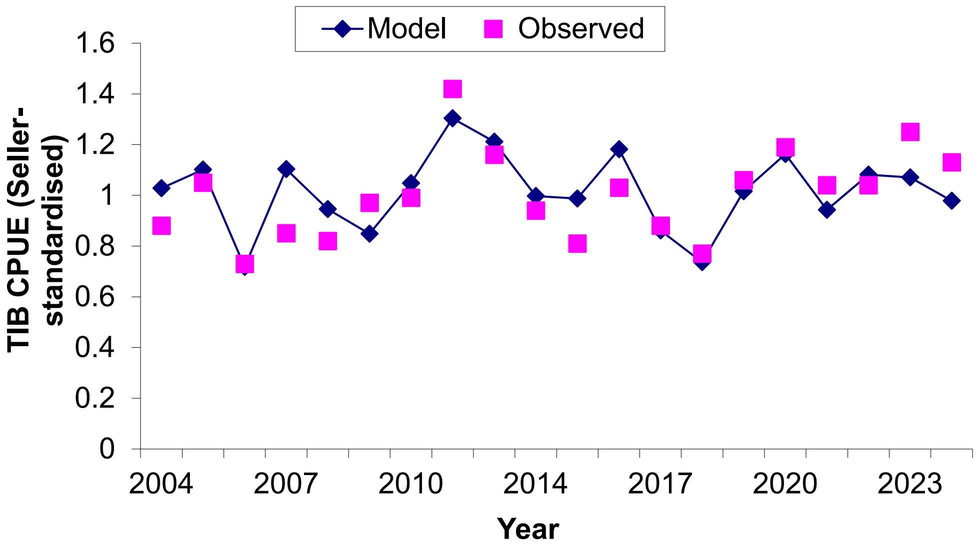
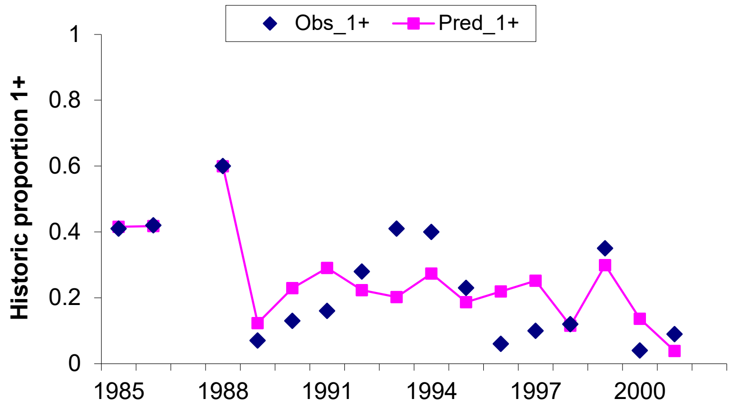


Figure 11.7. Comparison between historical data and model estimates of the proportions of 1+ and 2+ lobsters in the catch.



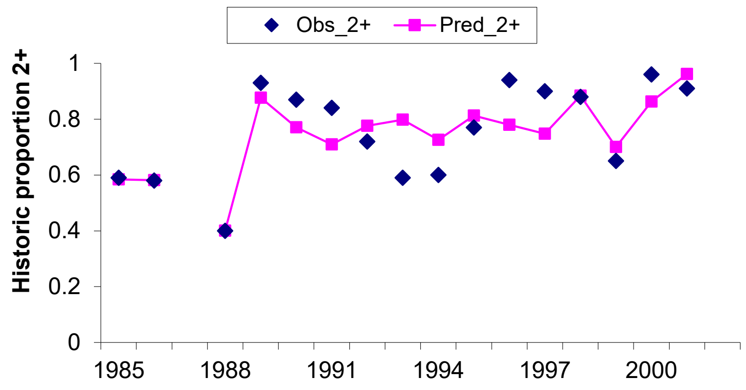


Figure 11.8. Integrated model stock recruitment relationship showing relative number of recruits (R) as a function of the spawning biomass (Bsp) for Revised Reference Case.

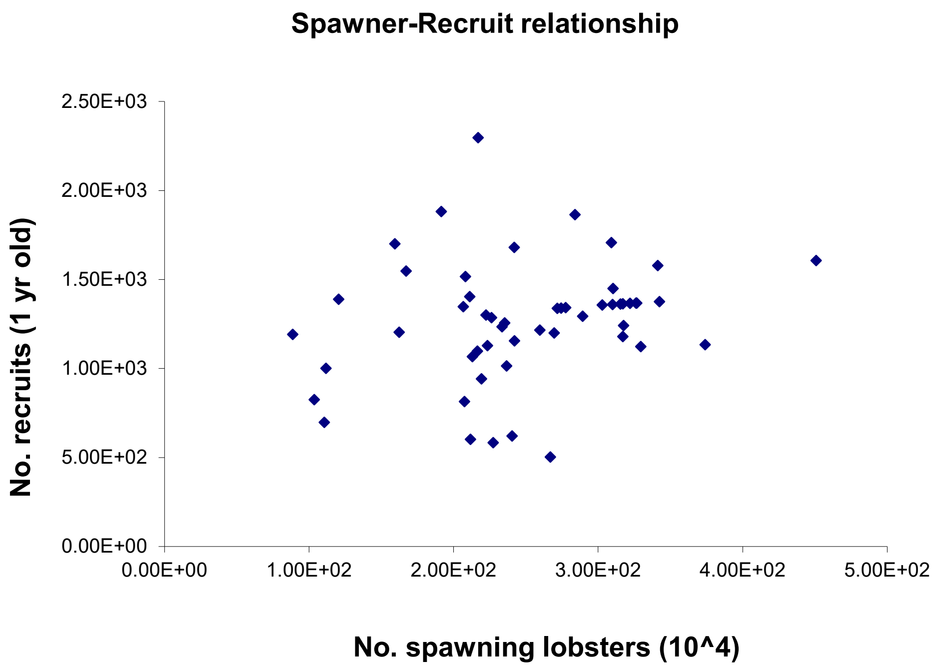
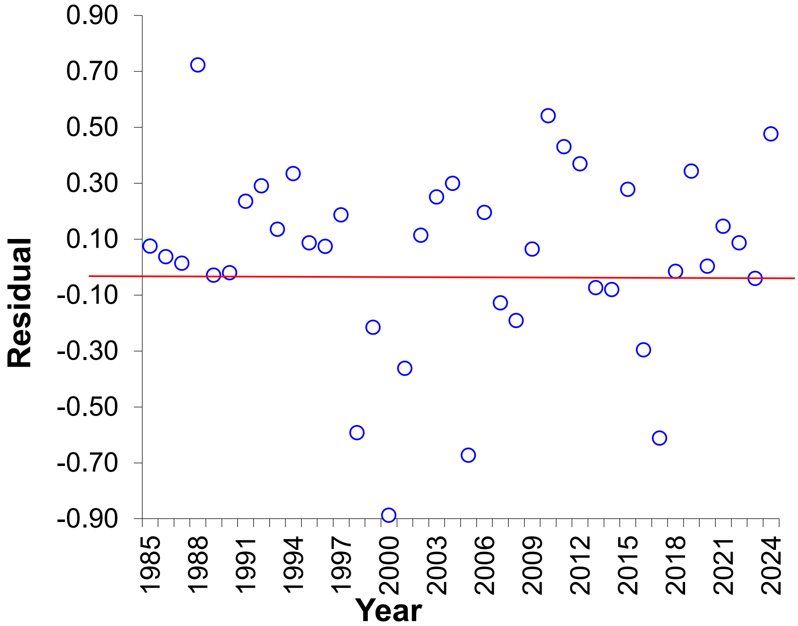


Figure 11.9. Plot of stock-recruit residuals, where recruits are defined as 1+ lobsters.



11.4.2 Estimates of model parameters

A full set of model parameter estimates, depletion statistics and likelihood contributions for the TRLRAG Reference Case is shown in Table 11.5, which also includes a comparison of the 2022 stock assessment parameter estimates. In all cases the 90% Hessian-based Confidence Intervals (CI) are given alongside. The model-estimated recruitment residuals are shown in Appendix K. The Revised Reference model estimates a total of 59 parameters, namely the starting biomass $B(1973)^{SP}$, natural mortality M, 1+ selectivity for the 1973-1988, 1989-2001 and post-2002 periods, 40 stock-recruit residuals and 14 additional variance parameters. The steepness parameter h could not be precisely estimated as the confidence interval associated with the previous estimate is very wide. Hence steepness h is fixed in the Reference Case at 0.7, based on the median of a fisheries database (Myers *et al.* 1999). However, sensitivities to this have also been tested given previous assessments suggesting h may be lower. The natural mortality estimate of 0.70 [90% C.I. 0.57 – 0.82] year^{-1} is reasonably estimated.

Full selectivity of the 2+ age class is assumed given they are the target of the fishery and are assumed caught before the end of September, before they migrate out Torres Strait. Selectivity of 1+ lobsters is substantially less because they are usually only susceptible to fishing after September and not all individuals will have attained the minimum legal size by that time. The selectivity coefficient for age 1+ lobsters was 0.42 for 1973-1988, 0.17 for the period of 1989-2001 and 0.02 for the remaining years. As expected, the decrease in selectivity during the recent time period is a consequence of a change in management measures having been introduced in 2002, which included an increase in the minimum legal size (to 115 mm tail length), a 4-month extension of the hookah ban (October to January) and a 2-month fishing closure (October-November) (Ye et al., 2006).

Following from the above, the level of fishing mortality on age 1+ lobsters is expected to be substantially less than that on age 2+ lobsters (Figure 11.10), with a decreasing trend evident following the implementation of the new management measures in 2002. The fishing mortality rate historical average (from 1989) for age 2+ lobsters is estimated as 0.15 year^{-1} and ranged from 0.26 year^{-1} to recent lows of 0.08 year^{-1} (all sectors combined) (Figure 11.10). The target fishing mortality rate is 0.15 year^{-1}. Since 2020, catches are all assessed to have been below the target fishing mortality rate (0.15). The TRLRAG have discussed in an ongoing manner that external factors such as COVID-19, fuel prices and market may have contributed to under-catches in these years (Plagányi *et al.* 2021; Plagányi *et al.* 2025).

The fishing mortality estimates above refer to the combined estimate when lumping all TRL catches in the Torres Strait, except the trawling sector (Australian and PNG combined) catches. The latter are assumed to target 2+ lobsters only and were substantial in the early years (1973 – 1984) (Figure 11.11) with small catches taken during the period (2001-2003) and zero values for all other years, except for some more recent reports as previously discussed by the TRLRAG.

The TRLRAG have also recommended adding bycatch estimates based on Observer data of TRL caught as bycatch in the Torres Strait prawn trawl fishery. Model sensitivity tests presented at TRLRAG suggested that adding the bycatch estimates to total catch estimates in the model had a small impact only, but that this depends also on assumptions regarding post-capture mortality.

Figure 11.10. Model-estimated fishing mortality trends for 1+ and 2+ lobsters. Note that the fishing mortality since 2020 is estimated to have been below the target fishing mortality rate which is indicated by a horizontal line. *The 2025 fishing mortality is shown for comparison and is set equal to the target value of 0.15.*

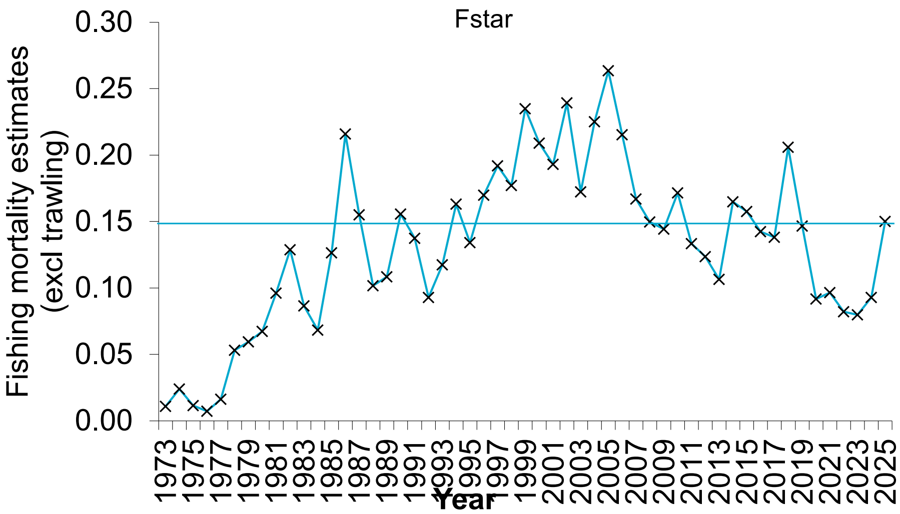
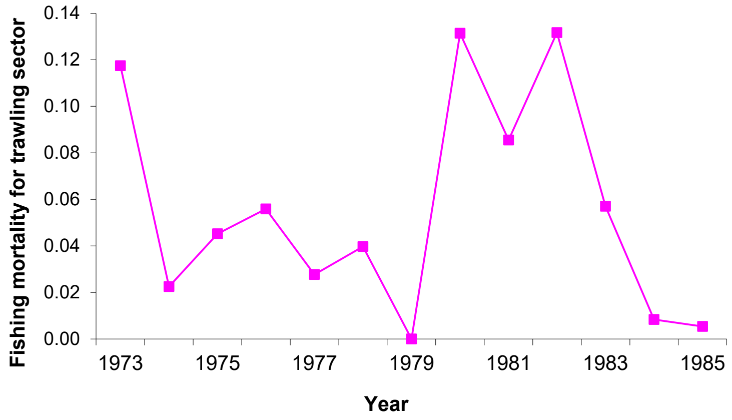


Figure 11.11. Model-estimated trawling sector fishing mortality trends for the early period of the fishery from 1973 - 1985.



11.4.3 Model trajectories

The model-predicted numbers of 1+ and 2+ lobsters for the entire model period are shown in Figure 11.12. There is considerable inter-annual variability in stock size, with the extent of the variability consistent with that observed from field studies.

The lobster spawning biomass (t) trajectory is given in Figure 11.13. The stock is currently (November 2024) estimated to be at 84% of the pristine (1973) spawning biomass level but is expected to fluctuate widely about the average target spawning biomass level, and to increase slightly in 2025.

Figure 11.12. Model trajectories of the annual numbers of lobsters in each age class at the start of each of years 1973 to 2025. *The increased variability from 1989 onwards is because the model estimates stock recruit residuals for years from 1989 to 2024.*

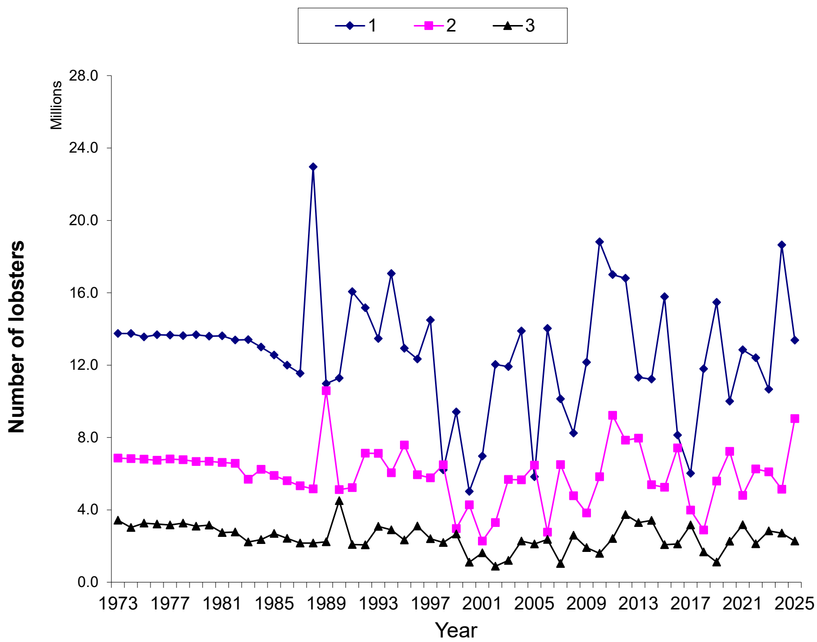


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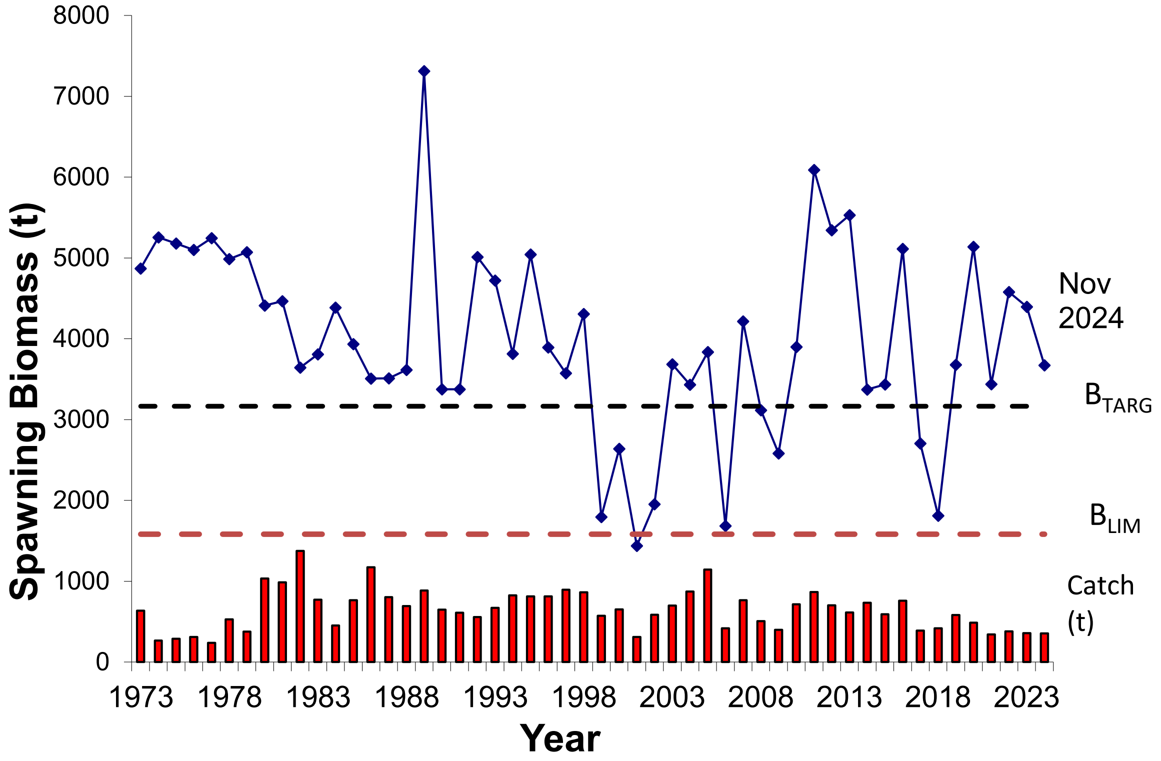
Figure 11.13. Model trajectories of the lobster spawning biomass (t) over the model period shown together with annual catches by the trawling and other sectors combined.



The model-predicted spawning biomass trajectory is shown in Figure 11.13 and the confidence limits are shown in Figure 11.14. The November 2024 spawning biomass for the TRLRAG Dec 2024 Reference Case is estimated to be 3618 t [2337; 4899] (Table 11.5). Figure 11.15 shows the model-predicted commercially available (also termed exploitable) lobster biomass, computed as the sum of all 1+ and 2+ lobsters which are "available" to be caught each year. The current 2024 available lobster biomass estimate is 3957 t [2705; 5210], and this is predicted to increase in 2025 Figure 11.15.

Figure 11.14. Model -predicted lobster November spawning biomass trajectory shown together with Hessian-based 90% confidence intervals for revised Reference Case model. *The vertical line indicates the separation between historical and predicted estimates.*

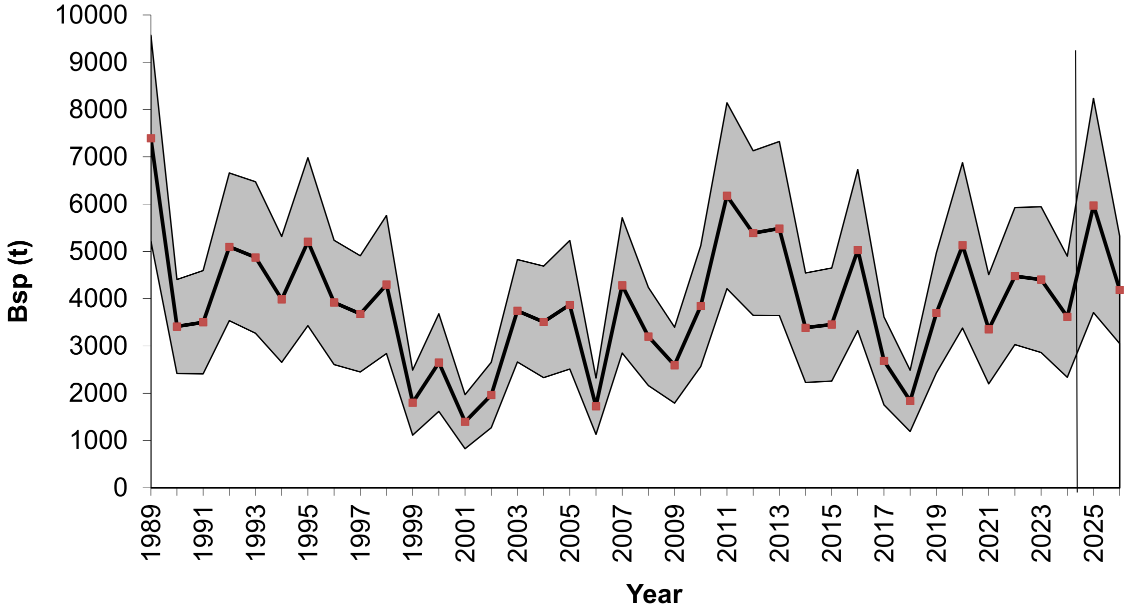
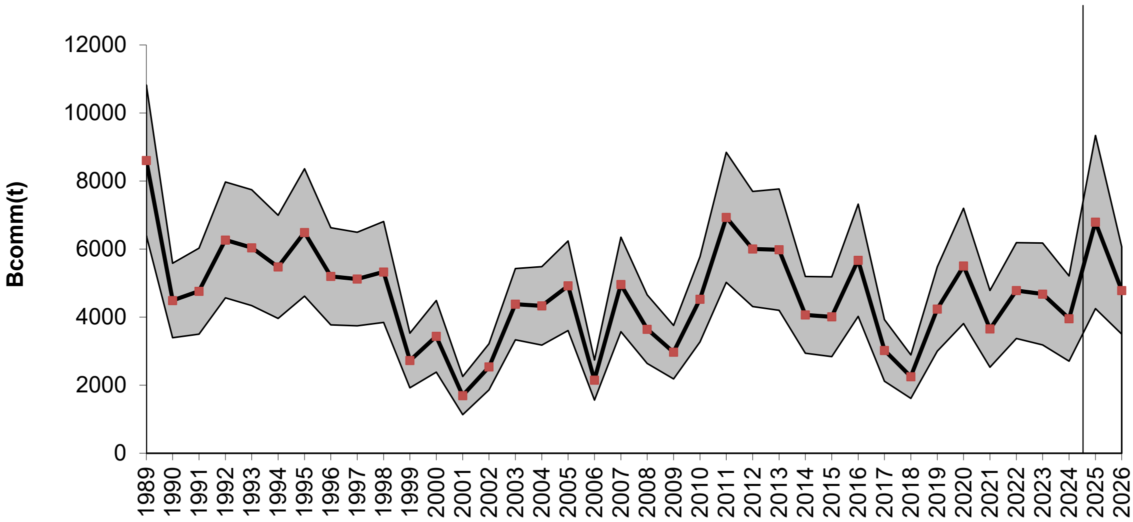


Figure 11.15. Model-predicted commercially available (also termed exploitable) lobster biomass (Bcomm), which is the sum of all 1+ and 2+ lobsters which are "available" to be caught each year. *The shaded area shows the Hessian-based 90% confidence intervals. The vertical line indicates the separation between historical and predicted estimates.*



11.4.4 Sensitivity Tests

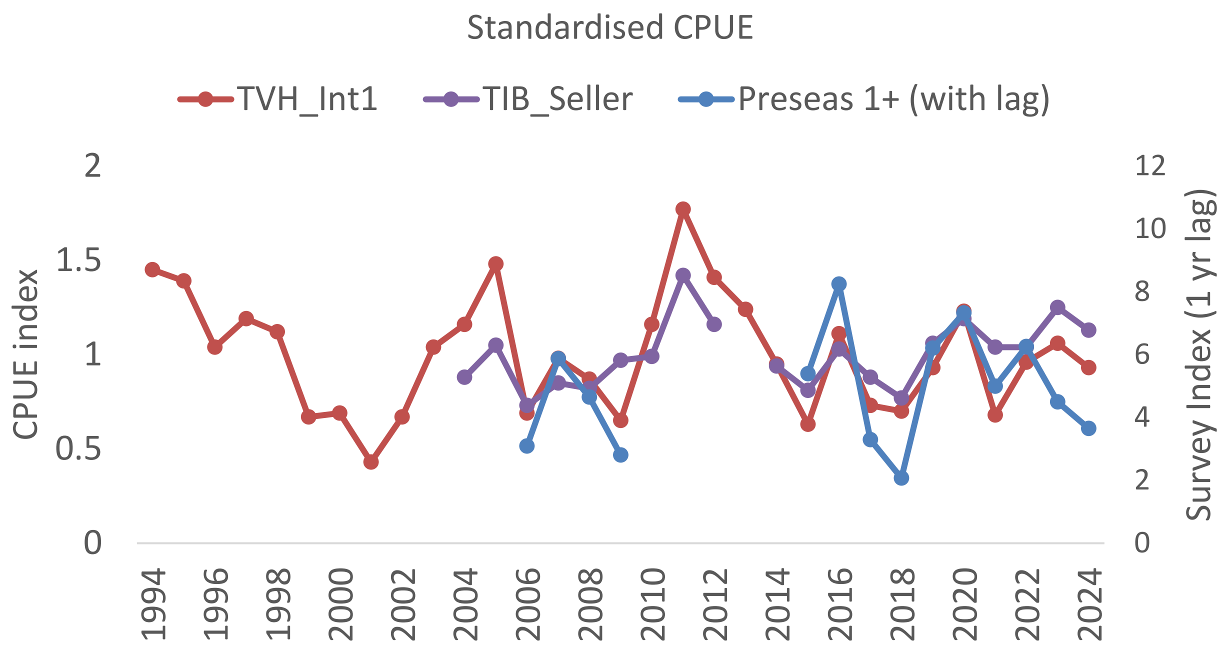
The robustness of model results have previously been tested across a number of sensitivity tests (see e.g., (Plagányi *et al.* 2012b; Plagányi *et al.* 2019a; Plagányi *et al.* 2020; Plagányi *et al.* 2022)) and model results were once again robust to a range of sensitivity tests. As previously, use of the alternative CPUE series had very little effect on model predictions and hence these results are not repeated here:

- CPUE TVH – Int3 standardised series
- CPUE TIB – Seller&A standardised series

As previously, assuming zero additional variance for preseason 0+ indices was not the preferred model based on AIC, and hence additional variance is estimated as shown in Table 11.1.

Given slight revisions in the reference case survey index (see Chapter 2) input to the model and eHCR, a sensitivity analysis was conducted which confirmed fairly minor changes only to the stock assessment model outputs (Table 11.6). The TVH, TIB and Preseason indices of abundance were also compared to confirm that they generally reflect similar abundance trends Figure 11.16.

Figure 11.16. Comparison of relative indices of abundance for TRL showing similar trends in the standardised TIB and TVH series, with these in turn compared with the Preseason 1+ index plotted with a one-year lag given CPUE is an index of 2+ abundance rather than age 1+ as is the case for the Preseason survey.

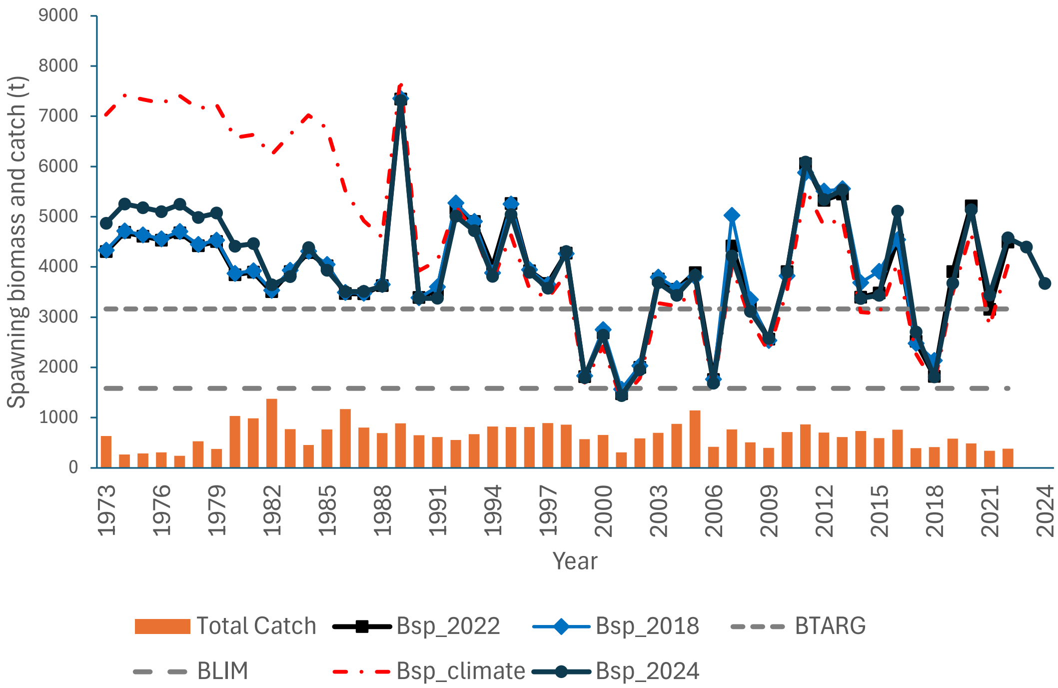


The long-term monitoring (Plagányi *et al.* 2024) of different lobster age-classes has also enabled reliable and robust estimation of the natural mortality parameter *M* for TRL: for example, the 2018 stock assessment estimate was 0.70 yr^{-1} [90% Hessian based confidence interval 0.57; 0.82] compared with 2022 stock assessment estimate of 0.69 yr^{-1} [0.57; 0.82] and current 2024 estimate 0.70 yr^{-1} [0.57; 0.82] such that this parameter has been estimated consistently in each annual stock assessment (Plagányi *et al.* 2023; Plagányi *et al.* 2024). The relative lack of time-variation in baseline *M* has in turn facilitated the ability to estimate additional time-varying sources of mortality such as due to recent temperatures considerably exceeding historical levels (Figure 11.17) (see (Plagányi *et al.* 2019b) for description of method). Although retrospective patterns can be a concern in stock assessments (Szuwalski *et al.* 2017), the monitoring data for TRL are highly informative and hence reduce retrospective patterns as shown in Figure 11.17.

Another challenge for stock assessments relates to estimation of reference points such as unfished biomass B_0, which in turn influences estimation of other model parameters (Mangel *et al.* 2013). The availability of long-term monitoring data can support accurate estimation of past stock levels (Plagányi *et al.* 2024), in this case stretching back to 1989 when survey data first became available Figure 11.17.

Although there were significant catches in the preceding period 1973 to 1988, the stock assessment has no information to support estimation of recruitment residuals and hence simplistically assumes recruitment is deterministic over this period. Although the 1973 (B_0) spawning biomass estimate remains similar in retrospective analyses, the climate-linked model version estimates a substantially higher 1973 starting biomass Figure 11.17. This is attributed to there being considerably more uncertainty regarding estimation of stock depletion levels over 1973 to 1988 (which are based on catch data only), whereas the availability of survey data since 1989 markedly reduces uncertainty in stock status and supports estimation of more minor differences in spawning biomass estimates, which are in turn critical when forward-projecting under future climate change scenarios (Plagányi *et al.* 2024).

Figure 11.17. TRL stock-assessment model trajectory (black circle symbols) of the lobster spawning biomass (t) over the model period 1973 to 2024, shown together with 2022 climate-linked model version (red dot-dash line) and retrospective assessments based on data available up until 2018 (blue diamond symbol) and 2022 (black square). *The upper dashed line is the target spawning biomass level (BTARG), and the lower dashed line corresponds to the lower biomass limit reference point (BLIM). Bars show the total annual catches (t) from all sectors combined.*



A key uncertainty relates to the influence of climate change on TRL – this is discussed in further detail in Plagányi et al. (2019, 2024) and see also Appendix I. The outcomes of the updated 2024 climate-linked stock assessment are shown in Table 6, whereas Figure 11.18 compares the spawning biomass trajectories with and without SST assumed to influence TRL survival. The longer-term projections under climate change are shown in Figure 11.19. A range of additional model sensitivities have also been explored as part of the related MSE testing of the harvest strategy.

Figure 11.18. Comparison of the spawning biomass trajectory when using the 2024 Reference case stock assessment model (BspNov_NoClimate) compared with the climate-linked (BspNov_Climate) model version.

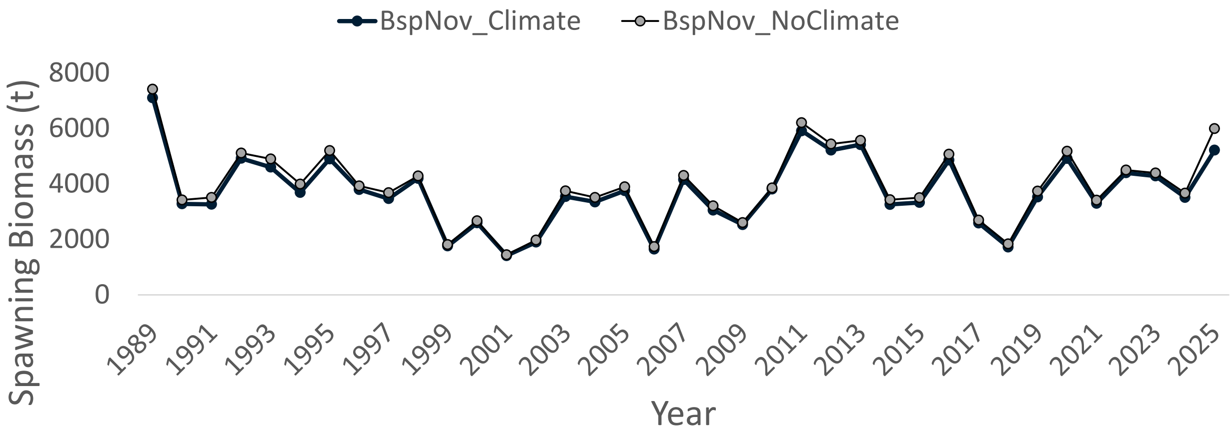
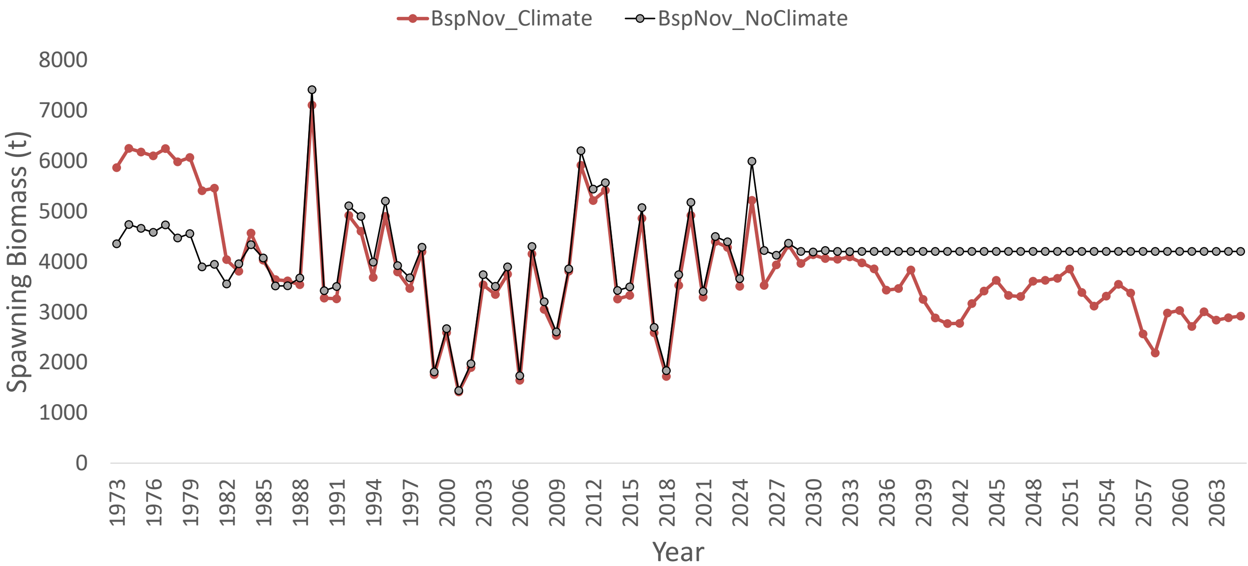


Figure 11.19. Comparison of TRL spawning biomass projections when using the 2024 Reference case stock assessment model (BspNov_NoClimate) compared with the climate-linked (BspNov_Climate) model version.



11.5 Discussion

The revised and updated model adequately fits the available data and integrates all available information. Parameter estimates and resource trajectories are presented together with confidence intervals to illustrate the extent of uncertainty associated with model predictions.

Although estimation of natural mortality within stock assessments is recommended, natural mortality is almost always pre-specified in lobster stock assessments (Punt 2024). However, consistent with eraleir data and analyses, the natural mortality parameter *M* for TRL has consistently been estimated within the stock assessment to be ca. 0.70 yr^{-1}. This is due to the distinctly recognisable cohorts and availability of long-term monitoring data (Plagányi *et al.* 2024).

The inherent variability of environmental influences in relatively short-lived highly variable stocks such as TRL confounds both the accuracy and precision of optimal sustainable yield estimates for the following year. Ongoing research is being conducted to better understand and incorporate this variability in the management process. In addition, a parallel climate-linked stock assessment model (see Appendix I) has been presented at TRLRAG meetings since 2017 and is currently being revised as part of the Torres Strait climate change project to utilise updated physical data and climate projections.

The empirical harvest control rule (eHCR) (see Chapter 10) used to set the TRL TAC is based on the results of the Pre-season survey and other data inputs to set the RBC, rather than annually running the stock assessment (Plagányi *et al.* 2018b). The advantage of this approach is that it has been simulation tested, and the harvest control rules agreed beforehand by all stakeholders, so that the TAC updating process is quick and efficient as is necessary given the short time between the pre-season survey completion (plus time for analysis of the data), and the opening of the fishing season.

The December 2024 Reference Case estimates a current spawning stock biomass $B(2024)^{sp}$ of 3,618 tonnes (Table 11.5). The model results indicate that the TRL spawning biomass $B(2024)^{sp}$ is at approximately 84% of the 1973 reference starting value $B(1973)^{sp}$, which is well above the agreed target reference point of 65 per cent unfished biomass under the harvest strategy. The agreed target reference point is relatively higher compared with other Australian fisheries and guidance under the Commonwealth Harvest Strategy Policy. This was deliberately designed to meet the objectives of the TRL fishery and protect the traditional way of life, and livelihoods of traditional inhabitants in the Torres Strait.

The TRL spawning biomass is estimated to have remained above the target reference level during the past six years, having recovered from the lower levels estimated over the period 2017 and 2018, plus possibly in response to low catches and favourable environmental conditions. The 2024 commercially available biomass estimate (i.e., the lobsters that are available to be caught by the fishery) of 4044t was about 76%of the long-term average (1989-2023). However, the model predictions for 2025 indicate this will increase to approx. 130% of the long-term average. Consequently, catch rates in 2025 are predicted to be good although catches may not correspondingly be above average given external factors (e.g. market access) influencing the fishery.

The December 2024 Reference Case model suggests an RBC (2025) of 946t [90% CI 592 – 1301 t]. The stock-assessment RBC for 2025 is thus likely to be much higher than the empirical Harvest Control Rule (eHCR) RBC because the latter rule is designed to dampen some of this inter-annual variability in TAC.

Table 11.6. Summary of model parameter estimates for sensitivity scenarios: (A) the Dec2024 Reference Case; (B) Dec2024 model testing sensitivity to revision of the survey MYO series and (C) climate-linked Reference Case, shown with Hessian-based 90% confidence intervals. *The climate-linked reference case uses the reference case estimate of M=0.7 y^{-1}, and estimates one or more parameters describing the relationship between SST and M (see text).*

	(A) Dec 2024 Reference Case			(B) Sensitivity with MYO survey index			(C) Dec 2024 Climate-linked Reference		
Parameter	**Value**	**90% CI**		Value	90% CI		Value	90% CI	
B(1973) ^{sp} (tons)	4399	3168	5630	4401	3171	5630	3750	2449	5052
M	0.70	0.57	0.82	0.69	0.57	0.82	fixed	0.00	0.00
h	fixed 0.7			fixed 0.7			fixed 0.7		
Sel (age 1+) 1973-1988	0.42	0.23	0.60	0.42	0.23	0.60	0.38	0.22	0.55
Sel (age 1+) 1989-2001	0.17	0.15	0.19	0.17	0.15	0.19	0.15	0.14	0.17
Sel (age 1+) post2002	0.02	0.00	0.02	0.02	0.00	0.02	0.01	0.01	0.02
SST-M par1	-			-			fixed		
SST-M par2	-			-			0.50	-0.89	1.90
hyps(TIB)	fixed 0.5			fixed 0.5			fixed 0.5		
hyps(TVH)	fixed 0.75			fixed 0.75			fixed 0.75		
Model estimates and depletion statistics									
B(2024) ^{sp} (tons)	3618	2337	4899	3584	2312	4856	3750	2449	5052
RBC(2025) model	946	592	1301	962	622	1301	902	497	1307
RBCforecast(2026) model	664	485	843	662	484	839	591	241	940
Current Depletion (Nov)									
B(2024) ^{sp} / B(1973)sp	0.84	0.60	1.08	0.83	0.59	1.07	0.61	0.39	0.82
Bexp(2024) (tons)	3957	2705	5210	3924	2680	5167	4036	2773	5299
No. parameters estimated	59			59			60		
'-lnL:overall	**-235.20**			***-232.58***			**-233.17**		
AIC	**-352.41**			***-347.15***			**-346.34**		
Likelihood contributions		**Sigma**	**q**		**Sigma**	**q**		**Sigma**	**q**
'-lnL:CAA	-85.23	0.04		-85.09	0.04		-84.87	0.04	
'-lnL:CAAsurv	-20.31	from data		-20.28	from data		-18.88	from data	
-lnL:CAA historic	-15.92	0.15		-16.64	0.15		-16.48	0.16	
-lnL:Survey Index 1+	-15.92	from data	3.970E-07	-16.64	from data	3.957E-07	-16.48	from data	3.456E-07
-lnL:Survey Index 2+	-15.59	from data	4.146E-07	-15.58	from data	4.142E-07	-15.30	from data	4.137E-07
-lnL:Survey benchmark	-3.14	from data		-3.14	from data		-2.99	from data	
'-lnL:PRESEASON	-19.44	from data	9.055E-07	-17.91	from data	8.299E-07	-19.43	from data	8.336E-07
-lnL:PRESEASON 0+	-3.21	from data	1.582E-07	-2.64	from data	2.072E-07	-3.09	from data	1.270E-07
-lnL:CPUE (TVH)	-32.91	0.21	0.0019	-32.87	0.21	0.0019	-32.54	0.22	0.0019
-lnL:CPUE (TIB)	-26.15	0.16	0.0157	-25.28	0.17	0.0157	-26.21	0.16	0.0157
'-lnL:RecRes	8.74	0.33	input	8.86	0.33	input	8.79	0.33	input

12. Torres Strait Tropical Rock Lobster Additional Research Outputs

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12.1 Long-Term Monitoring and TRL Fishery History

The first annual fishery-independent survey of TRL was conducted in 1989 (Figure 12.1), informed by a number of pilot studies conducted in 1988 (Pitcher *et al.* 1992b). A full-scale stratified random population survey involving 542 transects was conducted in 1989 and a second benchmark survey conducted in 2002 involved 354 dive transects plus 21 additional towed video transects (Ye *et al.* 2006). There were insufficient resources to effectively design a stratified random sample Pre-season survey and hence a fixed station monitoring survey design, referenced against the 2002 survey, was chosen after considering the power of detecting population changes (Ye *et al.* 2006). At least one annual survey has been conducted every year since 1989, with some changes over time in survey design and implementation as summarised in (Ye *et al.* 2005; Ye *et al.* 2006). As highlighted by (Plagányi *et al.* 2024), the TRL *Panulirus ornatus* survey is among the longest running fishery-independent dive surveys for any marine resource. Moreover, the advantages of conducting annual surveys were clearly highlighted by Dennis et al. (2015).

To celebrate the 35th annual survey and launch the new Torres Strait fisheries and climate change project, a science communication and public engagement event was held on Waibene in November 2023 (Figure 12.2). At the time of writing this report, CSIRO have also completed the 35th annual survey as detailed in Chapters 2 to 4. This builds on a long history of research on the biology, ecology, assessment and management of TRL as summarised in Figure 12.1 and detailed in numerous scientific publications and technical reports (see also Appendix L. Appendix References and Further Reading).

The COVID-19 pandemic (Hui *et al.* 2020) had a major impact on global scientific data collection – for example, in 2020, the U.S. alone cancelled over 50 fisheries surveys (Link *et al.* 2021). Australian fisheries were also negatively impacted by the COVID-19 pandemic (Greenville *et al.* 2020; Plagányi *et al.* 2021; Ogier *et al.* 2023). Fortunately, a detailed COVID Management Plan was developed for the TRL survey so that November 2020 survey was undertaken without incident (Plagányi *et al.* 2024).

Both COVID and other external factors such as fuel prices and export constraints compromised to some extent inferences that could be drawn from fishery-dependent catch and CPUE data (Plagányi *et al.* 2021). In comparison, the fishery-independent survey data were not similarly affected by factors external to the fishery and continued to serve as a reliable basis to underpin stock assessment and management (Plagányi *et al.* 2024).

Given ongoing supply chain and market access issues affecting TRL since 2020, research has also built on earlier work to develop a quantitative supply chain index (Plagányi *et al.* 2014; Lim-Camacho *et al.* 2017). This approach has been applied to TRL and other lobster supply chains to identify opportunities for increasing resilience to climate change and market shocks, including development of adaptation options (Plagányi *et al.* 2014). Moreover, recent research on socio-ecological resilience and sustainability implications of seafood supply chain disruption has also used TRL as a case-study (Subramaniam *et al.* 2023).

From 2019 to the present day, environmental variability and climate change have increasingly been considered and incorporated into all research activities, and environmental monitoring expanded (Figure 12.1) (see (Plagányi *et al.* 2024) for further details). Approaches used to account for climate change impacts build on previous approaches for this fishery (Plagányi *et al.* 2011; Dennis *et al.* 2013; Norman-López *et al.* 2013; Plagányi *et al.* 2013; Plagányi *et al.* 2018a; Plagányi *et al.* 2019b) as well as introducing novel new formulations (Plagányi *et al.* In review).

Figure 12.1. Timeline summarising changes in survey frequency, type and focus during the 35-years of continuous annual dive surveys of TRL in Torres Strait. From: Plagányi et al. (2024)

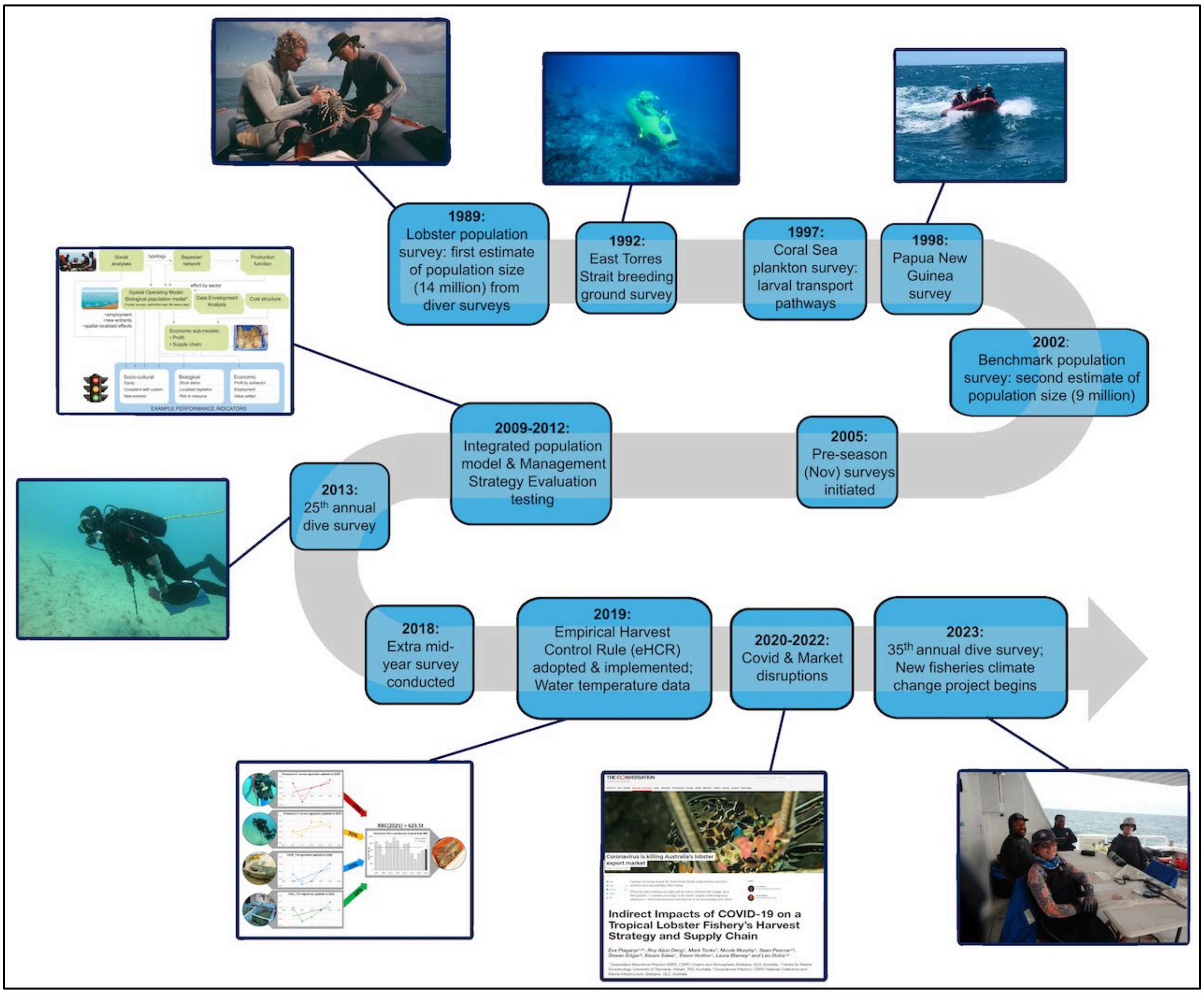


Figure 12.2. Copy of flyer used to advertise the November 2023 event to celebrate the completion of the 35th annual 'Kaiar' survey and launch of the new Torres Strait marine and fisheries climate change project.

12.2 Stock Structure of *Panulirus ornatus*

The tropical rock lobster (TRL) or 'Kaiar' *Panulirus ornatus* has a broad distribution across the Indian and Pacific Oceans, including the eastern coast of Africa, Australia, Vietnam, China and as far north as southern Japan (Plagányi *et al.* 2017; Plagányi *et al.* 2025). Recent genomics research reveals that although these are all the same species, there are distinct genetics differences between lobsters from northern Australia and South-East Asia (Farhadi *et al.* 2022). These authors suggest that recruitment for *P. ornatus* involves 'a greater degree of self-seeding at the regional scale and a lesser degree of broad connectivity than might be expected given the lengthy pelagic period (4–6 months) and the oceanic larval development in this species.

The northeastern Australian population is largely self-seeded, with mature lobsters migrating out of Torres Strait across the Gulf of Papua to breeding grounds along the coast of Papua New Guinea (Dennis *et al.* 2001; Dennis *et al.* 2004) (Figure 12.3). Here, eggs are released, and larvae enter the Coral Sea gyre that transports them back to northeastern Australia, where they settle six months later (Figure 12.3). Extensive tagging studies (~20000 tags) were conducted in Torres Strait and Queensland waters and recaptures showed the 500 km Autumn (Aug/Sept) breeding migration from Torres Strait to the eastern part of the Gulf of Papua, as well as clear separation of the Torres Strait and Queensland sub-populations (Moore and Macfarlane 1984; Skewes *et al.* 1997; Dennis *et al.* 2001). The Torres Strait stock assessment model thus assumes that the Torres Strait lobster population is a closed population, with the numbers of annual recruits (1+ lobsters) assumed to have originated solely from the Torres Strait spawning stock biomass. However, larval circulation models suggest that dependent on the Coral Sea gyre and local currents influencing the broader Coral Sea and Great Barrier Reef regions, some of the larvae may settle off Australia's north-east coast and similarly some of the larvae spawned by the East Coast *P. ornatus* component may be advected into Torres Straits due to the predominant northerly direction of the current, but tagging and modelling studies suggest this is a small proportion only (Dennis *et al.* 2001; Plagányi *et al.* 2018a; Plagányi *et al.* 2019b).

Strong retention in the Coral Sea gyre is, in part, a reason for the distinct genetic break between northeastern Australian and south-east Asian populations (Farhadi *et al.* 2022) and the creation of a *P. ornatus* 'hotspot' in Australia. Over thousands of years, this complex but efficient life-cycle of *P. ornatus* in northeastern Australia has allowed 'kaiar' to weave its way into the cultural, social and economic fabric of the Indigenous peoples of the Torres Strait (Plagányi *et al.* 2013). Good custodianship and precautionary management approaches have supported ongoing sustainable management of Kaiar.

Results from a genomics study (based on thousands of nuclear markers in the *P. ornatus* genome) suggests that lobsters in the Torres Strait and Queensland East coast populations should be considered a single genetic stock (separate to those in South-East Asia) for management purposes (Farhadi *et al.* 2022). There are fine-scale genetic differences with *P. ornatus* populations in Indonesia and the rest of South-East Asia, suggesting very limited connectivity between Australian and South-East Asian lobsters – and similarly among the other genetic units shown in Figure 12.4 below. This corroborates earlier genetics work (Yellapu *et al.* 2017) as well as the results of oceanographic / connectivity modelling (Dennis *et al.* 2001; Plagányi *et al.* 2018a; Plagányi *et al.* 2019b).

Figure 12.3. P. ornatus life cycle based on Dennis et al. (2001) showing major breeding grounds (green shading) and fishing grounds (red shading=Torres Strait fishery; blue shading=Queensland east coast fishery) in NE Australia and Papua New Guinea.

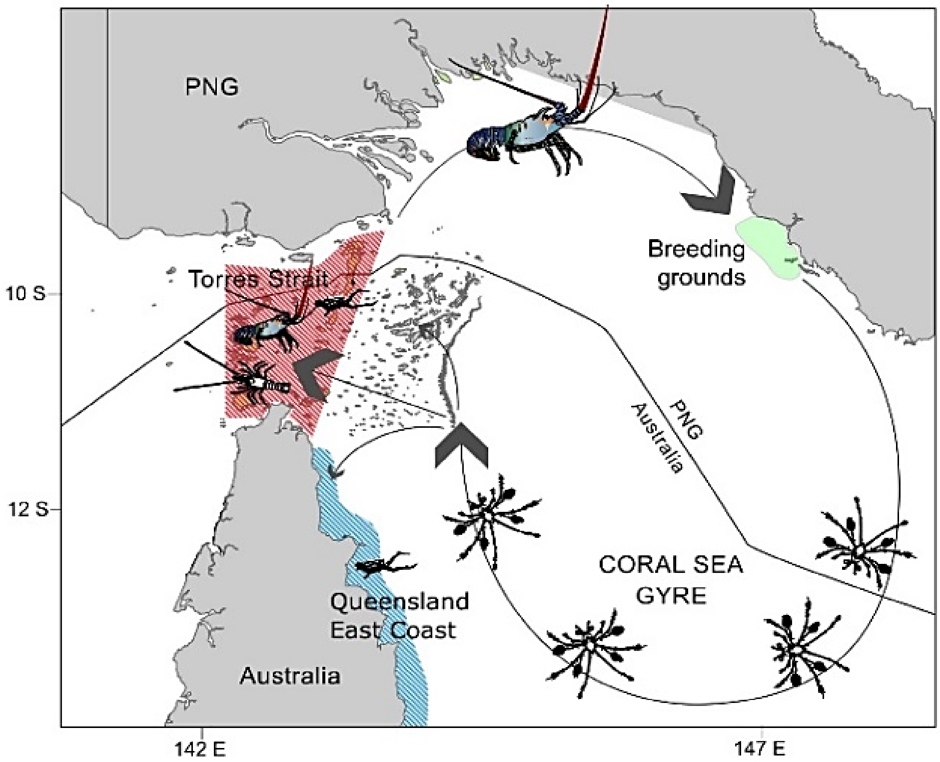
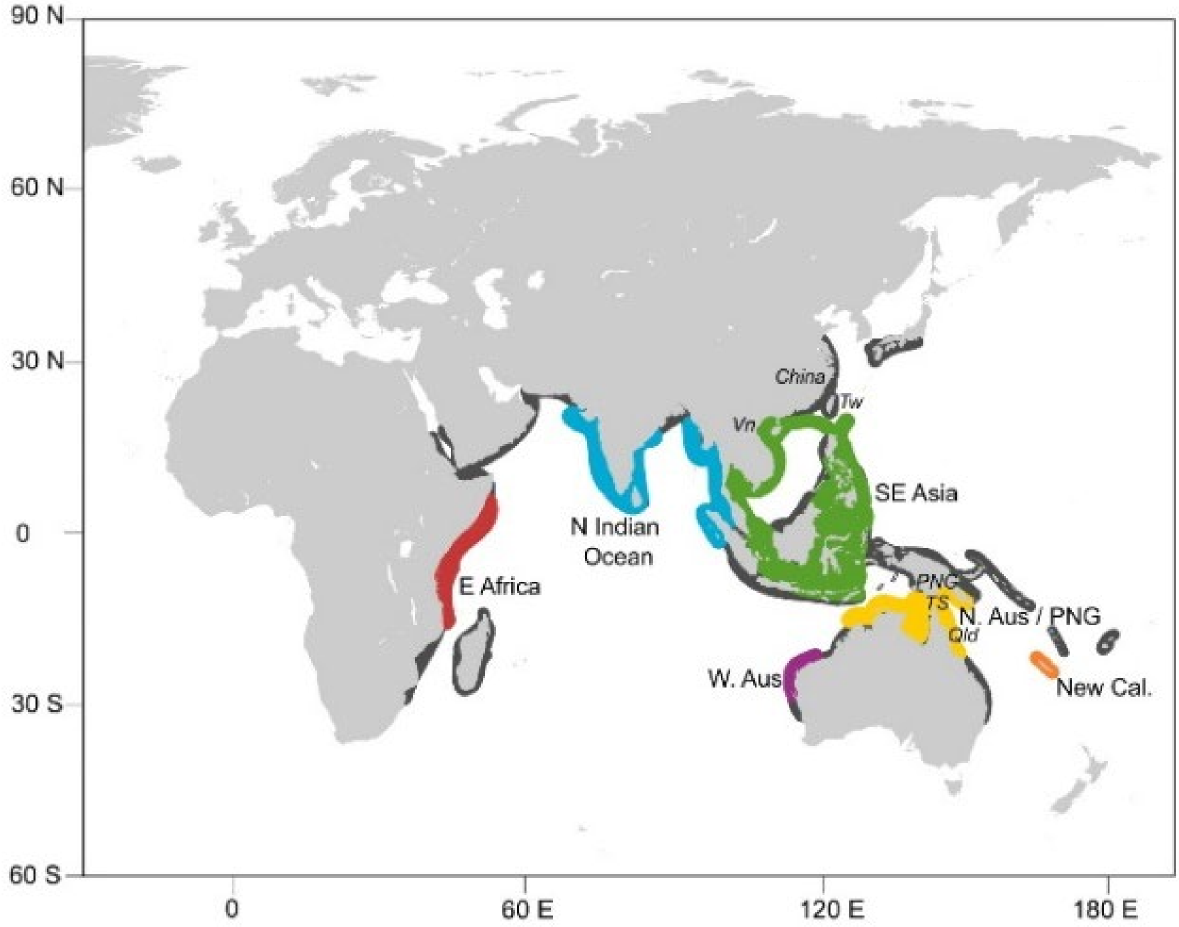


Figure 12.4. Proposed Panulirus ornatus management units (colours) based on data from Farhadi et al. (2022) supporting 5 distinct stock units: 1. South East Asia (SEA), 2. Northeastern Australia (NEA), 3. Central (northern) Indian Ocean (CIO), 4. Western Indian Ocean (WIO/East Africa), 5. West Australia (WA) (noting New Caledonia uncertain, and CIO intermediate to WIO and SEA). Source: modified from Plagányi et al. (2025)

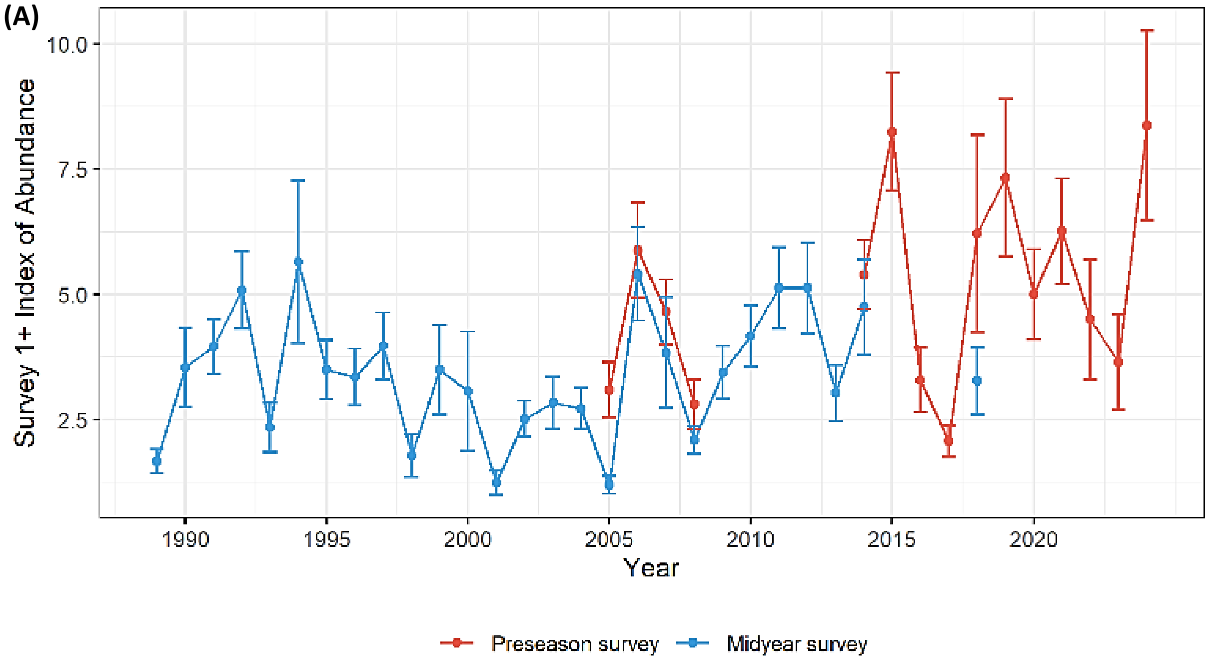


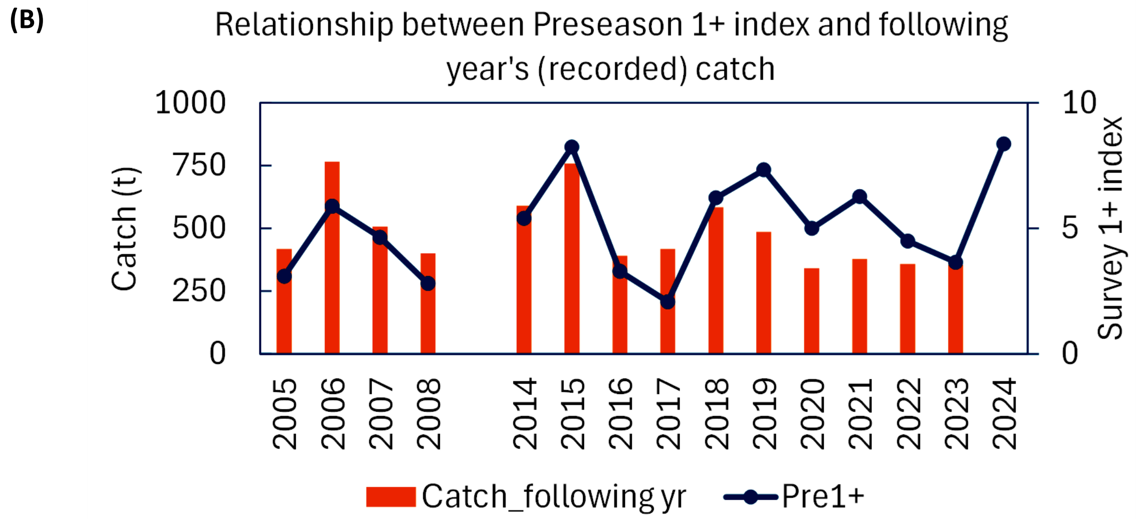
12.3 TRL Spatial Variability

TRLRAG38 participants queried whether the spatial distribution of settling TRL as presented in Chapter 2 changed during the fishing season. During 1989-2014 and in 2018, CSIRO conducted Mid-year surveys (May/June) to count and measure 1+ and 2+ Kaiar / tropical rock lobsters (TRL) in Torres Strait to inform the sustainable management of the fishery. During 2005-2008 and for all years since 2014, Pre-season (November) surveys counted 0+ and 1+ lobsters.

The relative counts of 1+ (recruiting) lobsters were similar between Mid-year and Pre-season surveys (Figure 12.5A). The main purpose of the survey is to provide an overall index of relative abundance of the 1+ recruiting TRL because they rapidly grow to become the majority of 2+ lobsters available to be fished and provide an index of the likely sustainable catch in the season ahead (e.g., Figure 12.5B).

Figure 12.5. (A) Comparison of the Mid-year and Pre-season survey relative abundance of recruiting (1+) TRL (modified from Plagányi et al. (2024)). (B) Preseason 1+ index plotted with following season's catch (2+ TRL total catch with lag effect and noting the TAC system since 2019 and external market factors also influence catch (e.g., 2020-2024) – missing last bar will be (unknown) catch for 2025.





12.3.1 Spatial Distribution Summary and Survey Results

The relative spatial distribution of 1+ lobsters during the Mid-year compared with the Pre-season survey is shown in Figure 12.6. In most areas, these matched fairly well over 2005-2008, although this is not always the case. Previous research (Skewes *et al.* 1997) showed TRL are distributed according to their size and age: 1+ lobsters occupy deep areas between reefs (likely because predation pressure is greater in shallow reef areas), 2+ lobsters live in both deep areas and shallow reefs and 3+ male lobsters live mainly on shallow reefs, with high fidelity to a reef system. Nearly all 2+ females and most

2+ males migrate out of Torres Strait during August and September each year to breed (Skewes *et al.* 1994). There appears to be little movement of 1+ lobsters onto shallow reefs between March and the breeding migration. As reported also by Moore and MacFarlane (1984), the most likely movement of 1+ TRL onto reefs thus occurs just after the annual breeding migration in August-September.

In summary, whereas the distribution of the 1+ TRL stays roughly the same until after the breeding migration, the distribution of the 2+ TRL does not always match the distribution of the 1+ TRL (Figure 12.6 to Figure 12.8) as larger lobsters will move in response to need for food and shelter, as well as wind direction as prefer the lee side of reefs.

Future work could also compare the spatial distribution of the Pre-season 1+ survey results and catches the following year (TRLRAG14 CSIRO presentation contains examples). However, we note that a large proportion of catch records do not include the area caught which limits use of the data for these analyses.

Figure 12.6. Comparison of 1+ relative abundance during Mid-year (blue bars) and ca. 5 months later Pre-season surveys (red bars) for selected survey strata as shown. *The green bars are the 2+ lobster counts from the following year's Mid-year survey.*

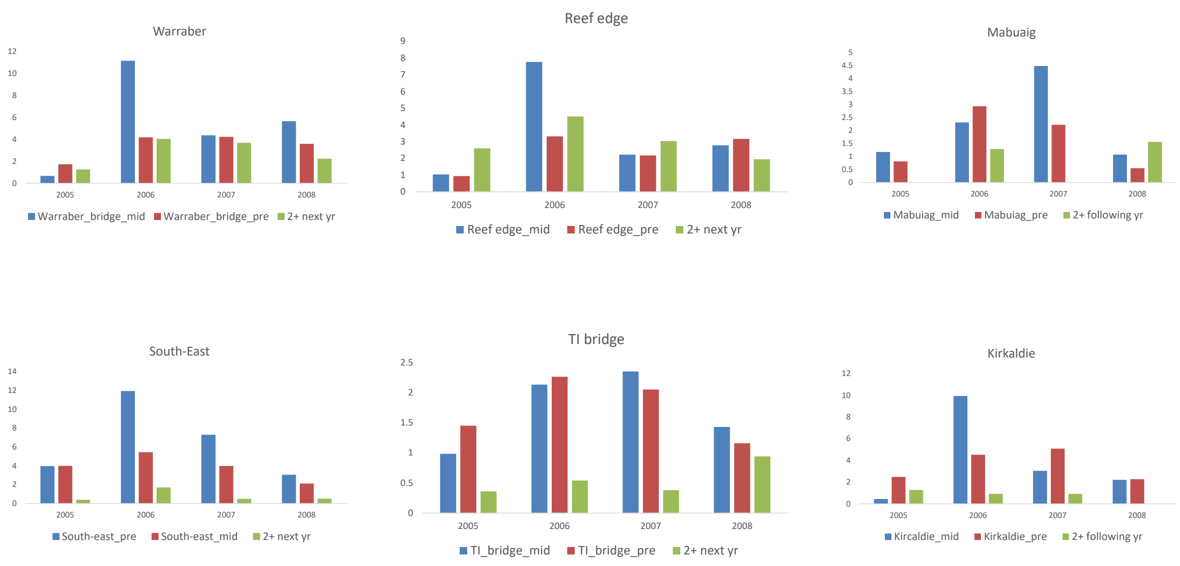


Figure 12.7. Examples of correlations for strata as shown between the Mid-year 1+ survey abundance and the following year's Mid-year 2+ index to highlight that the 1+ spatial distribution is often – particularly for the Kirkaldie and SE strata - a poor predictor of where 2+ TRL will be distributed. *Note for the Mabuiag and TI Bridge strata, low initial 1+ counts can yield high 2+ TRL counts later in the season.*

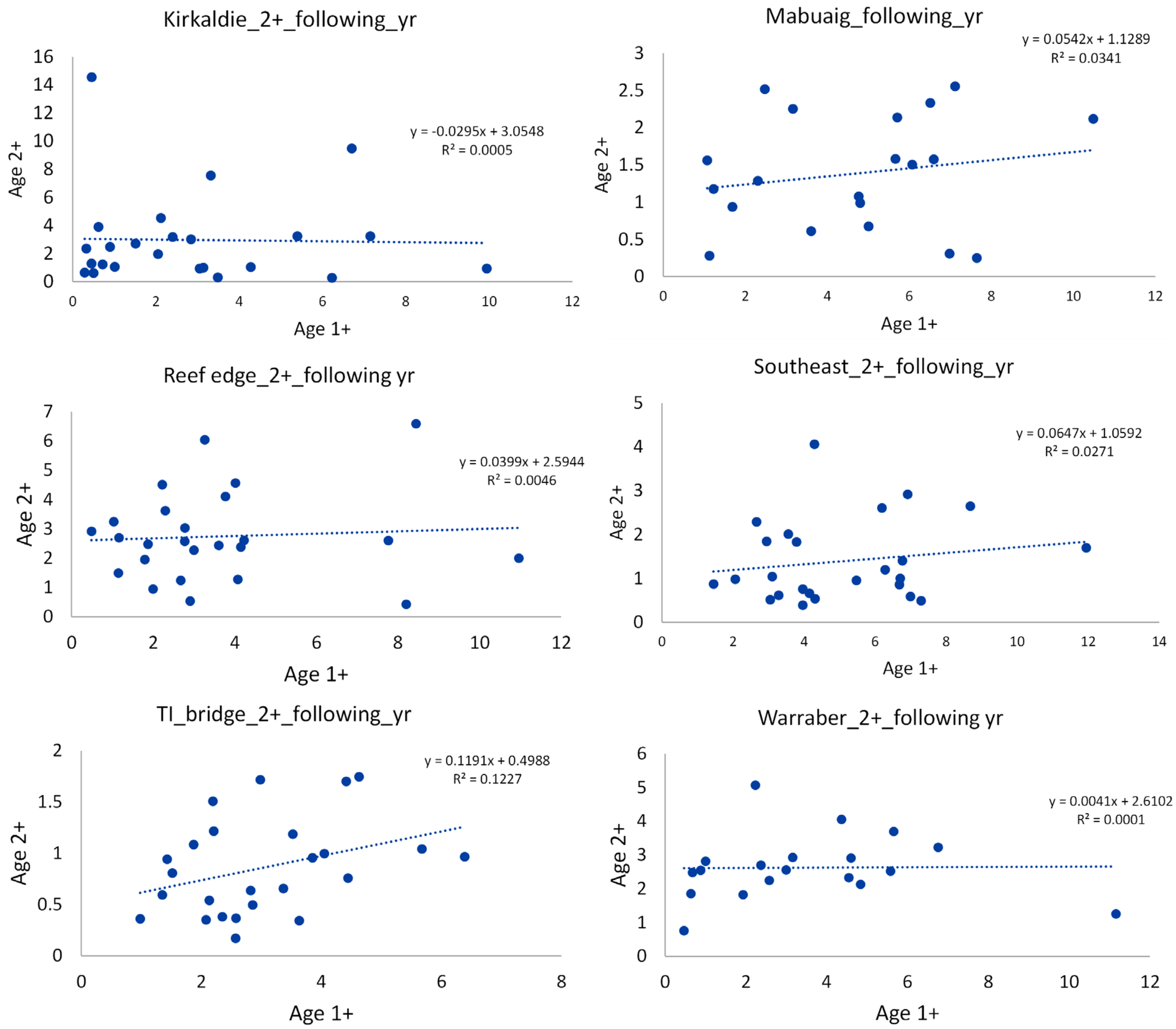
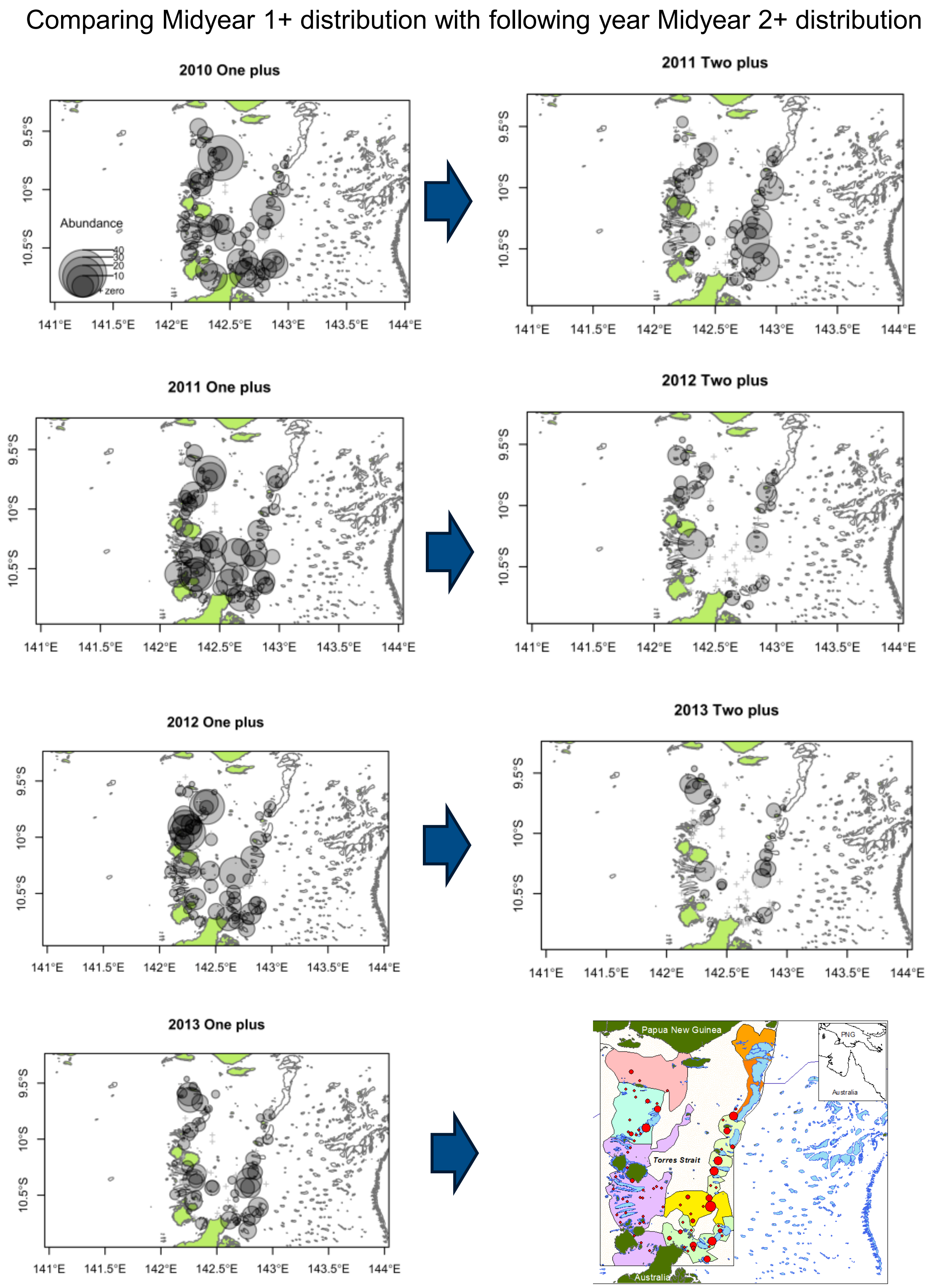


Figure 12.8. Torres Strait maps to compare the spatial distribution of the Mid-year survey recruiting (1+) TRL abundance and the following year's Mid-year 2+ relative abundance to highlight that the 1+ spatial distribution does not always match the 2+ TRL spatial distribution. *Plots from August 2014 presentation at TRLRAG14 (surveys led by Darren Dennis), and different format used for 2014.*

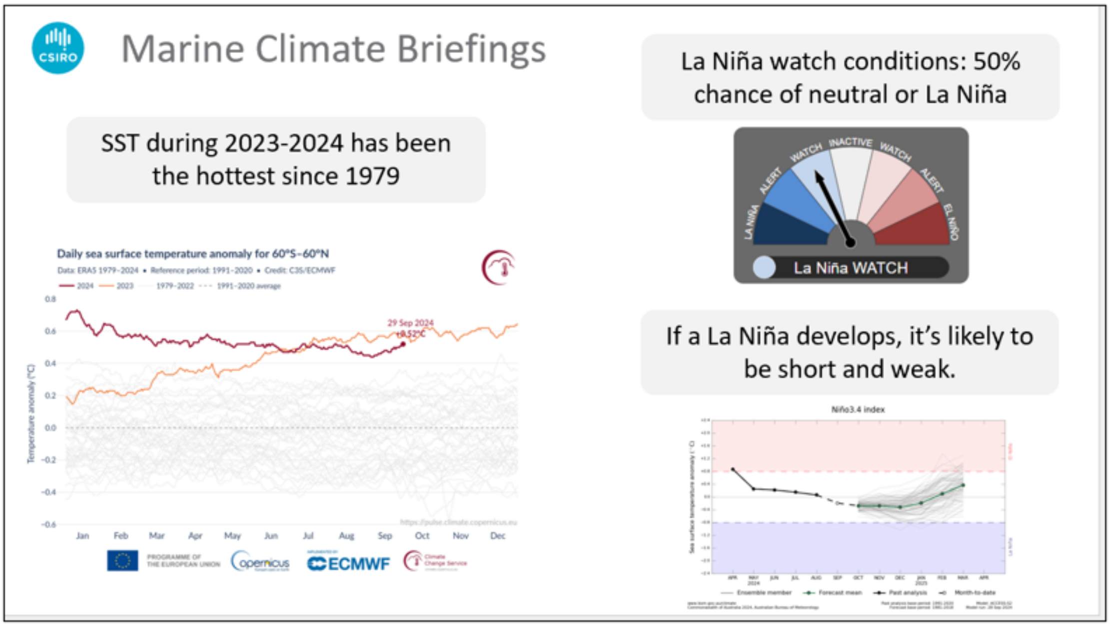


12.4 Climate Briefings and Report Cards

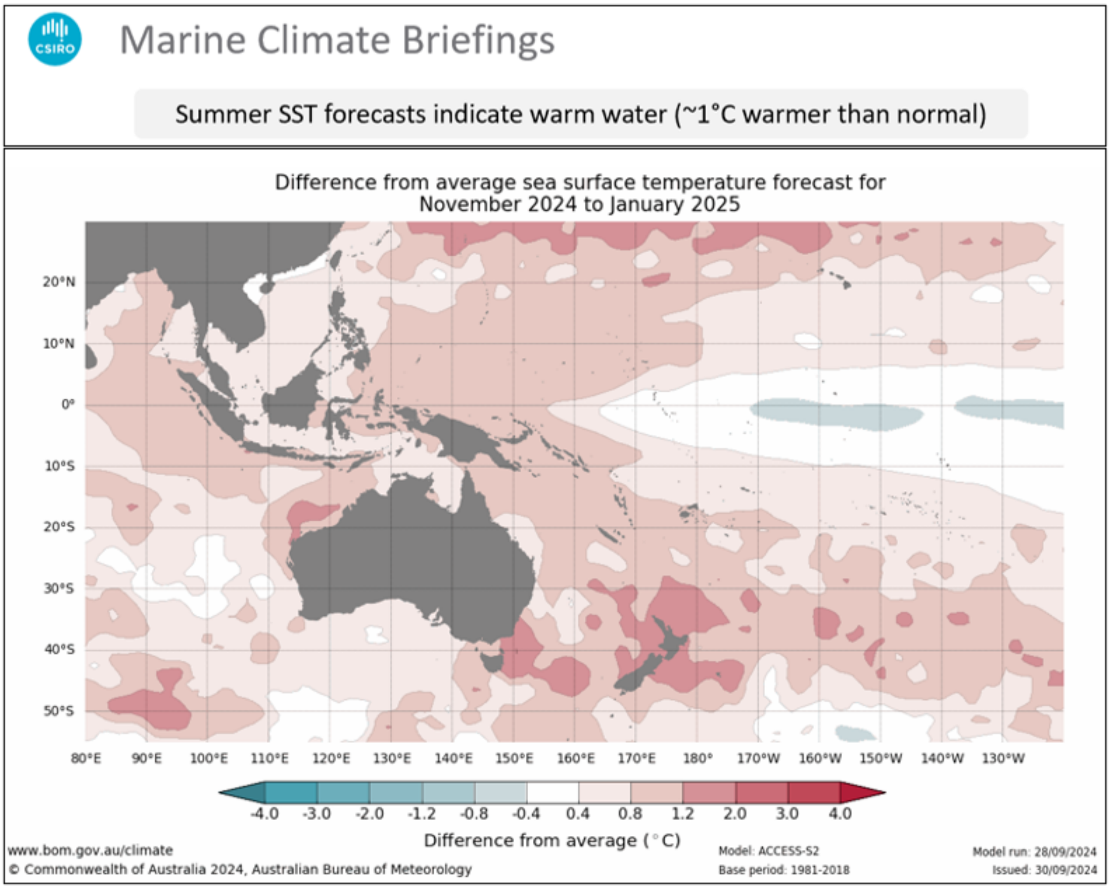
Climate change concerns have been discussed at TRLRAG meetings for at least the past decade, but with growing concerns, this has increasingly been integrated into the analyses, models, management and presentations, and has included sharing links to additional resources (see e.g., Figure 12.9). This is also in recognition of the importance of forecasting marine heat waves (Hobday *et al.* 2024). Recently a more formal process has been implemented to collate and share climate information with Traditional Owners and stakeholders through development of Climate and Ecosystem Status Reports (see (Brodie *et al.* In review) and https://www.afma.gov.au/climate-change). In addition, a new climate change project is being conducted by CSIRO and complements research carried out as part of this project.

Figure 12.9. Example of climate updates and forecasts presented at all TRL meetings (see (Brodie et al. In review) for further information) and at Northern Australian climate briefings.

(A)



(B)



Literature Cited

AFMA (2023) Australian Fisheries Management Authority Torres Strait Tropical Rock Lobster Resource Advisory Group Meeting 35, Thursday Island.

Babcock RC, Bustamante RH, Fulton EA, Fulton DJ, Haywood MD, Hobday AJ, Kenyon R, Matear RJ, Plaganyi EE, Richardson AJ (2019) Severe continental-scale impacts of climate change are happening now: Extreme climate events impact marine habitat forming communities along 45% of Australia's coast. *Frontiers in Marine Science* **6**, 411.

Bentley N (2006) Review of chapter 5 of Ye et al. (2006) "Sustainability Assessment of the Torres Strait Rock Lobster Fishery". Report submitted to AFMA.

Bentley N, Breen PA, Kim SW, Starr PJ (2005) Can additional abundance indices improve harvest control rules for New Zealand rock lobster (Jasus edwardsii) fisheries? *New Zealand Journal of Marine and Freshwater Research* **39**(3), 629-644. doi:10.1080/00288330.2005.9517341

Boavida-Portugal J, Rosa R, Calado R, Pinto M, Boavida-Portugal I, Araújo MB, Guilhaumon F (2018) Climate change impacts on the distribution of coastal lobsters. *Marine Biology* **165**, 1-7.

Brodie S, Blamey LK, Hobday A, Plagányi ÉE, Corrie D, Couchman N, Mc Donald A, Davies C, Williams A (In review) Building Climate-Smart Fisheries in Australia: Insights from Climate and Ecosystem Status Reports. Ecol. Appl.

Butterworth D Some lessons from implementing management procedures. Proceedings of Fisheries for global welfare and environment. 5th World Fisheries Congress, 2008, 2008. pp. 381-398. (Terrapub)

Butterworth DS, Punt AE (1999) Experiences in the evaluation and implementation of management procedures. *Ices Journal of Marine Science* **56**(6), 985-998. [In English] doi:DOI 10.1006/jmsc.1999.0532

Campbell RA (2004) CPUE standardisation and the construction of indices of stock abundance in a spatially varying fishery using general linear models. *Fisheries Research* **70**(2), 209-227. doi:https://doi.org/10.1016/j.fishres.2004.08.026

Campbell RA, Edgar S, Plaganyi E, Crous L, Murphy M, Dutra L (2021a) Use of TIB Logbook Data to construct an Annual Abundance Index for Torres Strait Rock Lobster – 2021 Update: Report to AFMA – TSRL RAG, December 2021.

Campbell RA, Edgar S, Plaganyi E, Crous L, Murphy M, Dutra L (2021b) Use of TVH Logbook Data to construct an Annual Abundance Index for Torres Strait Rock Lobster – 2021 Update: Report to AFMA – TSRL RAG, December 2021.

Campbell RA, Pease D (2017) Separating TIB, TVH and Processor catch records from Docket-Book Data. Report to AFMA – 2017 Update. Information paper to be presented to the 21st meeting of the Torres Strait Rock Lobster Resource Assessment Group, held 12-13 December 2017, Cairns.

Campbell RA, Plaganyi E, Deng R (2019a) Use of TIB Docket-Book Data to construct an Annual Abundance Index for Torres Strait Rock Lobster – 2019 update: TSRL RAG 27, December 2019.

Campbell RA, Plaganyi E, Deng R, Upston J (2019b) Use of TVH Logbook Data to construct an Annual Abundance Index for Torres Strait Rock Lobster – 2019 Update: Report to AFMA – TSRL TAG 27, December 2019.

Caputi N, Lestang de S, Frusher S, Wahle RA (2013) The impact of climate change on exploited lobster stocks. *Lobsters: biology, management, aquaculture and fisheries*, 84-112.

Caputi N, Melville-Smith R, de Lestang S, Pearce A, Feng M (2010) The effect of climate change on the western rock lobster (Panulirus cygnus) fishery of Western Australia. *Canadian Journal of Fisheries and Aquatic Sciences* **67**(1), 85-96.

Cooke J (1999) Improvement of fishery-management advice through simulation testing of harvest algorithms. *ICES journal of Marine Science* **56**(6), 797-810.

Cox SP, Kronlund AR (2008) Practical stakeholder-driven harvest policies for groundfish fisheries in British Columbia, Canada. *Fisheries Research* **94**(3), 224-237.

Dankel DJ, Edwards CT (2016) 'Management Science in Fisheries: An Introduction to Simulation-based Methods.' (Routledge)

de Moor CL, Butterworth DS, De Oliveira JAA (2011) Is the management procedure approach equipped to handle short-lived pelagic species with their boom and bust dynamics? The case of the South African fishery for sardine and anchovy. *ICES Journal of Marine Science* **68**(10), 2075-2085. doi:10.1093/icesjms/fsr165

de Moor CL, Butterworth DS, Johnston S (2022) Learning from three decades of management strategy evaluation in South Africa. *ICES Journal of Marine Science* **79**(6), 1843-1852.

Dennis D, Plaganyi E, Haywood M (2013) Environmental impacts on the TRL population in Torres Strait.

Dennis D, Plaganyi E, Van Putten I, Hutton T, Pascoe S (2015) Cost benefit of fishery-independent surveys: Are they worth the money? *Marine Policy* **58**, 108-115. [In English] doi:10.1016/j.marpol.2015.04.016

Dennis D, Y. Ye, A. Lara-Lopez, A. Jones, Cheers. S (2009) Commercial catch age composition and conversion ratio for the Torres Strait Tropical Rock Lobster Fishery. AFMA Project: RR2007/0835. .

Dennis DM, Pitcher CR, Prescott JH, Skewes TD (1992) Severe Mortality in a Breeding Population of Ornate Rock Lobster Panulirus-Ornatus (Fabricius) at Yule Island, Papua-New-Guinea. *Journal of Experimental Marine Biology and Ecology* **162**(2), 143-158. [In English] doi:Doi 10.1016/0022-0981(92)90198-J

Dennis DM, Pitcher CR, Skewes TD (2001) Distribution and transport pathways of Panulirus ornatus (Fabricius, 1776) and Panulirus spp. larvae in the Coral Sea, Australia. *Marine and freshwater research* **52**(8), 1175-1185.

Dennis DM, Ye Y, Pitcher CR, Skewes TD Ecology and stock assessment of the ornate rock lobster Panulirus ornatus population in Torres Strait, Australia. Proceedings of Spiny lobster ecology and exploitation in the South China Sea region: proceedings of a workshop held at the Institute of Oceanography, Nha Trang, Vietnam, 2004. pp. 29-40)

Dutra LXC, Plagányi E.E., Kenyon R., Hutton T., Murphy N., Blamey L., Edgar S., C. M (2020) Expected climate change implications for key Torres Strait Fisheries: a review. Report for Australian Fisheries Management Authority 81pp.

Farhadi A, Pichlmueller F, Yellapu B, Lavery S, Jeffs A (2022) Genome-wide SNPs reveal fine-scale genetic structure in ornate spiny lobster Panulirus ornatus throughout Indo-West Pacific Ocean. *ICES Journal of Marine Science* **79**(6), 1931-1941.

Fournier D, Archibald CP (1982) A general theory for analyzing catch at age data. *Canadian Journal of Fisheries and Aquatic Sciences* **39**(8), 1195-1207.

Francis RC (2011) Data weighting in statistical fisheries stock assessment models. *Canadian Journal of Fisheries and Aquatic Sciences* **68**(6), 1124-1138.

Francis RC (2017) Revisiting data weighting in fisheries stock assessment models. *Fisheries Research* **192**, 5-15.

Froese R (2006) Cube law, condition factor and weight–length relationships: history, meta-analysis and recommendations. *Journal of applied ichthyology* **22**(4), 241-253.

Fulton E, Hobday A, Pethybridge H, Blanchard J, Bulman C, Butler I, Cheung W, Dutra L, Gorton R, Hutton T, Lozano-Montes T, Matear R, Pecl G, Plaganyi E, Villanueva C, Zhang X (2018) Decadal scale projection of changes in Australian fisheries stocks under climate change, Report Fisheries Research and Development Corporation Project 2016/139.

Geromont HF, Butterworth DS (2015) Complex assessments or simple management procedures for efficient fisheries management: a comparative study. *ICES Journal of Marine Science* **72**(1), 262-274. doi:10.1093/icesjms/fsu017

Green BS, Gardner C, Hochmuth JD, Linnane A (2014) Environmental effects on fished lobsters and crabs. *Reviews in Fish Biology and Fisheries* **24**(2), 613-638. doi:10.1007/s11160-014-9350-1

Greenville J, McGilvray H, Cao L, Fell J (2020) Impacts of COVID-19 on Australian agriculture, forestry and fisheries trade. *Canberra, Australia*.

Harley SJ, Myers RA, Dunn A (2001) Is catch-per-unit-effort proportional to abundance? *Canadian Journal of Fisheries and Aquatic Sciences* **58**(9), 1760-1772.

Hobday A, Spillman C, Allnutt J, Coleman M, Bailleul F, Blamey L, Brodie S, Chandrapavan A, Hartog J, Maynard D, Mundy C, Plagányi E (2024) Forecasting a summer of extremes: building stakeholder response capacity to marine heatwaves *Oceanography* **37(3): 42-51**.

Hui DS, Madani T, Ntoumi F, Kock R, Dar O, Ippolito G, Mchugh T, Memish Z, Drosten C, Zumla A (2020) The continuing 2019-nCoV epidemic threat of novel coronaviruses to global health-The latest 2019 novel coronavirus outbreak in Wuhan, China. *International journal of infectious diseases: IJID: official publication of the International Society for Infectious Diseases* **91**, 264.

Johnston S, Butterworth D (2013) An operational management procedure for the Tristan da Cunha rock lobster fishery. Document MARAM/TRISTAN/2013/OCT/14, 11 pp. Available at: http://www. mth. uct. ac. za/maram/pub/2013/MARAM_Tristan_ 2013_OCT_14. pdf (accessed 10 November 2014).

Johnston SJ, Butterworth DS (2005) Evolution of operational management procedures for the South African West Coast rock lobster (Jasus lalandii) fishery. *New Zealand Journal of Marine and Freshwater Research* **39**(3), 687-702. [In English]

Klymasz-Swartz AK, Allen GJ, Treberg JR, Yoon GR, Tripp A, Quijada-Rodriguez AR, Weihrauch D (2019) Impact of climate change on the American lobster (Homarus americanus): Physiological responses to combined exposure of elevated temperature and pCO2. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology* **235**, 202-210.

Lim-Camacho L, Plagányi ÉE, Crimp S, Hodgkinson JH, Hobday AJ, Howden SM, Loechel B (2017) Complex resource supply chains display higher resilience to simulated climate shocks. *Global Environmental Change* **46**, 126-138. doi:https://doi.org/10.1016/j.gloenvcha.2017.08.011

Link JS, Werner FE, Werner K, Walter J, Strom M, Seki MP, Schwing F, Rusin J, Porch CE, Osgood K (2021) A NOAA Fisheries science perspective on the conditions during and after COVID-19: challenges, observations, and some possible solutions, or why the future is upon us. *Canadian Journal of Fisheries and Aquatic Sciences* **78**(1), 1-12.

Long B, T. Skewes, T. Taranto, M. Thomas, P. Isdale, R. Pitcher, Poiner I (1997) Seagrass dieback in north western Torres Strait - REPORT MR-GIS 97/6. CSIRO Marine Research.

Mangel M, MacCall AD, Brodziak J, Dick EJ, Forrest RE, Pourzand R, Ralston S (2013) A perspective on steepness, reference points, and stock assessment. *Canadian Journal of Fisheries and Aquatic Sciences* **70**(6), 930-940. doi:10.1139/cjfas-2012-0372

Martínez-Calderón R, Lozano-Álvarez E, Briones-Fourzán P (2018) Morphometric relationships and seasonal variation in size, weight, and a condition index of post-settlement stages of the Caribbean spiny lobster. *PeerJ* **6**, e5297.

McAllister M, Starr P, Restrepo V, Kirkwood G (1999) Formulating quantitative methods to evaluate fishery-management systems: what fishery processes should be modelled and what trade-offs should be made? *ICES Journal of Marine Science* **56**(6), 900-916.

McLeay LJ, Doubell MJ, Linnane AJ (2019) Spatial and temporal variations in female size at maturity of a Southern Rock Lobster (Jasus edwardsii) population: A likely response to climate change. *PLoS One* **14**(11), e0225144.

Miller R, Breen P (2010) Are lobster fisheries being managed effectively? Examples from New Zealand and Nova Scotia. *Fisheries Management and Ecology* **17**(5), 394-403.

Moore R, Macfarlane JW (1984) Migration of the Ornate Rock Lobster, Panulirus-Ornatus (Fabricius), in Papua-New-Guinea. *Australian Journal of Marine and Freshwater Research* **35**(2), 197-212. [In English]

Myers RA, Bowen KG, Barrowman NJ (1999) Maximum reproductive rate of fish at low population sizes. *Canadian Journal of Fisheries and Aquatic Sciences* **56**(12), 2404-2419.

Norman-López A, Plagányi É, Skewes T, Poloczanska E, Dennis D, Gibbs M, Bayliss P (2013) Linking physiological, population and socio-economic assessments of climate-change impacts on fisheries. *Fisheries Research* **148**, 18-26. doi:https://doi.org/10.1016/j.fishres.2012.02.026

Ogier EM, Smith DC, Breen S, Gardner C, Gaughan DJ, Gorfine HK, Hobday AJ, Moltschaniwskyj N, Murphy R, Saunders T (2023) Initial impacts of the COVID-19 pandemic on Australian fisheries production, research organisations and assessment: shocks, responses and implications for decision support and resilience. *Reviews in Fish Biology and Fisheries* **33**(2), 513-534.

Pascoe S, Hutton T, van Putten I, Dennis D, Skewes T, Plaganyi E, Deng R (2013) DEA-based predictors for estimating fleet size changes when modelling the introduction of rights-based management. *European Journal of Operational Research* **230**(3), 681-687. [In English] doi:10.1016/j.ejor.2013.04.054

Pavičić M, Matić-Skoko S, Vrdoljak D, Vujević A (2021) Population Characteristics of the European Lobster, Homarus gammarus in the Adriatic Sea: Implications for Sustainable Fisheries Management. *Water* **13**(8), 1072.

Pecl G, Frusher S, Gardner C, Haward M, Hobday A, Jennings S, Nursey-Bray M, Punt A, Revill H, Van Putten I (2009) The east coast Tasmanian rock lobster fishery–vulnerability to climate change impacts and adaptation response options. Report to the Department of Climate Change, Australia. *Department of Climate Change, Canberra*.

Pitcher C, C. Turnbull, J. Atfield, D. Griffin, D. Dennis, Skewes. T (2005) Biology, larval transport modelling and commercial logbook data analysis to support management of the NE Queensland rock lobster *Panulirus ornatus* fishery. .

Pitcher CR, Dennis DM, Skewes TD (1997) Fishery-independent surveys and stock assessment of Panulirus ornatus in Torres Strait. *Marine and Freshwater Research* **48**(8), 1059-1067. [In English] doi:Doi 10.1071/Mf97199

Pitcher CR, Skewes TD, Dennis DM, Prescott JH (1992a) Distribution of Seagrasses, Substratum Types and Epibenthic Macrobiota in Torres Strait, with Notes on Pearl Oyster Abundance. *Australian Journal of Marine and Freshwater Research* **43**(2), 409-419. [In English]

Pitcher CR, Skewes TD, Dennis DM, Prescott JH (1992b) Estimation of the Abundance of the Tropical Lobster Panulirus-Ornatus in Torres Strait, Using Visual Transect-Survey Methods. *Marine Biology* **113**(1), 57-64. [In English] doi:Doi 10.1007/Bf00367638

Plagányi É, Deng R, Dennis D, Hutton T, Pascoe S, van Putten I, Skewes T (2012a) An integrated Management Strategy Evaluation (MSE) for the Torres Strait Tropical Rock Lobster Panulirus ornatus fishery. (CSIRO/AFMA Final Project Report)

Plagányi É, Deng RA, Tonks M, Murphy N, Pascoe S, Edgar S, Salee K, Hutton T, Blamey L, Dutra L (2021) Indirect Impacts of COVID-19 on a Tropical Lobster Fishery's Harvest Strategy and Supply Chain. *Frontiers in Marine Science* **8**, 730.

Plagányi É, Dennis D, Campbell R, Deng R, Haywood M, Pillans R, Murphy N, Hutton T (2016a) Torres Strait Tropical Rock Lobster Fishery Survey and Stock Assessment - Research Project RR2013/803 - Final Report. Thursday Island.

Plagányi É, Dutra L, Murphy N, Edgar S, Salee K, Deng RA, Blamey LK, Parker D, Brodie S (2024) Lessons from long-term monitoring of tropical rock lobsters to support fisheries management. *Fisheries Research* **275**, 107030.

Plagányi E, Haywood M, Gorton B, Condie S (2018a) Environmental drivers of variability and climate projections for Torres Strait tropical lobster *Panulirus ornatus*. CSIRO/AFMA Technical Report, March 2018. 156 pp.

Plagányi É, Tonks M, Murphy N, Campbell R, Deng R, Edgar S, Salee K, Upston J (2020) Torres Strait Tropical Rock Lobster (TRL) Milestone Report 2020 on fishery surveys, CPUE, stock assessment and harvest strategy: AFMA Project R2019/0825. May 2020 Final Report. 183 pp.

Plaganyi E, Upston J, Tonks M, Murphy N, Campbell R, Salee K, Edgar S, Deng R, Moeseneder C (2018) Preliminary summary regarding 2018 assessment of Torres Strait tropical lobster TRL stock. TRLRAG document December 2018.

Plagányi ÉE, Blamey LK, Deng RA (2025) Key role of fisheries genomics to support conservation, fisheries management and trade of widely-distributed spiny lobsters. *Fisheries Research* **281**, 107266.

Plagányi EE, Campbell R, Tonks M, Upston J, Murphy N, Salee K, Edgar S (2019a) Torres Strait rock lobster (TRL) 2018 stock assessment. TRLRAG document, February 2018, 54 pp.

Plagányi ÉE, Darren Dennis, Marco Kienzle, Yimin Ye, Michael Haywood, Ian Mcleod, Ted Wassenberg, Richard Pillans, Quinton Dell, Greg Coman, Mark Tonks, Murphy N (2009) TAC estimation & relative lobster abundance surveys 2008/09. AFMA Project Number: 2008/837. CSIRO Final Report, October 2009. 80 pp.

Plagányi ÉE, Deng AR, Blamey L (In review) Revising an empirical harvest control rule to strengthen climate and market resilience

Plagányi ÉE, Deng R, Campbell R, Dennis D, Hutton T, Haywood M, Tonks M (2018b) Evaluating an empirical harvest control rule for the Torres Strait Panulirus ornatus tropical rock lobster fishery. *Bull. Mar. Sci* **94(3)**, 1095–1120.

Plagányi ÉE, Dennis D, Campbell R, Haywood M, Pillans R, Tonks M (2012b) Refined Stock Assessment & TAC estimation for the Torres Strait rock lobster (TRL) fishery. AFMA Project Number: 2011/806. Final Report, June 2012.

Plagányi ÉE, Dennis D, Deng R, Campbell R, Hutton T, Tonks M (2016b) Torres Strait tropical lobster (TRL) Panulirus ornatus Harvest Control Rule (HCR) development and evaluation. CSIRO/AFMA Final Report, September 2016

Plagányi ÉE, Dutra L, Murphy N, Edgar S, Campbell R, Deng R, Upston J, Salee K, Blamey L (2022) Torres Strait Tropical Rock Lobster ‘kaiar’ (TRL) Fishery: surveys, CPUE, stock assessment and harvest strategy - 2022 Final Report. AFMA Project No. 2019/0825. 209 pages.

Plagányi ÉE, Dutra L, Murphy N, Edgar S, Deng R, Blamey L, Salee K, Roos M, Parker D (2023) Torres Strait Tropical Rock Lobster ‘kaiar’ (TRL) Fishery: surveys, CPUE, stock assessment and harvest strategy - 2023 Milestone Report. AFMA Project No. 2021/0816. 153 pages.

Plagányi ÉE, Haywood MDE, Gorton RJ, Siple MC, Deng RA (2019b) Management implications of modelling fisheries recruitment. *Fisheries Research* **217**, 169-184. doi:https://doi.org/10.1016/j.fishres.2019.03.007

Plagányi ÉE, McGarvey R, Gardner C, Caputi N, Dennis D, de Lestang S, Hartmann K, Liggins G, Linnane A, Ingrid E (2017) Overview, opportunities and outlook for Australian spiny lobster fisheries. *Reviews in Fish Biology and Fisheries*, 1-31.

Plagányi EE, Rademeyer RA, Butterworth DS, Cunningham CL, Johnston SJ (2007) Making management procedures operational - innovations implemented in South Africa. *Ices Journal of Marine Science* **64**(4), 626-632. [In English] doi:10.1093/icesjms/fsm043

Plagányi EE, van Putten I, Hutton T, Deng RA, Dennis D, Pascoe S, Skewes T, Campbell RA (2013) Integrating indigenous livelihood and lifestyle objectives in managing a natural resource. *Proceedings of the National Academy of Sciences of the United States of America* **110**(9), 3639-3644. [In English] doi:10.1073/pnas.1217822110

Plagányi EE, van Putten I, Thebaud O, Hobday AJ, Innes J, Lim-Camacho L, Norman-Lopez A, Bustamante RH, Farmery A, Fleming A, Frusher S, Green B, Hoshino E, Jennings S, Pecl G, Pascoe S, Schrobback P, Thomas L (2014) A Quantitative Metric to Identify Critical Elements within Seafood Supply Networks. *Plos One* **9**(3). [In English] doi:10.1371/journal.pone.0091833

Plagányi EE, Weeks SJ, Skewes TD, Gibbs MT, Poloczanska ES, Norman-Lopez A, Blamey LK, Soares M, Robinson WML (2011) Assessing the adequacy of current fisheries management under changing climate: a southern synopsis. *Ices Journal of Marine Science* **68**(6), 1305-1317. [In English] doi:10.1093/icesims/fsr049

Preen A, Marsh H (1995) Response of dugongs to large-scale loss of seagrass from Hervey Bay, Queensland Australia. *Wildlife Research* **22**(4), 507-519.

Punt AE (2024) Stock assessment of rock lobster stocks: Past, present and future. *Fisheries Research* **274**, 106996.

Punt AE, Butterworth DS, de Moor CL, De Oliveira JAA, Haddon M (2016) Management strategy evaluation: best practices. *Fish and Fisheries* **17**(2), 303-334. doi:10.1111/faf.12104

Punt AE, McGarvey R, Linnane A, Phillips J, Triantafillos L, Feenstra J (2012) Evaluating empirical decision rules for southern rock lobster fisheries: A South Australian example. *Fisheries Research* **115**, 60-71. [In English] doi:10.1016/j.fishres.2011.11.010

R Development Core Team (2020) R: A Language and Environment for Statistical Computing.

Rademeyer R, Butterworth D, Plagányi É (2008) A history of recent bases for management and the development of a species-combined Operational Management Procedure for the South African hake resource. *African Journal of Marine Science* **30**(2), 291-310.

Rademeyer RA, Plaganyi EE, Butterworth DS (2007) Tips and tricks in designing management procedures. *Ices Journal of Marine Science* **64**(4), 618-625. [In English] doi:10.1093/icesjms/fsm050

Radhakrishnan E, Thangaraja R, Vijayakumaran M (2015) Ontogenetic changes in morphometry of the spiny lobster, Panulirus homarus homarus (Linnaeus, 1758) from southern Indian coast. *Journal of the Marine Biological Association of India* **57**(1), 5-13.

Sheppard JK, Preen AR, Marsh H, Lawler IR, Whiting SD, Jones RE (2006) Movement heterogeneity of dugongs, Dugong dugon (Müller), over large spatial scales. *Journal of Experimental Marine Biology and Ecology* **334**(1), 64-83.

Shields JD (2019) Climate change enhances disease processes in crustaceans: case studies in lobsters, crabs, and shrimps. *The Journal of Crustacean Biology* **39**(6), 673-683.

Skewes TD, Pitcher CR, Dennis DM (1997) Growth of ornate rock lobsters, Panulirus ornatus, in Torres Strait, Australia. *Marine and Freshwater Research* **48**(6), 497-501. [In English] doi:Doi 10.1071/Mf96063

Skewes TD, Pitcher CR, Trendall JT (1994) Changes in the Size Structure, Sex-Ratio and Molting Activity of a Population of Ornate Rock Lobsters, Panulirus-Ornatus, Caused by an Annual Maturation Molt and Migration. *Bulletin of Marine Science* **54**(1), 38-48. [In English]

Smedbol RK, Wroblewski J (2002) Metapopulation theory and northern cod population structure: interdependency of subpopulations in recovery of a groundfish population. *Fisheries Research* **55**(1-3), 161-174.

Subramaniam RC, Ruwet M, Boschetti F, Fielke S, Fleming A, Dominguez-Martinez R, Plaganyi E, Schrobback P, Melbourne-Thomas J (2023) The socio-ecological resilience and sustainability implications of seafood supply chain disruption. . *Rev. Fish. Biol. Fish., 1-26.* .

Szuwalski CS, Ianelli JN, Punt AE (2017) Reducing retrospective patterns in stock assessment and impacts on management performance. *ICES Journal of Marine Science* **75**(2), 596-609. doi:10.1093/icesjms/fsx159

Upston J, Plagányi E, Tonks M, Campbell R (2019) Tropical Rock Lobster abundance surveys – data conflicts and different analysis approaches. TRLRAG document February 2019.

Wood S, Wood MS (2015) Package ‘mgcv’. *R package version* **1**(29), 729.

Wood SN (2017) 'Generalized additive models: an introduction with R.' (chapman and hall/CRC)

Ye Y, D.M. Dennis, T.D. Skewes, P. Polon, F. Pantus, D. Brewer, M. Haywood, I. Mcleod, T. Wassenberg, R. Pillans, D. Chetwynd, Sheils J (2007) 2006 Relative Abundance and Pre-season Surveys, Assessment of the Torres Strait Rock Lobster Fishery and TAC estimation. CSIRO Marine and Atmospheric Research Final Report, August 2007. Pp 108. ISBN 9781921232824.

Ye Y, Dennis D, Skewes T, Taranto T, Haywood M, Brewer D, Wassenberg T, Chetwynd D, McLeod I, Donovan A (2006) Sustainability assessment of the Torres Strait rock lobster fishery. CRC-TS Project Task Number: 1.3. CRC Torres Strait Research Task Final Report, July 2006. 128 pp. ISBN 1 921232 06 4.

Ye Y, Pitcher C, Dennis D, Skewes T, Polon P, Kare B, Wassenberg T, Haywood M, Austin M, Koutsoukos A (2004) Benchmark abundance and assessment of the Torres Strait lobster stock. Australian Fisheries Management Authority, Australia.

Ye YM, Pitcher R, Dennis D, Skewes T (2005) Constructing abundance indices from scientific surveys of different designs for the Torres Strait ornate rock lobster (Panulirus ornatus) fishery, Australia. *Fisheries Research* **73**(1-2), 187-200. [In English] doi:10.1016/j.fishres.2004.12.010

Yellapu B, Jeffs A, Battaglene S, Lavery SD (2017) Population subdivision in the tropical spiny lobster Panulirus ornatus throughout its indo-West Pacific distribution. *ICES Journal of Marine Science* **74**(3), 759-768.

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Appendices

Appendix A. Non-Technical Chapter Summaries

Chapter 1: Torres Strait Rock Lobster Fishery – Summary of the Catch and Effort Data Pertaining to the 2024 Fishing Season (Dec-2023 to Sep-2024)

Chapter 1 summarizes the catch and effort data of the Torres Strait tropical rock lobster's fishery provided by AFMA. In the fishing season 2024 (period of Dec 2023 to Sep 2024), combined catch recorded by the TIB and TVH sectors was 200.2 tonnes, which represents a 19.3% decrease from last season and equates to about 55.9% of the quota for that year. TIB and TVH caught 107.7 and 92.5 tonnes, respectively, representing a 16.9% and 21.9% decrease from the previous season. The Australian sector catches represent 45.4% and 76.4% of the allocations for the TIB and TVH sectors, respectively. PNG 2024 catch data were provided for Dec 2023 as 0.08 tonnes and Jan to Sep 2024 totals 120.6 tonnes. After extrapolation for late season catch plus the adjustment of implementing a hookah ban from 15 Nov 2024 to 31 March 2025, the estimated PNG total season catch was 154 tonnes. The 2024 TVH sector fishing effort was 452 tender-days and TIB sector was 1,659 days fished which equates to a 60.9% and 31.8% decrease, respectively, relative to the previous season.

Chapter 2: Torres Strait Tropical Rock Lobster 2024 Pre-Season Population Survey

In 2024, the CSIRO team surveyed 77 sites in Torres Strait to count and measure lobsters. The data is used to calculate abundance indices for three age classes: Age 0+ (recently settled), Age 1+ (recruiting), and Age 2+ (adults). The sites were surveyed by two divers, scanning a 2m by 500m area (2000m² belt transect). A new abundance index (Ref2024) was proposed after review of regions and incorporation of data from three sites that were surveyed consistently over the past five years. The average transect distance achieved was 442m, covering 88% of the total distance planned, which contributes positively to the accuracy of the calculations. Analysis presented at TRLRAG35 showed that the overall transect length recorded in 2024 is within the range that do not cause a significant impact on the calculation of the Age1+ index. A total of 391 lobsters were observed, with 162 measured for weight and sex; males made up 51% and females 49% of the measured lobsters. Age 1+ lobsters were the most frequently observed group (n=363), showing the highest pre-season point estimate on record. The index for Age 0+ lobsters showed a significant decrease from 2023; the second lowest level since 2005, only above 2017. The survey results indicate variability in the spatial distribution of TRL from year to year in the region.

Chapter 3: Monitoring of Torres Strait Seabed Habitat

Tropical Rock Lobster (TRL; *Panulirus ornatus*) use different habitats during their life cycle. Monitoring seabed habitats over time is important because it helps to provide understanding for TRL growth, reproduction and survival (Green et al., 2014). Habitat data have been recorded alongside TRL abundance data since 1989. Key habitat observations for the most recent 2024 survey include - algae cover remained at the highest level since 2017. There was less hard substrate in 2024 in comparison to 2023 (but there is normally little change between years). Live coral cover was the highest for all pre-season surveys, after the lowest levels seen in 2018. Sand cover was similar to the lowest levels seen in 2015 (for all pre-season surveys). Seagrass cover was at the highest level seen for all pre-season surveys, after being at the lowest level seen in 2020.

Chapter 4: Water Temperature and Habitat Correlation

From 2019 to 2024, a small data logger has been attached to TRL divers during the Torres Strait TRL surveys, allowing for continuous recording of water depth and temperature. These data are important to measure and compare as high water temperatures may have negative impacts on the TRL fishery from impacts to habitats and food chains. The data show an approximate increase of 1°C in temperature from 2019 to 2022, 2023 was found to be 2°C cooler (similar to 2019) and in 2024 there was another 1°C increase in temperature from the previous year (2023). These temperature changes were also found across all depths, including over 20 metres and across survey site locations, suggesting that the waters of Torres Strait are well mixed.

Chapter 5: Pre-Season Survey Size Distribution

Chapter 5 summarizes the size distributions of Torres Strait tropical rock lobsters based on the 2024 pre-season survey and other recent surveys. In 2024, 162 lobsters were measured, which is slightly higher than previous years. More lobsters were measured in the South (115) compared to the North (47) and the survey covered 77 locations, but lobsters were measured from only 40. The sex ratio for the 2024 survey was slightly skewed toward males, with 1.025 males for every female.

Chapter 6: Commercial Catch Length Frequency Analysis

Chapter 6 provides a summary of monthly commercial size data since 2001. Sampling continued in 2024, and this chapter describes the distribution of size data across years, months, and sex, with emphasis on the 2024 and recent years.

Chapter 7: Use of TVH Logbook Data to Construct an Annual Abundance Index for Torres Strait Rock Lobster – 2024 Update

This research component analyses 30 years of catch data from the Torres Strait Tropical Rock Lobster Fishery to understand trends in lobster abundance. Kaiar populations are highly variable each year and changes in the catch rates (how many are caught per standard effort measure) can be used as an indicator of population abduance. However, we need to account for factors which influence catches and catch-rates apart from the underlying abundance of the fished resource. For example, changes in fishing efficiency, time of year, moon phase and changes in spatial-temporal aspects of the fishery. The aim of standardizing CPUE is thus to estimate abundance had all other factors remained constant apart from the underlying abundance. We use statistical models called GLMs. The results indicate that lobster abundance has fluctuated over time, but with no clear long-term trend. The 2024 catch rates were lower than expected. Variation in catch were largely influenced by the individual vessel and area fished.

Chapter 8: Use of TIB Logbook Data to Construct an Annual Abundance Index for Torres Strait Rock Lobster – 2024 Update

Similar as Chapter 7, Chapter 8 analyses catch data from the TIB sector to understand trends in lobster abundance. The analysis found that catch rates have increased since 2015, though there are variations in recent years which can be attributed to individual Seller effect. While the TIB data shows potential for tracking broader trends in stock abundance, it lacks the precision needed to monitor more detailed changes over time.

Chapter 9: Updating Tropical Rock Lobster (*Panulirus ornatus*) Morphometric Conversion Ratios

Morphometric conversion ratios, such as length-weight relationships, for TRL were established 20 years ago. Given changing climate conditions across northern Australia, it is useful to revisit these relationships and see if they remain the same or have changed. It is also useful to explore spatially variable length-weight relationships. Carapace length and total weight measurements were collected from TRL catch samples in 2023. We compared a length-weight relationship based on these data to the original relationship.

We found no significant difference between the two relationships. Using 2023 data we also explored differences in length-weight relationships between male and female lobsters and between lobsters from different locations. We found no difference in length-weight relationships between male and female lobsters but there were not enough samples across the year and from different locations to reliably make a conclusion about spatial differences in length-weight relationships. We recommend the original carapace length-weight relationship continue to be used until this can be further explored with more data.

Chapter 10: Summary or Torres Strait TRL eHCR Analyses

Over the past year, the TRLRAG/WG meetings have sought advice on revisions to the empirical Harvest Control Rule (eHCR) under the TRL Harvest Strategy in response to ongoing external circumstances that have been impacting the RAG's ability to apply the eHCR when providing advice on a Recommended Biological Catch (RBC). It is considered best practise to review and revise harvest strategies every five years or so, and hence it is also timely to revise the current harvest control rule. This allows an opportunity to better account for market and other external factors that have impacted the fishery in the past few years, in different ways to conditions when the current rule was first implemented. In addition, as our understanding of the impacts of climate change improves, it is important to use this information in testing any new harvest control rule to ensure it has as good a chance as possible to maintain stock sustainability even under a changing climate. Revising the harvest control rule is time consuming and requires considerable analysis and computer simulations using Management Strategy Evaluation to support checking and comparing how well proposed changes to the harvest control rule perform in meeting objectives. Feedback from Traditional Owners and stakeholders is also incorporated, and everyone can consider the trade-offs between different rules, to collectively support choosing a revised harvest control rule that satisfactorily achieves the management objectives agreed on for the kaiar fishery.

Chapter 11: Stock Assessment

The TRL stock assessment is a lobster population model that combines a large quantity of measurements (growth, size structure, recruitment, deaths etc …) into a mathematical description of changes that happened to the lobster population over the past five decades. It summarizes all sources of information on lobsters made available to CSIRO and presents them in an understandable form. This model is a simplification of reality. Its purpose is to capture important changes that occurred in the lobster fishery in order to use this knowledge for the benefit of the communities exploiting this natural resource. Mathematical population models have been developed for most commercially important species around the world. This model is necessary to calculate the chance of survival of the lobster population in Torres Strait. Contrary to commercial or survey densities, survival is not a quantity that is measured in the field: it is derived from a mathematical model that represents how quickly the number of lobsters falls throughout the year. We need this model of the population to understand whether catch levels are reducing lobster survival beyond the point where not enough of them are left to provide an abundant future generation.

The other reason to develop and update the model of the lobster population is to use the knowledge derived from past observations to forecast what the future might look like.

The lobster fishery relies on mature adult lobsters completing their migration and breeding, larvae surviving to settlement, and pre-spawning lobsters escaping the Torres Strait fishery. To ensure this cycle and hence the fishery continues into the future it is important to know how many lobsters can be caught before the cycle breaks down. What is the risk to the fishery of different levels of fishing? How quickly do lobsters grow, reproduce and die? To answer these questions requires a mathematical model of the lobster population. To check that the model is accurately representing what is actually happening in the field, it is cross-checked against all available survey and fishery information – it needs to replicate the same trends in population size and age structure as is observed in the field. It can then be used as a tool to investigate what the effect of different catches (or effort levels) are on the lobster population, and what level of fishing achieves the desired balance between adequately conserving the resource and ensuring satisfactory economic gains from harvesting.

The most recent TRL stock assessment suggests that the TRL stock is at a very healthy level, slightly above the target level and hence the stock is not overfished. Total catches for the past five years have been less than the full amount that could be safely taken, and hence overfishing is not estimated to be occurring.

Chapter 12: Torres Strait Tropical Rock Lobster Additional Research Outputs

This chapter provides a short history of the TRL fishery to place the long-term monitoring survey in a broader context as well as some of the supply chain and trade issues facing the fishery. We also summarise some further research results that were prepared in response to topical issues raised by the TRLRAG and TRLWG participants. These relate in the main to questions around stock structure, spatial variability and climate change as summarised in this chapter.

Other non-technical resources (e.g. Factsheets, community brochures, CSIRO blogs and other media) available on request or online, e.g. Marine climate change adaptation.

Appendix B. Dive Site Information

Table B.1. Dive site information including site number and depth.

Site	Depth (m)	Site	Depth (m)
1031	13.4	751	23.3
1081	18	781	20.4
1112	22	801	22
1121	19.1	851	15.8
1151	20.6	901	8.2
1161	3.7	9991	10
1181	7.6	E10	4.8
1201	11.1	E16	5.6
1211	3.8	E19	10.7
1251	5.5	E2	3.8
1321	6.1	N1020	8.8
1371	7	N111	5.1
141	13.7	N126	15.1
1701	12.1	N150	8.4
1702	11.7	N166	6.8
1781	10.1	N167	6.7
182	10.7	N169	6.3
1831	21.7	N177	16.8
1911	21.6	N207	15.2
2071	9.3	N283	13
211	11.4	N284	13.3
241	17.2	N291	11.9
331	15.6	N363	22
341	24	N393	21.2
352	16.3	N70	15.5
401	16	N72	14.2
421	18.4	N908	22.3
431	8.9	N909	22.4
461	23.2	N912	20.4
471	20.1	N93	15.5
481	17.1	N934	21.5
511	15.3	N96	15
521	4.3	N960	21.3
541	21.9	N961	21.1
551	24.1	N963	21.5
571	21.4	N987	24.7
591	16.6	N990	17.7
611	19.3	N995	22.6
721	16.6		

Appendix C. Survey Data Sheet

Figure C.1. Standard site lobster count and habitat data sheet used in the surveys.

Transect:	Date: / /		Time:	Duration:	Depth:	
Vis:	Current:		Direction:	Distance:	Bag #:	
	Diver 1:			Diver 2:		
# Measured						
# Missed	0+:	1+:	2+:	0+:	1+:	2+:
Substrate	Mud:	Sand:		Rubble:	Boulders:	
	Consrub:	Pavement:		Bommies:	LiveCoral:	
Biota	∑Seagrass:					
	∑Algae:					
	HCFS:	Whips:	Softs:	Ascids:	Hydroids:	Crinoids:
	Xestos:	Solenocolon:	Ianthella:	Cymbast:	Gorgs:	Tubes:
	Coralmas:	Coralencr:	Coralbra:	Pearls:	BDM:	

Appendix D. Morphometric Relationships for TRL

Below is a summary of morphometric relationships used for TRL based on Pitcher et al. (2005) and Dennis et al. (2009).

Table D.1. Current morphometric relationships where M = male, F = female, TW = tail width (mm), CL = carapace length (mm), TL = tail length (mm), TOTWT: total weight (grams), TAILWT: weight of removed tail (grams), TAILWT is approximately 42% of TOTWT. Taken from Pitcher et al. (2005).

Sex	Relation	Relationship	Range	R^2
M	TW/CL	CL=(1.493*TW)-0.132	CL:6-160	0.998
F	TW/CL	CL=(1.371*TW)+2.485	CL:6-160	0.997
All	TW/CL	CL=(1.433*TW)+1.089	CL:6-160	0.992
All	TW/TL	TL=(1.920*TW)+1.413	TW:6-80	0.996
All	CL/TL	CL=(0.778*TL)+0.014	CL:6-120	0.994
All	TW/TAILWT	TAILWT=0.00114*(TW^2.97537)	TW:22-98	0.974
All	CL/TOTWT	TOTWT=0.00258*(CL^2.76014)	CL:6-120	0.992
All	CL/TAILWT	TAILWT=0.00097*(CL^2.77007)	CL:30-150	0.954
F	TOTWT/TAILWT	TOTWT=2.312*TAILWT	TOTWT<3kg	0.991
M	TOTWT/TAILWT	TOTWT=2.431*TAILWT		0.989
All	TOTWT/TAILWT	TOTWT=2.385*TAILWT		
	or	TAILWT=41.93% of TOTWT		

Table D.2. Live total weight to tail weight conversion ratio developed by Dennis et al. (2009).

Sex	Relation	Relationship
All	TOTWT/TAILWT	TOTWT=2.7*TAILWT
	or	TAILWT=37% of TOTWT

Appendix E. Data Collection Sheet Supplied to Processors

Figure E.1. Data collection sheet supplied to processors

TORRES STRAIT KAIAR FISHERY

LOBSTER SIZE AND WEIGHT DATA COLLECTION

Please record the sex, weight and size of 50 – 80 randomly selected[1] lobsters for each month, preferably near the neap tide of each month. Please sms a copy (photo) of each completed form to 0413248551 or email to Laura.Blamey@csiro.au and forward hard copies to the Thursday Island AFMA Office

DATE:________________________ PROCESSOR LOCATION: ______________________

LOCATION LOBSTERS CAUGHT:________________________

Sex	Carapace Length (mm)	Total Weight (grams)	Comments (e.g. tarspot, moult stage (hard/soft), eggs)

[1] Random selection means one doesn't select particular lobsters (eg preferably large lobsters) but randomly selects individual lobsters to be measured such that every lobster in that day's sampling pool has the same chance of being selected – this leads to a representative sample for the study.

Appendix F. Summary – Revision of TRL/Kaiar empirical Harvest Control Rule (eHCR)

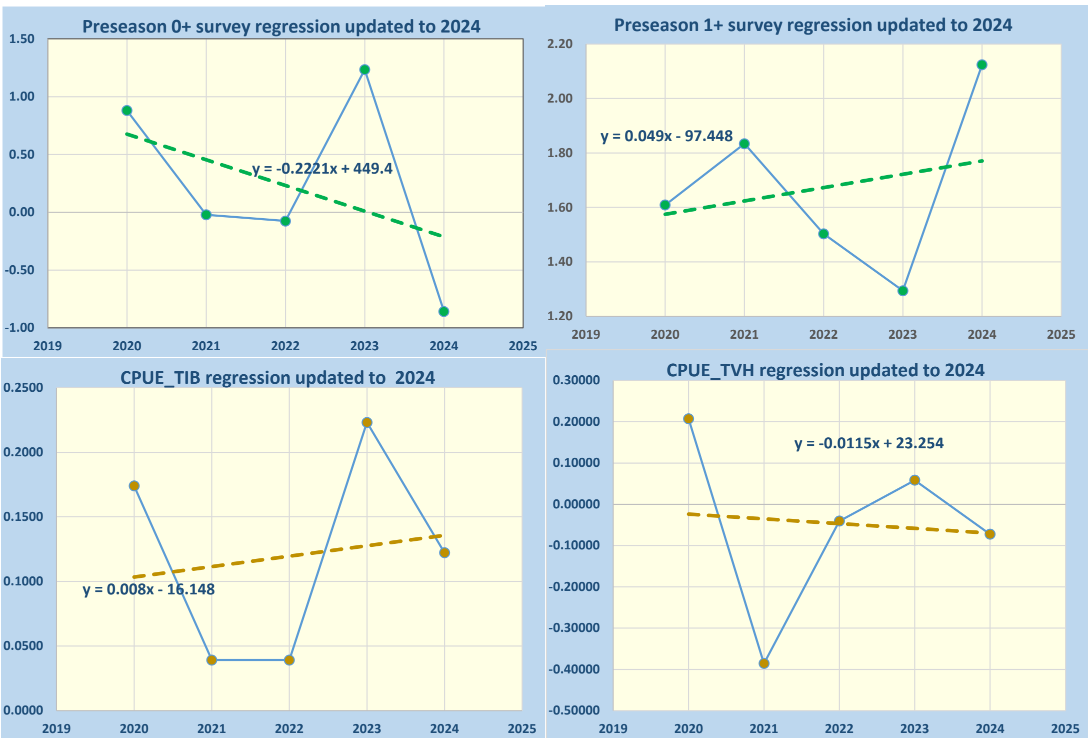
Non-technical summary prepared by Éva Plagányi, CSIRO
Update to version first presented at TRLRAG 9 Oct 2024

Why a need to revise?

- The eHCR adopted in 2019 uses total catch in the formula but a number of external factors (e.g. covid, markets) mean catches have been well below the TAC (Total Allowable Catch) so ‘ad hoc’ adjustments have been made in the last few years (substitute TAC for total catch).
- Best practice is to revise an HCR every 5 years if possible.
- Provides an opportunity to retest the eHCR to improve robustness to climate change and other concerns such as discards and differences between total catches and TACs.
- Process is like having a car that’s running but then giving it a minor service (turtle rule) or adding some further fine tuning to run even better (dolphin rule).

What’s staying the same in the eHCR?

- It’s a data-based rather than model-based rule i.e. it only uses data as inputs to inform the RBC (Recommended Biological Catch).
- No changes to relative weighting (i.e. relative contribution) of different data sources: Preseason survey 1+ index is the most important (70% weighting) whereas other data (Preseason 0+ survey index, CPUE(TIB), CPUE (TVH)) have 10% weighting each.
- Uses trend based on 5 most recent data points (i.e. annual adjustments to the RBC rely on whether recent trends are mostly up or down (especially Preseason 1+ index) – for example, plot below shows the slopes used in Dec 2024.



THE REVISED CANDIDATES

As part of revising the Harvest Strategy (HS) and select a preferred revised eHCR, CSIRO developed a number of alternative kinds of rules that incorporated feedback received. The versions considered were those tuned to meet the HS objectives (e.g., keep the TRL/kaiar population fluctuating about the (precautionary) target reference level with very low risk of fishing causing the population to decrease to the limit reference level). The rules were tested by CSIRO using a set of 4 alternative operating models with different parameter settings, different levels and types of uncertainties and climate change impacts, and assuming considerable natural variability.

The TRLRAG and TRLWG focussed on comparisons between three types of rules in particular, named the Turtle, Seahorse and Dolphin rules to help capture key features of each. As no consensus was reached at the December 2024 meetings, the decision as to which rule to apply to set the 2024/25 TRL TAC was passed to the PZJA. They advised using the midpoint of the outputs from each of the Seahorse and Dolphin rules, which resulted in setting a total TAC (all sectors) of 688t for the current season, but they also encouraged selecting a preferred rule for longer term implementation.

To assist the process going forward, CSIRO developed and added to the list of candidates a new rule, termed the Osprey rule, which gives the equivalent TAC for the current season as the PZJA compromise solution. The Osprey rule is thus intermediate in its behaviour between the Seahorse rule and the Dolphin Rule. This is because it adjusts the RBC (Recommended Biological Catch) upwards or downwards depending on the strength of the incoming recruitment class as well as other stock indicators, and the ups and downs in the RBC are less than that in the Dolphin rule but more than in the Seahorse rule, as shown below (see also Table F.1, Figure F.1.).

1. TURTLE RULE

(so-named because it results in catches cruising more stable)

- Only change is to replace average catch multiplier in current eHCR with a new multiplier (619) that has been tuned to meet fishery objectives.
- Basically, rule is: RBC = Combined Average Slope of Indicators * 619
- Depending on whether indicator slopes are going up or down, rule will adjust RBC but dampen inter-annual variability, so RBC roughly expected as in Table below.

2. SEAHORSE RULE

(so-named because it clings to something familiar and doesn't move very much)

- Similar to current eHCR
- Only change is to replace average catch multiplier in current eHCR with a new multiplier that is calculated as the average of the 5 most recent TACs
- Basically, rule is: RBC = Combined Average Slope of Indicators * average recent TAC

3. DOLPHIN RULE

(so-named because it’s a survey-smart highly adaptable rule)

- Similar to current eHCR and turtle rule but includes an extra multiplier term based on the most recent Preseason 1+ index that has been designed so it brings the RBC down more in years when the Preseason 1+ index is low and allows a small bonus in good years. This is not symmetrical as e.g. can decrease the RBC in bad years by up to about 40% versus in good years bonus is up to about 12% at most. Design feature was to address feedback from Traditional Owners to be more precautionary in poor years.
- Rule also accounts for survey precision (e.g. large variability in average survey index could be due to survey method or spatial stock variability): more precise survey index has greater weight versus downweight less precise survey estimate.
- Basically, rule is: RBC = Combined Average Slope of Indicators * 670 * Sqr(SurvI), where SurvI = Preseason 1+ index relative to median, divided by observed survey measure of precision (technically, the survey coefficient of variation).
- Depending on whether indicator slopes are going up or down, AND how good or bad current year’s Preseason 1+ index is, PLUS how precise it is, rule will adjust RBC more strongly up or down (i.e. more variable) and RBC roughly expected as in Table below.

4. OSPREY RULE

(so-named because it’s a smart, targeted and adaptable rule but the flight path is smoother than a dolphin’s movements)

- Also includes an extra multiplier term based on the most recent Preseason 1+ index that has been designed so it brings the RBC down more in years when the Preseason 1+ index is low and allows a small bonus in good years. However, this rule allows smaller increases in the TAC in good years than the Dolphin rule and also doesn’t decrease the TAC in poor years as much as the Dolphin rule does, but it does result on average in bigger increases and decreases in TAC than the Seahorse rule or the Turtle rule (least variable).
- Rule also accounts for survey precision (e.g. large variability in average survey index could be due to survey method or spatial stock variability): more precise survey index has greater weight versus downweight less precise survey estimate.
- Basically, rule that matches compromise solution is: RBC = Combined Average Slope of Indicators * 619 * cube-root of (SurvI).
- Depending on whether indicator slopes are going up or down, AND how good or bad current year’s Preseason 1+ index is, PLUS how precise it is, rule will adjust RBC **moderately** up or down (i.e., intermediate variability).

Table F.1. Table showing statistics based on MSE testing of eHCR. RBC summary statistics are computed using 800 simulations of 20-year projections using 4 operating models. *Comparison is shown here only for single variant of Turtle rule, the Seahorse rule (no variants), the optimal Dolphin rule and the 'compromise'-equivalent Osprey rule. Other statistics for these and other rules available on request.*

	Median RBC (20 yr projection period)	50% of time RBC in range	80% of time RBC in range	Minimum	Maximum
Turtle rule (619)	608t	555-658t	521-701t	300t	873t
Seahorse rule	560t	521-605t	486-642t	300t	818t
Dolphin rule (619)	580t	484-711t	402-845t	300t	1000t
Osprey rule (619)	591t	513-690t	445-787t	300t	1000t

What about if the Preseason survey and other information suggests the stock may be in trouble?
The HS includes a number of other safety checks:

- If the Preseason 1+ survey index is lower than a trigger limit of 1.25 (e.g. as in 2001 and 2005 in past (midyear survey)) this triggers additional precautionary action.
- Stock assessment is run every 3 years to check to stock status.
- If the stock is assessed as declining to below the limit reference level for 2 years in a row, the fishery is closed the following season.

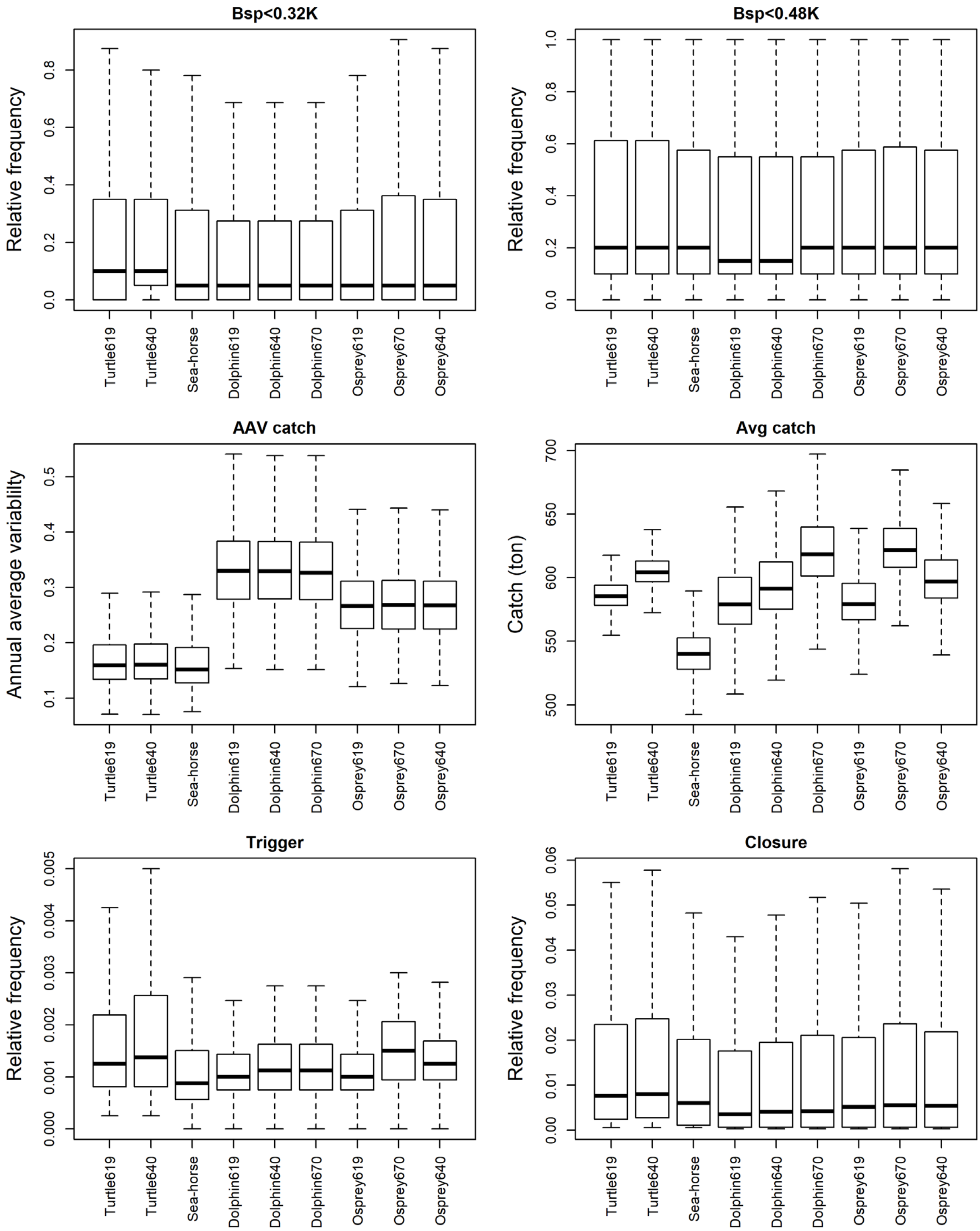
Exceptional circumstances:

- Exceptional circumstances mean that something happens which wasn't anticipated and possibly has a big impact on the stock or fishery. In such cases, the usual approach to managing the fishery isn't implemented without first considering and discussing the anomalous event and deciding if additional action is needed e.g. another survey, a stock assessment, modified rule or maybe previous testing adequately covered this possibility and no immediate action necessary.
- If there are no updated data to inform setting an RBC, the backup option is to set a low fixed TAC. This needs to be a low number such as 300t (200t currently used to open the fishery each year) as need to ensure that it works okay even in the worst years. The rules are all adaptive and could bring the TAC down as low as 300t in very bad periods and hence if there are no updated data to inform on stock status, the precautionary approach dictates that one needs to set a precautionary low TAC that accounts for the greater uncertainty of not using updated indicators of stock status. This is why setting a fixed constant TAC for a highly naturally variable stock like kaiar/TRL doesn't work well and needs to be very low to be adequately precautionary.

What happens if total catches are below or above the TAC?

- If total catches exceed (are greater than) the TAC, overfishing is considered to be occurring.
- If total catches are below the TAC, no impact on the revised eHCRs (as they don't use catch data).
- If total catches are low relative to the TAC, empirical indicators may show a positive trend over time which could slightly increase the TAC, but the fishery relies on a new recruitment pulse every year, so TACs will mainly depend on how much incoming recruitment there is.

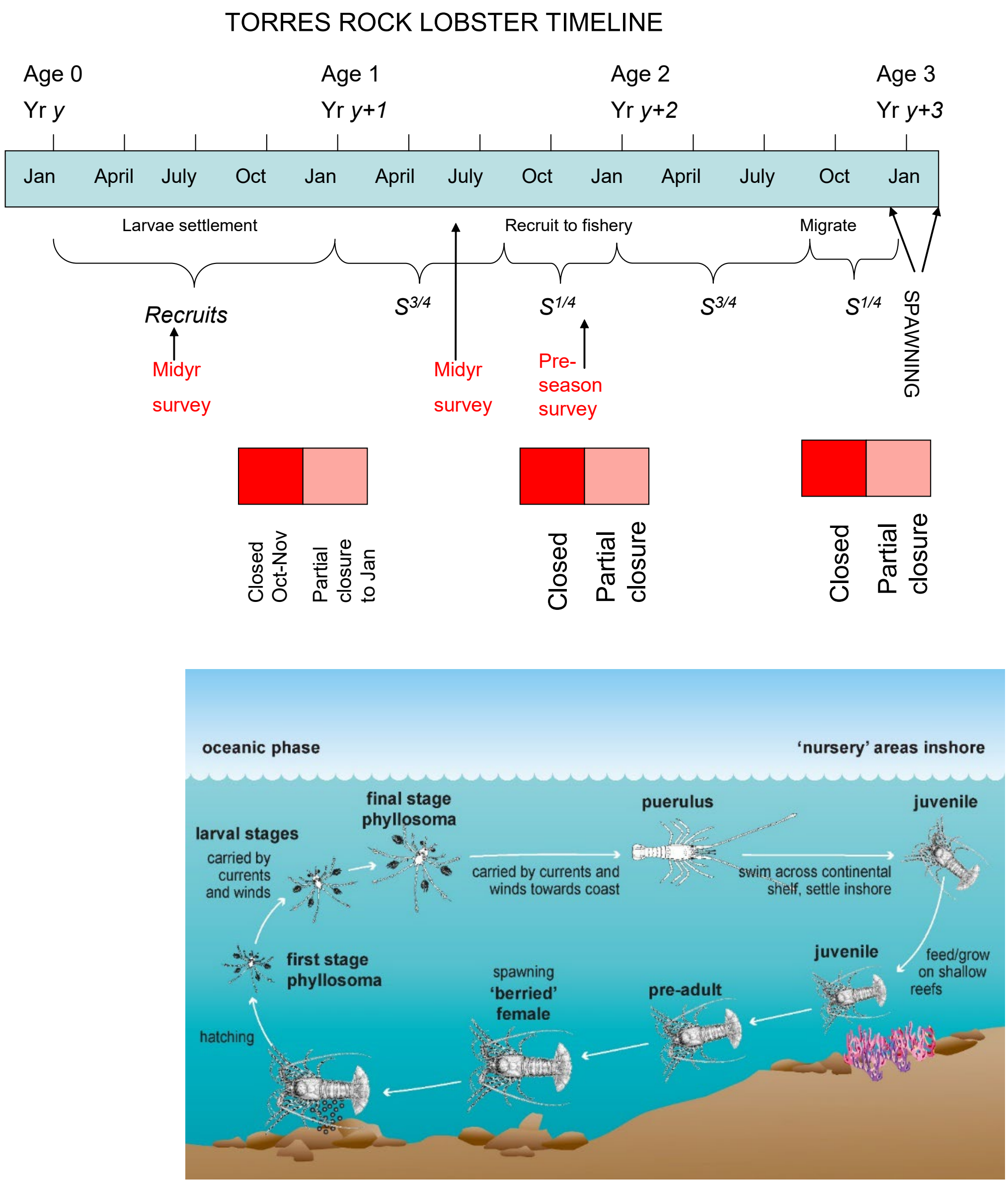
Figure F.1. Comparison of some key performance statistics for eHCRs. Plots show the probability of depletion below each of two reference levels, B_{LIM} = 0.32K and precautionary level 0.48K limit reference point, together the Average Annual Variability (AAV) of catch, the total annual catch (t) and relative number of fishery closures triggered in the simulations. *The central line shows the median, the box the 75^{th} and 25^{th} percentiles and the whiskers represent the spread of the outputs (1.5 interquartile range, outliers not shown).*



Appendix G. Stock Assessment Model Equations

Torres Strait rock lobsters emigrate in spring and breed during the subsequent summer (November-February) (Moore and MacFarlane, 1984; MacFarlane and Moore, 1986). Therefore, the number of age 2+ lobsters at the middle of the breeding season (December) should represent the size of the spawning stock (Figure G.1). A schematic summary timeline underlying the Integrated model is presented in Figure G.1. To simplify computations, the new model assumes catches, migration and spawning occur at discrete times, with quarterly updates to the dynamics of each age class. Catches of 2+ individuals are assumed taken as a pulse at midyear, with individuals migrating out of Torres Strait at the end of the third quarter, and a spawning biomass being computed at the end of the year. Catches of 1+ lobsters are assumed taken at the end of the third quarter, when a proportion of this age class have grown large enough to be available to fishers.

Figure G.1. Summary timeline for Torres Strait Rock Lobster model.



P. ornatus is an unusually fast growing lobster and hence analyses are expected to be sensitive to changes in assumption regarding growth rate (length vs age) and mass-at-length. Previous modelling studies used the Trendall et al. (1988) relationship:

$$CL_m = 177\left(1 - e^{-0.386(m/12-0.411)}\right)$$

where *CL* is carapace length (mm), and *m* is age in months for aspects of the computations. However, after converting length to mass using the morphometric relationship:

TOTWT=0.00258*(CL^2.76014)

The Trendall et al (1988) relationship translates into average individual masses that are less than the observed average mass of lobsters caught in the fishery. The Integrated model thus uses the Phillips et al. (1992) male growth relationship:

$$CL = L_\infty\left(1 - e^{-kt}\right)$$

where

$L_\infty = 165.957 \quad mm$;

$\kappa = -0.0012$; and

t is age in DAYS.

The integrated model

An age-structured model of the Torres Rock Lobster population dynamics is developed and fitted to the available abundance indices by maximising the likelihood function. The model equations and the general specifications of the model are described below, followed by details of the contributions to the log-likelihood function from the different sources of data available. Quasi-Newton minimization is used to minimize the total negative log-likelihood function (the package AD Model BuilderTM (Fournier et al. 2012)) is used for this purpose.

Lobster population dynamics

Numbers-at-age

The resource dynamics are modelled by the following set of population dynamics equations:

$$N_{y+1,1} = R_{y+1} \qquad 1$$

$$N_{y+1,a+1} = \left(N_{y,a}\, e^{-3M_a/4} - C_{y,a}\right)e^{-M_a/4} \qquad \text{for a=1} \qquad 2$$

$$N_{y+1,a+1} = \left(N_{y,a}\, e^{-M_a/2} - C_{y,a}\right)e^{-M_a/2} \qquad \text{for a=2} \qquad 3$$

where

$N_{y,a}$ is the number of lobsters of age a at the start of year y (which refers to a calendar year),

R_y is the recruitment (number of 1-year-old lobsters) at the start of year y,

M_a denotes the natural mortality rate on lobsters of age a, and

$C_{y,a}$ is the predicted number of lobsters of age a caught in year y

These equations simply state that for a closed population, with no immigration and emigration, the only sources of loss are natural mortality (predation, disease, etc.) and fishing mortality (catch). They reflect Pope's form of the catch equation (Pope, 1972) (the catches are assumed to be taken as a pulse at midyear for the 2+ class and at the start of the third quarter for the 1+ class) rather than the more customary Baranov form (Baranov, 1918) (for which catches are incorporated under the assumption of steady continuous fishing mortality). Pope's form has been used in order to simplify computations.

Recruitment

The number of recruits (i.e. new 1-year old lobsters – it is simpler to work with 1- rather than 0-year old lobsters as recruits) at the start of year y is assumed to be related to the spawning stock size (i.e. the biomass of mature lobsters) by a Beverton-Holt stock-recruitment relationship (Beverton and Holt, 1957), allowing for annual fluctuation about the deterministic relationship:

$$R_y = \frac{\alpha B_{y-1}^{sp}}{\beta + \left(B_{y-1}^{sp}\right)^{\gamma}} e^{(\varsigma_y - (\sigma_R)^2/2)} \qquad 4$$

where

α, β and γ are spawning biomass-recruitment relationship parameters (note that cases with γ > 1 lead to recruitment which reaches a maximum at a certain spawning biomass, and thereafter declines towards zero, and thus have the capability of mimicking a Ricker-type relationship),

ς_y reflects fluctuation about the expected recruitment for year y, which is assumed to be normally distributed with standard deviation σ_R (which is input in the applications considered here); these residuals are treated as estimable parameters in the model fitting process. Estimating the stock-recruitment residuals is made possible by the availability of catch-at-age data, which give some indication of the age-structure of the population.

B_y^{sp} is the spawning biomass at the start of year y, computed as:

$$B_y^{sp} = w_3^{st} \cdot N_{y,3} \qquad 5$$

where

w_3^{st} is the mass of lobsters of age 3 (i.e. in December during the spawning season).

In order to work with estimable parameters that are more meaningful biologically, the stock-recruitment relationship is re-parameterised in terms of the pre-exploitation equilibrium spawning biomass, K^{sp}, and the "steepness", *h,* of the stock-recruitment relationship, which is the proportion of the virgin recruitment that is realized at a spawning biomass level of 20% of the virgin spawning biomass:

$$\beta = \frac{\left(K^{sp}\right)^{\gamma}\left(1 - 5h0.2^{\gamma}\right)}{5h - 1} \qquad 6$$

and

$$\alpha = \frac{\beta + \left(K^{sp}\right)^{\gamma}}{SPR_{virg}} \qquad 7$$

where

$$SPR_{virg} = w_3^{st} N_3^{virg} \qquad 8$$

with

$$N_1^{virg} = 1 \qquad 9$$

$$N_a^{virg} = N_{a-1}^{virg} e^{-M_{a-1}} \qquad \text{for } 2 < a \leq m \qquad 10$$

where

m is the maximum age considered (taken to be 3).

Total catch and catches-at-age

The catch by mass in year *y* is given by:

$$C_y = w_1^{land} N_{y,1} e^{-3M_a/4} S_{y,1} F_y^{1+} + w_2^{mid} N_{y,2} e^{-M_a/2} S_{y,2} F_y^{2+} \qquad 11$$

where

w_a^{land} denotes the mass of lobsters of age *a* that are landed at the end of the third quarter,

w_a^{mid} denotes the mid-year mass of lobsters of age *a*,

$S_{y,a}$ is the commercial selectivity (i.e. vulnerability to fishing gear) at age *a* for year *y*; and

F_y is the fished proportion (of the 1+ and 2+ classes) of a fully selected age class.

The model estimate of the exploitable ("available") component of biomass is calculated by converting the numbers-at-age into mass-at-age (using the individual weights of the 1+ lobsters assumed landed at the end of the third quarter, and the 2+ lobsters assumed landed at midyear):

$$B_y^{ex,1+} = w_1^{land} S_{y,1} N_{y,1} e^{-3M_a/4} \qquad 12$$

$$B_y^{ex,2+} = w_2^{mid} S_{y,2} N_{y,2} e^{-M_a/2} \qquad 13$$

and hence:

$$B_y^{ex} = B_y^{ex,1+} + B_y^{ex,2+} \qquad 14$$

The model version computes the catch by mass separately for the trawling sector, which is assumed to target 2+ lobsters only. The exploitable component of biomass for this sector is thus based on Equation (13) only and assumes full selectivity of the 2+ age group.

The model estimates of the midyear numbers of lobsters are:

$$N_y^{mid} = N_{y,1} e^{-M_1/2} + \left(N_{y,2}\, e^{-M_2/2} - C_{y,2}\right) \qquad 15$$

i.e.

$$N_{y,1}^{mid} = N_{y,1} e^{-M_1/2} \quad (16)$$
$$N_{y,2}^{mid} = N_{y,2}\, e^{-M_2/2} - C_{y,2} \quad (17)$$

Similarly, the model estimate of numbers for comparison with the Pre-Season November survey are as follows:

$$N_{y,1}^{pre} = \left(N_{y,1} e^{-3M_1/4} - C_{y,1}\right) e^{-M_1/6} \quad (18)$$
$$N_{y,2}^{pre} = N^{mid}{}_{y,2}\, e^{-5M_2/12} \quad (19)$$

The proportion of the 1+ and 2+ age classes harvested each year (F_y^{1+}) are given respectively by:

$$F_y^{1+} = C_y^{1+} \,/\, B_y^{exp,1+} \quad (20)$$
$$F_y^{2+} = C_y^{2+} \,/\, B_y^{exp,2+} \quad (21)$$

where C_y^{1+} and C_y^{2+} are the catch by mass in year *y* for age classes 1 and 2, such that:

$$C_y^{1+} = p_{y,1+} C_y \quad (22)$$

and

$$C_y^{2+} = \left(1 - p_{y,1+}\right) C_y \quad (23)$$

with $p_{y,1+}$ representing the 1+ proportion of the total catch.

Given different fishing proportions for the two age classes, the numbers-at-age removed each year from each age class can be computed from:

$$C_{y,1} = S_{y,1} F_y^{1+} N_{y,1} e^{-3M_a/4} \qquad \text{for } a = 1\text{, and} \quad (24)$$
$$C_{y,2} = S_{y,2} F_y^{2+} N_{y,2} e^{-M_a/2} \qquad \text{for } a = 2 \quad (25)$$

The fully selected fishing proportion (*F*) is related to the annual fishing mortality rate (*F**) as follows:

$$1 - F = e^{-F^*} \quad (26)$$

Initial conditions

Although some exploitation occurred before the first year for which data are available for the lobster stock, this is considered relatively minor and hence the stock is assumed to be at its pre-exploitation biomass level in the starting year and hence the fraction (θ) is fixed at one in the analysis described here:

$$B_{y_0}^{sp} = \theta \cdot K^{sp} \quad (27)$$

with the starting age structure:

$$N_{y_0,a} = R_{start} N_{start,a} \qquad \text{for } 1 \le a \le m \quad (28)$$

where

$$N_{start,1} = 1 \quad (29)$$
$$N_{start,a} = N_{start,a-1} e^{-M_{a-1}} \qquad \text{for } 2 \le a \le m-1 \quad (30)$$

The (penalised) likelihood function

Model parameters are estimated by fitting to survey abundance indices, commercial and survey catch-at-age data as well as standardised CPUE data in some cases. A penalty function is included to permit estimation of residuals about the stock-recruitment function. Contributions by each of these to the negative of the log-likelihood (-$\ell\text{n}L$) are as follows.

Survey abundance data

The same methodology is applied for the midyear and pre-season surveys, except that for the former there are indices for both the total 1+ and 2+ numbers, whereas for the pre-season the fit is only to the 1+ lobsters as most of the older lobsters will have migrated out of the region by November. The likelihood is calculated assuming that the observed midyear (and pre-season) survey abundance index is log-normally distributed about its expected value:

$$I_y^i = \hat{I}_y^i \exp\left(\varepsilon_y^i\right) \quad \text{or} \quad \varepsilon_y^i = \ell\text{n}\left(I_y^i\right) - \ell\text{n}\left(\hat{I}_y^i\right)$$

31

where

I_y^i is the scaled survey abundance index for year *y* and series *i*,

$\hat{I}_y^i = \hat{q}_s \hat{N}_y^{survey}$ is the corresponding model estimate, where $\hat{N}_y^{survey}$ is the model estimate of midyear numbers, given by equation 16 and 17 for the midyear survey, and for the pre-season survey it is given by equation 18.

$\hat{q}_s$ is the constant of proportionality (catchability) for the survey, and

ε_y^i from $N\left(0, \left(\sigma_y^i\right)^2\right)$.

The contribution of the survey data to the negative of the log-likelihood function (after removal of constants) is then given by:

$$-\ell\text{n}\, L^{Surv} = \sum_i \sum_y \left[\ell\text{n}\left(\sigma_y^i\right) + \left(\varepsilon_y^i\right)^2 / 2\left(\sigma_y^i\right)^2\right] \qquad 32$$

where $\left(\sigma_y^s\right)^2 = \ln\left(1 + \left(CV_y\right)^2\right)$ and the coefficient of variation (CV_y) of the resource abundance estimate for year *y* is input.

The survey catchability coefficient $\hat{q}_s$ is estimated by its maximum likelihood value:

$$\ell n\, \hat{q}_s = 1/n_i \sum_y \left(\ln I_y^i - \ln N_y^{ex}\right) \qquad 33$$

Commercial catches-at-age

The contribution of the catch-at-age data to the negative of the log-likelihood function under the assumption of an “adjusted” lognormal error distribution is given by:

$$-\ell\text{n}\, L^{CAA} = \sum_y \sum_a \left[\ell n\left(\sigma_{com} / \sqrt{p_{y,a}} \right) + p_{y,a} \left(\ell n\, p_{y,a} - \ell n\, \hat{p}_{y,a} \right)^2 / 2\left(\sigma_{com} \right)^2 \right] \quad (34)$$

where

$p_{y,a} = C_{y,a} / \sum_{a'} C_{y,a'}$ is the observed proportion of lobsters caught in year y that are of age a,

$\hat{p}_{y,a} = \hat{C}_{y,a} / \sum_{a'} \hat{C}_{y,a'}$ is the model-predicted proportion of lobsters caught in year y that are of age a, where

$$\hat{C}_{y,1} = N_{y,1}\; e^{-3M_a/4}\; S_{y,1}\; F_y^{1+} \quad (35)$$

$$\hat{C}_{y,2} = N_{y,2}\; e^{-M_a/2}\; S_{y,2}\; F_y^{2+} \quad (36)$$

and

σ_{com} is the standard deviation associated with the catch-at-age data, which is estimated in the fitting procedure by:

$$\hat{\sigma}_{com} = \sqrt{\sum_y \sum_a \left(\ell n\, p_{y,a} - \ell n\, \hat{p}_{y,a} \right)^2 / \sum_y \sum_a 1} \quad (37)$$

The same approach is applied when fitting to the historic catch proportion data.

Survey catches-at-age

The survey catches-at-age are incorporated into the negative of the log-likelihood in an analogous manner to the commercial catches-at-age, assuming an adjusted log-normal error distribution (equation 25) where:

$p_{y,a} = C_{y,a}^{surv} / \sum_{a'} C_{y,a'}^{surv}$ is the observed proportion of lobsters of age *a* in year *y*,

$\hat{p}_{y,a}$ is the expected proportion of lobsters of age *a* in year *y* in the survey, given by:

$$\hat{p}_{y,a} = N_{y,a} \Big/ \sum_{a'=1}^{2} N_{y,a} \quad (38)$$

Benchmark Survey Estimates of Absolute Abundance

The absolute abundance of lobsters is estimated by fitting to data from two benchmark midyear surveys. The total 2002 population estimate, together with 95% confidence interval, was T_{89} = 9.0 (±1.9) million lobsters, and for 1989, T_{89} = 14.0 (±2.9) million lobsters (Pitcher et al. 1992). The 2+ year class was estimated at 1.77 (±0.38) million in 2002, and the 1+ year-class was at 5.2 (±1.5) million.

The approach is similar to that described above for the survey relative abundance index. The contribution of the survey data to the negative of the log-likelihood function (after removal of constants) is then given by:

$$-\ell\text{n}\, L^{Bench} = \ell\text{n}\left(\sigma_{89}\right) + \left(\varepsilon_{89}\right)^2 / 2\left(\sigma_{89}\right)^2 + \ell\text{n}\left(\sigma_{02}\right) + \left(\varepsilon_{02}\right)^2 / 2\left(\sigma_{02}\right)^2 \quad (39)$$

where

$\varepsilon_{89} = \ell\text{n}\left(T_{89}\right) - \ell\text{n}\left(\hat{N}_{1989,1}^{mid} + \hat{N}_{1989,2}^{mid}\right)$;

$\varepsilon_{02} = \ell n\left(T_{02}\right) - \ell n\left(\hat{N}^{mid}_{2002,1} + \hat{N}^{mid}_{2002,2}\right)$; and

$\left(\sigma_y\right)^2 = \ln\left(1 + \left(CV_y\right)^2\right)$ and the two coefficients of variation (CV_{89} and CV_{02}) are input.

Stock-recruitment function residuals

The stock-recruitment residuals are assumed to be log-normally distributed. The contribution of the recruitment residuals to the negative of the (now penalised) log-likelihood function is given by:

$$-\ell nL^{pen} = \sum_{y=y1+1}^{y2} \frac{\left(\lambda_y\right)^2}{2\sigma_R^2} \qquad 40$$

where

$\lambda_y = \varepsilon_y$ is the recruitment residual for year *y*, which is estimated for year *y*1 to *y*2 (see equation 4),

ε_y from $N\left(0,(\sigma_R)^2\right)$,

σ_R is the standard deviation of the log-residuals, which is input.

Model parameters

Natural mortality:

Natural mortality (M_a) is generally taken to be age independent and is estimated in the model fitting process.

In sensitivity tests where age-dependence is admitted, it is taken to have the form:

$$M_a = \mu_1 + \mu_2/a \qquad 41$$

Fishing selectivity-at-age:

The commercial selectivity is taken to differ over the 1973-2002 and 2002+ periods. Full selectivity of the 2+ class is assumed, with a separate selectivity parameter being estimated for each period for the 1+ class.

Appendix H. Relative Weighting Assigned to the 0+ Index

Previously, Plagányi et al. (2019) presented additional analyses undertaken to reduce the conflict between the November 2017 0+ survey index (which was very low relative to historical) and the 2018 1+ index (which was closer to average). Given we are reasonably confident in survey observations of 1+ lobsters (for reasons outlined in Plagányi et al. (2018)), the focus was on the anomalous 0+ observations. The stock assessment model is sensitive to the inclusion or exclusion (or downweighting) of the 2017-2018 0+ index, and hence it was deemed important to consider the basis for including, revising, further downweighting or excluding the index.

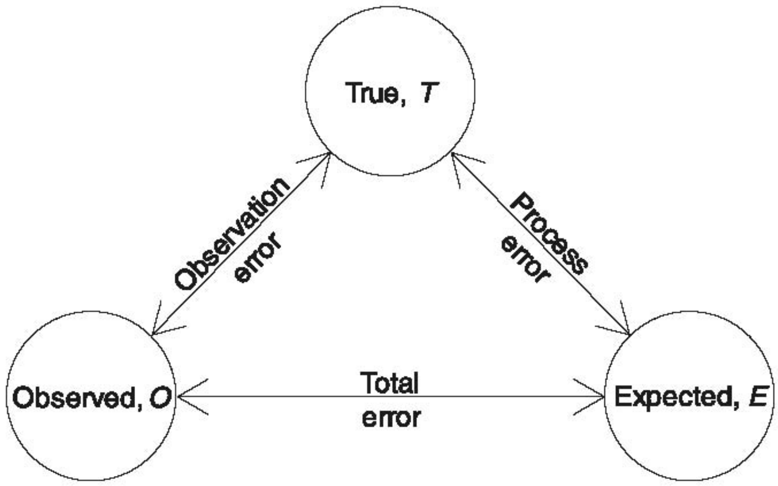
The previous investigation identified that the 0+ survey index is less reliable than the 1+ index, mainly due to the cryptic nature of recently-settled lobsters making them more difficult to survey, and that there may be additional biases that influence the reliability of the 0+ index, including diver experience in sampling 0+ lobsters. In addition, it was acknowledged that there were major environmental anomalies over the recent period which may have influenced the distribution and timing of settlement, and hence the representativeness of the 2017 0+ index (noting that these animals were spawned in late 2016/early 2017 during a period of the hottest recorded sea surface temperatures). Hence there are three aspects that are being investigated in an ongoing fashion:

1. Reviewing the relative weighting assigned to the 2017 0+ index (Upston *et al.* 2019);
2. Analysing and standardizing the 0+ index to take into account additional factors that may have influenced it, for example, using a General Linear Model approach (see Campbell et al. 2019);
3. Quantifying and accounting for environmental influences (see (Plagányi *et al.* 2018a))

Integrated fisheries stock assessments that simultaneously utilize multiple types of data in a likelihood framework need to consider data weighting, i.e. the relative influence of each data type (Francis 2011, 2017). The contribution to the total likelihood of each survey abundance datum is defined by the associated observed survey C.V. (coefficient of variation), and a lognormal distribution of the error associated with the survey data is assumed.

Dealing with apparent data conflict among data sets in fisheries stock assessments is not straight forward; this is an evolving field of study and there are many different approaches (Maunder et al 2017). Two key guiding principles proposed in the seminal paper by Francis (2011) were adhered to in the preliminary stock assessment: (i) don't let other data stop the model from fitting abundance data well; and (ii) don't downweight abundance data because they may be unrepresentative. An example of an unrepresentative data set could be a CPUE series that does not reliably index the stock abundance, and this is one of the reasons considerable care is taken in the TRL assessment to standardise the CPUE series so that it might, as far as possible, provide an index of true underlying stock abundance. The gold standard being a research survey abundance index. Francis (2011) cites as an example of an unrepresentative survey one which covers different fractions of a population each year. Rather than downweighting data sets, he recommends that alternative assessments be considered in which possibly unrepresentative data sets are excluded, and this uncertainty be communicated to fishery managers, as was done at the previous TRLRAG.

It is important to recognize that the total error that exists between an Observed and Expected (by stock assessment model) quantity depends on both observation error (i.e. the sampling error) and process error (process variation and model misspecification (Maunder et al. 2017), i.e. how well the model represents the 'real world'), as illustrated in the schematic below from Francis (2011):



The survey c.v. represents the observation error, and the c.v. associated with the 0+ survey is larger than that for the 1+ survey, with a range of 0.2 to 0.37. Process error is sometimes computed external to a stock assessment and then added to the total error, with most examples finding process and observation error to be approximately equal in variance (Francis 2011). Examples of factors that may contribute to process error include variable spatial distribution of 0+ lobsters and timing of the survey relative to spawning activity. Future work could consider methods for trying to quantify process error outside the stock assessment model. One method for accounting for process error within a stock assessment model is to estimate a single or series of additional variance parameters. The first approach assumes that the process error is roughly constant from year to year, whereas the latter assumes it is year-dependent, which is more closely aligned with the current hypotheses.

For TRL it is possible to estimate the additional variance for all years except the most recent survey 0+ datum because 1+ surveys have been conducted in all previous years, enabling validation of the earlier 0+ estimates. This approach was considered preferable to a less internally consistent option of only singling out the current anomalous year and estimating an associated additional variance. It also has the advantage that it can then be applied consistently in future analyses and would again be helpful in future should another anomalous year occur. The fact that the additional variance can't be estimated for the last survey datum isn't a major problem because the 0+ only forecast the future fished age class 2 years ahead. Hence the proposed approach used here used the average of all previous additional variance parameters as the process error for the current survey 0+ datum, and then this is re-estimated in each subsequent assessment once the following year 1+ survey data become available.

Standard model selection criteria can be used to decide whether the estimation of further model parameters (i.e. the additional variance parameters for all survey years except the last year) is justified and also the Hessian-based standard errors associated with each parameter estimate indicate the reliability with which each parameter is estimated (Table H.1).

Table H.1. Summary of Additional Variance (AV) parameter estimates and associated model-estimated 90% confidence interval (CI) when using the 2024 Reference Case model.

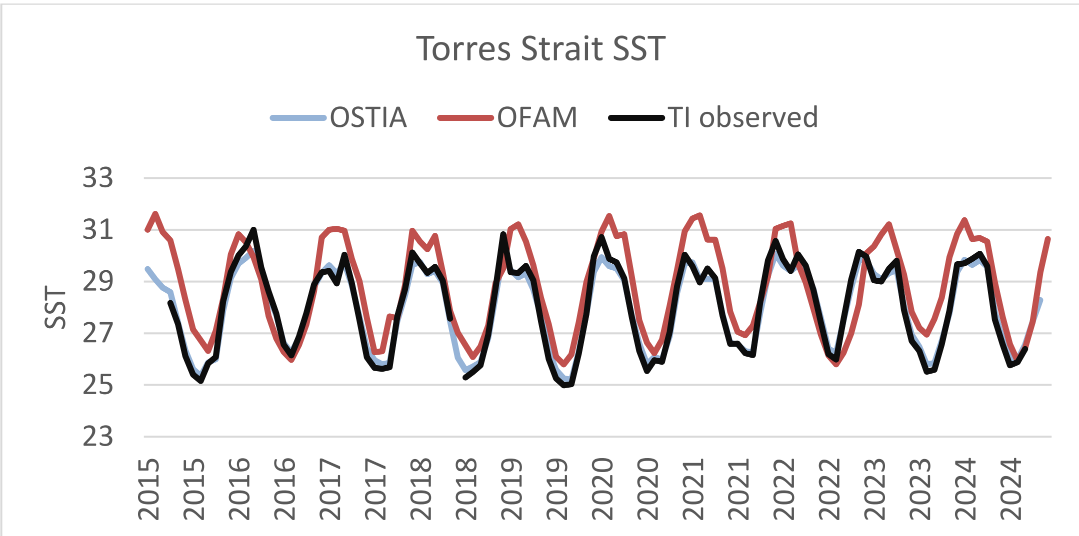
	(A) Dec 2024 Reference Case		
Parameter	Value	90% CI	
Recruitment residuals (1985-2024)		40 parameters	
Additional Variance parameter 2005	0.34	-0.70	1.38
AV 2006	0.00	0.00	0.00
AV 2007	0.00	0.00	0.00
AV 2008	0.41	-2.65	3.46
AV 2014	0.00	0.00	0.00
AV 2015	0.00	0.00	0.00
AV 2016	0.45	0.45	0.45
AV 2017	0.45	0.45	0.45
AV 2018	0.44	0.19	0.69
AV 2019	0.00	0.00	0.00
AV2020	0.00	0.00	0.00
AV2021	0.45	0.45	0.45
AV2022	0.45	0.45	0.45
AV2023	0.00	0.00	0.00

Appendix I. Climate-linked Stock Assessment Model

The climate-linked version of the stock assessment model has previously been described in Plagányi et al. (2019 a,b). A short update is provided below. As previously, the model uses as an input data from the Model Intercomparison Project Phase 5 (CMIP5) climate models. The global OGCM is integrated over the historical period (1979-2014) then projected from 2006 to 2101 under a high emission scenario (RCP8.5). Climate data were provided by Richard Matear and Xuebin Zhang (CSIRO) starting in 1992 and climate change (rcp8p5) and control projections up to 2050. The data consists of monthly surface data of temperature (SST; °C), salinity (SSS), phosphate (SPO4; mmol m^{-3}), phytoplankton (SPHYL; mmol N m^{-3}) and primary productivity (PP; mmol C m^{-2} day^{-1}). The downscaled OFAM sea surface temperature estimates do not exactly match available (limited) observations from monitoring stations in Torres Strait but were considered useful as a first approximatio. However, this has been revsied as part of ongoing research examining this issue.

The December 2024 revsied climate-linked stock assessment model replaced these SST data with a satellite-derived OSTIA series (high emissions scnerio) based on the Torres Strait climate change project. A comparison between these data sources is shown in Figure I.1.

Figure. I.1. Plot of SST (Sea Surface Temperature) (°C) observations form Thursday Island (TI), Torres Strait over 2015 to 2024, compared with modelled SST using OFAM and satellite-derived SST called OSTIA, showing closer match between OSTIA and actual observations.



The updated stock assessment model as described in this chapter is used, and results are presented for the model version with the SST-mortality function implemented as well as the growth-SST relationship as described in Plagányi et al (2019).

As previously, we assume an optimal temperature for *P. ornatus* of 29°C and assume a non-symmetric pejus type relationship between lobster survival (assumed to be the net outcome of a number of physiological responses to changes in temperature) and SST. We parameterise this as two separate quadratic functions that intersect at the optimum SST, such that the slope of the response to decreasing versus increasing SST can be different i.e. the impacts of temperatures greater than the optimum are more severe than those of temperatures less than the optimum. Hence the functional forms assumed for the mortality multiplier functions (*SST_multiplier*) are:

$$SST\_multiplier_t = 1 + \tau_1 \left(SST_t - T_O \right)^2 \quad SST_t \le T_0$$
$$SST\_multiplier_t = 1 + \tau_2 \left(SST_t - T_O \right)^2 \quad SST_t > T_0$$

Where T_0 is the optimum SST and SST_t is the monthly average Sea Surface Temperature (°C) at time *t*, with the annual composite SST multiplier (SST_M_y) for year *y* computed as the average of the multipliers for the 12 months of each year. The two slope parameters τ_1, τ_2 can be fixed (at the same or different values) or estimated by fitting to historical data (as has been done here). In the model, for all years since 1992 (start of the SST input series), the fixed annual natural mortality *M* is therefore adjusted using the average annual SST-dependent multiplier:

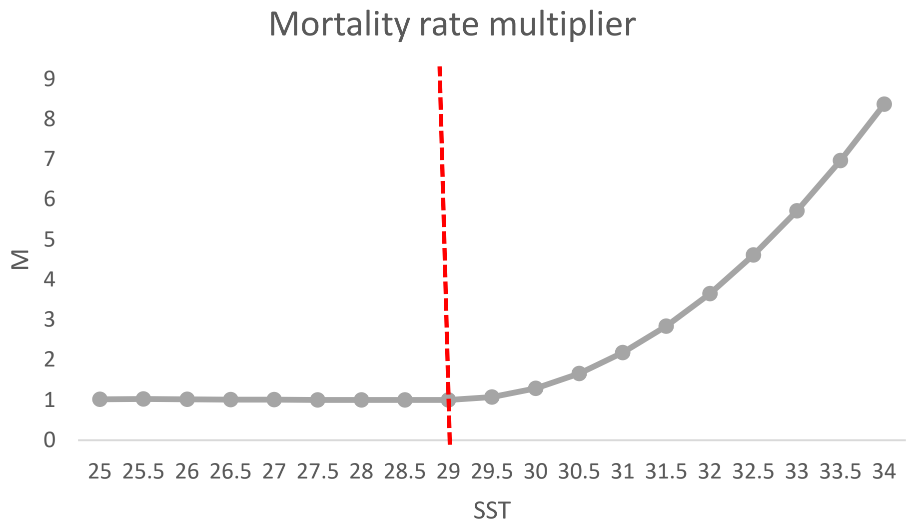
$$M_y^{SST} = M \times SST\_M_y$$

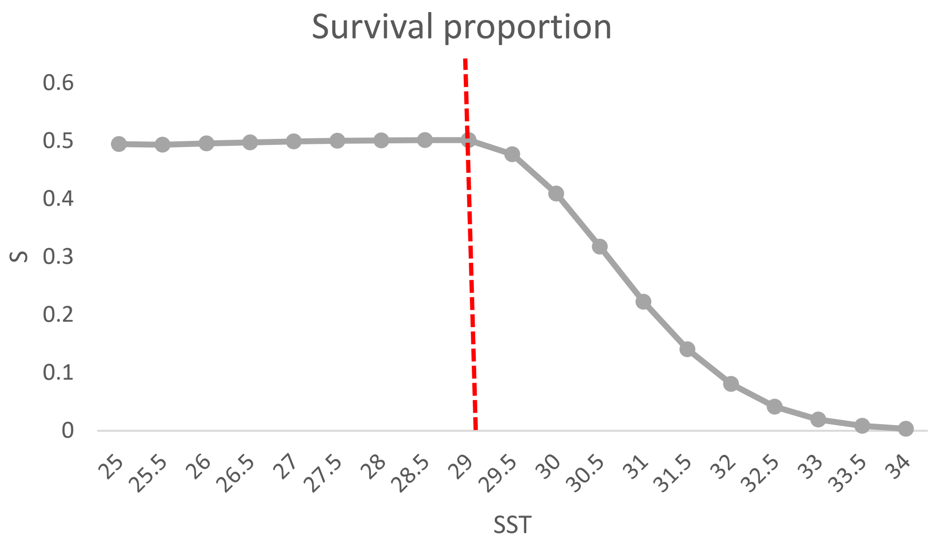
Conversely, the average survival proportion S_y for each year *y* is computed simply as:

$$S_y = e^{-M_y}$$

And an example of the SST-S relationship is shown in Figure I.2.

Figure I.2. (a) Natural mortality multiplier shown as a function of SST, with relatively large increases in M as SST increases above the optimal SST, but small changes only down to lower limit of 25°C. (b) Survival proportion S shown as a function of SST.





The model estimates the 2 slope parameters of the SST-mortality relationship by fitting to all available data, with climate data available since 1992. The annual average mortality rate was fixed at the Reference Case level (because otherwise it would be confounded with the multiplier functions being estimated). A growth-SST model version is also tested.

These results are conditioned on historical data which have an overall monthly maximum of 32.04°C, whereas the maximum monthly averages in the SST-projections to 2050 and 2100 respectively are 33.06°C and 34.24°C. Hence there is some confidence in the model projections in the near-term, but less confidence in longer-term model projections when SST is predicted to increase beyond the bounds observed in the historical data.

Appendix J. Stock Structure Assumptions

An important assumption of the current and previous assessments is that the Torres Strait rock lobster resource is a closed population, but this is clearly not the case given they migrate eastwards out the Torres Straits (Moore and MacFarlane 1984, Skewes et al. 1994). It is not known to what extent mixing occurs with the eastern component of the stock, and hence whether these two stock components should rather be treated as a single stock in computing a spawning stock biomass. This aspect has been investigated in related work (Figure J.1 and Figure J.2; Plagányi et al. 2019b). In addition, more recent studies as summarised in Plagányi et al. (2025) and Chapter 12 provide further support for this model assumption.

Figure J.1. Map showing location of Torres Strait dive fishery (red shading) between Australia and Papua New Guinea (PNG) and migratory route of P. ornatus eastwards to breeding grounds off Yule Island, with larvae then transported via currents and settling back in Torres Strait after c. 5-6 months. *The Queensland East Coast (blue hatching) stock also acts as a source and sink for larvae as breeding grounds such as off Princess Charlotte Bay may contribute larvae to Torres Strait. (Source: Plagányi et al. 2019b).*

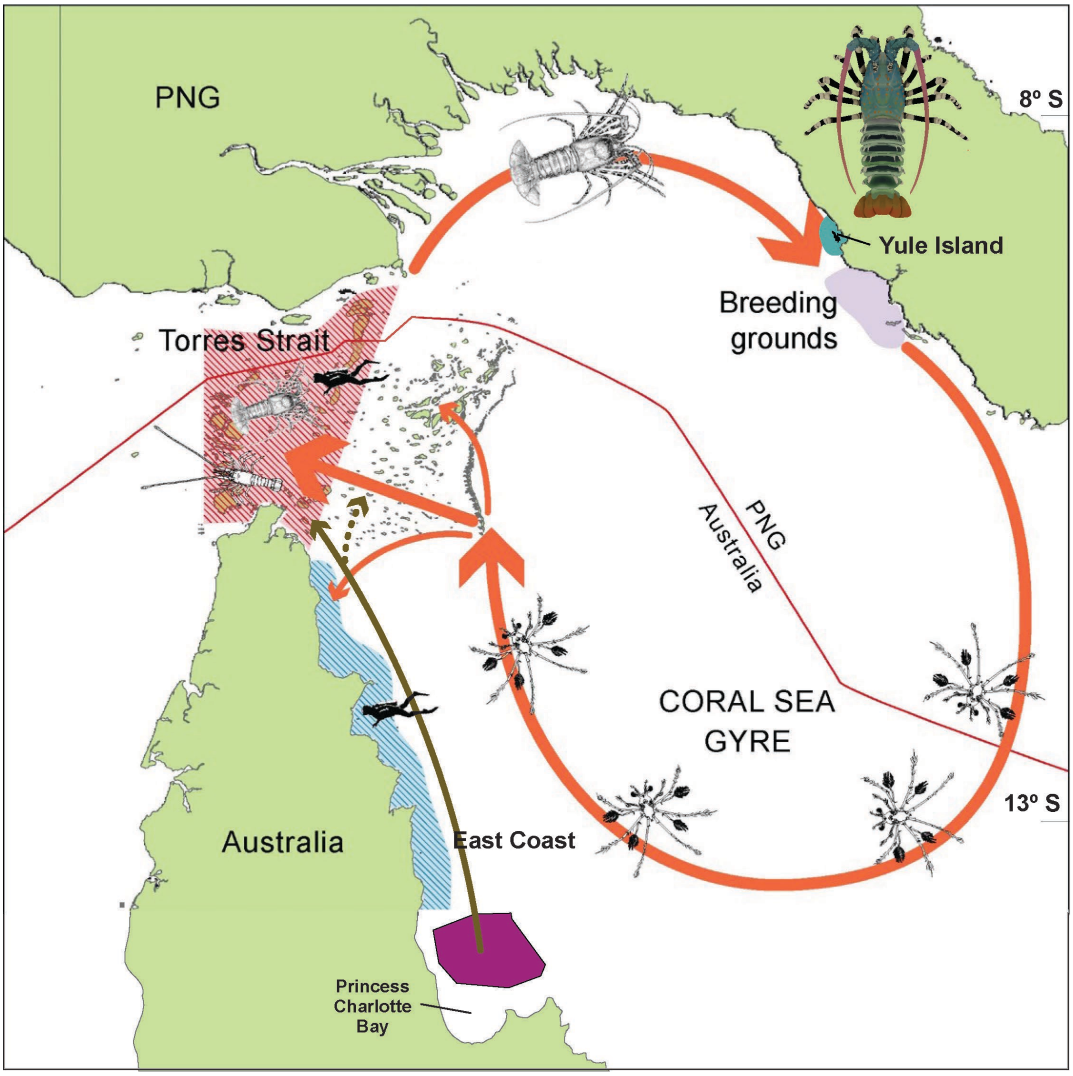
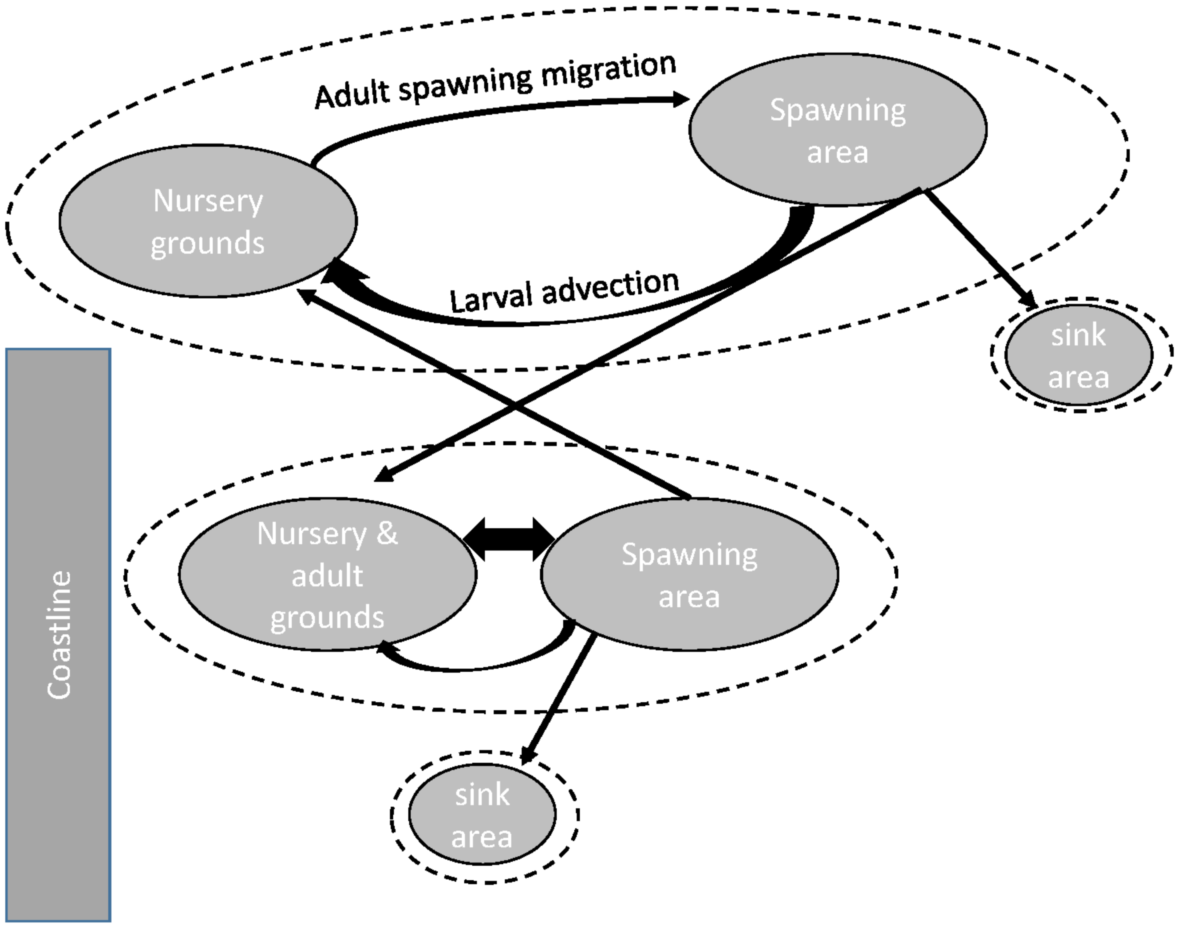


Figure J.2. Conceptual summary showing mixed metapopulation structure, based on diagram in Smedbol and Wroblewski (2002) where dotted lines are boundaries of subpopulations, and arrows indicate exchange between subpopulations. (Source: Plagányi et al. 2019b).



Appendix K. Reference Case Stock Assessment Recruitment Residual Estimates

	Parameter estimate	90% Hessian-based confidence interval	
1985	0.08	-0.35	0.50
1986	0.04	-0.64	0.72
1987	0.01	-0.51	0.54
1988	0.72	0.49	0.96
1989	-0.03	-0.26	0.20
1990	-0.02	-0.24	0.20
1991	0.24	0.03	0.44
1992	0.29	0.08	0.50
1993	0.14	-0.07	0.34
1994	0.33	0.11	0.55
1995	0.09	-0.12	0.29
1996	0.07	-0.12	0.27
1997	0.19	-0.02	0.39
1998	-0.59	-0.81	-0.37
1999	-0.21	-0.44	0.01
2000	-0.89	-1.15	-0.62
2001	-0.36	-0.59	-0.14
2002	0.11	-0.09	0.32
2003	0.25	0.04	0.46
2004	0.30	0.10	0.50
2005	-0.67	-0.87	-0.48
2006	0.20	0.00	0.39
2007	-0.13	-0.32	0.07
2008	-0.19	-0.37	-0.02
2009	0.06	-0.14	0.27
2010	0.54	0.34	0.74
2011	0.43	0.23	0.63
2012	0.37	0.15	0.59
2013	-0.07	-0.28	0.14
2014	-0.08	-0.30	0.14
2015	0.28	0.07	0.49
2016	-0.30	-0.52	-0.07
2017	-0.61	-0.82	-0.40
2018	-0.02	-0.24	0.21
2019	0.34	0.11	0.58
2020	0.00	-0.22	0.23
2021	0.15	-0.07	0.36
2022	0.09	-0.17	0.34
2023	-0.04	-0.29	0.21
2024	0.48	0.16	0.79

Appendix L. Appendix References and Further Reading

Anon. (2007). Commonwealth Fisheries Harvest Strategy Policy-draft guidelines. DAFF. 59 pp.

Anon. 2019. Report of the Torres Strait Tropical Rock Lobster Resource Assessment Group (TRLRAG) Data Sub-Group Meeting 1, held 18 June 2019, Cairns.

Bentley, N. 2006. Review of chapter 5 of Ye et al (2006). “Sustainability Assessment of the Torres Strait Rock Lobster Fishery”. Report submitted to AFMA.

Bentley, N., Kendrick, T.H., Starr, P.J., Breen, P.A. 2012. Influence plots and metrics: tools for better understanding fisheries 1 catch per unit effort standardisations. ICES Journal of Marine Science: 69, 84-88.

Campbell, R.A., 2004. CPUE standardization and the construction of indices of stock abundance in a spatially varying fishery using general linear models. Fish. Res. 70, 209–227.

Campbell, R. 2015. Constructing stock abundance indices from catch and effort data: Some nuts and bolts. Fisheries Research 161 (2015) 109–130.

Campbell, R.A., 2016a. Data issues pertaining to the Torres Strait rock lobster fishery – discussions with AFMA. Information paper presented to the 18th meeting of the Torres Strait Rock Lobster Resource Assessment Group, held 2-3 August 2016, Thursday Island.

Campbell, R.A., 2016b. Separating TIB, TVH and Processor catch records from Docket-Book Data. Report to AFMA.

Campbell, R.A, Dennis, D., Plagányi, E., Deng, R., 2014. Use of TIB Logbook Data to construct an Annual Abundance Index for Torres Strait Rock Lobster – 2014. Information paper presented to the 13th meeting of the Torres Strait Rock Lobster Resource Assessment Group, held 27-28 August 2014, Brisbane.

Campbell, R.A, Dennis, D., Plagányi, E., Deng, R., 2015. Use of TIB Logbook Data to construct an Annual Abundance Index for Torres Strait Rock Lobster – 2015 Update. Information paper presented to the 14th meeting of the Torres Strait Rock Lobster Resource Assessment Group, held 25-26 August 2015, Thursday Island.

Campbell, R.A, Dennis, D., Plagányi, E., Deng, R., 2016. Use of TIB Logbook Data to construct an Annual Abundance Index for Torres Strait Rock Lobster – 2016 Update. Information paper presented to the 19th meeting of the Torres Strait Rock Lobster Resource Assessment Group, held 13 December 2016, Cairns.

Campbell, R., Plagányi, É., Deng, R. 2017a. Use of TVH Logbook Data to construct an Annual Abundance Index for Torres Strait Rock Lobster – 2017 Update. CSIRO report presented to TRL RAG, December 2017. 23 pp.

Campbell, R., Plagányi, É., Deng, R. 2017b. Use of TIB Docket-Book Data to construct an Annual Abundance Index for Torres Strait Rock Lobster – 2017 Update. CSIRO report presented to TRL RAG, December 2017. 27 pp.

Campbell, R.A., Pease, D. 2017. Separating TIB, TVH and Processor catch records from Docket-Book Data. Report to AFMA – 2017 Update. Information paper to be presented to the 21st meeting of the Torres Strait Rock Lobster Resource Assessment Group, held 12-13 December 2017, Cairns.

Campbell, R.A. Plagányi, E, Deng, R., 2017. Use of TIB Docket-Book Data to construct an Annual Abundance Index for Torres Strait Rock Lobster – 2017 update. Information paper presented to the 21st meeting of the Torres Strait Rock Lobster Resource Assessment Group, held 12-13 December 2017, Cairns.

Campbell, R.A., Plagányi, E., Deng, R., Tonks, M, Haywood, M. 2018. Torres Strait Rock Lobster Fishery – Summary of the Catch and Effort Data pertaining to the 2018 Fishing Season (Dec-17 to Apr-18). Information paper presented to the 23rd meeting of the Torres Strait Rock Lobster Resource Assessment Group, held 15 May 2018, Cairns

Campbell R, Plagányi E, Upston J, Tonks M, Murphy N, Deng AR (2019) Alternative Analysis of Pre-Season Survey Data to Calculate the Annual Index for 0+ Lobsters. TRLRAG document February 2019, 8pp (Appendix F in this report)

Carvalho, F.E., Punt, A.E., Chang, Y., Maunder, M.N., Piner, K.R. 2017. Can diagnostic tests help identify model misspecification in integrated stock assessments? Fish. Res. 192,28–40

Dennis, D., Plagányi, É., Haywood, M. 2013. Environmental impacts on the TRL population in Torres Strait. CSIRO Final Report to AFMA, 52pp.

Dennis DM, Plagányi ÉE, Haywood MDE, Arlidge B, Kelly C 2017. Summary of Torres Strait and QLD east Coast lobster commercial catch monitoring by MG Kailis Pty Ltd 2001-2017. Draft report for TRLRAG, April 2017

Dennis, D., Plagányi, É., van Putten, I., Hutton, T., Pascoe, S. 2015. Cost benefit of fishery-independent surveys: are they worth the money? Marine Policy 58: 108-115

Dennis, D., Ye, Y., Lara-Lopez, A., Jones, A., Cheers, S. Commercial catch age composition and conversion ratio for the Torres Strait Tropical Rock Lobster Fishery. AFMA Project: RR2007/0835. Final Report, February 2009.

Dutra, L.X.C., Plagányi, É.E., Kenyon, R., Hutton, T., Murphy, N., Blamey, L.K., Edgar, S., Moeseneder, C., (2021) Scoping a future project to address impacts from climate variability and change on key Torres Strait Fisheries. Final Report for Project Climate variability and change relevant to key fisheries resources in the Torres Strait to Australian Fisheries Management Authority, Brisbane, p. 179.

Fournier DA, Skaug HJ, Ancheta J, Ianelli JN, Magnusson A, Maunder MN, Nielsen A, Sibert JR (2012) AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optim. Methods Softw. 27:233-249.

Francis RC (2011) Data weighting in statistical fisheries stock assessment models. Can J Fish Aquat Sci 68:1124-1138

Francis, R.C., and Hare, S.R. 1994. Decadal-scale regime shifts in the large marine ecosystems of the north-east Pacific: A case for historical science. Fish Oceanogr **3**(4): 279-291

Francis RC (2017) Revisiting data weighting in fisheries stock assessment models. Fish Res 192:5-15

Green, B.S., Gardner, C., Hochmuth, J.D., Linnane, A. (2014) Environmental effects on fished lobsters and crabs. Reviews in Fish Biology and Fisheries 24, 613-638.

Harley, S.J., Myers, R.A., and Dunn, A. (2001) Is catch-per-unit-effort proportional to abundance? Canadian Journal of Fisheries and Aquatic Science. 58: 1760-1772.

Hjort J Fluctuations in the great fisheries of northern Europe viewed in the light of biological research. ICES

Hutton, T., van Putten, I., Pascoe, S., Deng, R., Plagányi, É. and D. Dennis. 2016. Trade-offs in transitions between indigenous and commercial fishing sectors: the Torres Strait Tropical Rock Lobster Fishery. Fisheries Management and Ecology 23(6):463-477

Ianelli, J.N. 2002. Simulation analyses testing the robustness of productivity determinations from west coast Pacific ocean perch stock assessment data. North American Journal of Fisheries Management **22**(1): 301-310.

Lo, N.C., Jacobson, L.D. and Squire, J.L. 1992. *Indices of relative abundance from fish spotter data based on delta-lognormal models.* Can. J. Fish. Aquat.Sci., 49, 2515-2526.

Long, B., Skewes, T., Taranto, T., Thomas, M., Isdale, P., Pitcher, R., Poiner, I. (1997) Seagrass dieback in north western Torres Strait - REPORT MR-GIS 97/6. CSIRO Marine Research, Cleveland.

MacCall, A.D., Klingbeil, R.A., and Methot, R.D. 1985. Recent increased abundance and potential productivity of Pacific mackerel (Scomber japonicus). Calif. Coop. Oceanic Fish. Invest. Rep **26**: 119-129

MacFarlane, J. W., and Moore, R. (1986). Reproduction of the ornate rock lobster, *Panulirus ornatus* (Fabricius), in Papua New Guinea. Australian Journal of Marine and Freshwater Research 37: 55–65.

Maunder, M.N., Crone, P.R., Valero, J.L., Semmens, B.X., 2014. Selectivity: theory,estimation, and application in fishery stock assessment models. Fish. Res. 158,1–4.

Maunder, M.N., Crone, P.R., Punt, A.E., Valero, J.L., Semmens, B.X., 2016. Growth:theory, estimation, and application in fishery stock assessment models. Fish.Res. 180, 1–3.

McKoy, J.L. 1985. Growth of tagged rock lobsters (*Jasus edwardsii*) near Stewart Island, New Zealand. New Zealand Journal of Marine and Freshwater Research. 19: 457-466.

Moore, R., MacFarlane, W. (1984). Migration of the ornate rock lobster, Panulirus ornatus (Fabricius), in Papua New Guinea. Australian Journal of Marine and Freshwater Research, 35: 197-212.

Myers, R.A., Bridson, J., Barrowman, N.J. (1995). Summary of worldwide stock and recruitment data. Canadian Technical Report of Fisheries and Aquatic Sciences. 2024: 327.

Pascoe, S., Hutton, T., van Putten, I., Dennis, D. Plagányi, É. and R. Deng. 2013. Implications of quota reallocation in the Torres Strait Tropical Rock Lobster Fishery. Canadian Journal of Agricultural Economics 6: 335–352

Pennington, M. 1983. *Efficient estimators of abundance for fish and plankton surveys*. Biometrics, 39, 281-286.

Pennington, M. and Berrien, P. 1984. *Measuring the precision of estimates of total egg production based on plankton surveys*. J. Plankton Res.., 6, 869-879.

Phillips, B.F., Palmer, M.J., Cruz, R., Trendall J.T. (1992). Estimating growth of the spiny lobsters Panulirus cygnus, P. argus and P. ornatus. Aust. J. Mar. Freshw. Res. 43: 1177-88.

Plagányi, É.E., Dennis, D., Campbell, R., Haywood, M., Pillans, R., Tonks, M., Murphy, N., McLeod, I. 2015a. Torres Strait rock lobster (TRL) fishery surveys and stock assessment: TRL fishery model, used to calculate the upcoming TAC updated using the 2014 survey data and the previous year's CPUE data. AFMA Project 2013/803. June 2015 Milestone report. 64 pp.

Plagányi, É.E., Dennis, D., Campbell, R., 2015b. Torres Strait TRL 2015 catch comparison with TAC and reasons for the difference. Report for presentation at TRL Resource Assessment Group teleconference, December 2015. 10pp

Plagányi, É.E., Darren Dennis, Marco Kienzle, Yimin Ye, Michael Haywood, Ian Mcleod, Ted Wassenberg, Richard Pillans, Quinton Dell, Greg Coman, Mark Tonks, Nicole Murphy (2009). TAC estimation & relative lobster abundance surveys 2008/09. AFMA Project Number: 2008/837. CSIRO Final Report, October 2009. 80 pp.

Plagányi, É.E., Kienzle, M., Dennis, D., Venables, W. Tonks, M., Murphy, N. and T. Wassenberg, 2010. Refined stock assessment and TAC estimation for the Torres Strait rock lobster (TRL) fishery.

Australian Fisheries Management Authority Torres Strait Research program Final Report. AFMA Project number: 2009/845. 84 pp.

Plagányi, E. E., Dennis, D. M., Campbell, R., Deng, R., Hutton, T., Haywood, M. H. 2012. Refined survey, stock assessment and MSE for the Torres Strait rock lobster (TRL) fishery. Australian Fisheries Management Authority Torres Strait Research Program Final Report AFMA Project Number: 2012/810. 106 pp.

Plagányi, É.E., van Putten, I., Hutton, T., Deng, R., Dennis, D., Hutton, T., Pascoe, S., Skewes, T. and R. Campbell. 2013. Integrating indigenous livelihood and lifestyle objectives in managing a natural resource. P Natl Acad Sci USA **110(9): 3639-44**

Plagányi, É.E., Dennis, D., Campbell, R. 2014. 2014 Preliminary Assessment of the Tropical Rock Lobster (*Panulirus ornatus*) Fishery in the Torres Straits. Report for presentation at TRL Resource Assessment Group, August 2014. 43 pp

Plagányi, E., van Putten, I., Dennis, D., Caputi, N., de Lestang, S., Gardner, C., Hartmann, K., Liggins, G., Linnane, A., McGarvey, R., Arlidge, B., Green, B., Villanueva, C. 2017a. Overview, Opportunities and outlook for Australian lobster fisheries. *Rev. Fish Biol Fish* 28(1): 57-87.

Plagányi, E.E., Haywood, M., Gorton, B. & S. Condie. 2017b. Environmental drivers of variability and climate projections for Torres Strait tropical lobster *Panulirus ornatus*. Draft AFMA/CSIRO technical report presented to TRLRAG, December 2017. 160 pp

Plagányi E, Haywood M, Gorton B, Condie S (2018a) Environmental drivers of variability and climate projections for Torres Strait tropical lobster *Panulirus ornatus*. CSIRO/AFMA Technical Report, March 2018 156 pp

Plagányi ÉE, Deng R, Campbell R, Dennis D, Hutton T, Haywood M, Tonks M (2018b) Evaluating an empirical harvest control rule for the Torres Strait *Panulirus ornatus* tropical rock lobster fishery. Bull Mar Sci 94(3):1095–1120

Plagányi E, Upston J, Tonks M, Murphy N, Campbell R, Salee K, Edgar S, Deng R, Moeseneder C (2018) Preliminary summary regarding 2018 assessment of Torres Strait tropical lobster TRL stock. TRLRAG document December 2018

Plagányi EE, Campbell R, Tonks M, Upston J, Murphy N, Salee K, Edgar S (2019a) Torres Strait rock lobster (TRL) 2018 stock assessment. TRLRAG document, February 2018, 54 pp

Plagányi, É.E., Haywood, M., Gorton, R., Siple, M. & Deng, R. 2019b. Management implications of modelling fisheries recruitment. *Fisheries Research* 217: 169-184

Plagányi, É., Dutra, L., Murphy, N., Edgar, S., Salee, K., Deng, R.A., Blamey, L.K., Parker, D. and Brodie, S., 2024. Lessons from long-term monitoring of tropical rock lobsters to support fisheries management. *Fisheries Research*, *275*, p.107030.

Plagányi, É.E., Blamey, L.K. and Deng, R.A., 2025. Key role of fisheries genomics to support conservation, fisheries management and trade of widely-distributed spiny lobsters. *Fisheries Research*, *281*, p.107266.

Pope, J.G. 1984. Notes of the scientific problems of TAC management. Papers presented at the Expert Consultation on the regulation of fishing effort. Rome, 17–26 January 1983. FAO Fisheries Report No. 289 Supplement 2. FAO. Rome.

Preen, A., Marsh, H. (1995) Response of Dugongs to Large-Scale Loss of Seagrass from Hervey Bay, Queensland, Australia. Wildlife Research 22, 507-519.

Punsley, R.G., 1987. Estimation of the relative abundance of yellowfin tuna, *Thunnus albacares*, in the Eastern Pacific Ocean during 1970-1985. Inter-Amer. Trop. Tuna Comm. Bull. 19, 98-131.

Punt, A.E., 2017. Some insights into data weighting in integrated stock assessments. Fish. Res. 192:52–65.

Punt, A.E., A'Mar, T., Bond, N.A., Butterworth, D.S., de Moor, C.L., De Oliveira, J.A.A., Haltuch, M.A., Hollowed, A.B., and Szuwalski, C. 2014. Fisheries management under climate and environmental uncertainty: control rules and performance simulation. Ices J Mar Sci **71**(8): 2208-2220. doi:10.1093/icesjms/fst057.

Sheppard, J.K., Preen, A.R., Marsh, H., Lawler, I.R., Whiting, S.D., Jones, R.E. (2006) Movement heterogeneity of dugongs, Dugong dugon (Muller), over large spatial scales. Journal of Experimental Marine Biology and Ecology 334, 64-83.

Skewes. T, Pitcher. R, Dennis. D. (1997) Growth of ornate rock lobsters, Panulirus ornatus, in Torres Strait, Australia. Marine and Freshwater Research. 48, 497-501

Skewes, T.D., C.R. Pitcher, J.T. Trendall (1994). Changes in the size structure, sex ratio and molting activity of a population of ornate rock lobsters, Panulirus ornatus, caused by an annual maturation molt and migration. Bull. Mar. Sci. 54: 38-48

Smedbol, R.K., and Wroblewski, J. 2002. Metapopulation theory and northern cod population structure: interdependency of subpopulations in recovery of a groundfish population. Fish Res **55**(1-3): 161-174

Trendall, J.T., Bell, R.S., Phillips, B.F. (1988). Growth of the spiny lobster Panulirus ornatus, in the Torres Strait. Proc. Workshop on Pacific Inshore Fisheries, Noumea, 1988, South Pacific Commission, 345/88.

Upston J, Plagányi E, Tonks M, Campbell R (2019) Tropical Rock Lobster abundance surveys – data conflicts and different analysis approaches. TRLRAG document February 2019 (Appendix G in this report)

Wilson D, Curtotti R, Begg G, Phillips K (eds) (2009) Fishery status report 2008: status of fish stocks and fisheries managed by the Australian Government. Bureau of Rural Sciences & Australian Bureau of Agricultural and Resource Economics, Canberra.

Ye, Y., D.M. Dennis, T.D. Skewes, P. Polon, F. Pantus, D. Brewer, M. Haywood, I. Mcleod, T. Wassenberg, R. Pillans, D. Chetwynd, J. Sheils (2007). 2006 Relative Abundance and Pre-season Surveys, Assessment of the Torres Strait Rock Lobster Fishery and TAC estimation. CSIRO Marine and Atmospheric Research Final Report, August 2007. Pp 108. ISBN 9781921232824.

Ye, Y., D.M. Dennis, T.D. Skewes, T. J. Taranto, M. D. E. Haywood, D. T. Brewer, T. J. Wassenberg, D. Chetwynd, I. M. McLeod, A. G. Donovan. (2006). Sustainability Assessment of the Torres Strait Rock Lobster Fishery: CRC-TS Project Task Number: 1.3. CRC Torres Strait Research Task Final Report, July 2006. 128 pp. ISBN 1 921232 06 4.

Ye Y, Dennis D (2009). How reliable are the abundance indices derived from commercial catch-effort standardization? Can J Fish Aquat Sci 66:1169–1178

Ye, Y., Pitcher, C. R., Dennis, D. M., Skewes, T. D., Polon, P. K., Kare, B., Wassenberg, T. J., Haywood, M. D. E., Austin, M. D., Koutsoukos, A. G., Brewer, D. T., Bustamante, R. H., Taranto, T. J. (2004). Benchmark Abundance and Assessment of the Torres Strait Lobster Stock. CSIRO Marine Research Final Report. Pp 79

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